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FINAL REPORT

TELEVISION BROADCAST FROM SPACE

SYSTEMS - TECHNOLOGY - COSTS

by

C. LOUIS CUCCIA

FORD AEROSPACE AND COMMUNICATIONS CORPORATION

WESTERN DEVELOPMENT LABORATORIES DIVISION

3939 FABIAN WAY

PALO ALTO, CALIFORNIA 94303

For:
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA 91109

August 2, 1980
Rev. July 1, 1981
CONTRACT NO: 955641
PROGRAM MONITOR:
MR. ARVYDAS VAISNYS

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ABSTRACT

This report has been prepared to present the technology and cost aspects of broadcast satellite systems. The device and technological basis for broadcast satellite systems, both in space and on earth, rely heavily on present experience in both telecommunication and broadcast satellites which have been operated with a variety of earth terminals during the last decade. With such experience as a resource, and the growing technologies of small antennas, low noise FET's, receivers, and space type high power amplifiers, it is possible to now build operational systems; i.e., the West German TV-SAT system and the COMSAT direct broadcast system and the second generation Japanese BSE (Broadcast Satellite for Experiment Purposes).

This report will describe broadcast satellite systems, past, present, and in the planning stage. It will then describe the technologies which are unique to both high power broadcast satellites and small TV receive-only earth terminals. It will then conclude with a cost assessment of both space and earth segments, and appendices will present both a computer model for satellite cost and the pertinent reported experience with the Japanese BSE.

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1.0 INTRODUCTION

Television broadcasting from space is a maturing service with a rapidly evolving technology. It has been extensively tested in its two forms, community service and direct-to-home service. As a result of The World Broadcasting Satellite Administrative Radio Conference (WARC-77) held in Geneva in 1977 and WARC-79, many international guidelines relative to frequency, coverage, and EIRP have been established which is resulting in considerable activity in various countries for implementing this service.

Television distribution via satellite is now a very mature and common technology. It became a significant international service of the Intelsat System relaying TV images from one country to another following the successful video transmissions from Great Britain to Andover, Main via TELSTAR in the early 1960's, and the relay of the Japanese Olympics from Tokyo to Pt. Mugu via SYNCOM-1 in 1964. Today, video transmission on a worldwide basis is the bulwark of news and sports events reporting and has become virtually commonplace in all of the 104 countries of the Intelsat System .

Television distribution satellite for domestic service is also commonplace. It was first implemented by the USSR via the ORBITA System in the late 1960's for distributing TV from Moscow to stations in Russia west of the Urals, and was the principal objective of the Canadian Anik satellite system and the U.S. WESTAR satellite in the mid 1970's. Today, television distribution by satellite is a thriving business in the United States to service the vast cable TV networks which reach almost 35% of U.S. TV viewers; this domestic TV distribution service has also created new users of TV; i.e., the religious broadcasters; the Spanish and Black networks, Mutual and PBS TV and radio distribution, and "super-TV stations" to name only a few.

TV broadcast from space for community reception and direct-to-user service has developed from systems distinctly separate from international and domestic telecommunication systems. The use of NASA's ATS-6 brought direct-to-user TV service at 2.5 GHz for educational systems (Rocky Mountain, Appalachia, etc.) in both the U.S. and India in the 1970's. The joint U.S.-Canada CTS (Hermes) satellite used the then new 11/14 GHz frequencies to provide direct-to-user experimental TV service to users in both Canada and the U.S.; indeed the writer recalls viewing a hocky game originating in Montreal while a guest at the Canadian Embassy in Lima, Peru in 1978. These 11/14 GHz frequencies were also used by Japan for an experiment in direct-to-user TV broadcasting using the Japan BSE (Broadcast Satellite for Experimental Purposes) which was built in the U.S. by General Electric. In the Soviet Union, the EKRAN system was created in 1974 using the STATSIONAR-T satellite operating at a 714 MHz down-link (6 GHz up-link) to provide community reception of TV (rebroadcast at 50 MHz) in Siberia.

The above activities have served to call attention - worldwide - to the use of communication satellites from television broadcasting for community and direct-to-user services, and WARC-77 and WARC-79 provided the necessary frequency allocations and interference requirements which now are encouraging many other countries to make commitments to direct TV broadcasting from space. These countries include India, Australia, France, Germany, The Scandinavian Countries, Italy, PRC, and as a "Phase 2", both Canada with Anik's B and C, and Japan with plans for an advanced commercial broadcast satellite. In the United States, a partnership of COMSAT General and Sears Roebuck explored the feasibility of introducing direct-to-user TV broadcast from space into the U.S. mainland.

The activity has provided the impetus for what is a virtual technological explosion based on the use of giant satellites with high EIRP which can access small inexpensive earth terminals.

This report is intended to document and identify this technological explosion in both satellite design and earth terminal design. It will introduce present and planned TV space broadcasting systems; provide an overview of WARC-77 and WARC-79 requirements which relate to EIRP, interference, and G/T; discuss critical satellite technology relative to generating EIRP up to 65 dbw at 12 GHz from modern shaped-beam antennas positioned with proper satellite pointing accuracy; discuss the technology of small TV broadcast earth terminals from the standpoint of design for achieving low side lobes and high G/T and using modern integrated circuits, and provide a cost analysis of both the satellite and the earth terminal which will indicate the economics of satellite television broadcasting networks with a large number (100,000, 1 million, 10 million) of receiving terminals.

2.0 FREQUENCY AND SYSTEM REQUIREMENTS

2.1 Introduction - Heritage of WARC-77.

Following WARC-77, television broadcasting from space and conservation of both radio spectrum and geosynchronous orbit became worldwide concerns which recently led 154 nations to meet in Geneva, Switzerland during the final months of 1979 at WARC-79 to consider how to regulate and plan the future implementation of TV-broadcasting using TV-satellites on a global basis.

WARC-77 was convened in Geneva on January 10, 1977, under recommendation of the Plenipotentiary Conference, Malaga, Torremolinos, of 1973 in response to Resolution No. SPA 2-2 of WARC-71 for space telecommunications. WARC-77 was held to plan for broadcast satellite service in the frequency bands 11.7-12.2 GHz for Regions 2 and 3 and 11.7-12.5 GHz for Region 1. The objectives of this conference were to:

- o Establish the sharing criteria for the bands 11.7-12.2 GHz (in Regions 2 and 3) and 11.7-12.5 GHz (Region 1) between the broadcasting satellite service and the other services to which these bands are allocated.
- o Plan for the broadcasting satellite service in these bands.
- o Establish procedures to govern the use of these bands by the broadcasting satellite service and by the other services to which these bands are allocated.
- o Consider the results of the work of the Group of Experts on the possible rearrangement of the Radio Regulations and the Additional Radio Regulations.

These objectives resulted from a growing awareness of the potential of TV broadcasting from space, and recognized that the very nature of satellite communications offered a tool to bring government, education, and entertainment to areas heretofore not satisfactorily reached by terrestrial systems.

WARC-77 resulted in a priori planning for Regions 1 and 3, by providing a plan that divided up the 11.7-12.5 GHz band into 40 TV channels and provided special orbital positions spaced at 6 degrees. Each administration in these regions was assigned one or more assignment units, each consisting of five TV channels and an associated fixed orbit location. Larger countries, such as PRC, were assigned three units and the USSR six assignment units. Each channel at each orbital position was assigned a special elliptical contour on earth centered by a boresight specified in geographical coordinates, an antenna beamwidth, orientation of the ellipse, a polarization, and the satellite EIRP. Figure 2 shows a typical assignment of patterns on earth from various orbital positions for a single selected channel, showing how this a-priori planning also attempted to solve the problem of interference. One advantage of this assignment, which is unique to TV broadcast, is the ability to structure an orbital system using similar or homogeneous satellites with EIRPs in the 62-to-67-dBw range. This system was designed to use small earth terminals with a G/T of 6 dB/K and antenna beamwidth of 2 degrees (around one meter in diameter) to make possible very-low-cost earth segments operating with high-power, costly space segments.

Region 2 (North and South America) was accorded only interim provisions pending future establishment of a detailed plan for broadcast satellites in the 11.7-12.2 GHz frequency band. This future plan was postponed to a regional WARC to be held in 1982 with the specific objective of using WARC-79 decisions to foster a mutually acceptable plan to all countries concerned, designed to reduce technical difficulties and incompatibilities with systems of other regions.
The WARC-77 directive specifically said, "It should be laid down as a matter of principle that each administration in the Region should be guaranteed a minimum number of channels (4) for the operation of the broadcasting-satellite service.

Above this minimum, the special characteristics of the countries (size, time zones, language differences, etc.) shall be taken into account."

Region 2 had a problem of frequency allocations at 11 GHz that was not present in Regions 1 and 3. In Regions 1 and 3, the present bands, 10.95-11.2 GHz and 11.45-11.7 GHz, are shared by fixed satellite (non-TV broadcast) with terrestrial radio and mobile radio. TV broadcast is allocated separately from fixed satellite service into the higher frequency bands of 11.7-12.5 GHz in Region 1 and 11.7-12.2 GHz in Region 3. In Region 2, the present allocation for North and South America includes these fixed satellite bands, but the 11.7-12.2 GHz band is shared by broadcast satellites and fixed satellites. The early status of satellite communications, when these allocations were made, and the understandable myopia involved in looking forward at that time, led to this incredible example of the danger of a-priori planning. It forced the United States and Canada to seek higher-frequency bands to escape the crowded C-band up-down links. This led to the development of Anik-B, Anik-C, and Satellite Business Systems (SBS) for fixed satellite service in the 11.7-12.2 GHz band, which had been used by the pioneering CTS broadcast satellite. Immediate concern arose for the problems caused by inhomogeneous satellites (high and low EIRP) sharing for same frequency band and orbit space. WARC-77 compromised by separating the orbital locations used by broadcast satellites from an orbit space used by fixed service satellites such as Anik-B and SBS, i.e., broadcast satellites were authorized for the geostationary orbit from 75°W to 100°W longitude (however, for service to Canada, the United States, and Mexico, the space was restricted to 75°W and 95°W) and from 140°W to 170°W longitude (Fig. 3).

WARC-79 then responded to recommendations by the United States to provide for a Ku-band TV broadcast downlink frequency band which would escape potential interference from the growing use of the 11.7-12.2 GHz band in fixed satellite services by allocating the frequency band 12.2-12.7 GHz exclusively for broadcast satellite services with the provision of sharing the lower portion of this band with fixed satellite services until a resolution could be made at SPACE WARC to be held in 1983.

2.2 TV Space Broadcasting Frequencies.

Table 2-1 lists the principal TV space broadcasting frequencies now assigned by WARC-79 for Regions 1, 2, and 3.

The UHF band and S-band downlink frequencies are for community television services; i.e., reception from space and retroadcast locally. These frequencies are presently, or will be, in use in operational systems. The Soviet Statsionar-T community-service broadcast satellite uses a downlink of 714 MHz, while the India satellite INSAT will provide community service TV-broadcast in S-band.

As indicated by Table 2-1, the 12.2-12.7 GHz band is now the broadcast satellite service downlink for Region 2 (North and South America, etc.) and this report will address this frequency band in consideration of both broadcast satellites and earth terminals in the succeeding sections.

Millimeter wave frequencies had also been allocated for broadcast satellite service and have been considered for digital systems in Europe, but are not a consideration of this report.

2.3 WARC-77 and WARC-79 Requirements.

Table 2-2 lists the basic requirements of both individual reception (direct to user) and community reception provided by WARC-77 for Regions 1 and 3. These requirements list not only the basic satellite, signal, and earth terminal characteristic but also allocated certain channels of the 40 channels in the 11.7-12.5 GHz band to each country complete with beam size and footprint, orbital location and boresight angles. Figure 2-1 illustrates the typical layout of footprints at one channel.

TABLE 2-1

(A) SUMMARY OF PRINCIPAL TV BROADCASTING SATELLITE DOWNLINK FREQUENCY ALLOCATIONS FOR REGIONS 1 AND 3

Frequency		Available Bandwidth
*620-790 MHz (UHF)		170 MHz
*2500-2690 MHz (S-Band)		190 MHz
11.7-12.2 GHz	$\left.\right\}$ (Ku-Band) Region 3	500 MHz
*12.5-12.75 GHz		250 MHz
11.7-12.5 GHz (Ku-Band)	Region 1	800 MHz
40.5-42.5 GHz		2000 MHz
84-84 GHz		2000 MHz

(B) SUMMARY OF PRINCIPAL TV BROADCASTING SATELLITE DOWNLINK FREQUENCY ALLOCATIONS FOR REGION 2

Frequency	Available Bandwidth
*620-790 MHz (UHF)	170 MHz
*2500-2690 MHz (S-Band)	190 MHz
**12.1-12.3 GHz	200 MHz
12.2-12.7 GHz (Ku-Band)	500 MHz
40.5-42.5 GHz	2000 MHz
84-86 GHz	2000 MHz

* Community reception systems only
** Lower part of band allocated at WARC-79 to be shared with fixed satellite service. To be resolved at Space WARC-1983.

TABLE 2-2

BROADCASTING SATELLITE PLAN BY WARC-77 FOR REGIONS 1 & 3

System Characteristics	
Satellite Spacing	6 degrees
Frequency Band	11.7-12.5 GHz
Channel Spacing	19.18 MHz
Number of Channels	50
Polarization	Circular (RH and LH)
Modulation	FM
Signal Processing	CCIR Pre-emphasis
Energy Dispersal	600 kHz, pk-pk
RF Channel Bandwidth*	28 MHz
C/N Objective	14 dB
C/I Objective (co-channel)	31 dB
PFD (Individual Reception)	-103 dBW/m^2, edge of coverage
PFD (Community Reception)	-111 dBW/m^2
Protection Ratio between Two FM Signals	31 dB Co-Channel 15 dB Adjacent Channel
Satellite Characteristics	
EIRP per Beam	from 60.8 to 68 dBW
Minimum Required Transmit Beamwidth	0.6° elliptical or circular
Pointing Accuracy	$\pm 0.1^\circ$ N-S and E-W
Station-keeping	$\pm 0.1^\circ$ N-S and E-W
Earth Stations	
G/T Individual Reception	6 dB/$^\circ$K
G/T Community Reception	14 dB/$^\circ$K
Antenna Beamwidth (individual)	2°
Antenna Diameter (individual)	about 1.0 meter
Antenna Beamwidth (community)	1°

* 525 line in Region 2, 18 and 23 MHz

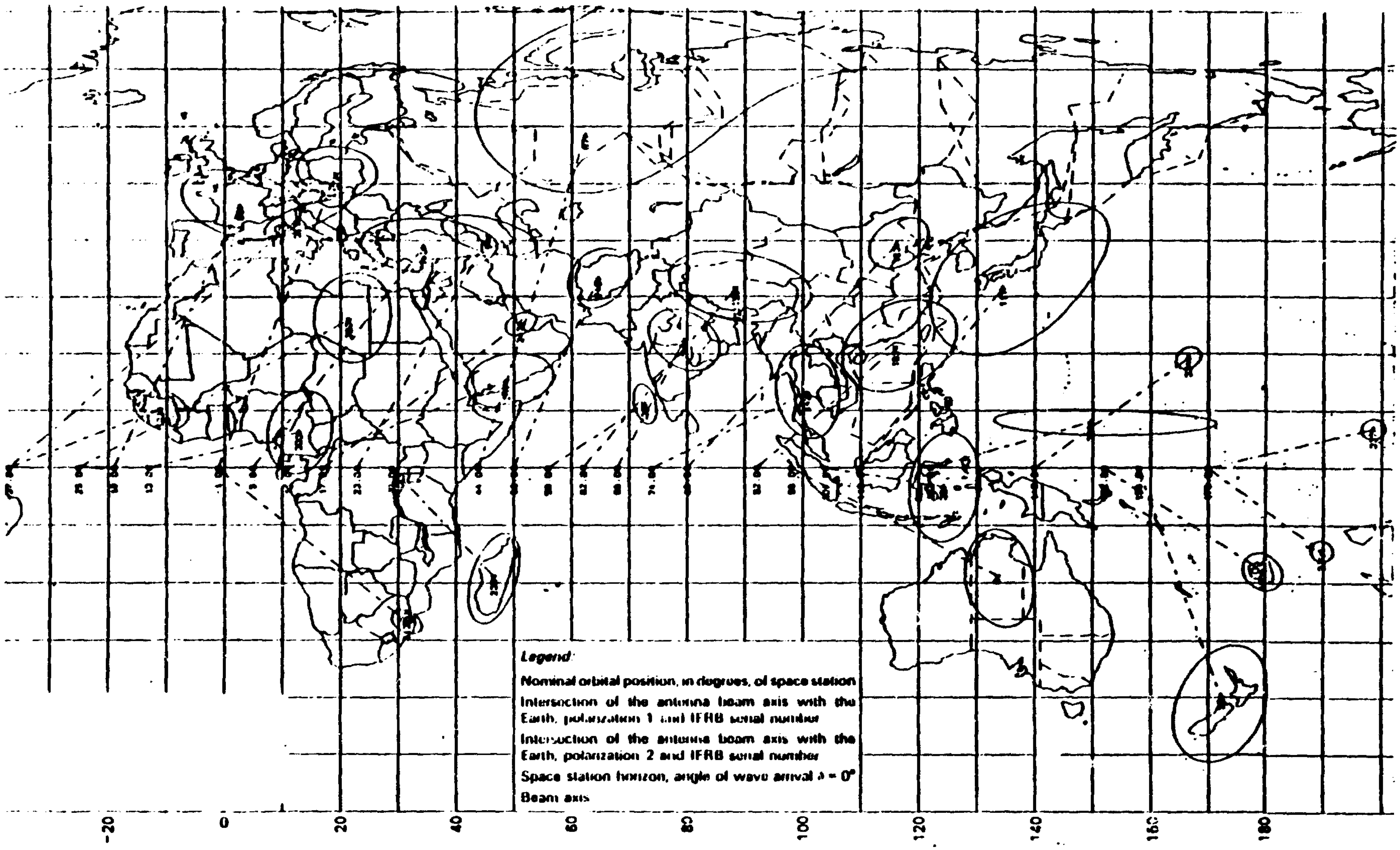

Figure 2-1

Ford Aerospace & Communications Corporation
Western Development Laboratories Division

Region 2 was allotted the 12.2-12.7 GHz band at WARC-79 for broadcast satellite service as discussed above, but while the general guidelines of Regions 1 and 3 can be still considered as baseline to Region 2, many issues relating to channels, orbital spacing, orbital location, interference and protection ratios are yet to be resolved and will no doubt be addressed at SPACE WARC-83.

2.4 Satellite EIRP and Earth Terminal G/T for Broadcasting Satellite Service in Region 2.

Table 2-3 lists the present CCIR power flux density limits for broadcasting satellites, and Figure 2-2 shows how existing satellites up to 1975 approached this limit using high power amplifiers and high gain antennas in the satellites.

The critical EIRP and G/T parameters to be used as guidelines in this report are derived from these limitations and are listed as follows:

	EIRP	G/T
UHF	42 dBW	0 dB/$^{\circ}$K
S-band	54 dBW	0 dB/$^{\circ}$K
Ku-band	63 dBW	8 dB/$^{\circ}$K

While these guidelines are arbitrary, they are in accordance with not only the PFD limits, but at Ku-band, are consistent with the EIRP in dBW now permitted in Regions 1 and 3.

2.5 Protection Requirements for Sharing.

The broadcast satellite service has been given specific sharing criteria by the CCIR with respect to protection requirements relative to the carrier-to-interferences ratio arising from an interfering signal. Table 2-4 lists the protection requirements for Regions 1, 2 and 3 for broadcast satellite service at 12 GHz from a variety of interfering services as stated in the WARC-77 "FINAL ACTS" published by The International Telecommunication Union in Geneva,

TABLE 2-3

POWER FLUX DENSITY LIMITS FOR BROADCASTING SATELLITES

Frequency Band	PFD Limits* (E = Elevation Angle)
620-790 MHz	-129 dBw/m^2/2 MHz for E $<20^\circ$ -129 + 0.4 (E-20) dBw/m^2 2 MHz for $20 < E \leq 60$
2500-2690 MHz	-152 dBw/m^2/4 kHz for E $<5^\circ$ $-152 + \frac{3\ (E-5)}{4}$ dBw/m^2/4 kHz for $5^\circ < E < 25^\circ$ -137 dBw/m^2/4 kHz for E $> 25^\circ$
11.7-12.2 GHz	-125 dBw/m^2/4 kHz Circular Polarization** -128 dBw/m^2/4 kHz Linear Polarization**
22.5-23 GHz (Region 3)	Subject to PFD Limits for the Protection of Terrestrial Services in this Band.
41-43 GHz	None
84-86 GHz	None

* May be exceeded on the territory of any country the administration of which has so agreed.

** Into Regions 1 and 3 from stations in Region 2.

TABLE 2-4

Wanted Service[1]	Wanted Signal[1]	Interfering Service[1]	Interfering Signal[1]	Protection Requirements[2,3]	
				Total Acceptable	Single Entry
BSS	TV/FM	BSS, FSS, FS, BS	TV/FM	C/I = 30 dB	C/I - 35 dB
BS	TV/VSB	BSS	TV/FM	C/I = 50 dB	Not Appliable

Notes: 1 - BSS = broadcasting-satellite service
FSS = fixed-satellite service
BS = broadcasting service
FS = fixed service
TV = television
FM = frequency modulation

2 - These limits include both up-link and down-link contributions. They are expressed:

- in dB for carrier-to-interference ratio
- in pWOp for noise
- in $dBW/m^2/4$ kHz for power flux density in a 4 kHz band

3 - For antennae larger than 100λ (2.5m) in the fixed-satellite service, the gain of the side-lobes is given by the equation 32-25 log θ, where θ is the angle from the boresight (CCIR Recommendation 465). The side-lobe gain is independent of antenna diameter.

Switzerland. As indicated, a total acceptable C/I of 30 db of protection from an interfering signal is required, which in turn will largely specify the pattern satellite and earth terminal antenna patterns for maximum utilization of the orbital arc.

2.6 Orbital Position Considerations.

Optimal orbital use by broadcasting satellites is a subject far beyond the scope of this report. However, the relation between orbital spacing, earth terminal antenna diameter, frequency, and db level of interfering signal has been studied by J. McElroy (Fig. 2-2) and W. Morgan (Fig. 2-3) showing the critical nature of orbital spacing which will dominate the worldwide consideration of the geostationary orbit for years to come.

In the a-priori planning of both broadcast satellite orbital utilization and channel allocation provided by WARC-77, an orbital spacing for Regions 1 and 3 of 6° was adopted. This spacing was adopted using the spacecraft antenna pattern criterion shown in Figure 2-4 and earth terminals adhering to the 32-25 log θ formula. However, in Region 2, there is an opportunity to develop more technologically paced guidelines for orbital spacing based more on the use of sophisticated multiple-beam antennas, without the restrictions of a-priori planning.

Actually the 6° spacing of broadcast satellites adhering to the modest antenna sidelobe requirements of Figure 2-4 will provide illumination with significant flux density far beyond individual national boundaries in most cases - and the multiple-beam spacecraft antenna - to be discussed in this report is the technology which can alleviate a severe potential political problem based on the so-called "Prior Consent Issue" and the "Spillover Issue".

According to Dr. Delbert Smith, writing in Satellite Communications for March, 1979, "The issue of prior consent seems to be the most difficult issue to resolve. Most nations have agreed to or actively advocate a prior consent requirement. The United States has been the only major dissenter. The practical fact is that sovereign states will not accept a broadcast, much less pay for one, unless they can maintain some control over the program content to prevent "harmful effects". Using this argument, one can see that broadcasters can expect higher sales to receiving states by giving the buyer control through a contract. This is a type of limited prior consent which would be consistent with U.S. constitutional law and broadcasting practice.

The technical issue of spillover also falls under the prior consent issue. As the satellites become more sophisticated it will be possible for the broadcaster to maintain a good deal of control over the direction of the signal. But, in certain areas of the world there may always be some inadvertent irradiation from the satellite. For those broadcasts not of a regional character, this may cause some international political friction.

The burden to control this problem will probably fall with the broadcasting rather than the receiving country. This would be consistent with regulations concerning spillover as determined by the ITU. The Swedish-Canadian approach, is based on these regulations.

If prior consent is accepted as a means to deal with spillover, it will probably come into effect in a limited number of situations. Exemptions will probably be provided in situations where the elimination of the spillover is technically impossible, as defined by the ITU Radio Regulations. Other situations not requiring consent could be those where a broadcast is entirely domestic in character and where the broadcast cannot be easily received in the third state.

Consent would still be required where the spillover broadcast was aimed at a particular audience within the receiving state. Some provision promoting international consultations as a means to avoiding dispute will probably also receive support for inclusion in a final document.

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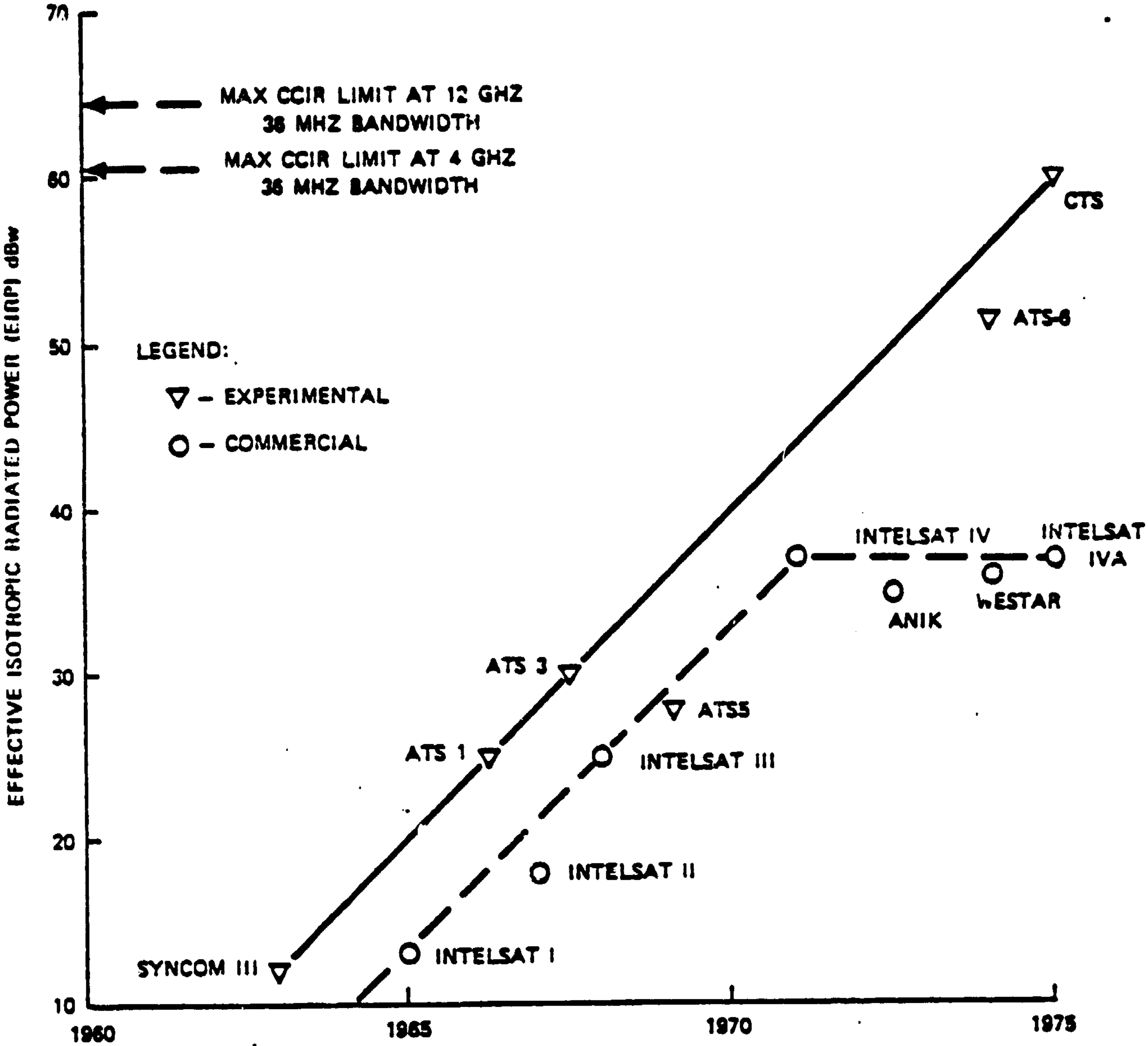
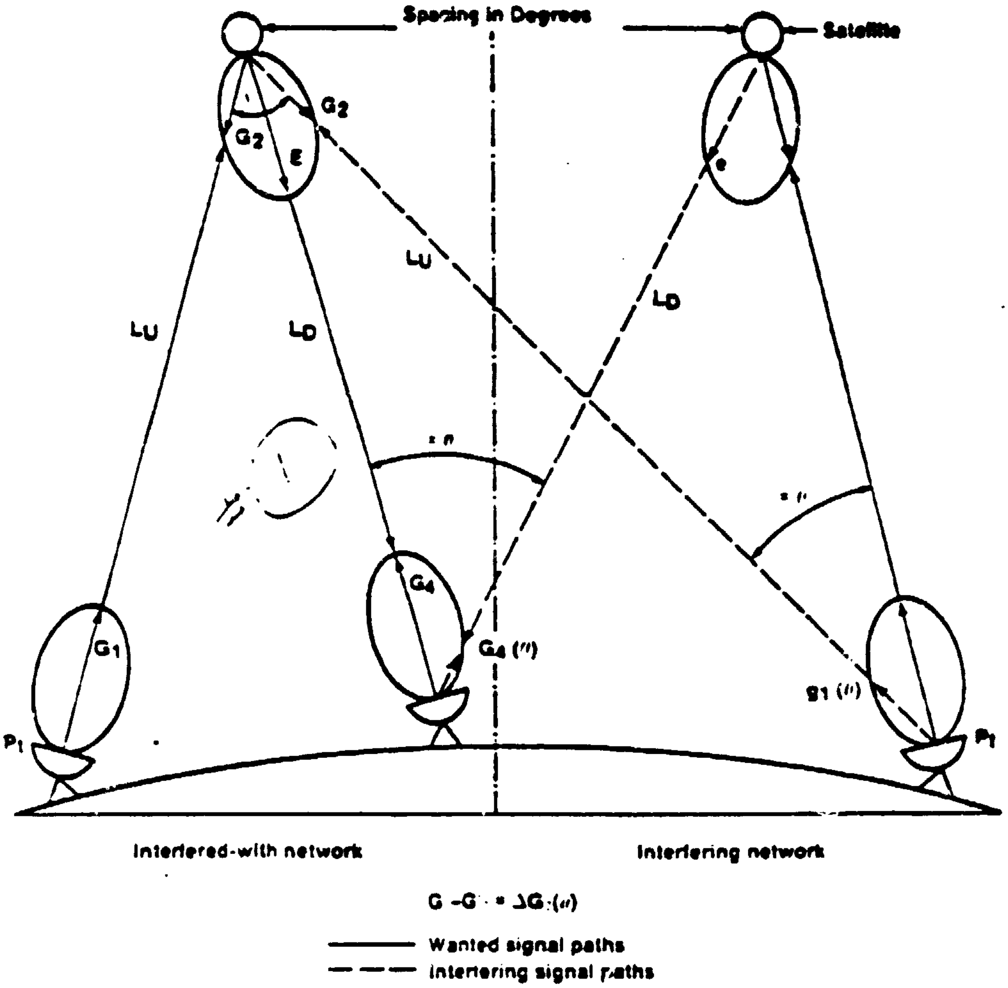


Figure 2-2

Growth in Geosynchronous Communication Satellite Radiated Power with Time.

Satellite Spacing vs Earth Station Sidelobe Interference Levels

Interference Geometry Between Satellite Networks



Effect of Increased Frequency on Earth Station Sidelobe Interference Levels and Permissable Satellite Spacing—Dr. John McElroy of NASA

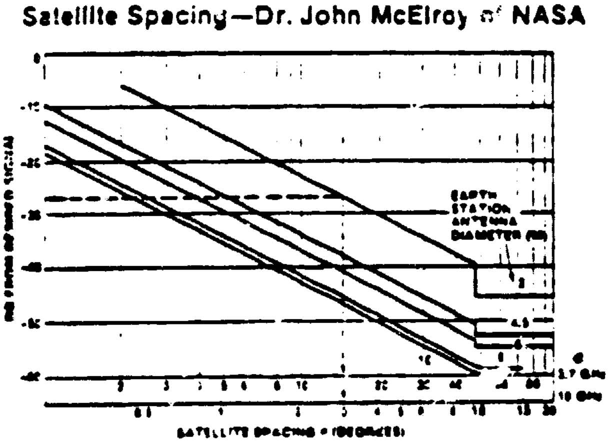


Figure 2-2A

Earth Station Sidelobe Interference Levels—W. Morgan

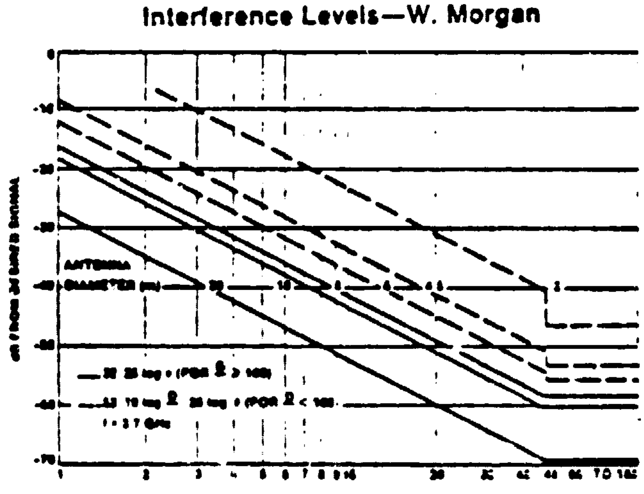
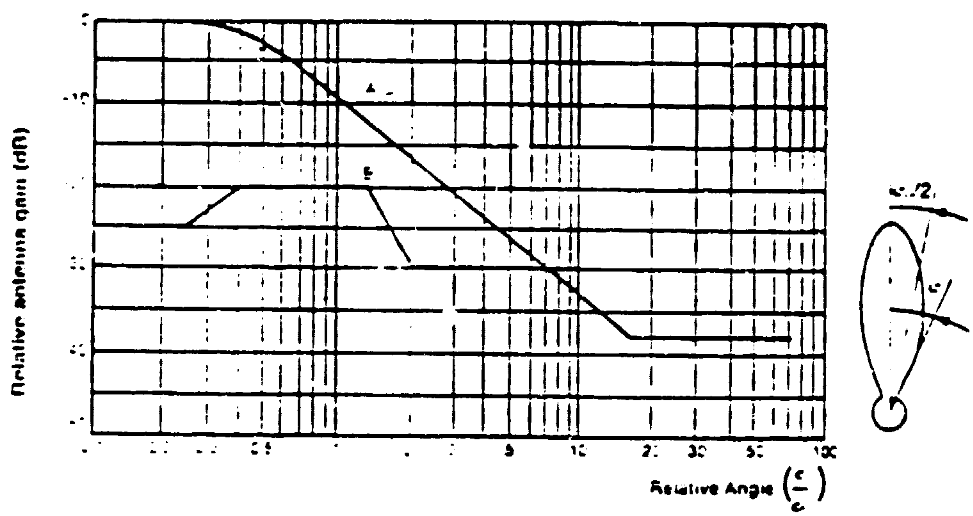


Figure 2-3

Antenna Patterns For TV Satellite Broadcasting According to WARC-77



Reference patterns for co-polar and cross-polar components for receiving antennas for individual reception in Region 2

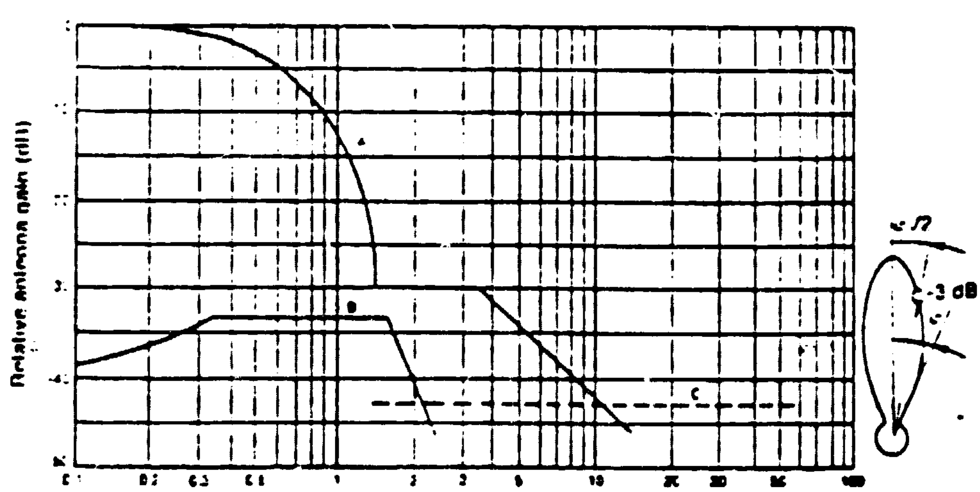


FIGURE 2-4

Reference patterns for co-polar and cross-polar components for satellite transmitting antenna

3.0 PRESENT AND PLANNED BROADCAST SATELLITE SYSTEMS

3.1 Introduction.

Broadcast satellite technology by 1980 was already entering its second generation of satellite. ATS-6 and CTS had both been retired after long years of service for testing community service TV-broadcast and individual-user TV-broadcast; the USSR Statsionar-T broadcast satellite was transmitting operationally into thousands of community terminals in Siberia; Japan's Broadcast Satellite for Experimental Purposes (BSE) was in test,* and Anik-B followed CTS. In development were India's INSAT, and both France and Germany had authorized a start of construction of a TV-Sat for each country.

Tables 3-1 and 3-2 list the principal parameters of the broadcast satellites which have achieved operational or experimental use in space at UHF, S-band, and Ku-band. Note that the EIRP's are not to the range of 60-68 db used by WARC-77 to permit broadcasting into small 1-meter terminals at 12 GHz. Rather EIRP's of 50-60 db were used which actually was a significant technical advance over the 34-36 dbW typical of conventional fixed services satellites.

The next paragraph will discuss the salient parameters of those satellites which provide a technology base to high power broadcast satellites of the future where EIRP's of around 63 db will be commonplace. However, attention is called to the Canadian Anik-B experiment, which after the pioneering high power CTS, is now testing broadcast satellite operation using EIRP's as low as 51 dbW which is intended to simplify satellite design while retaining the feature of small inexpensive earth terminals.

The next section will provide signal and modulation formats, link budgets, and key operating characteristics service of the broadcast satellites listed in this section as an introduction to the satellite and earth terminal design and technology descriptions to be described in Sections 5 and 6 respectively.

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* BSE failed in Spring 1980.

TABLE 3-1

TV BROADCAST SATELLITES WHICH HAVE ACHIEVED OPERATION IN SPACE

Satellite:	ATS-6	CTS-Hermes	Japanese BSE Broadcast Satellite for Experimental Purposes	Stationar-T
Country of Origin:	USA	Joint USA and Canada	Japan - Satellite Built in USA	USSR
Countries Used:	USA, India	USA, Canada	Japan	Siberia
Frequencies Used for Broadcast:	860 MHz, 2.6 GHz	11.7-12.2 GHz	11.7-12.2 GHz	716 MHz
Launch Vehicle:	Titan III-C	Thor-Delta 2194	Thor-Delta 2914	
Number of TV Channels/ Transponders:	2 TV Channels at 2.6 GHz or one TV Channel at 860 MHz	Two 85 MHz transponders	Two TV Channels 50 MHz and 80 MHz	One
EIRP:	52.5 dBw Either Channel	60 dBw with 200 Watt TWT	55 dBw	55 dBw
Power Amplifier:	Transistor Power Amp 80-100 Watt	200 Watt TWT 20 Watt TWT	100 Watt TWT	200 Watt Klystron
Satellite G/T:	-----	7.8 dB/k^{o}	8.2 dB/k	5 dB/k

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TABLE 3-2

	CTS	Japan BS	ANIK B	INSAT		Statsionar T
Service	Fixed Experimental	Broadcast Experimental	Fixed Tel.	Fixed TV and Radiometry		Fixed
Frequencies	Ku	Ku	C/Ku	S	C	UHF
Launch Vehicle	Thor-Delta 2914	Thor-Delta 2914	Thor-Delta 3914	3910		A-2 Soyuz
Prime Contractor	CRC Canada	Toshiba/GE	RCA	Ford		
Stabilization	3-axis	3-axis	3-axis	3-axis		3-axis
Mass (kg)	350	352	440	1,054 (into transfer)		1,250
Primary Power (W)	1,260	1,000	840	1,250		2,000
Coverage	1,850-km spot	Japan	Canada	India		Spot on Siberia
Number of Transponders	2	2	12/6	2	12	2
Transponder Bandwidth (MHz)	85	50 80	36 72	36	36	40
Number of Antenna Beams	2	1	1 4/1	1		1
Polarization	linear	linear	linear	linear		linear
G/T (dB/k) (Figure of Merit)	7.8	-8.2	-6/-1	---		-15.8
EIRP (dBw) (Effective Isotropic Radiated Power)	60	55	36 47.5	34	42	60
Modulation	fm video	fm and digital	FDM/fm QPSK SCPC	fm QPSK		fm
Multiple Access	FDMA	SCPC	FDMA TDMA	FDMA		

The broadcast satellites to be described in this section did more than innovate the use of down-links from geostationary orbit for TV-broadcast; they started the development of new technologies which are needed to implement the basic requirement of high satellite EIRP to make possible the use of small inexpensive earth terminals. These satellites helped pioneer 3-axis body-stabilized technology, creating stationary platforms in space which could be used in fixed service satellites.

3.2 U.S. Systems.

The United States has been the pioneer in the development of TV-broadcasting satellites; NASA's ATS-6 and the joint U.S.-Canadian CTS (Hermes) were the first to introduce this unique service to a variety of users in more than ten countries and these satellites have done much to demonstrate to the world the advantages of both community reception and individual user reception in the areas of education, public service, disaster relief, direct broadcast into the home, and many other services which have wide appeal to governments which have rural areas and widely dispersed population areas which cannot be normally reached by conventional terrestrial communication systems.

The United States has a situation relative to TV-broadcasting from space which is perhaps unique in the world. The existence of powerful TV networks connected by terrestrial microwave radio, and the enormous growth of a free-enterprise cable TV system using domestic satellite transponders at 4/6 GHz for TV distribution has made TV-broadcast to the home less than attractive to most populated areas.

Accordingly, while the technical interest in TV-broadcast satellites was high in the United States during the 1970's, the actual user and government interest was relatively low and will probably remain low until broadcast satellites with only a few channels can compete with low cost Cable TV systems offering more than 24 channels.

3.2.1 ATS-6.

ATS-6, shown in Figure 3-1, was the pioneering broadcast satellite providing TV down-links at 2.54 GHz and 860 MHz. This satellite, launched in May 1974 (Table 3-3), provided significant experimental experience which "opened the doors" to broadcast satellite development.

Table 3-4 lists the experiment details which were used to provide a significant educational experiment in India at 860 MHz (UHF) for one year, and transmission at 2.54 GHz (S-band) in the United States for many educational systems including a 150 terminal Rocky Mountain Education Experiment which brough educational materials to schools in remote mountainous areas.

ATS-6 was among the first, with Russia's Statsionar-T, to use high transmitter power in space (around 100 watts from powerful transistor amplifiers - the Statsionar-T used a 200 watt Klystron). Another innovation was the development of a low cost 2.54 GHz low noise transistor amplifier and a direct frequency discriminator developed by Hewlett Packard and a 10-foot diameter reinforced plastic antenna developed by Prodelin Company of Santa Clara, California. These terminals inaugurated the era of low cost terminals representing individual total terminal costs of less than $5000.

3.2.2 COMSAT System

In 1979, COMSAT and SEARS ROEBUCK announced intention to provide a broadcast satellite to be designed by COMSAT and marketed by Sears. While the details of this satellite were not made public and the partnership was dissolved, it is known that the satellite design that was considered was for use at 12 GHz providing four beams into four time zones respectively in the United States and using small 1-meter TVRO terminals at each home on a subscription basis.

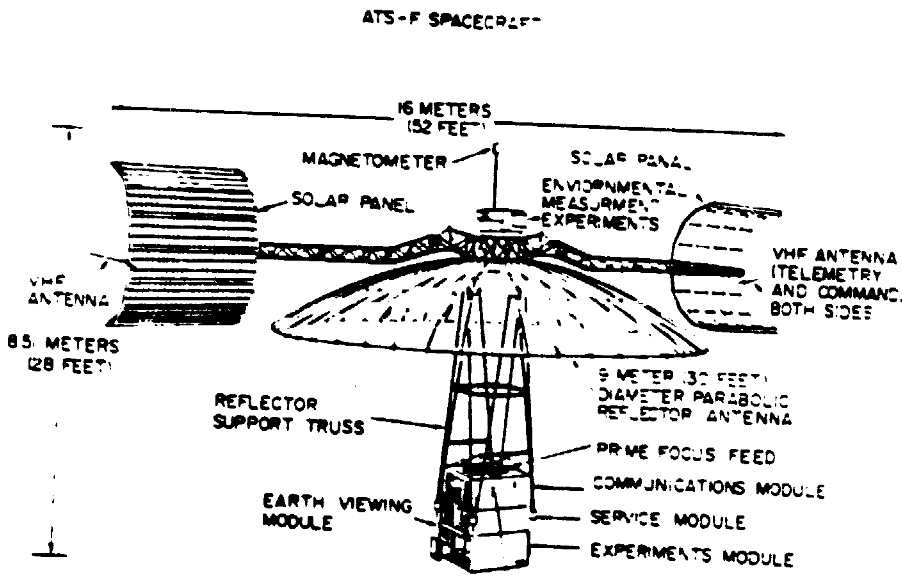


Fig. 2. Orbital configuration for ATS-6

Figure 3-1

TABLE 3-3

ATS-6 SATELLITE CHARACTERISTICS

Shape, Size	30-ft. diameter parabolic reflector, 6.5-ft. diameter hub section with copper-coated dacron mesh supported by 48 aluminum ribs. Earth-viewing module at antenna focus with experiment sections and supported subsystems, 54 x 54 x 65 in. 2 solar arrays (deployed in space), each half a cylinder, 54-in. radius, 94 in. long. Maximum height 27 ft. 6 in. Maximum span 51 ft. 8 in.
Weight	2970 lbs.
Power	Solar cells and NiCd batteries 645-W initial maximum 415-W minimum after 5 yrs.
Stabilization	3-axis stabilized, 0.1° pointing accuracy Pointing to any location on earth Tracking of low altitude satellite over $\pm 11^{\circ}$ from local vertical.
Design Life	2 yrs. (required) 5 yrs. (goal)
Orbit	Synchronous equatorial; 94°W longitude until June 1975, 35°E longitude from July 1975 to July 1976, 105°W longitude thereafter.
Orbital History	Launched 30 May 1974 Tital IIIC launch vehicle In use (June 1976)
Developed By	NASA Fairchild

TABLE 3-4

ATS-6 TV Broadcast Experiment Details

Satellite Instructional Television Experiment (SITE)

Configuration	40-MHz bandwidth double conversion repeater	
Transmitter	860 MHz (3750 MHz used occasionally to monitor signals	
	80-W output, 51.0-dBw ERP peak	
Receiver	5950 MHz	
	G/T:	-17 dB/$^{\circ}$K peak
	Transmit:	30-ft. parabola, 33-dB peak gain, 2.8° beamwidth, circular polarization
	Receive:	Horn, 16.3-dB peak gain
		13° x 20° field of view, linear polarization
		(30-ft. parabola might be used for receiving instead of horn, 48.4-dB peak gain, 0.4° bandwidth, +13.7 dB/$^{\circ}$K G/T)

Health/Education Experiment

Configuration	Forward Link:	Two 30-to 40-MHz bandwidth repeaters for 2 FM-TV carriers with sound subcarriers plus separate telephone carriers
	Return Link:	For telephone carriers
Transmitter	2470 and 2670 MHz (also C-band for monitoring)	
	15-W output, 53.0-dBw peak ERP	
Receiver	5950 MHz	
	G/T: -17 dB/$^{\circ}$K peak	
Antenna	Transmit:	30-ft. parabola, 41.5-dB peak gain, 1° beamwidth, circular polarization
	Receive:	Horn, 16.3-dB peak gain
		13° x 20° field of view, linear polarization
		(30-ft. parabola might be used for receiving instead of horn, 48.4-dB peak gain, 0.4° bandwidth, -13.7 dB/$^{\circ}$K G/T)

Presently, COMSAT has formed a subsidiary to provide direct broadcast satellite service and has obtained permission to proceed with satellite and earth terminal design. (See section 3.8.4)

3.2.3 FCC Deregulation Results.

In 1979, the FCC deregulated the use of the 4 GHz commercial satellite down-links making it now within the law to receive commercial TV-modulated carriers provided by the transponders, WESTAR, SATCOM 1, 2, and COMSTAR, for commercial users of TV signal distribution, without requiring a license.

This deregulation now eliminates the need for expensive coordination and filing by commercial earth terminal users and has indeed made possible a massive business directed toward private TVRO terminals.

As a result of the growing use of C-band transponders for TV distribution, commercial earth TVRO terminal quantities are soaring (3400 in April 1980 and to exceed 10000 by 1983), and costs for 3, 4.5, and 7 meter terminals using $85^{o}K$ FET LNA's are coming into the 5000-15000 dollar range for commercial network quality reception; with earth terminal sales to exceed 1.1 billion dollars by 1990*.

In addition to the growth in commercial TVRO earth terminal production, a home-experimenter activity also developed in the U.S. with home-made TVRO terminals costing as low as 1-2 thousand dollars using unique and interesting new antenna techniques while making significant inroads into the development of low cost receivers using integrated circuits and components derived from modern color TV production lines and commercial microwave receivers.

3.3 Canadian Systems.

The Canadians were the first in the free world to build a domestic satellite, and they have continued their innovation in broadcast satellite technology by the development of CTS and ANIK-B.

*Microwaves, July 1979, Pg. 17

3.3.1 CTS (Hermes)

On April 20, 1971, the governments of the United States and Canada signed a Memorandum of Understanding. They agreed to undertake, on a joint basis, the development and launching of an experimental satellite, designated the CTS, Communications Technology Satellite, to extend communications technology to much higher power levels of transmission than had been previously used. This would permit the use of small, low-cost, ground terminals that would make communications services practical in areas not now served. Under this agreement, Canada designed and built the spacecraft at their Communications Research Center (CRC). NASA provided spacecraft test facilities at the Lewis Research Center and the Goddard Space Flight Center (GSFC) and also a high efficiency 200-watt traveling-wave-tube amplifier and power supply that operated in the 12- to 14-GHz band. A NASA Thor-Delta model 2914 launch vehicle placed the satellite in geostationary orbit. A consortium of European nations, through the European Space Research Organization (ESRO), also participated in association with the Canadian Government. U.S. and Canadian experimenters shared equally in the time allocation during the satellite's expected 2-year life.

The objective of the CTS program is to advance the technology of both spacecraft-mounted and related ground-based components and systems applicable to high-radiated-RF-power satellites. In order to achieve this objective, the spacecraft was designed to demonstrate new technology applications and conduct experiments on components and systems that will be applicable to future commercial communications satellites. The program also included communications experiments with user agencies, universities, and industrial groups in the United States and Canada.

Specific objectives included demonstrations of:

- A 12-GHz traveling-wave tube (TWT) with about 50 percent efficiency and with a nominal RF output power of 200 watts and the associated power processor required to convert the solar array power into an acceptable form to operate the TWT.
- The operation of an unfurlable solar-cell array delivering over 1 kW of useful power to the spacecraft.
- A three-axis stabilization system to maintain antenna boresight pointing accuracy to $\pm 0.1^{\circ}$ in pitch and roll and $\pm 1^{\circ}$ in yaw on a spacecraft with large flexible appendages.
- Color television transmission at 12 GHz from a satellite to small, low-cost ground terminals.
- Uplink television transmission at 14 GHz from small terminals.
- Audio broadcast to very small ground terminals.
- Two-way voice communication, wideband data transmission, and data relay.

Figure 3-2 shows the 3-axis body-stabilized CTS while Table 3-5 lists its pertinent technical details. It was a significant contribution to satellite by providing high radiated power ($\approx$60 dbw) at 12 GHz using a special 200 watt TWT built by Litton Industries in the United States. CTS pioneered the use of the 12 GHz down-link for broadcast satellites and gave impetus to the development of small 1-meter and 2-meter TVRO earth terminals for use in not only Canada and the United States but also in Japan where the Japanese NASDA and Radio Research Laboratories were pointing toward the Japan BSE.

3.3.2 Anik-B. (Figure 3-3).

Anik-B, built by RCA with both C-band and 11/14 GHz transponders is a 3-axis body-stabilized satellite using for 12 GHz 20 watt TWTs which, using

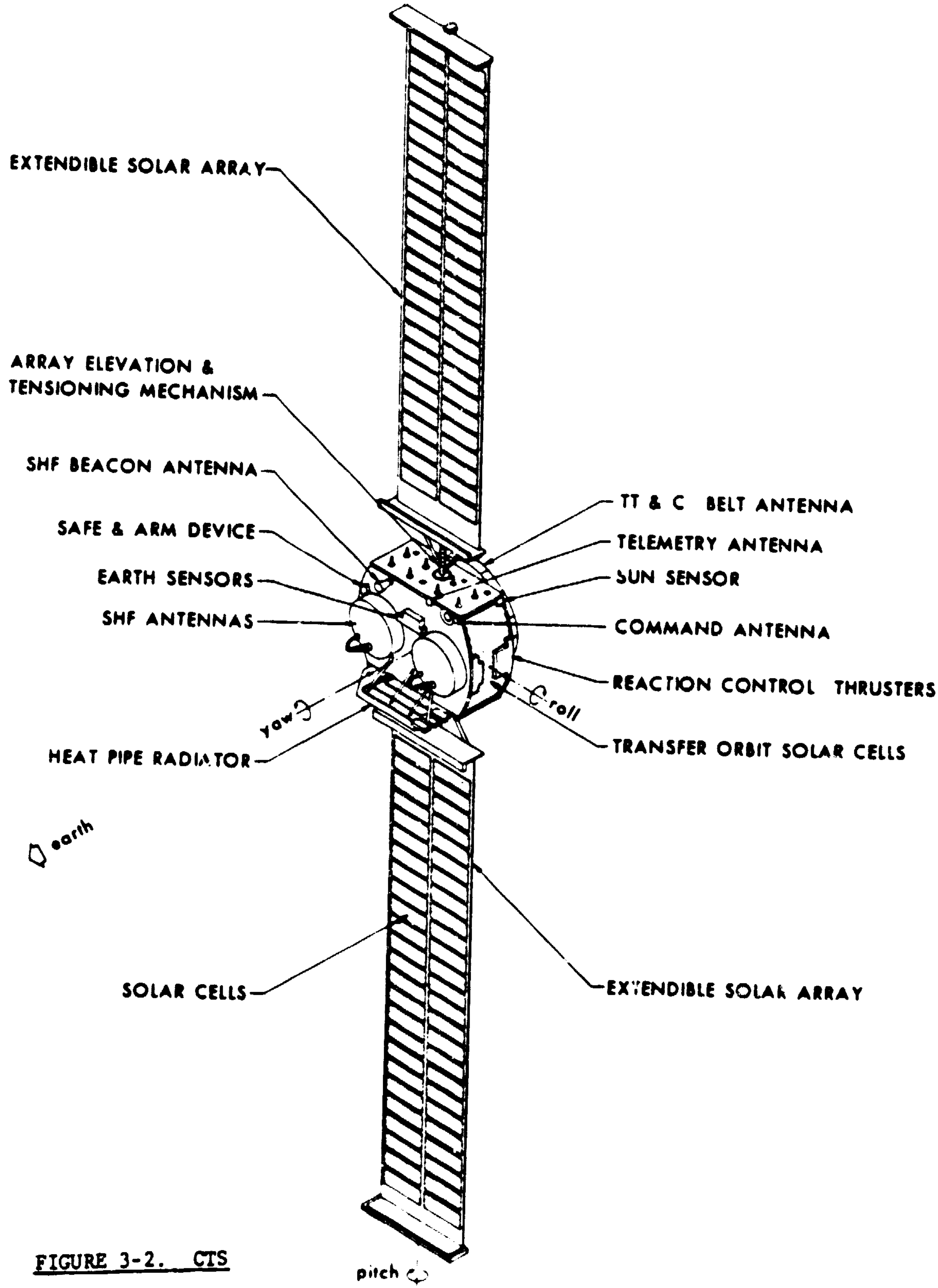
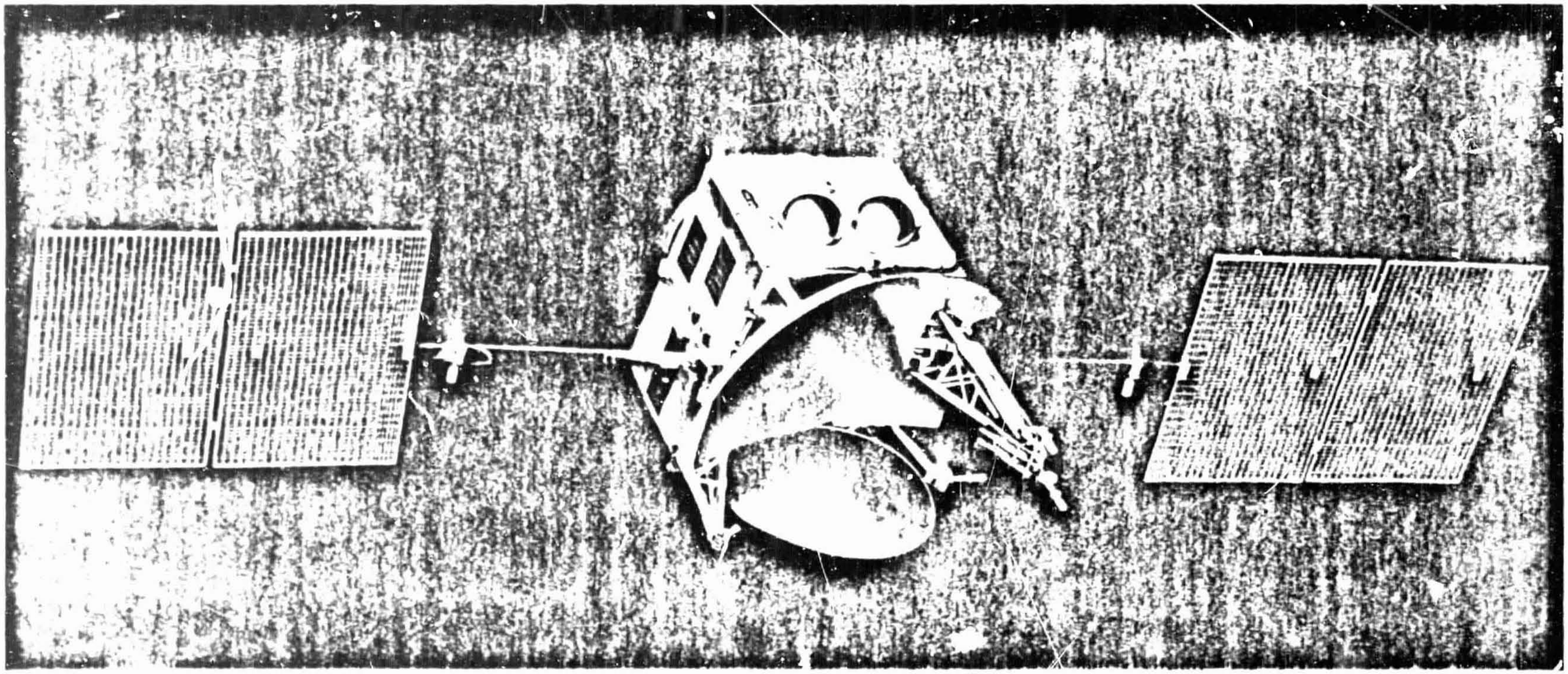


FIGURE 3-2. CTS

TABLE 3-5

CTS TECHNICAL DETAILS

Satellite	Body 72-in. diameter, 74 in. high with 2 solar arrays 50 in. wide, 20 ft. 4 in. long; total satellite span 52 ft. 9 in. 738 lbs. Solar cells and NiCd batteries, 1260 W initially, 918-W minimum after 2 yrs. 3-axis stabilization, $\pm 0.1^{\circ}$ about pitch (north-south) and roll (velocity vector) axes, $\pm 1.1^{\circ}$ about yaw (radial) axis
Configuration	Two 85-MHz bandwidth single conversion repeaters
Transmitter	11.843 to 11.928, and 12.038 to 12.123 GHz Normal configuration 20-W TWT on low band and 200-W TWT on high band, alternately both bands share the 20-W TWT (at reduced capability)
Receiver	14.010 to 14.095 and 14.205 to 14.290 GHz 2 preamplifier chains (1 on, 1 standby) Noise figure: $\leq$ 8.5 dB with tunnel diode preamplifier $\leq$ 4 dB with parametric amplifier
Antennas	Two 28-in. diameter antennas, 36.2-dB gain on axis for transmit and receive, 2.5° beamwidth, steerable over $\pm 7.25^{\circ}$, linear polarization
Design Life	2 yrs.
Orbit	Synchronous equatorial, 116°W longitude, $\pm 0.2^{\circ}$E-W station-keeping
Orbital History	Launched 19 January 1976 Delta 2914 launch vehicle In use (June 1976)
Developed By	Canadian Department of Communications



Artist's conception showing the ANIK B spacecraft scheduled for launch in November 1978

Figure 3-3

high gain antennas, provided EIRP's in the 46.5 dbw to 49.5 dbw range (peak of 51 dbw). This experimental satellite was designed to operate with fifty 1.2-meter TVRO terminals and fifty 1.8-meter TVRO terminals.

The objectives of Anik-B were to test the usefulness of lower EIRP satellites in small TVRO terminals and to demonstrate, evaluate and gain experience with both direct-to-home and small community reception using a low broadcast power flux density level.

Initial tests with Anik-B have shown that with a 1.2-meter antenna TVRO a margin above static threshold of 3.7 db was measured while the 1.8-meter antenna TVRO terminal provided a margin of 7.2 db above static threshold. The 1.2-meter TVRO antenna terminal operated just above the threshold where noise appears in the color bars, while no noise appeard in the color bars provided by the 1.8-meter antenna TVRO terminals.

3.4 Japanese Systems.

3.4.1 BSE.

The Japanese Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) was launched in February 1978 from ETR, U.S.A., using a Delta 2914 launch vehicle, and located at 110°E in a synchronous orbit. The BSE is a three-axis stabilized spacecraft having sun-oriented solar array for high power generation and 14 GHz/12 GHz direct conversion mission transponders capable of two channels color TV relay broadcasting. On the orbit, various experiments of TV broadcasting, K-band radio wave propagation and spacecraft control were conducted. BSE failed in Spring 1980.

Figure 3-4 shows the BSE; Figure 3-5 shows the extensive BSE experiment system which included 1, 1.6, and 2.5 meter TVRO antennas. Some of the

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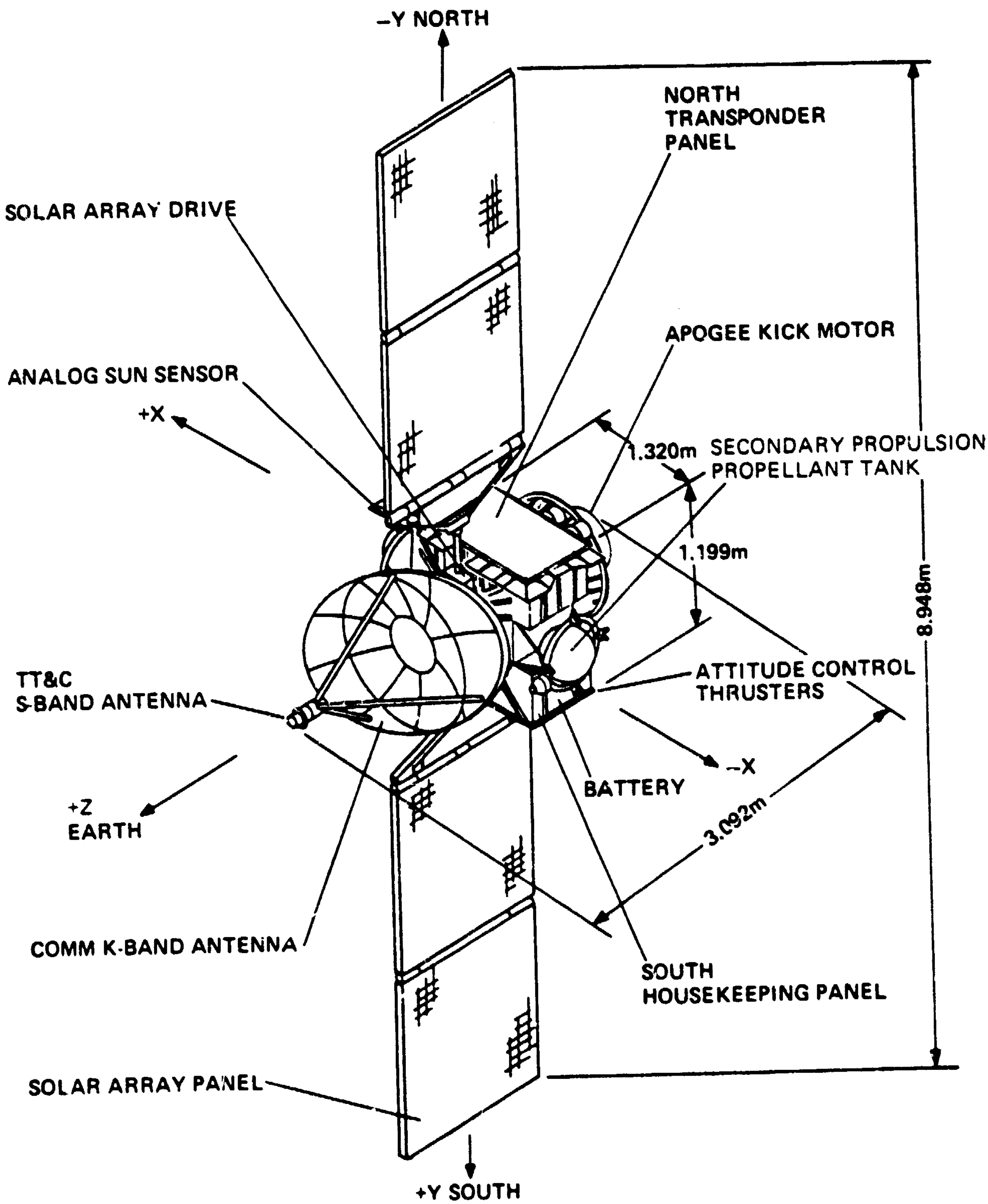

FIGURE 3-4

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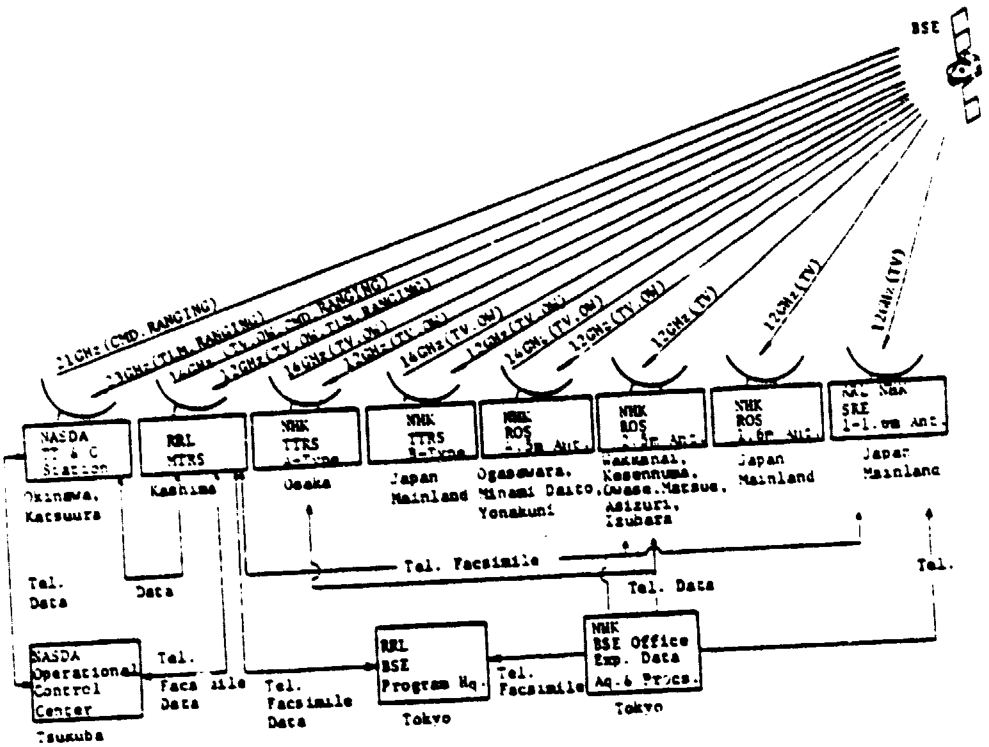

Figure 3-5. The Total BSE Experiment System

technologies developed in Japan for use with the 1-meter TVRO terminals will be discussed in Section 6.

Tables 3-6 through 3-9 describe in detail the technical parameters of the 3-axis body-stabilized satellite which used 100 watt TWT manufactured by Hughes in the United States and a 36 db gain antenna to provide an EIRP of 56 dbW (59 dbW peak). (NEC now manufactures a 100-watt space TWT).

3.5 Indian System.

3.5.1 INSAT.

India is having INSAT-1A built by Ford Aerospace and Communications Corporation according to the description in Table 3-10. India has decided to continue using the 2.55 GHz down-link frequencies with 42 dbw EIRP (using 40 watt transistor amplifiers and a 25 db gain antenna) to furnish community reception in the same fashion provided in the 1970's by ATS-6.

This broadcast satellite concept - combined with data and telephone channels and a radiometer is a novel and innovative approach to multiple-purpose satellite utilization. (See Figure 3-6).

The Indian Government is yet to take investment decisions concerning the radio and television ground-segment for the INSAT-I system. As far as the direct TV broadcasting service is concerned, the INSAT-I System has the capability to provide 2 direct broadcast channels over the entire country. For reception of INSAT-I direct TV broadcast signals with a reception quality similar to that for the ATS-6 Satellite Instructional Television Experiment (SITE) of 1975-76, Direct Reception Sets (DRS) with Figure-of-Merit (G/T) of 8.2 dB/^{o}K are required which can be achieved with a 12' diameter low-cost chicken-mesh antenna and a receiver noise figure of or better than 4.5 dB. In some of the north-eastern areas, DRSs of better sensitivity will be required; this could be accomplished by having a larger antenna or a better receiver or a suitable combination of

TABLE 3-6

JAPANESE BROADCAST SATELLITE FOR EXPERIMENTAL PURPOSES (BSE)

1. Communications Subsystem Functional Requirements

- Provide 2 100-Watt K_u-Band TV Channels
  - 150 MHz Bandwidth
  - 180 MHz Bandwidth
- Antenna Beam to be Shaped to Provide at Least +37 dB Gain Over Japanese Main Island
  - Not to Exceed +28 dB Level on China, Korea or Russia
- Provide Service to Outlying Islands
  - Okinawa
  - Ogasawara

2. Communications S/S Performance Summary

Parameter	Design Performance
Receive	
. Peak G/T	8.2 dB/^{o}K, Minimum
. Bandwidth	
- Transmit/Receive Diplexer	500 MHz
- Communications	250 MHz
. Noise Figure	8 dB Maximum 7.1 dB Nominal
. Frequency Stability (Long Term) (Parts per Million, PPM)	$\pm$ 1 PPM/Day $\pm$ 10 PPM/3 Years
Transmit	
. Peak EIRP	+59 dBw, Minimum
. 100 Watt TWTA Drive Level Control	Controllable from Ground Between -20 dBw and -35 dBw
. Spurious Outputs	$>$50 dB Below Carrier

3. Power Capability

- Prelaunch: Up to 6 hours on battery power
- Transfer Orbit: 14% excess power from array
- Daylight On-Orbit Load Power
  - BOL Autumnal Equinox 951 watts
  - BOL Summer Solstice 866 watts
  - 3-Year Autumnal Equinox 823 watts
  - 3-Year Summer Solstice 767 watts
  - 9.8% Margin Minimum
- Eclipse On-Orbit Load Power
  - 100 watts at 60% DOD
  - 68% Margin

TABLE 3-7

JAPANESE BROADCAST SATELLITE SYSTEM PARAMETERS

Satellite Location	110° East Longitude
Experimental Coverage	Japanese Territory
Frequency Bands	14.25 - 14.43 GHz uplink 11.95 - 12.13 GHz downlink
Number of TV Channels	2
Picture Quality	S/N = 45 dB (TASO Grade 1)
Power Flux Density	Japan mainland (-108 dBw/m^2) Remote territory (-117 dBw/m^2)
System Life	3 years
Booster	Thor-Delta 2914
Command and Control	S-Band and K-Band from Control Stations in Japan

TABLE 3-8

BROADCASTING SATELLITE BSE TECHNICAL DETAILS

Satellite	Rectangular body, ~ 4 ft. square; overall depth (body and antenna) 10 ft. overall span 29 ft. 4 in. 770 lbs. Solar cells and NiCd batteries, 970 W at beginning of life, 780-W minimum after 3 yrs. 3-axis stabilization, $\pm 0.2^{\circ}$ pointing accuracy (3σ)
Configuration	2 single conversion channels, 50- or 80-MHz bandwidth
Capacity	2 color TV channels
Transmitter	11.95 to 12.00 and 12.05 to 12.13 GHz 3 transmitters (2 on, 1 standby) 100-W output per channel ERP per channel: 55-dBw minimum for primary area 46-dBw minimum for fringe areas
Receiver	14.25 to 14.30 and 14.35 to 14.43 GHz 2 receivers (1 on, 1 standby) $\leq$ 8.5 dB noise figure
Antennas	Single parabolic reflector, 3.4 x 5.2 ft. $1.4^{\circ} \times 2^{\circ}$ beamwidth (at -4 dB), 40.3-dB peak transmit gain 3 feeds are used together to shape the beam (80% of the power goes theough the main feed)
Design Life	3 yrs.
Orbit	Synchronous equatorial, 110°E longitude, $\pm 0.1^{\circ}$ E-W and N-S stationkeeping
Orbital History	Launch scheduled for first quarter 1978 Delta 2914 launch vehicle
Developed By	National Space Development Agency of Japan General Electric Tokyo Shibaura

TABLE 3-9

BSE SYSTEM KEY PARAMETERS

Satellite Location	110°E Longitude
Experimental Coverage	Japanese Territory
Carrier Frequency	
TT&C	
Command/Ranging	2110.8 MHz (1 MHz BW) 14.0125 GHz (1 MHz BW)
Telemetry/Ranging	2286.5 MHz (1 MHz BW) 11.7125 GHz (1 MHz BW)
Television	
Up-Link	14.250 - 14.300 GHz (25 MHz BW/TV Channel) 14.350 - 14.430 GHz (25 MHz BW/TV Channel)
Down-Link	11.950 - 12.000 GHz (25 MHz BW/TV Channel) 12.050 - 12.130 GHz (25 MHz BW/TV Channel)
Channel Capacity	2 - Color TV Channels
Received Quality	
TV-Video	S/N = 45 dB at 1 dB Rain Loss (TASO Grade 1)
TV-Sound	S/N = 50 dB
Power Flux Density	
Japan Mainlands	-108 dBw/m^2
Remote Territory	-117 dBw/m^2
K-Band Antenna Pointing Accuracy	$\pm$ 0.2° (3σ)
On-Orbit Station-keeping Accuracy	$\pm$ 0.1° (N/S and E/W, 3 years)
Initial Solar Array Generated Power	970 watts at worst case
Reliability	0.725
System Design Life	3 years
Launch Vehicle	Delta 2914
Launch Capability	675.8 Kg

TABLE 3-10

The INSAT-I Satellite

The INSAT-IA satellite will be located at 74° E longitude and INSAT-IB at 94° E longitude. Each of the INSAT-I satellites, being built by the Ford Aerospace & Communications Corporation (FACC) of USA to Indian specifications and requirements under a contract from the Department of Space (DOS), is designed to provide the following capabilities over individual 7 year in-orbit life:

- o Two 36 MHz wide direct TV broadcast transponders in 5855-5935 MHz (earth-to-satellite)/2555-2635 MHz (satellite-to-earth) with 42 dbW (min) EOL EIRP each. National coverage. Utilization for direct TV broadcasting to augmented low-cost community TV sets in rural areas, TV program distribution, radio program distribution, and disaster warning.

- o Twelve 36 MHz wide transponders operating in 5935-6425 MHz (earth-to-satellite)/3710-4200 MHz (satellite-to-earth) frequency bands with 32 dbW (min).

- o A data channel (200 kHz bandwidth) operating in 402.75 ± 0.1 MHz (earth-to-satellite)/4038.1 ± 0.1 MHz (satellite-to-earth) bands for relay of data from unattended data collection/transmission platforms.

- o A Very High Resulution Radiometer (VHRR) instrument with a Visible (0.55-0.75 μm) and an Infra-Red (10.5-12.5 μm) channel with resolutions of 2.75 kms and 11 kms respectively and with full earth coverage.

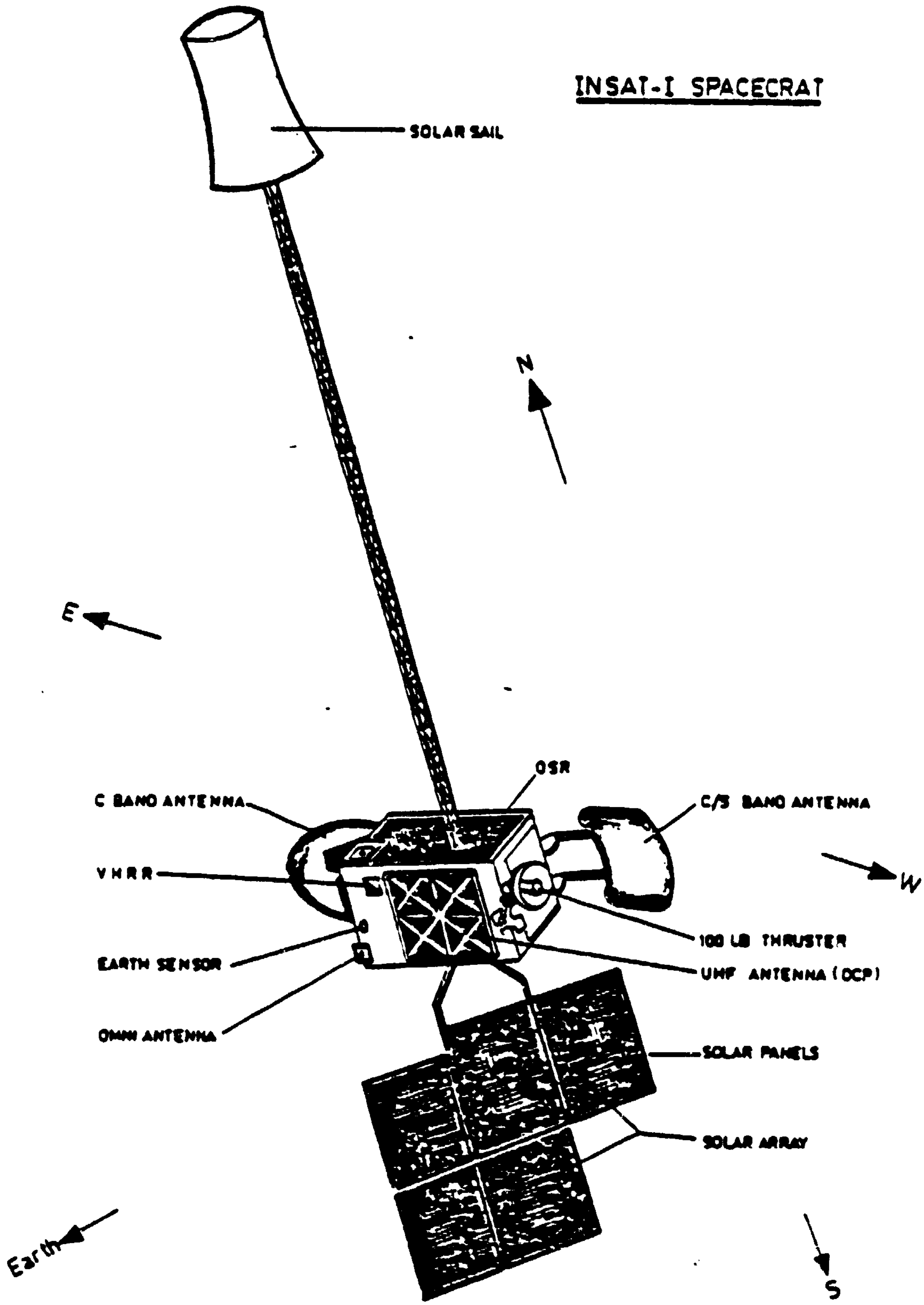
INSAT-I SPACECRAT
SOLAR SAIL
N
E
W
S
Earth
OSR
C BAND ANTENNA
C/S BAND ANTENNA
VHRR
100 LB THRUSTER
EARTH SENSOR
UHF ANTENNA (DCP)
OMNI ANTENNA
SOLAR PANELS
SOLAR ARRAY

Figure 3-6

both. The Indian Space Research Organization (ISRO) of the Department of Space have the S-band (2.5 GHz) DRS technology required for the INSAT-I system and have offered the same to Indian Industry as a part of their technology transfer program. A number of industries in India are currently discussing S-band DRS technology transfer from ISRO.

The high-power S-band (2.5 GHz) transponders on board INSAT-I satellites can provide, simultaneously with direct TV broadcast, a national radio program channel and disaster warning channel in injected carrier mode of working. A low-cost S-band receive system colocated with radio transmitters, having a 12' diameter chicken-mesh antenna and a 3 dB Noise Figure (NF) low-noise amplifier (LNA), will be able to receive high-quality/fidelity 15 KHz audio signals for radio networking.

Figure 3-7 shows the INSAT-I system concept illustrating the variety of earth terminals to be used to receive all of the various down-links and to provide all up-links. Note that these terminals range from small terminals for direct TV broadcasting, to large telephone earth stations, to emerging communication terminals to terminals serving at least 100 data collection platforms, deployed all over India and the surrounding ocean.

3.6 European Systems.

In many aspects, Europe can be considered to be the principal beneficiary of the ATS-6 broadcast experiment, which gave rise to both national and European efforts, sometimes cooperative, sometimes competitive, in the development of large broadcast satellites. These developments have been made in conjunction with the development of the ARIANE Launch Vehicle, for which a large European-sponsored boradcast satellite was to be the first principal payload.

The satellite development activity in Europe is very complex; it is performed at European Space Agency (OTS, ECS, H-SAT, L-SAT, etc.) as a result

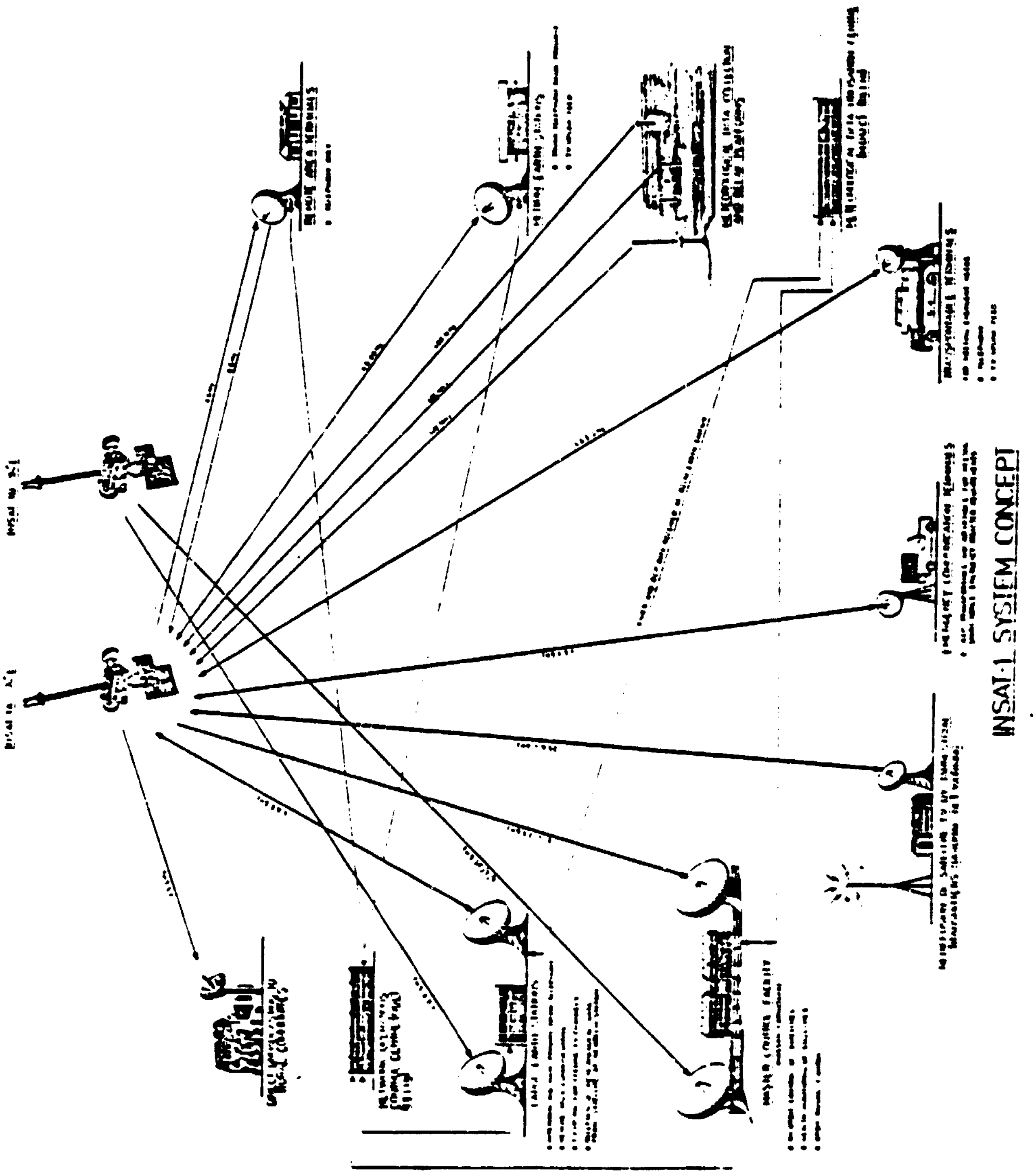

Figure 3-7

of a cooperative arrangement of eleven European countries, and it is performed bi-nationally: (SYMPHONIE - France and FRG), and nationally: Italy (SIRIO), France (TELCOM), Great Britain (SKYNET), and FRG (Federal Republic of Germany) (HELIOS and soon TV-SAT).

In 1971, the FGR* commissioned Siemens, SEL and MBB to prepare a feasibility study of a television broadcast satellite. This study, completed in 1973, described a satellite which had many new unique features; i.e., a 3-axis body-stabilized platform, with 0.1^{o} pointing accuracy, an EIRP of 67 dBW into the FRG and 64.5 dBW into neighboring German speaking areas, using a 40.8 dB peak gain antenna and a 500 watt TWT. Four channels were planned in a satellite designed to be launched on Atlas Centaur, and to serve small home TV receivers with 4 dB/K for G/T and using community receivers with 7 dB/K G/T. This study was particularly memorable in that it produced FRG-sponsored TWT development at the 750 watt level at SIEMENS, at 1.5 KW and 500 watt at VALVA, and at 450 watts at AEG - Telefunken. It was also the first to recognize the applicability of the low noise FET (then not fully developed for 12 GHz use) for the answer to the sensitivity of a TVRO ground terminal having diameters from 0.41 meters to 1 meter for a range of receiver noise figures from 4.5 dB to 8.5 dB.

Following the FGR study, interest in broadcast satellites by the FRG was transferred to ESA of which FRG was a key member and consideration was made of a broadcast satellite known as H-SAT by ESA, as a payload for ARIANE and as a developmental companion to the highly successful 11/14 GHz Orbital Test Satellite (OTS) launched in 1978, and in the forthcoming European Communication Satellite (ECS).

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*Commissioned by Gesellschaft Fur Weltraumforschung, Contract RV11/1-V14/72-QH-01-00.

These joint efforts produced considerable national technological skills directed toward 3-axis body-stabilization at MBB/TELDIX, high power tube development at both AEG-Telefunken in the FRG and Thomson-CSF in France. These efforts produced a technological fall-out which, in addition to the technological skills produced by the Franko-German SYMPHONIE and Italy's SIRIO, and participation in Intelsat's IV, IV-A, and V, has procuded a broadcast satellite competence and experience of considerable magnitude.

3.6.1 ESA L-SAT.

The ESA H-SAT or ARIANE HEAVY SATELLITE as it was described by R. L. Herndon at the AIAA 7th Communication Satellite Systems Conference in San Diego, Calif., April 1978, was designed to match the launch capability (1700 Kg) of ARIANE 1. This satellite was under design with the objectives of providing a TV-broadcast payload with two channels in the 11/14 GHz band and a 20/30 GHz communication payload which included a 2 x 2 port switch matrix to test SS-TDMA. This satellite design never got beyond the feasibility and preliminary design phase - although it led to the design and realization of 450 watt TWT at AEG-Telefunken and 150 watt TWT at Thomson-CSF, and explored in depth the technology of maintaining beam pointing accuracy of 0.05° for at least 12 hours a day continuously.

The growing expertise in TV-Satellite design and technology at MBB in FRG, spurred by Dr. D. Koelle, and the interest by FRG in providing TV-broadcast services to the German speaking nations of Europe caused FRG to withdraw its support in H-SAT, to concentrate on the development of the German TV-SAT to be described in Section 3.6.2. With the impetus of first German, and then French interest in building large TV-broadcast satellites, ESA then returned to broadcast satellite arena with the L-SAT, a large 3-axis body-stabilized satellite now sized to the lift-off weight of ARIANE-3 of 2300 Kg and including the following payloads now under consideration:

- a two channel 12 GHz television direct broadcast payload with one channel providing preoperational services for one European country and the other steerable to support experiments and demonstration in time sharing mode over the whole European region.
- a payload for pilot European specialized or business services in the 12.5-12.75 GHz downlink band for operation with small terminals located at private or local premises.
- a payload for experiments and demonstration in the 20/30 GHz band as relevant to its future utilization for specialized services such as videoconferencing, and supporting scientific and technical objectives of relevance to a range of other future applications.
- a payload to support experimental measurements of propagation effects in the 20/30 GHz bands.

L-SAT would serve as a test vehicle for U.K., Italy, Netherlands, Belgium, Switzerland, Denmark, Spain, Austria and Canada; in other words, the countries in Europe not served by German and French national broadcast satellites.

3.6.2 German TV-SAT (FRG).

The FRG Ministry of Research and Technology (BMFT) has become a staunch advocate of high power TV-broadcast satellites as fitting addition to the present German nationwide TV-broadcasting system with two TV programs and one regional program. Since no additional frequencies were available for conventional terrestrial broadcasting, the TV broadcasting satellite had the feature of providing an additional five channels to serve both direct-to-home interests and to serve the extensive German cable TV system.

Following the feasibility study of a TV broadcast satellite for Germany described in 3.6, the MBFT in 1979 directed MBB, supported by AEG-Telefunken, Dornier, ERNO, and SEL to build a satellite with a target launch date of a pre-operational satellite on Ariane 3 in early 1983 and an operational satellite in 1985. This satellite was specified as being compatible with both ARIANE and STS/SSUS-A (TV-SAT A3).

This broadcast satellite shown in Figure 3-8 has five TV channels in the 11.7-12.5 GHz band with an EIRP of 65.5W using 260 watt TWTA and high gain (40 dB) antennas with 0.72 x 1.62 degree beamwidths from a satellite position at 19° West (± 0.1).

Tables 3-11 and 3-12 describe the pertinent details of TV-SAT. The uplinks are not described since they are anticipated as being in the 18.5 to 14.1 GHz range pending finalization of allocations by WARC-79.

The technological innovations of this satellite are substantial and very significant; they include:

- Travelling wave tubes of 200 to 450 watts
- Power repeater chains
- CFC-antenna dishes as large as 2m in diameter
- Feed system of the transmitting antenna
- Ultra-lightweight solar generator
- Double-gimbaled momentum wheel
- High-precision infrared earth sensor
- Digital reprogrammable attitude and orbit measurement and control system
- Digital TM/TC system
- RF-sensor
- Liquid apogee thrust system
- Bearing and power transmission assembly for high power

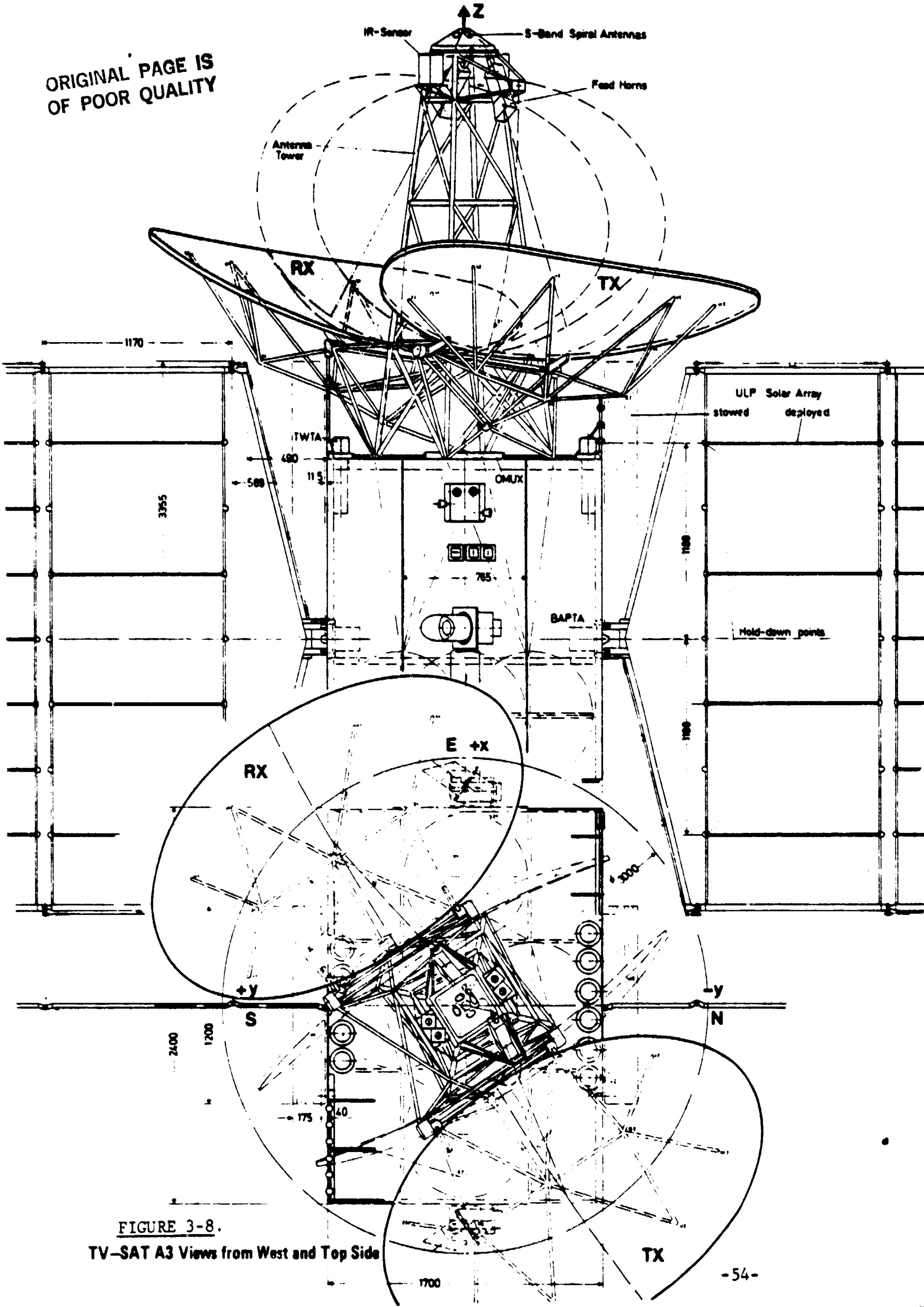


FIGURE 3-8.
TV–SAT A3 Views from West and Top Side

TABLE 3-11

MAIN SYSTEM REQUIREMENTS OF GERMAN TV-SAT

Communication	5 Channels for Germany 3 Operated Simultaneously
Orbit Position, Nominal	19°W/0° N-S
Station Keeping	Longitude $\pm$ 0, 1° Latitude $\pm$ 0, 1°
Antenna Pointing Direction (Rx and Tx)	$9,66^{\circ}$E/$49,9^{\circ}$N
Antenna Beam Pointing Accuracy	Any Direction $\pm$ $0,1^{\circ}$
Antenna Ellipse Orientation Accuracy	$\pm$ 2°
Antenna Beamwidth	Transmit $1,62^{\circ}$ x $0,72^{\circ}$ elliptic Receive $1,05^{\circ}$ x $0,47^{\circ}$ elliptic
DC Power EOL	2533 watts
Lifetime	Design 7 years Operation 5 years
Communication Frequency Bands	Uplink 18,3 ./. 18,7 GHz Downlink 11,7./. 12,1 GHz
Polarization	Uplink RHC Downlink LHC
EIRP	Channel No2 65,5 dBw 6 65,6 dBw 10 65,6 dBw 14 65,7 dBw 18 65,7 dBw
Cross Polar Component	Relative Angle $x = \emptyset / \emptyset_o$ — Relative Gain Gr_B (dB) $0 \leq X \leq 0,33$ — -40 (1+log/x-11) $0,33 \leq x \leq 1,67$ — -33 $1,67 \leq x$ — -40 (1+log/x-11)
Transfer Orbit Mass	1600 Kg

TABLE 3-12

TV-SAT A3 SYSTEM CHARACTERISTICS

1. Payload

3 + 2 (spare) Channels with 260 W TWTA s.
Separate Transmit and Receive Antennas

Total Mass	167.3 kg
Power Requirement	2238 Watt
Reliability (5 years)	0.930

2. Spacecraft

Power BoM/EoM 5 y		3400/2850 W
System Reliability (5 y)		0.837
Bus Reliability (10 y)		0.800
Payload Module Mass		280.0 kg
Service Module Mass		300.0 kg
Propulsion Module Mass		210.0 kg
Propellant for Transfer, Apogee Maneuver and Acquisition ARIANE: 693 kg,	SHUTTLE:	825.0 kg
Propellants for Attitude and Orbit Control	95 (max.	150) kg
Mercury for Ion Thrusters		10.0 kg
Total Mass after Separation from		
ARIANE		1712.0 kg
SHUTTLE + SSUS-A		1880.0 kg
Total Length with Extended Arrays		19.25 m

3. Subsystems

Antenna System with Two Deployable CFC Dishes and Central Tower	56.7 kg
Repeater with 5 TWTA's of 260 W	110.7 kg
Power Subsystem (50 V bus)	59.5 kg
ULP Solar Array	93.5 kg
Array Drive Assembly (BAPTA)	14.4 kg
Data System (TT&C, Data Handling)	24.9 kg
Attitude/Orbit Measurement & Control	48.5 kg
Unified Propulsion System	91.5 kg
RITA-1 Electrical Thruster Package (2)	32.6 kg
Structure (Excl. Adapter)	144.7 kg
Thermal Control Hardware	63.5 kg
Bus Harness, Pyrotechnics	26.4 kg
Balance Mass, Miscellaneous	5.0 (A) to 30 (S) kg

TABLE 3-12

TV-SAT A3 SYSTEM CHARACTERISTICS (Continued)

4. Electrical

Antenna Gain	40.6 dB
EIRP	62.5 dBw
Received Power Flux Density (Edge Coverage)	104 dBw/m^2

5. The Legal and Administrative Basis for TVBS in Europe had been created by the WARC-77 in Geneva, allocating 5 channels to each country in Europe and defining the antenna beams and main parameters. For Germany these parameters are as follows:

TV Channels	2, 6, 10, 14, 18 (11.7-12.5 GHz-Band)
Polarization	Left-Hand
EIRP	65.5 dBw (260 W TWTA Output)
Antenna Beam	0.72 x 162 deg.
Satellite Position	19° West (+ 0.1)

Figure 3-9 indicates the antenna coverage to be served by the German TV-SAT and shows the various -103 dBW/M^2 contours as viewed from orbital position 19° west for beam pointing errors from 0 to 0.1°.

3.6.3 <u>French TV-SAT</u>.

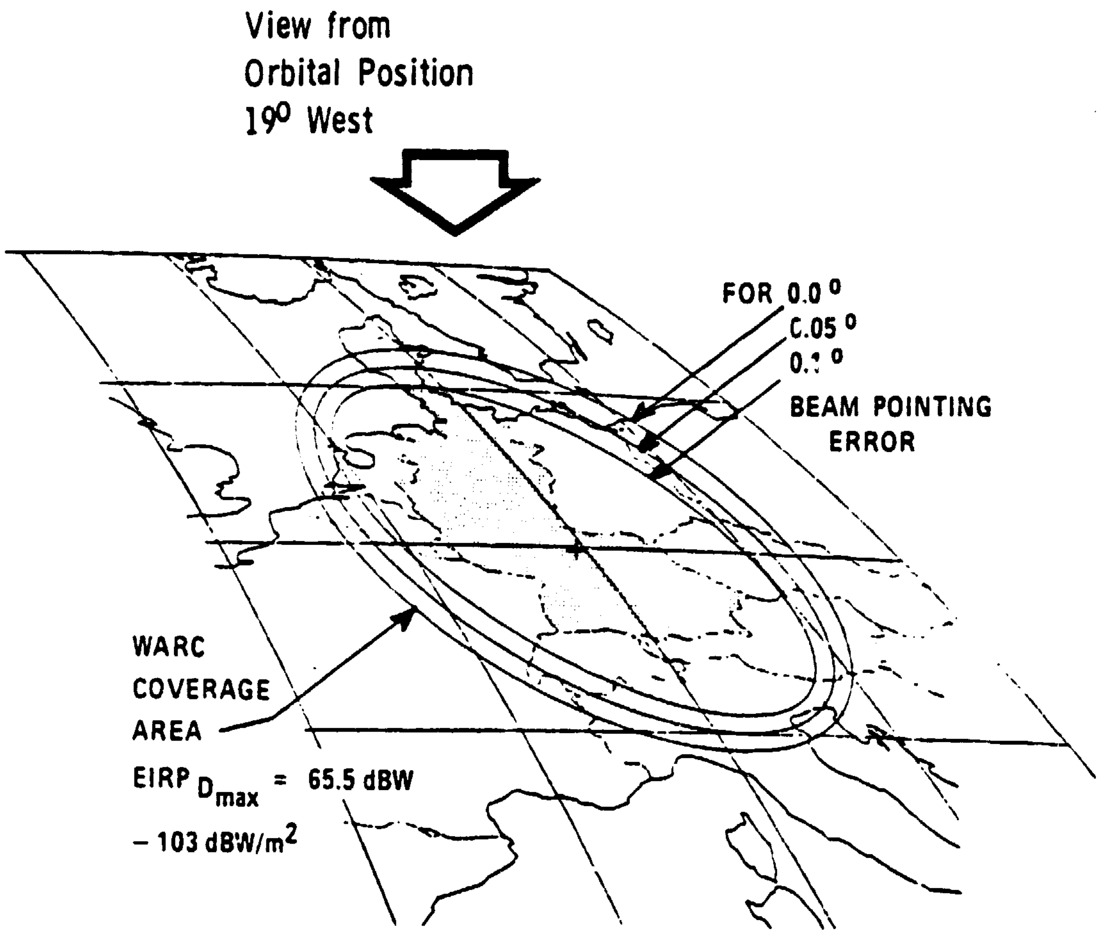
In 1979, France started the process of building a domestic communication satellite TELECOM, with transponders in C-band and X-band. This satellite is being built by MATRA with Thomson-CSF responsible for the transponders.

After the announcement of the start of the German TV-SAT France also, in October 1979, indicated that it intended to build a French broadcasting satellite to serve French interests. The early details and system aspects of this satellite were announced by J. Arnaud, Telediffusion de France, and C. Derieux and A. Pouzet of CNES at the 1980 AIAA 8th Communication Satellite Systems Conference in Orlando, Florida, in April 1980.

The satellite design is a 12 GHz 3-axis body-stabilized satellite which is very close to that of the German TV-SAT and indeed, one could expect close cooperation and therefore similarity in building both satellites. Its structure is that shown in Figure 3-10 and its footprint coverage, following the WARC-77 allocations. In its initial design phase, it is designed as a 3-channel satellite (1900 Kg) to be launched on ARIANE 1, or a 5-channel satellite (2300 Kg) to be launched on ARIANE 3.

Early design considerations indicate the use of the WARC-77 approved EIRP's in the 64 dBW range; however, it will use special 230 watt TWTA developed by Thomson-CSF, with groups of two TWTA combined by a T-Circuit to produce a power output of 350 watts per channel. It will carry 10 TWTA including spares.

The French broadcasting satellite will use the up-link frequency of 17.3-18.1 GHz, will be pointed with an accuracy of $\pm 0.05^\circ$, and will operate into small 1-meter TVRO antennas as specified by WARC-77.



Antenna Coverage Area for the FRG as Defined by WARC 1977

Figure 3-9

T D F - 1

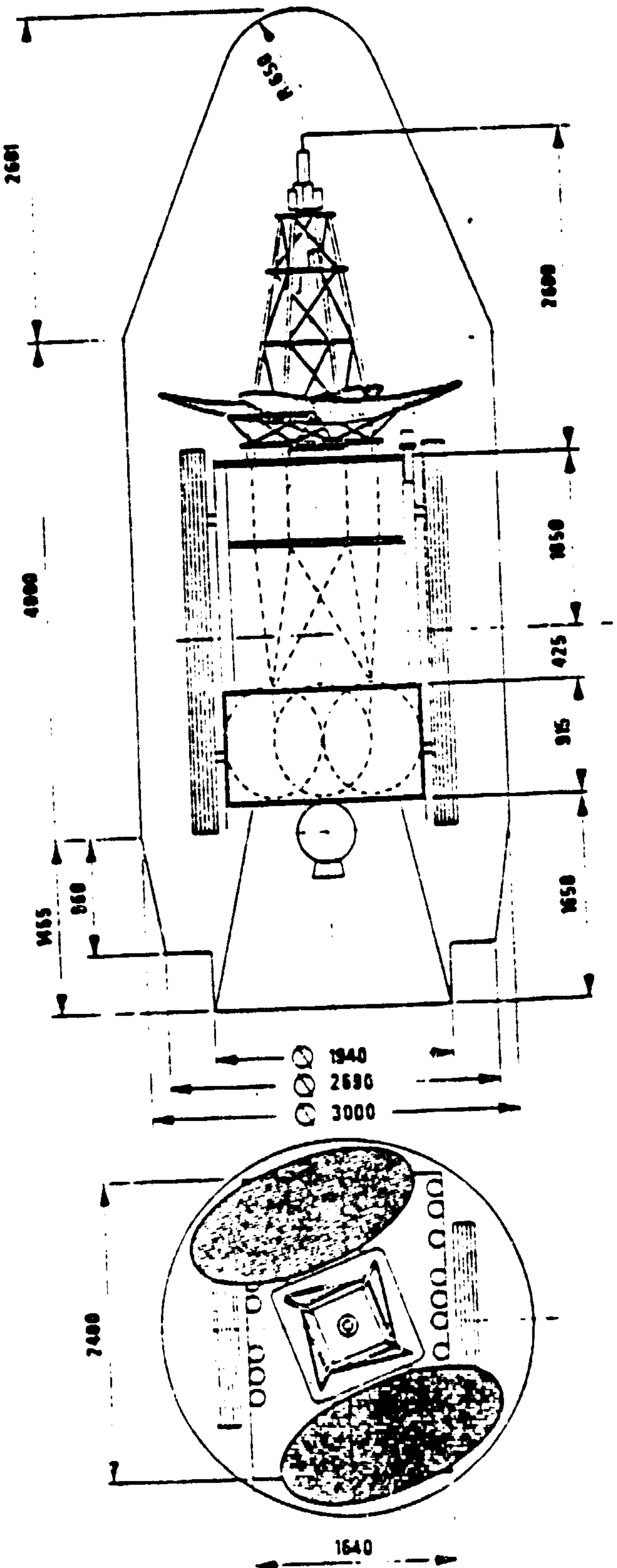


Figure 3-10. French TV-SAT

	FRENCH SATELLITE		GERMAN SATELLITE	
	Preoperational	Operational	Preopérational	Operational
Capacity	3 TV channels	5 TV channels	3 TV channels	5 TV channels
End of life power of so-largenerator	3,9 KW	5,8 KW	3,2 KW	5,2 KW (including EPS needs)

FRENCH COVERAGE

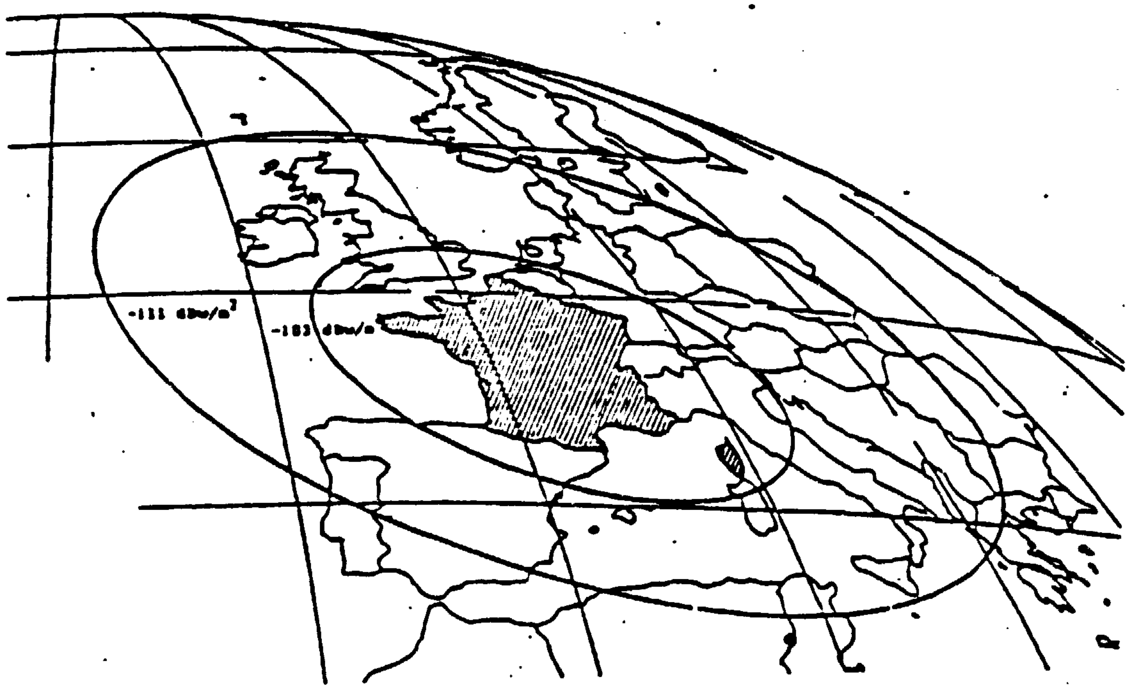


Figure 3-11. Coverage of French TV-SAT

3.6.4 NORDSAT Regional Satcom and Broadcast System.

The Nordic countries, Denmark, Finland, Iceland, Norway and Sweden, have at present a total of seven TV programs and ten radio programs. However, none of the five countries has more than two national programs and except for very limited spillover, there is at present no access by one Nordic country to the programs of the neighboring Nordic countries. There are mainly three technical means to expand the national broadcasting distribution to a Nordic coverage as described by L. Anderson of the Swedish Space Corporation at the AIAA 7th Satellite Systems Conference in San Diego in April 1978.

- o A cable system would be theoretically feasible. The obstacle is the cost and the time to reach an acceptable coverage which is considered to be 98%. The cost for a 6-channel cable system in Sweden has been calculated by the Telecommunication Administration to an investment of 3500 M US dollars. The time needed to reach a 98% coverage is estimated to be 30 years, as a vast land area is thinly populated.
- o Another possibility could be the establishment of new networks of ground-transmitters. However, a serious constraint is that the WARC frequency regulations limit the number of TV channels to 4, which is insufficient for a total exchange of even the present Nordic programs.
- o The third possibility is to use direct broadcasting satellites. The Swedish Space Corporation's Feasibility Study shows that a DBS system is the superior solution for making available all Nordic TV and radio programs to all Nordic households. Some of the advantages are:
  - Almost 100% coverage from the start of the new service.
  - Only 4 to 5 years needed to implement the direct broadcasting service after project go-ahead.

- Low cost compared to other solutions to provide the same service. An investment of 160 M US dollars will give an 8-channel DBS system with Nordic coverage.

A feature of NORDSAT which is reflected in most regional systems which actually cannot employ INTELSAT leased channels, is the use of high satellite EIRP which results in the practical use of 10-meter reflector receivers leading to very low cost receiving stations for TV, as compared to the need for at least 4.5 meter diameter antennas for use with INTELSAT-IVA or INTELSAT-V channels. NORDSAT system summary is given in Table 21.

A view of the ultimate decision with regard to NORDSAT was given by Jan Nyheim of the Norwegian NRK in April 1978 Satellite Communications, when he commented "when will it be possible to have an operational Nordic satellite broadcasting system? There are no authoritative timetables available. If a Nordic Council "yes" is given in 1980, when more information will be available, this still "only" amounts to a recommendation directed to the national governments. If the Nordic governments agree, the different problems outlined might be attached and solved during the early 1980's. The broadcasting equipment in the space segment may then be specified. Allowing a few years for systems testing, it would not be until the late 1980's for a satellite system to become operational, and it may easily be delayed beyond that. Thus, I believe that a NORDSAT system will not be operational before circa 1990". The political implications of this regional system will eventually govern the future of NORDSAT over the technological questions involved.

The characteristics of NORDSAT as conceived in 1979, are listed in Table 3-13. It will use 450 watt TWTA in each of four TV broadcast channels at 12 GHz and a 200 watt TWTA in a channel for Iceland. Its initial design concept follows

TABLE 3-13

NORDSAT SYSTEM SUMMARY

- <u>COMMUNICATION SERVICES STARTING IN 1983</u>
  - PREOPERATIONAL PHASE: 4 NORDIC CHANNELS, 1 ICELANDIC CHANNEL
  - OPERATIONAL PHASE: 8 NORDIC CHANNELS, 2 ICELANDIC CHANNELS
  - DIRECT BROADCASTING TO DENMARK, FINLAND, NORWAY, SWEDEN AND ICELAND
  - SEMI-DIRECT BROADCASTING TO GREENLAND
  - TELEPHONY AND DATA TRANSMISSION

- <u>NUMBER OF SATELLITES</u>

1 SATELLITE IN THE <u>PREOPERATIONAL PHASE</u> SUCCESSIVELY EXPANDING TO 3 IN THE <u>OPERATIONAL PHASE</u> WITH 2 OPERATIONAL AND 1 SPARE IN ORBIT.

- <u>SATELLITE</u>

ON-STATION MASS	950 kg
- COMMUNICATIONS PAYLOAD	
NORDIC COVERAGE	4 CHANNELS 450 W/CHANNEL
ICELANDIC COVERAGE	1 CHANNEL, 200 W
TELEPHONY TRANSPONDERS	20 W/TRANSPONDER
ANTENNA POINTING	$\leq 0.05^{\circ}$
- PLATFORM	
ATTITUDE CONTROL	THREE AXIS STABILIZATION
ELECTRICAL POWER	5.4 kW SOLAR ARRAY
THERMAL CONTROL	VARIABLE CONDUCTANCE HEAT PIPE RADIATORS, $8m^2$

- <u>TRANSMITTING STATIONS</u>

ONE MAIN STATION PER COUNTRY FOR DENMARK, FINLAND, NORWAY, SWEDEN AND ICELAND

- <u>INDIVIDUAL RECEIVERS</u>

EFFECTIVE G/T	≥ 6 dB/K
ANTENNA DIAMETER	≥ 0.9 m

that of the German TV-SAT and ESA's L-SAT and it will no doubt conform closely to European design concepts and use European technology where possible.

3.6.5 ITALSAT.

Following the successful experimental use of SIRO (uplink 18 GHz, downlink 11 GHz), Italy has now started construction of a unique satellite using the 20/30 GHz frequencies for television distribution. It is presently conceived as producing up to 17 spot beams into principal Italian areas, and while not a broadcasting satellite in the WARC-77 sense, its role as a TV-distribution satellite will inaugurate the use of these frequencies in Europe for TV-use and no doubt influence many future designs including the present design consideration of L-SAT which will include a 20/30 GHz payload.

ITALSAT will use 20 watt 18 GHz TWTA made by Hughes EDD of Torrance, California, who made the 10 watt TWT mode for SIRIO and the 4 watt 18 GHz TWTA mode for Japan CS.

3.7 USSR.

The first practical utilization of Earth artificial satellites for broadcasting television programs to TV transmitting earth stations started in the USSR in 1967 when a TV distribution system consisting of "Molnya-1" communication satellites and 20 TV receiving stations of "Orbita" type was introduced. The system extended the TV coverage of the population by 20 million people. During the years that followed "Orbita" and then "Orbita-2" stations were continued to be rapidly constructed in the most remote regions of the country. Presently "Orbita -2" stations are not only located in big cities such as Novosibirsk, Khabarovsk, Vladivostok but used in relatively small locations as Uray, Kirensk, etc. Altogether more than 70 stations were built and brought into service.

However, the construction of "Orbita" stations is economically justified only in locations with high density of population. The further development of television broadcasting networks in regions with low population density cannot, therefore, be based on the construction of new stations of this type.

A demand arose to simplify and to reduce the cost of receiving stations in order that they could be available for the use in remote locations such as Siberia. It was obvious too, that the power radiated by the space station should be increased. The demand was satisfied by developing "Ekran" satellite system for television broadcasting.

The "Ekran" satellite shown in Figure 3-12 and called Statsionar-T was launched in the geostationary orbit at 99^{o} E on October 26, 1976. Its service area, Figure 3-13, is more than 9 million square kilometers (about 40% of the whole territory of the USSR) and it includes some regions of Siberia, the Extreme North and, partly, of the Far East (see Figure 3-14). When the "Ekran" satellite was launched, 60 receiving stations were established in its service area and by the end of 1980 their number will exceed one thousand.

As shown, the STATSIONAR-T is a large 3-axis stabilized satellite using a giant phased array of 96 helical spiral antennas as the antenna system.

The satellite transmitter operates at the central frequency of 714 MHz and uses a Klystron which has the power of 200 Watts at the antenna input. Antenna gain is 33.5 dB.

The receiving system parameters have to provide for the reception of a given quality at the edge of the service area when the field strength is 29 μV/m and the satellite antenna gain to the edge of the service area is 26 dB. The power flux density on the earth's surface at the edge of the service area is -116.5 dBW/m^2.

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ЭЛЕКТРОСВЯЗЬ

5 1978

В НОМЕРЕ:

РРЛ — РАЗВИТИЕ В УСЛОВИЯХ ВНУТРИОБЛАСТНЫХ И СЕЛЬСКИХ СЕТЕЙ

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АВТОМАТИЧЕСКИЙ КОРРЕКТОР ДЛЯ ТВ КАНАЛОВ

●

ДИСКУССИЯ:
УНИФИКАЦИЯ КОММУТАЦИОННЫХ СТАНЦИЙ — ШАГ К ИНТЕГРАЦИИ СЕТЕЙ

●

ТАСТАТУРНЫЙ ТЕЛЕФОННЫЙ АППАРАТ НА МОП-СТРУКТУРАХ

ЕЖЕМЕСЯЧНЫЙ НАУЧНО-ТЕХНИЧЕСКИЙ ЖУРНАЛ ПО ПРОВОДНОЙ И РАДИОСВЯЗИ, ТЕЛЕВИДЕНИЮ, РАДИОВЕЩАНИЮ

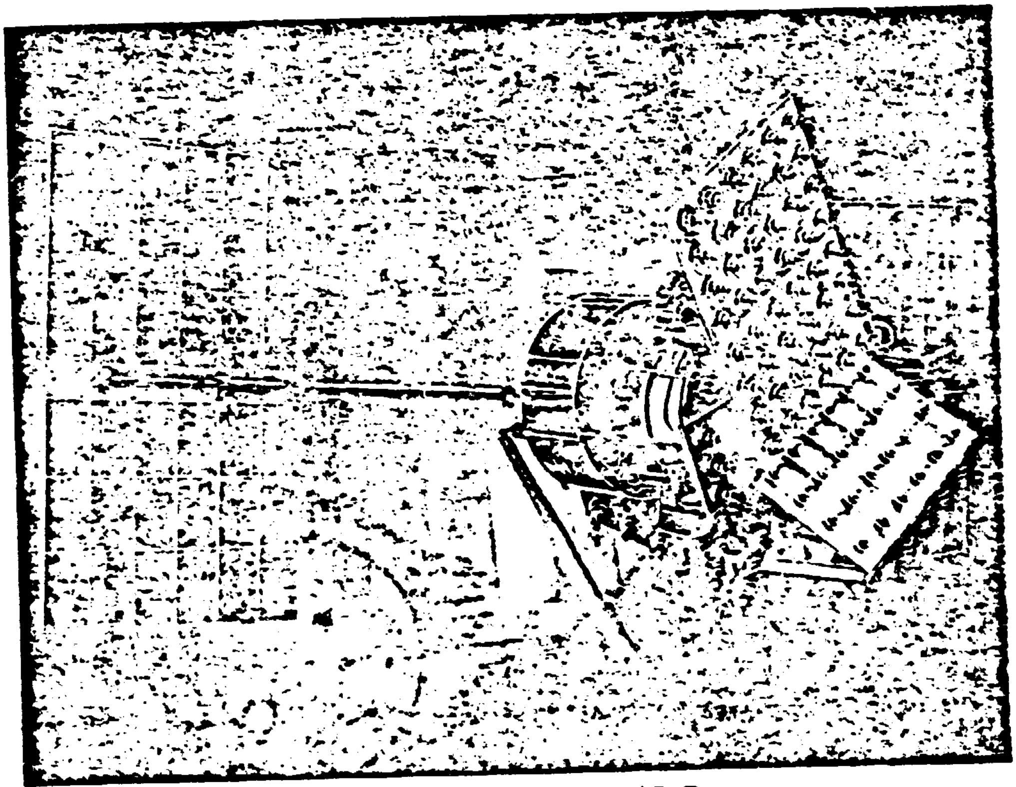

Figure 3-12. STATSIONAR-T

ТРУДЯЩИЕСЯ СОВЕТСКОГО СОЮЗА! БОРИТЕСЬ ЗА ВЫПОЛНЕНИЕ И ПЕРЕВЫПОЛНЕНИЕ ПЛАНА 1978 ГОДА! НАСТОЙЧИВО ДОБИВАЙТЕСЬ НАИВЫСШЕЙ ПРОИЗВОДИТЕЛЬНОСТИ ТРУДА, ЭФФЕКТИВНОСТИ ПРОИЗВОДСТВА И КАЧЕСТВА РАБОТЫ!

Из Призывов ЦК КПСС к 1 мая 1978 года

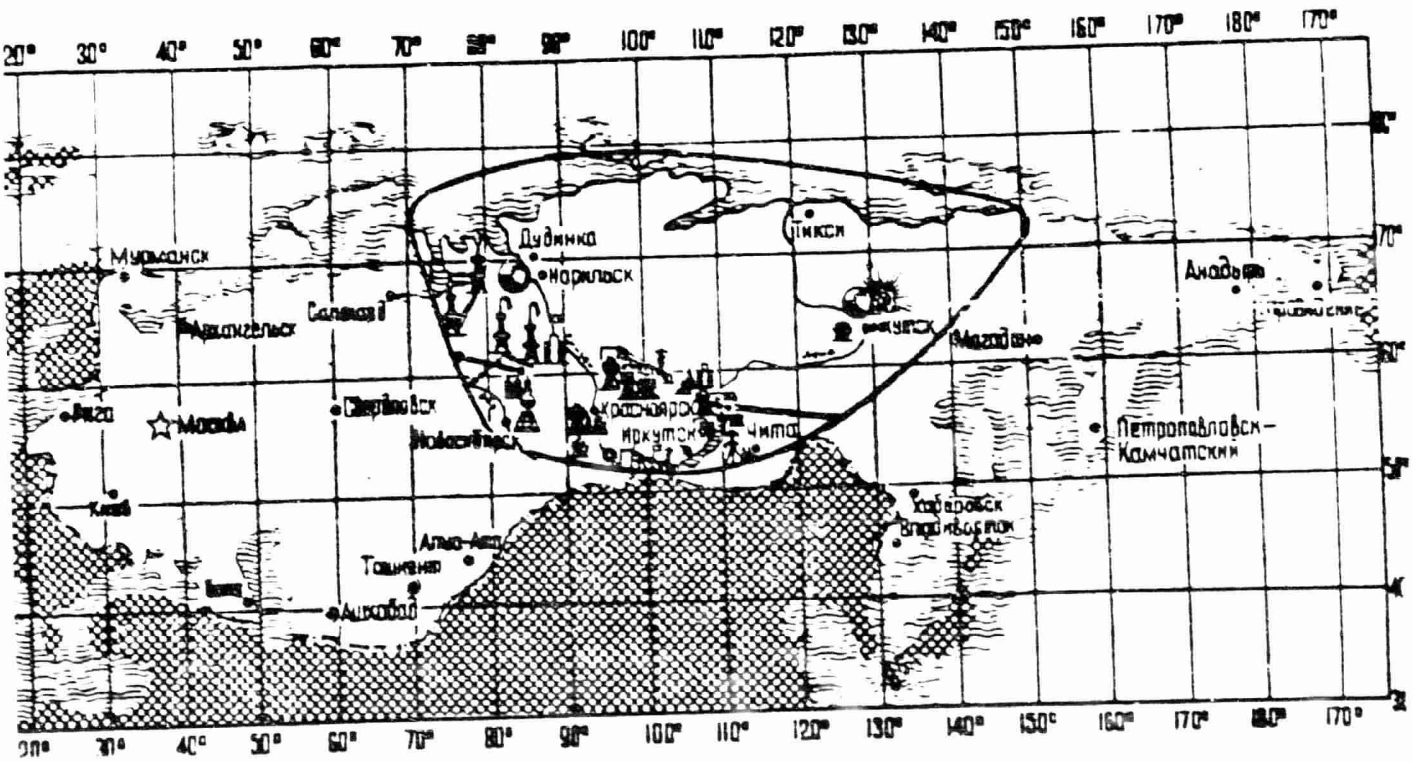

Figure 3-13. STATSIONAR-T Coverage

There are two types of receivers: the first and the second class. The first class receivers are designed to broadcast programs to local TV centers located in relatively big locations while the second class receivers are connected to low power TV repeater stations or to cable distribution networks in small locations.

The basic parameters of the "Ekran" system are listed in Table 3-14.

Signals are transmitted to the Statsionar-T transponder from a transmitting earth station near Moscow. Video and sound signals are fed to the station by the radio-relay link from the all-Union TV center in Ostankino. The station is equipped by a 5 kW transmitter operating at 6200 MHz and by a transmitting parabolic antenna of 12 m in diameter.

A first class receiving installation with an input parametric amplifier is used for reference. The parametric amplifier is uncooled, of a regenerative type with the noise temperature of about 80 K. The signal level at the IF amplifier output serves as a criterion of the transmitting antenna pointing accuracy.

The standard first class receiving installation, however, contains two identical FM receivers, one of which is operating and the other is back-up, the power to each being supplied from a separate 12.6 V rectifier. A low-noise transistorized amplifier with the noise temperature of 450 K and the gain of 18 dB is at the input of each receiver. The output of the transistor amplifier is then frequency converted o a 70 MHz IF amplifier. Following the frequency detector a video signal is amplified to the 1 V standard in a video amplifier while the 6.5 MHz subcarrier signal is demodulated in a separate unit which produces a sound signal at its output.

The first class installation uses an 18 Yagi element antenna array shown in Figure 3-14, and is designed to be connected with a local TV center or a high

TABLE 3-14

EKRAN "STATSIONAR-T" BROADCASTING SATELLITE SYSTEM

A. Earth-to-Space Characteristics

Frequency Range	6200 MHz
Bandwidth	24.10^3 kHz
Transmitting Antenna Gain	55 dB
Maximum Transmitted Power	5 kw
Receiving Antenna Gain	19 dB
Noise Temperature of Receiving Space Station	3000^oK
Location of Earth Terminal	Gus - Khrustalnys

B. Space Station: Statsionar T

Launch Date	Oct. 26, 1976
Geostationary Orbit Location Coordinates	99^oE 0^oN
Initial Orbital and Space Station Data:	
Altitude of Apogee	35,600 km
Altitude of Perigee	35,600 km
Inclination	0.3^o
Period	23 h 56 m
Frequency Range	714 MHz
Bandwidth	24 MHz
Klystron Power	200 Watts
Transmitting Antenna Gain on Satellite:	
Maximum	33.5 dB
To the Edge of the Service Area	29 mV, -116.5 dBW/m^2

C. Receiving Earth Terminal Characteristics - Space-to-Earth Terminus

Receiving Earth Station Gain:	
The 1st Class Station	30 dB
The 2nd Class Station	23 dB
Receiving Antenna Angular Width:	
The 1st Class Station	$4.5^o \times 2.5^o$
The 2nd Class Station	$9^o \times 9^o$
Receiving Station Feeder Losses	1 dB
Receiving Station Equivalent Noise Temperature	800 K
Output Receiver Power:	
The 1st Class	-106 dBw
The 2nd Class	-113 dBw
Noise Power at Receiver Input:	
The 1st Class	20.8 dB
The 2nd Class	13.8 dB
Video Signal to Weighted Noise Strength Ratio at Receiver Output:	
The 1st Class	55 dB
The 2nd Class	48 dB
Signal-to-Noise Ratio in the Sound Channel at Receiver Output:	
The 1st Class	56 dB
The 2nd Class	49 dB

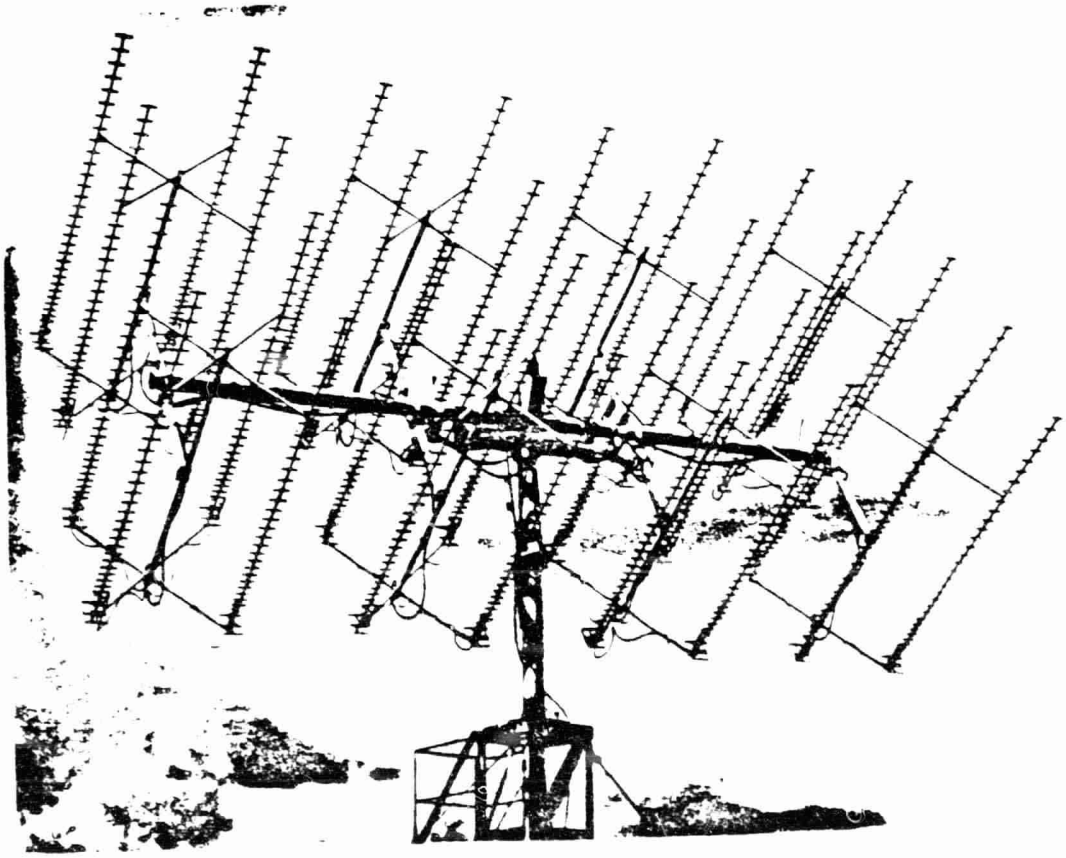

FIGURE 3-14. EKRAN Antenna

power repeater which has video and sound modulators and accordingly the receiver has two outputs - for a video and a sound signal.

The second class receiver antenna is a cophased array made of four Yagi antennas used for the first class receiver.

3.8 Others.

Other countries of the world are certain to join the superpowers of space to provide direct broadcasting from space according to the planning set forth by WARC-77. Because of the growing need for domestic telephony channels a logical conclusion would be for a country to acquire a satellite having both TV-channel at Ku-band or S-band, and telephony channels at C-band or at lower Ku-band. However, the principle of apriori-planning adopted at WARC-77 makes it unlikely that any country with pre-assigned orbital slots at Ku-band for TV broadcast, will be able to get an assignment to the same slot in C-band due to the present orbital crowding at the 3.7-4.2 GHz frequencies. Also, the enormous dc power needed to power the TV channel power amplifiers may limit the C-band capability (if possible) unless an Intelsat-V bus is used.

The interest in TV-broadcast from space continues to rise worldwide and following paragraphs will summarize recent disclosures by Peoples Republic of China (PRC), Australia, the Arab countries, and Comsat General (USA).

3.8.1 PRC.

The Chinese Communications Satellite System will consist of two satellites on orbit, and a spare on the ground plus a pilot number of two kinds of ground stations. A brief summary of the satellite specifications, as told to an AIAA delegation in December 1979, is as follows:

- the satellites will be principally used at Ku-band for broadcast purposes with two channels of color TV using FM. These channels may be used sequentially to cover two different time zones;

- three TV voice channels will be used (again, sequentially used for two different time zones);
- there may be a two-beam usage requirement for the TV services;
- PRC will require more than 3,000 simplex telephone voice circuits at C-band (probably 6,000 circuits);
- PRC will use twenty to thirty 10-meter reflector earth terminals for telephone circuits, and more than 2,000 1.8-meter reflector TV, receive only, earth terminals;
- the launch will be required 30-36 months ARO; Shuttle/Delta compatible;
- the satellite life requirement is 5-7 years;
- the growth potential is a critical criterion.

CHISAT/CAST* will procure and operate the satellites. Ground stations may be procured and operated by users, the PTT and the Broadcast Bureau.

The PTT is studying the leasing possibility of Intelsat Indian Ocean channels as an interim measure.

In parallel, the Chinese are building an indigenous experimental satellite for launch in 1981 on "The Long March-III Launch Vehicle". This satellite will be used to develop ground networks for their operational system. Long March-III is their present launch vehicle (analogous to U.S. Titan-II) which is two-stage UDMH/Nitrogen Tetroxide. There is a third stage, LH_2/LOX, currently under development. With this third stage, Long March-III may have greater capability than Ariane and will be operational in 1981.

The PRC presently is using a 3-meter antenna at the earth station in Nanjing to pick up broadcast from the Japanese Broadcast satellite; and now

*CHISAT is the Chinese Communication Satellite Corporation, and CAST is the Chinese Academy of Space Technology.

have a 1.8-meter antenna under development for direct broadcast applications.

3.8.2 Australia.

Australia has issued a Tender in 1981 to various broadcast satellite manufacturers for a satellite to provide telephony and also broadcast television to both metropolitan areas and the vast range, desert, and out-back areas of Australia and New Guinea. Prior to issuing this Tender, Australia sought guidance from Canada, and will use the lower-power Ku-band broadcasting satellite approach (EIRP < 50 dbw) similar to that used with ANIK-B. This satellite will provide not only fixed satellite services on a continental average beam with an EIRP of 36 dbw, but also will use five spot beams which can be switched between fixed satellite service and homestead and community broadcast satellite service (HACBSS), the latter with an EIRP of 47 dbw (using 30 watt TWT's).

3.8.3 Arabsat.

Arabsat will provide the Arab countries with community service TV-Broadcast services using a transponder with an EIRP of 42 dbw at 2.56 GHz. This service is in addition to 24 channels of fixed satellite service at C-band.

3.8.4 Satellite Television Corporation (Comsat)

Comsat General's subsidiary, Satellite Television Corporation, has applied to the FCC for permission to place four broadcast satellites into orbit. These will operate at 13/12 GHz, one for each time zone. Each satellite will provide 3 channels with EIRP in the range 55.3-57.9 dbw, will use a 185 watt TWT in each channel, and will use an uplink at 17.3-18 GHz. The ground terminals will use antennas less than 1-meter in diameter and cost less than $300 each.

4.0 SYSTEM CONSIDERATIONS IN SATELLITE BROADCASTING

4.1 Television Links of Broadcast Satellites.

By the time television satellite broadcasting was first considered and then given system guidelines by study group 10/11 B of the CCIR, television broadcasting on a terrestrial basis was already a mature art. Three different television systems are now in use; NTSC in the U.S., Canada, and Japan; PAL in most of Europe other than France, and SECAM which is used in France and in the USSR.

Accordingly, television receive usage and manufacture is worldwide, and television standards and channel requirements have been in use for many years.

Terrestrial satellite broadcasting uses vestigial side-band modulation for the video portion of the signal and either FM (NTSC) or AM (SECAM) for the audio portion depending on the system used. The U.S. and Canada and Japan use 525-line systems (Region 2) while 625-line systems are used in Region 1 and most of Region 3.

In television broadcasting by satellites, as indeed in terrestrial radio relay systems, video is transmitted using FM, with the Audio, also on FM, usually transmitted on a separate carrier. In some systems the audio is digitized into PCM and included in the fly-back period of the video signal. The use of FM as a modulation technique, of course, provides a carrier with relatively constant amplitude which can pass through a non-linear amplifier such as a traveling wave tube with minimum or no distortion incurred due to AM-to-PM conversion.

The key system parameters of a broadcast satellite system required for operating at a CCIR specified quality include the following:

- o Channel bandwidth
- o Down-link budgets based on satellite EIRP, power flux density, and earth terminal G/T
- o Carrier-to-noise ratio (C/N) in the radio frequency bandwidth
- o Ratio of peak-to-peak luminance amplitude to weighted RMS noise (S/N) or signal-to-noise ratio (SNR)
- o Subjective viewer preferences

Typical service characteristics are listed in Table 4-1 - which includes the threshold CNR or bit error rate for each.

The system S/N or SNR is related to C/N as indicated in Figure 4-1 and a threshold is established which is related to system link margin. Figure 4-1 illustrates typical curves for FM modulation deviations of 6 MHz and 12 MHz and static and dynamic threshold. The static threshold is a convenient one to use since it is easily measured. It is defined as the 1 dB departure from linearity in the absence of video modulation. In the presence of video modulation, an additional flat noise component is added that raises the threshold to a dynamic value more appropriate to the actual situation. The difference between the two is above 1.5 dB in C/N_o.

The curves given on Figure 4-1 also reflect the fact that above threshold the noise has mainly a triangular spectral density, while well below threshold it is flat. This results in a variation in improvement due to low pass filtering, de-emphasis, and noise weighting at and below threshold. The improvement decreases from a theoretical value of 13.3 dB above threshold, to 8.5 dB at threshold, and 3 dB well below threshold.

Figure 4-1 is plotted using C/N_o rather than C/N (carrier-to-noise ratio) since this more easily allows a number of conclusions to be reached regarding the tradeoff between EIRP and G/T, namely:

TABLE 4-1

Service Characteristics

	Baseband	Mode	Protection Bandwidth MHz	Threshold CNR dB	SNR dB[1] or Equivalent
TV Teleconferencing	4.2 MHz/15 KHz	FM[2]	22	12	40.2
TV Teleconferencing (Compressed TV)	6 Mbps	QPSK[3]	9	9.1	BER = 10^{-4}
Audio/Fax Teleconferency	128 Kbps	QPSK	.077	9.1	BER = 10^{-4}
Multiplexed Data/Voice	768 Kbps	QPSK[3]	.922	9.1	BER = 10^{-4}
TV Broadcast	4.2 MHz/15 KHz	FM[2]	22	12	40.2
TV Distribution	4.2 MHz/15 KHz	FM[2]	32	12	50.6
Radio Distribution	15 KHz	FMFB[2]	.24	7	46
TV Distribution (compressed)	6 Mbps	QPSK[3]	9	9.1	BER = 10^{-4}
Radio Broadcast	6 KHz	FM[2]	0.1	7	40
Land Mobile	Toll quality 3.1 KHz	QPSK or FM[4]	0.02	7	43

(1) Test tone to noise ratio. (2) Emphasis. (3) Rate 1/2 convolutional code. (4) Emphasis & Compending.

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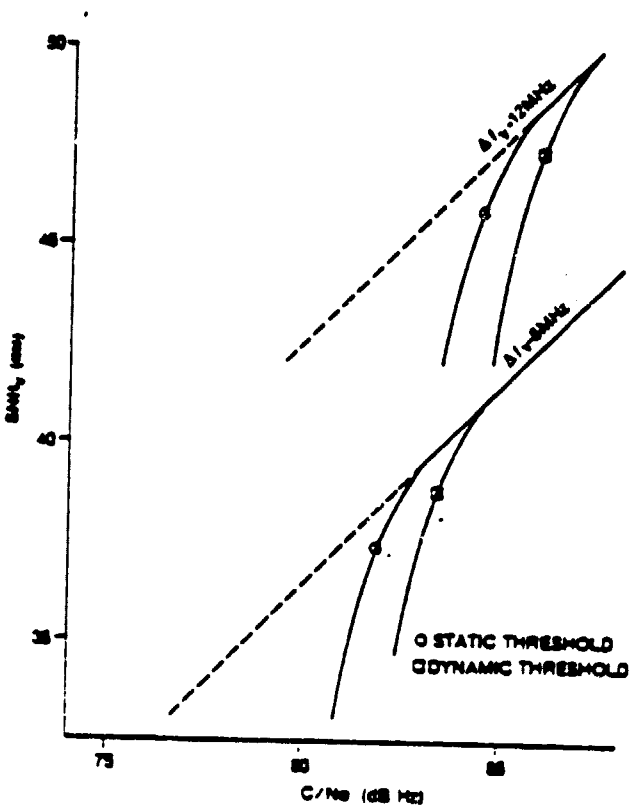

Curves of SNR_v vs. C/N_0 for FM.

Figure 4-1

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a) The level at which FM threshold occurs decreases with decreasing deviation.

b) For a given required SNR_v, a minimum C/N_o (and, hence, EIRP and/or G/T) is achieved with operation near threshold.

c) For operation at a given margin above threshold at a prescribed SNR_v, there is a specific video deviation and C/N_o that will allow optimum tradeoff between EIRP and G/T.

The picture signal-to-weighted continuous noise ratio of 56.8 dB (p-p/RMS) is allocated for a single satellite link, of which a noise allocation of 57.0 dB (p-p/RMS) was made for the up-link, satellite and down-path, thermal noises and an additional 70.0 dB (p-p/RMS) is for interference from other communications system and basic noise of earth station equipment.

The picture signal-to-weighted continuous random noise ratio can be expressed by the following equations for respective audio transmission schemes.

In the single-channel-per-carrier system, a separate RF carrier is used for each audio channel and carried through a single transponder separated from the video transponder. Therefore, the full transponder bandwidth can be allocated for the transmission of a TV video RF carrier.

$$S/N_v = C/N_v + 10 \log \frac{3 \cdot \{0.7\,(B - 2f_{cv})\}^2 \cdot B}{f^3_{CV}} + W_V$$

When the FM audio subcarrier is added to the video signal carrier, the baseband frequency range becomes wider, which makes the frequency deviation of the TV picture signal smaller with a certain satellite transponder bandwidth, or the satellite bandwidth wider with a certain picture quality.

$$S/N_v = C/N_v + 10 \log \frac{3 \cdot \{0.7\,(B - 2fs - \Delta Fsp\text{-}p)\}^2 \cdot B}{f^3_{CV}} + W_v$$

a. C/N_v = carrier-to-noise ratio (dB)

b. S/N_v = picture signal-to-weighted continuous random noise ratio (dB p-p/RMS)

c. B = satellite transponder bandwidth (MHz)

d. f_{CV} = maximum frequency of video signal (MHz)

e. fs = audio subcarrier frequency (MHz)

f. $\Delta Fsp\text{-}p$ = frequency deviation of RF carrier produced by subcarrier (Mhz, p-p).

g. W_V = weighting factor for pre-emphasized TV picture signal-to-continuous random FM (triangular) noise ratio (12.8 dB).

The CCIR standard for a 525 line color TV system is defined in terms of the peak-to-peak blanking-to-white signal and the rms noise:

$$SNR = \frac{\text{Peak-to-peak blanking-to-white signal}}{\text{rms noise}} = 56 \text{ dB} \qquad (1)$$

This signal is 9 dB higher than the rms test tone of same peak-to-peak excursion; thus

$$SNR, \text{ rms signal/rms noise} = 56-9 = 47 \text{ dB} \qquad (2)$$

The receiver generally uses a weighting network; typical improvement due to the weighting filters is 10.2 dB, leading to

$$SNR, \text{ unweighted, rms signal/rms noise} = 56-9-10.2 = 36.8 \text{ dB} \qquad (3)$$

Sometimes FM pre-emphasis is used, with an improvement of 2.5 to 4 dB; a typical value is 2.8 dB (for a combined improvement of 13.0 dB due to weighting and pre-emphasis). Then

$$\left.\begin{array}{l}\text{SNR, excl. improvements of pre-emph. \&} \\ \text{wghtg., for rms signal/rms noise}\end{array}\right\} = 56-9-13 = 34.0 \text{ dB} \qquad (4)$$

The SNR from (3) or (4) is used in the FM equation (output of FM detector):

$$SNR = 3.m^2.(m+1).CNR \equiv \text{FM improvement} + \text{CNR in dB} \qquad (5)$$

where m = modulation index, from $B = 2b\ (1+m)$

B = RF bandwidth

b = baseband (video) bandwidth = 4 MHz

Example: An FM system with B=40 MHz, b=4 MHz has a modulation index of 40/8 - 1 = 5-1 = 4. The FM improvement is 3x16x5 = 240, i.e., 23.8 dB. Using (4) with desired SNR of 34 dB, the required CNR is 34-23.8 = 10.2 dB. (The CNR threshold is approximately 8 to 10 dB).

4.1.1 Useful Relationships in Satellite Link Carrying Television

Tables 4-2 through 4-11 list many of the link parameters and relationships, and specifications for power flux density and signal to noise ratio which are in use today.

4.1.2 Analog Systems/Link Budgets.

Analog TV systems transmit the video and audio on an FM Carrier. In this paragraph, several important link budgets of existing or planned high p.m. broadcast satellites are listed; Tables 4-12, 4-13, 4-14 and 4-15 list the NORDSAT, CTS and BSE, and link budgets showing how a S/N or C/N is calculated given the satellite EIRP, ground terminal G/T for EIRP's in the 60 dbw range.

Table 4-16 is the link budget for Anik B which uses an EIRP of 50 dbw to achieve,with the earth terminal described in Table 4-17, the reception characteristics [illegible]ted in Tables 4-18 and 4-19. Figure 4-2 shows the threshold for the ANIK B system for a 1.2 meter antenna to be at least 3.7db below the S/N= [illegible]2db point.

Table 4-20 illustrates the link margin for a sound broadcast for individual reception (receive G/T = 4db). Note that an S/N of 56 db (unweighted) is achieved as a result of a satellite EIRP of 47 dbw in a channel bandwidth of 170 KC (2 x 150 + 2 x 15 KC).

TABLE 4-2

WARC-77 Bandwidth and Guard Bands Guidelines

Necessary Bandwidth

- .25 Line System: 27 MHz
- 525 Line System in Region 3: 27 MHz
- 525 Line System M in Region 2: 18 and 23 MHz

Guard Bands

Assuming maximum beam-center EIRP = 67 dBW in Regions 1, 3, and 63 dBW for Region 2; filter roll-off - 2 dB/MHz.

Regions	Guard Band at the Lower Edge of the Band (11.7 GHz)	Guard Band at the Upper Edge of the Band (12.2/12.5 GHz)
1	14 MHz	11 MHz
2	12 MHz	9 MHz
3	14 MHz	11 MHz

(Doc. 10-11/1104-E)

TABLE 4-3

Required width of radio-frequency channels (MHz) for frequency-modulation television systems (525-line

	Number of sound channels	Frequency (MHz)		
		700	2600	12 000
Equivalent rectangular bandwidth of receiver (1)	One	16–22	16–22	22-30
	Four	20–26	20–26	27-35
Radio-frequency channel width of satellite transmitter (2)	One	18–24	18–24	24–34
	Four	23–29	23–29	30–40

(1) The following equation can be used to determine the approximate video peak-to-peak deviation which is applicable:

$B \approx 1{\cdot}1\,(D_{p-p} - 2f_b)$

where: B : equivalent rectangular bandwidth (MHz)

D_{p-p} : video peak-to-peak deviation (MHz)

f_b : top baseband frequency including highest sound sub-carrier (MHz).

(2) Equal to the radio-frequency channel spacing.

TABLE 4-4

Required width of radio-frequency channels (MHz) for frequency-modulation television (625-lines systems)

	Number of sound channels	Frequency (MHz)		
		700 ([3])	2600	12 000
Equivalent rectangular bandwidth of receiver ([1])	One	20–22	20–22	27 ([4])
	Four	24–26	24–26	
Radio-frequency channel width of satellite transmitter ([2])	One	22–25	22–25	25–30 ([5])
	Four	25–28	25–28	

([1]) The following equation can be used to determine the approximate video peak-to-peak deviation which is applicable:

$$B \approx 1{\cdot}1\,(D_{p-p} + 2 f_b)$$

where: B : equivalent rectangular bandwidth (MHz)

D_{p-p} : peak-to-peak deviation at video-frequencies (MHz)

f_b : top baseband frequency including highest sound sub-carrier (MHz).

([2]) The channel spacing may differ from the channel bandwidth, depending on the value chosen for the adjacent-channel protection ratio.

([3]) These determinations are tentative and require further study.

([4]) Corresponds to a frequency deviation of 13 MHz/V, and distortion introduced by the receiver equal to 10° for the differential phase and 15 % for the differential gain, with a filter having a sharp cut off (6 poles), and with a sound sub-carrier producing a deviation of ±2·8 MHz of the carrier.

([5]) Estimated limits for the channel spacing, with the parameters given in ([4]) above and with an adjacent-channel protection ratio of −6 dB.

TABLE 4-5

Relationship between Satellite EIRP and
Earth-Station Figure of Merit G/T

$$C/N = EIRP - \underline{L} - \underline{B} + \underline{G}/\underline{T} - \underline{K} \quad \text{or}$$

$$EIRP = \underline{C}/\underline{T} + \underline{L} - \underline{G}/\underline{T} \quad \text{dB}$$

where,

$\underline{C}/\underline{T}$ = carrier-to-noise temperature ratio of the space-to-earth path, in dB($\underline{W}/\underline{K}$);

$\underline{K}$ = 10 log Boltzmann's constant in dB($\underline{W}/\underline{K}$ • Hz);

$\underline{L}$ = free space path loss on the space-to-earth path, in dB;

= 20 log $4\pi\underline{R}/\lambda$ (where $\underline{R}$ is the distance and λ is wavelength measured in the same unit);

$\underline{G}/\underline{T}$ = gain-to-noise temperature ratio of the earth receiving station in dB; ($\underline{T}$ expressed in $\underline{K}$);

$\underline{B}$ = 10 log $\underline{b}$ ($\underline{b}$ in Hz).

The required satellite EIRP can be converted into required satellite transmitter output power, $\underline{P_S}$, if the satellite antenna gain, $\underline{G_T}$ is known:

$$\underline{P_S} = EIRP - \underline{G_T} \quad \text{dB}$$

The half-power beamwidth θ_0 can be determined once satellite antenna gain is specified:

$$\theta_0 \approx \sqrt{27\,000/\underline{G_T}} \approx 223 \;\; \lambda/\pi \;\; \underline{D}$$

where $\underline{G_T}$ is the antenna gain expressed as a ratio and $\underline{D}$ is the diameter of the antenna expressed in the same units as λ, the wavelength. An antenna aperture efficiency of 55% has been assumed.

TABLE 4-6

Formulae Governing System Performance in a Frequency-Modulation System

$$S/N = C/N - F_{dB} - K_w$$

where,

$\underline{S/N}$ = ratio of peak-to-peak luminance amplitude to weighted RMS noise (dB);

$\underline{C/N}$ = pre-detection carrier-to-noise ratio in the radio-frequence bandwidth (dB);

$\underline{F}$ = $3(D_{p-p}/f_v)2 \bullet (b/2f_v)$ (power ratio which equals F_{dB}, when expressed in dB);

$\underline{D_{p-p}}$ = peak-to-peak deviation by video signal (including synchronization pulses);

$\underline{f_v}$ = highest video frequency; (e.g., 4.2 MHz in the case of System M)

$\underline{b}$ = radio-frequency bandwidth (usually taken as $D_{p-p} + 2f_v$);

$\underline{K_w}$ = combined de-emphasis and weighting improvement factor in frequency modulation systems (dB).

TABLE 4-7

The Relation between the EIRP of a Geostationary Satellite and the Power Flux-Density at the Surface of the Earth

The EIRP (dBW) minus the spreading loss in dB (m^2) is equal to the power flux-density (dB(W/m^2)); atmospheric loss not included.

For the point on the Earth at latitude φ^o and relative longitude (sub-satellite point = 0^o) λ^o and with $\cos \Delta = \cos \lambda \cos \varphi$, we obtain the following relationship:

Angle Δ (degrees)	Spreading loss, dB (m^2)
0 (sub-satellite point)	162.1
80	163.4

For an angle of elevation ϵ, with $\tan \epsilon = (\cos \Delta - 0.1513)/\sin \Delta$, we obtain the following relationship:

Angle ϵ (degrees)	Spreading loss, dB (m^2)
0	163.4
90	162.1

The power flux-density required for satisfactory television reception in a broadcasting-satellite system depends on the desired down-link carrier-to-noise ratio (C/N, dB), the receiver figure of merit (G/T, dB), the frequency (<u>f</u>, GHz) and the receiver bandwidth (<u>B</u>, MHz) in the following way:

$$PFD = (\underline{C}/\underline{N}) - (\underline{G}/\underline{T}) + 20 \log \underline{f} + 10 \log \underline{B} - 147.1$$

where PFD is the power flux-density in dB (W/m^2).

From: Doc. 10-11/1114-E

TABLE 4-8

Characteristics of Representative Receiving Systems and Resulting Power Flux-Densities

Type of reception	Individual				Community			
	A	B	C	D	A	B	C	D
HP beamwidth (degrees)	2.4	1.5	2.0	1.8	1.0	0.75	1.0	1.0
Antenna diam. (m)	0.75	1.2	(0.9)	(1.0)	1.8	2.4	(1.8)	(1.8)
Noise factor (dB) (1)	6.2	3.7 (2)	(5.0)	(6.7)	4.2	2.2 (2)	(4.2)	(4.2)
G/T (dB)	4	12	6	6	14	20	14	14
Overall C/N required (dB)	14	14	14	14	14	14	14	14
Frequency band (GHz)	12	12	12	12	12	12	12	12
Bandwidth (MHz)	18	27	27	18/23	18	27	27	18/23
PFD (dBW/m^2) (3)	-103	-109	-103	(-104/ -103)	-112	-117	-111	(-112/ -111)

(1) Computed by assuming the same losses and conditions as in the example in Annex I of Report (473-2), except that an antenna efficiency of 55% was used.

(2) In these cases the losses assumed in the example were reduced by 1 dB.

(3) Includes an allowance of 0.5 dB for retransmission of up-link noise.

A: readily achievable
B: achievable at additional cost
C: adopted by WARC-BS for Regions 1 and 3
D: adopted by WARC-BS for Region 2

TABLE 4-9

Video (Picture) Signal-to-Noise Ratio

The network requirements prepared by ABC, CBS and NBC give the performance objective for TV picture to weighted continuous random noise ratio of 56.0 dB (p-p/RMS) on a studio-to-studio basis. A picture signal to noise ratio of 56.8 dB is typically allocated for a single earth station-satellite-earth station link, based on the following allocation for the various segments of the television link.

Noise allocation of video signal:

Studio-to-Studio
56.0 (dB)

- Transmit Terrestrial Link
  66.7 (dB)
- Satellite Link
  56.8 (dB)
- Receive Terrestrial Link
  66.7 (dB)

TABLE 4-10

Audio Signal-to-Noise Ratio

The network requirement for maximum audio signal (+9 dBm) to psophometrically weighted noise ratio is 65.0 dB (RMS/RMS) which is equivalent to a noise level of -56.0 dBmOps. (The expression dBmOps is used to indicate noise levels in a program circuit which are psophometrically weighted and measured in decibels relative to 1 mW at a point of zero relative level in the circuit). The maximum audio signal-to-noise ratio of 66.0 dB is allocated for a single satellite link as listed below:

Noise allocation of audio signal:

Studio-to-Studio
65.0 (dB)

- Transmit Terrestrial Link
  74.9 (dB)
- Satellite Link
  66.0 (dB)
- Receive Terrestrial Link
  74.9 (dB)

TABLE 4-11

Subjective Picture Quality of 525-Line System/NTSC

System M: USA and Canada*

Picture Quality Grade as Reported by Viewers		Radio-Frequency Signal-to-Noise Ratio for the Percentage of Viewers Indicated (dB) (1)	
		50%	75%
1.5	half-way between excellent and fine	39.5	42.5
2	fine	35.2	38.2
3	passable	30.0	33.0
4	marginal	25.6	28.6
5	inferior	20.4	23.4

(1) Radio-frequency RMS signal during sync. peaks, no weighting, over 6 MHz bandwidth, amplitude-modulation vestigial-sideband.

Equivalent rectangular bandwidth in transmission:

- frequency-modulation: 18 MHz
- amplitude-modulation, vestigial-sideband: 4 MHz

Ratio of luminance signal to weighted RMS noise value is 43 dB* (rated "excellent" by 50% of the viewers).

* Approximately 46 dB for System M (Japan).

* See Section 6 for TASO Grade definition

TABLE 4-12

NORDSAT DOWN-LINK POWER BUDGETS

TWT Power Output (BOL)	+26.55 dBw
TWT Power Output (BOL)	450 w
Peak Antenna Gain*	-42.3 dB
Waveguide and Isolator Losses	+0.35 dB
Multiplexer Losses	+0.7 dB
TWT Output Circuit Losses	+0.3 dB
Peak EIRP (EOL)	+67.0 dBw
Ageing	+0.5 dB
Receive Carrier	-146.1 dBw
Atmospheric Loss (99%)	+3.4 dB
Space Loss	+206.2 dB
Pointing Loss	+0.5 dB
Relative Antenna Gain at the Edge of Coverage	+3.0 dB
C/N	+14.0 dB
Receive Bandwidth (27 MHz)	+74.3 dB/Hz
Boltzmann's Constant	-228.6 dBw/Hzk
Up-Link Noise Contribution	+0.2 dB
Receive G/T	-6.0 dB/K

* The down-link budget for the East-Nordic beam is given for the "worst" point in the coverage area which is southeastern Finland.

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TABLE 4-13

Sample Uplink Calculation for Lewis Ground Station
[Uplink frequency, 14.2 GHz.]

Characteristic	Spacecraft receiver noise temperature, K: 1315	Spacecraft receiver noise temperature, K: 2315
Terminal:		
Transmitter power (1250.0 W), dBW	30.97	30.97
Feed loss, dB	-2.00	-2.00
Antenna gain (4.88 m (16.0 ft), 0.31° half-power beam width (HPBW)	54.53	54.53
Effective Isotropic Radiated Power (EIRP), dBW	83.50	83.50
Antenna pointing error (0.05°), dB	-0.26	-0.26
Margin, dB	-3.00	-3.00
Propagation loss (23 074 statute miles; latitude, 41.4°; relative longitude, 35.1°), dB	-207.22	-207.22
Atmospheric loss (0.100% outage; CCIR Rainfall Region 2), dB	-2.23	-2.23
Polarization loss, dB	-0.25	-0.25
Spacecraft:		
Feed loss, dB	-0.00	-0.00
Antenna gain (0.70 m by 0.70 m (2.3 ft by 2.3 ft); 2.15 by 2.15 HPBW)	37.68	37.68
Antenna pointing error (0.38°), dB	-0.31	-0.31
Received carrier power, dBW	-92.03	-92.03
Noise power density, dBW/Hz	-197.41	-194.96
Bandwidth, dB (Hz) (27.0 MHz)	-123.10	-120.04
Carrier-power receiver-noise ratio, dB	31.02	28.56

Sample Downlink Calculation for Lewis Ground Station
[Downlink frequency, 12.1 GHz.]

Characteristic	Spacecraft Receiver noise temperature K: 1315	Spacecraft Receiver noise temperature K: 2315
Spacecraft:		
Output tube power (200 W), dBW	23.01	23.01
Feed loss, dB	-0.00	-0.00
Antenna gain (0.70 m by 0.70 m (2.3 ft by 2.3 ft); 2.52 by 2.521 HPBW), dB	36.28	36.28
Effective Isotropic Radiated Power (EIRP), dBW	59.29	59.29
Antenna pointing error (0.38°), dB	-0.22	-0.22
Margin, dB	-3.00	-3.00
Propagation loss (23 074 statute miles; latitude, 41.4°; relative longitude, 35.1°), dB	-205.81	-205.81
Atmospheric loss (0.100% outage; CCIR Rainfall Region 2), dB	-1.52	-1.52
Polarization loss, dB	-0.25	-0.25
Terminal:		
Feed loss, dB	-1.00	-1.00
Antenna gain (4.88 m (16.0 ft); 0.30° HPBW)	53.12	53.12
Antenna pointing error (0.05°), dB	-0.18	-0.18
Received carrier power, dBW	-99.58	-99.58
Noise power density (T=800 K), dBW/Hz	-199.57	-199.57
Bandwidth, dB (Hz) (27.0 MHz)	74.31	74.31
Terminal receiver noise power, dBW	-125.26	-125.26
Uplink noise contribution (C/N, 31.02; 28.6 dB), dB	0.95	1.80
Terminal net noise power, dBW	124.14	123.45
Terminal carrier-power receiver-noise ratio, dB	24.56	23.87
FM improvement (M=2.00), dB	21.58	21.58
Noise weighting factor (CCIR), dB	10.20	10.20
Preemphasis improvement, dB	2.40	2.40
Signal/noise ratio, dB	58.91	58.05

Typical Link Budgets for
The Communications
Technology Satellite (CTS)

TABLE 4-14

DOWN-LINK LINK BUDGET (TV CHANNEL) OF JAPANESE BROADCAST SATELLITE (BSE) at 12 GHz

Service Area	Mainland	Remote Islands
Antenna diameter of ground receiver	1.6 mØ	4.5 mØ
Satellite		
Transmitting power (dBw/ch)	20.0	20.0
Feeder loss	-1.7	-1.7
Antenna gain	37.0	28.0
Propagation loss		
Free space attenuation (dB)	-205.8	-205.4
Atmospheric attenuation (dB) (99% of any month)	-1.0	-1.0
Ground receiver		
Antenna gain (dB)	43.5	52.5
Received carrier power (dBw)	-108.0	-107.6
System noise power (dBw/25 MHz)	-126.4	-126.4
Noise increase by up-link	-0.1	-0.1
Down-link C/N	18.3	18.7
S/N improvement factor by FM (dB)	18.3	18.3
Picture weighting factor (dB)	10.2	10.2
Signal to noise ratio	46.8	47.2

C-2

TABLE 4-15

Link Budget for Japan BSE

Up-Link (Kashima to BSE)		
TX power (dBW/ch)	20.0	
TX feeder loss (dB)	-3.5	
TX antenna gain (dB)	62.0	
Free space loss (dB)	-207.2	
RX antenna gain (dB)	39.5	
RX feeder loss (dB)	-0.5	
Noise power (dBW/25 MHz)	-122.6	
C/N	32.9	

Down-Link

Service Area	Mainland	Remote Ils.
Antenna of RX	1.6 mϕ	4.5 mϕ
TX power (dBW/ch)	20.0	20.0
TX feeder loss (dB)	-1.7	-1.7
TX antenna gain (dB)	37.0	28.0
Free space loss (dB)	-205.8	-205.4
RX antenna gain (dB)	43.5	52.5
Received Carrier (dBW)	-109.7	-109.4
Noise power (dBW/25 MHz)	-126.4	-126.4
C/N	19.4	19.8
Total C/N* (dB)	19.2	19.6
Threshold C/N (dB)	9.0	9.0
Rain attenuation (dB) (99.99% of any month)	-7.0	-7.0
Link margin (dB)	3.2	3.6

*The transmission parameters pertinent to the color TV broadcasting by BSE are as follows:

System	NTSC Standard (525 lines, 30 frames/sec)
Sound subcarrier	
Frequency	4.5 MHz
Modulation	FM, Freq. deviation ±25 KHz (0-p)
Modulation	FM, Freq. deviation 12 MHz (p-p)
Sound/video ratio	1/6
Emphasis	CCIR Rec. 405-1

TABLE 4-16

ANIK-B LINK BUDGET

Uplink C/N		
SFD* (dBw/m^2)	-83.56	(Measured at Ottawa)
Spacecraft G/T (dB/K)	+ 2.2	(From Pre-Launch Data)
$\lambda^2/4$ (dB)	-44.54	
K (dBw/Hz/K)	+228.6	(Boltzmann's Constant)
B (dB-Hz)	-72.60	(Measured Noise Bandwidth of 18.2 MHz)
C/N_u (dB)	30.09	
Downlink C/N		
EIRP (dBw)	50.12	(Measured at Ottawa)
Path Loss (dB)	-205.8	(At Ottawa)
K (dBw/Hz/K)	+228.6	
B (dB-Hz)	-72.60	
Gain of Receiving Antenna (dB)	+40.70	
System Temperature (dB-K)	-27.61	(Measured noise figure of 4.5 dB plus 50 K for antenna noise and miscellaneous loss)
Total C/N (dB)	13.32	

* Saturating flux density

TABLE 4-17

ANIK-B EARTH TERMINALS (11.7-12.2 GHz)

Antenna Size	1.2 m	1.8 m
System G/T	13.0 dB/K	16.5 dB/K
Receive Flux Density	-113.5 dBw/m^2	-117.0 dBw/m^2
Video SNR*	$\geq$40 dB	$\geq$40 dB
Tuning Range	11.7-12.2 GHz	11.7-12.2 GHz
Video Bandwidth	4.2 MHz	4.2 MHz
Peak Video Deviation	6 MHz	6 MHz
Audio Subcarrier Frequency	5.14 MHz	5.14 MHz
Peak Subcarrier Deviation of Main Carrier	1 MHz	1 MHz
Peak Deviation of Subcarrier	60 kHz	60 kHz
Peak Energy Dispersal Deviation	200 kHz	200 kHz

* At a C/N 2 dB above static threshold.

TABLE 4-18

PERFORMANCE OF LOWER-POWER SATELLITES

Assumed parameters are

EIRP 50 dBW

Δf_v 6 MHz

Bandwidth 18 MHz

SERVICE TYPE	ANTENNA SIZE (M)	TERMINAL G/T (dB)	C/N_0 (dB-Hz)	SNR_v (dB)	MARGIN TO STATIC THRESHOLD (dB)	MARGIN TO PICTURE LOSS (dB)
Individual Reception	1.2	13.0	85.5	42.0	3.7	7.7
Small Community or School	1.8	16.5	89.0	45.5	7.2	11.2

TABLE 4-19

Performance of Lower-Power Satellite

CARRIER POWER (dB RELATIVE TO STATIC THRESHOLD)	PICTURE QUALITY
+4	No threshold noise
+2	Threshold noise just starts to appear on color bars; not generally noticeable on pictures except those having wide deviation components.
+1.5	Dynamic threshold; threshold noise just starts to appear on pictures.
0	Significant threshold noise on color bars; noticeable on pictures.
-2	Large amount of threshold noise on color bars; significant on pictures.
-4	Large amount of noise on all pictures; at some point below this the picture will be lost.

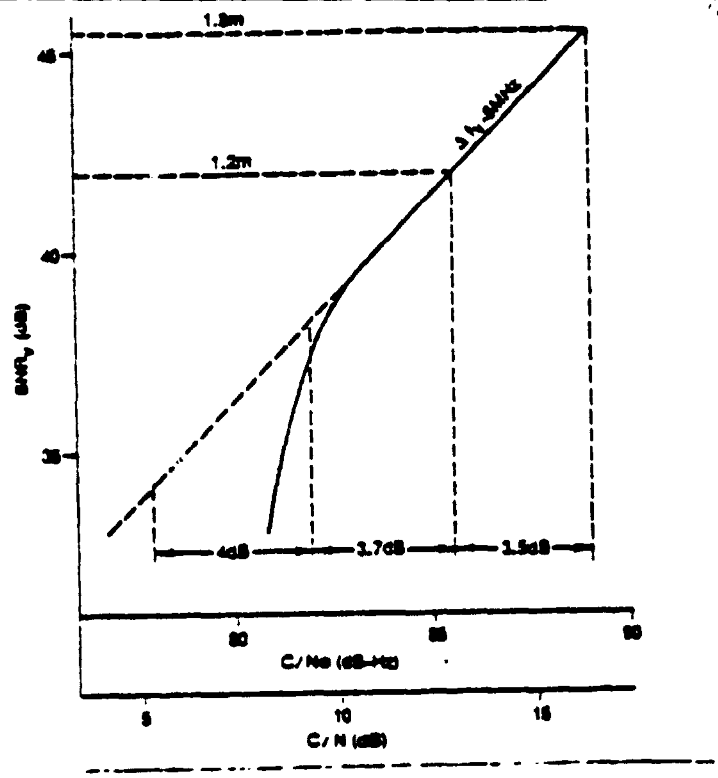

Figure 4-2

TABLE 4-20

Examples of System Parameters for Monophonic Sound Broadcasting for Individual Reception(1)

Parameter	Example
1. **System**	
Frequency of carrier (MHz)	12000
Type of modulation	FM
Frequency deviation (kHz)	±75
Audio-frequency bandwidth (kHz)	15
Total radio-frequency bandwidth required (kHz)	180
Carrier-to-noise ratio before demodulation (for 99% of the time in the least favorable month) (edge of beam) (dB)	19
Corresponding audio-frequency signal-to-unweighted noise ratio (edge of beam) (dB)	56
Audio-frequency signal-to-weighted noise ratio (dB)	47
2. **Receiving Installation**	
Figure of merit, G/T, of receiver (dB)	4
Required flux (edge of beam (99% of time in most unfavorable month) (dB(W/m^2))	-117.5
Free-space attenuation between isotropic sources 35 786 km apart (dB)	205.1
Additional free-space attenuation for an angle of elevation of 40° (dB)	0.5
Total atmospheric attenuation for 99% of the time in the most unfavorable month (dB)	1.5
Up-path noise (provisional value)(dB)	0.5
Required EIRP from satellite at edge of beam (dBW)	47
3. **Satellite Transmitter**	
Antenna beamwidth at -3 dB points (degrees)	1.4
Antenna gain at edge of service area relative to an isotropic source (dB)	38
Loss in feeders, filters, joints, etc. (dB)	1
Required satellite transmitter power: (dBW)	10
(W)	10

(1) These examples will probably not be valid for sound broadcasting alone, unless the receiving antenna and the pre-amplifier or frequency-changer were also used for television.

4.1.3 Digital Systems/Link Budgets.

In digital video communication using a broadcast satellite (Table 4-1), bit error rate (BER) is the criterion of system performance rather than C/N to achieve a S/N of say 48 db.

Bit error rate is a criterion which differs for various uses. BER of 10^{-4} for example may give a most acceptable (viewer) television picture, while 10^{-6} is required for voice, and 10^{-8} for computer data. Note from Figure 4-3, that for quadriphase modulation in a system requiring a 10^{-5} BER, a signal to noise power ratio of 9.6 db is required. Note a characteristic of digital communications; i.e., when signal to noise power ratio decreases slightly, a major increase in BER is experienced. Table 4-21 lists the characteristics of several modern modulation techniques using various level phase-shift keyed carriers shown in Figure 4-4; the respective BER's are shown in Figure 4-5.

The figure of merit of the "efficiency" of bandwidth utilization refers to the number of bits per unit of bandwidth for a particular modulation technique. Bits/Hertz is now becoming a familiar part of the communication system lexicon and has, obviously, considerable economic connotations to a user who wishes to purchase or lease a portion or all of a channel bandwidth. Biphase (BPSK) modulation (QPSK), and its derivatives staggered QPSK (SQPSK) are now standard in the world today. Other derivatives include 8Ø-PSK, 16Ø-PSK, FFSK and multilevel amplitude modulation. 2 bits/Hertz will be used for SQPSK in Intelsat-V and 3 bits/Hertz is now virtually standard with 8Ø-PSK for terrestrial radio at 11 GHz. More advanced workers in this art, such as Dr. K. Miyauchi of Japan NTT ECL Laboratories, Joel Smith at NASA's JPL Laboratories and G. Welti at Comsat Laboratories are experimenting with more advanced combined multi-dimensionally coded amplitude and phase shift modulation which has already achieved a bandwidth efficiency of

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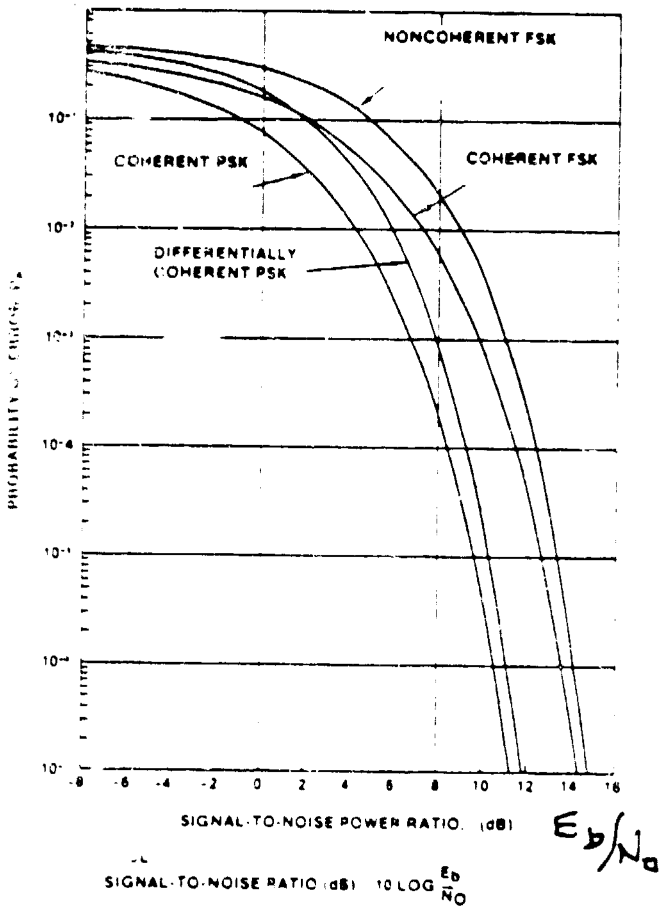
Graph of Probability of Error Rates for Selected Binary Coding Systems



REFERENCES MODERN COMMUNICATION PRINCIPLES STEIN AND JONES
BUREAU OF STANDARDS TECHNICAL NOTE 167 MARCH 1963

Figure 4-3

TABLE 4-21

CHARACTERISTICS OF MODERN MODULATION TECHNIQUES

MODULATION TECHNIQUE	BANDWIDTH OF MAIN LOBE	REQUIRED E/N_o AT BER = 10^{-6}
BIPHASE	2 x BR	10.6 dB
QPSK	1 x BR	10.6 dB
8Ø	0.75 BR	12.7 dB
QPRK	0.75 BR	14.7 dB
16 PHASE	0.5 BR	18.2 dB

Vector Diagrams of Phase Modulation Systems

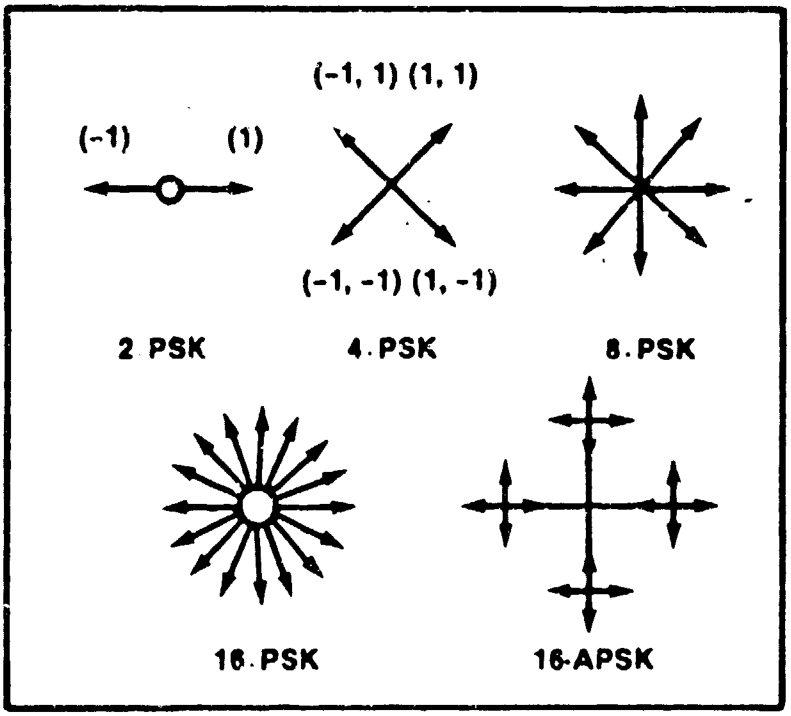


Figure 4-4

Bit Error Rate Performance of Various Modulation Systems

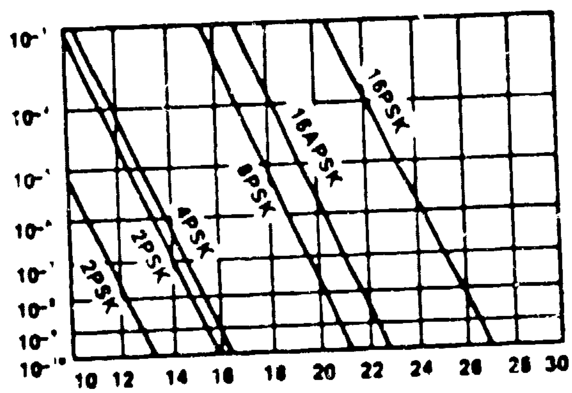


Figure 4-5

4 bits/Hertz, can be extended to as much as 8 bits/Hertz and beyond. Table 4-22 lists some of the achievements in use as reported in the literature of satellite communications.

The theoretical capacity of some of these modulation techniques, with various levels have been charted for bits/Hertz versus E_b/N_o for 10^{-7} BER by W. Wood of Raytheon. According to Wood, at 3 b/Hz, 8-phase and 2-level 4-phase schemes are identical but at higher efficiencies a departure in favor of combined AM and PM hybrid techniques becomes apparent. At exactly 3 b/Hz, performance must be measured in terms of implementation complexity and overall system gain in that hybrid AM/PM techniques require linear transmission systems with microwave amplifier backoff to achieve the required amplitude linearity.

In order to encourage the use of bandwidth-efficient modulation, the Federal Communications Commission wisely issued Docket 19311 in 1974, which specified a minimum channel capacity of 1152 channels in a 30 MHz band in the 6 GHz terrestrial radio band. This requires a data configuration using two T3 carriers or 89.472 Mb/s or, which with bit stuffing and framing information brings the operating data rate to 90 Mb/s. This requires a bits/Hz of 3 and is now being met in the U.S. by Raytheon and Collins, and others, using 8-phase PSK.

Table 4-23 provides an FM link and digital link using an EIRP of 55dbw illustrating both the relative characteristics for a TV signal represented by a 20 Mbps data stream.

Figure 4-6 compares satellite transmission power at bandwidth for FM and quadriphase showing that for data rates up to 50 Mbps for the particular system illustrated, the digital system requires less satellite power.

TABLE 4-22

BANDWIDTH EFFICIENCY MODULATION TECHNIQUE

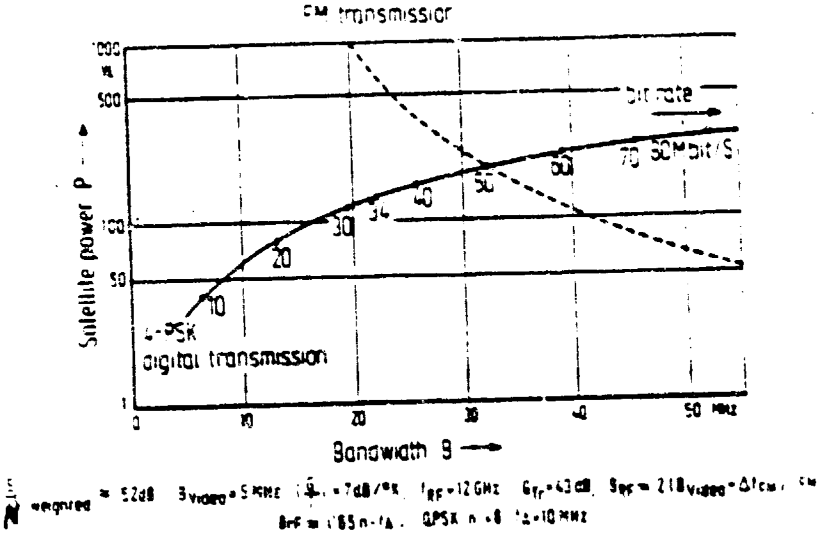
Level	Type Modulation	Bits/Sec/Hz	Where Used
2	2Ø PSK (using M)	0.50	Canada Thin Route Norway Marisat TTY
4	QPSK QPSK QPSK	0.94 1.12 1.53	SBS SPADE (INTELSAT) TELSAT
4	SQPSK SQPSK	1.30 2.00	Bell System T3 transmission via 11 GHz radio Intelsat V
4	FFSK	2.20	CTS Canada Experiment (11/14 GHz through 85 MHz BW)
6	QPRK	2.25	Microwave Associates 11 GHz terrestrial radio
7	Zero-Memory Nyquist Correlative Coding: Modulating a PCM-FM System	4.00	Lenkurt system for transmitting 6.312 Mb/s T2 over 3 MHz terrestrial radio channel
8	8Ø PSK 8Ø PSK	1.81 3.0	TDMA thru Intelsat IV by Fujitsu Ltd. Collins terrestrial radio for 11 GHz
16	16Ø PSK 16 APSK[1]	4.00 4.00	Comsat Labs/Japan NTT/ECL Japan NTT/ECL[4]
32	4-bit QASK[2]	4.00	JPL for Space Lab[3]
49	Hexagonal type signal format using super-imposed modulation	4.00	Japan NTT/ECL[4] (experimental)

1 Combined Amplitude and Phase Shift Keying
2 Quadrature Amplitude Shift Keying
3 J. Smith AIAA paper 76-230
4 K. Myauchi, IEEE Trans Comm, Feb. 1976

TABLE 4-23

12 GHz Link With Minimum Performance (G/T = 14 db/K) Community Reception Station

FM LINK		DIGITAL LINK	
EIRP	55.0 dBW	EIRP	55.0 dBW
Space Loss	-205.0 dB	Space Loss	-205.0 dB
Receiving Antenna Gain (1^{o} Beamwidth)	44.0 dB	Receiving Antenna Gain	44.0 dB
Received Signal Level	-106.0 dBW	Received Signal Level	-106.0 dBW
No (T_{sys} = $1000^{o}K$)	-198.6 dBW/Hz	No	-198.6 dBW/Hz
$C/_{No}$	92.6 dB	$C/_{No}$	92.6 dB
Bandwidth (18 MHz)	72.6 dB	Data Rate (20 Mbps)	73.0 dB
C/N	20.0 dB	$E/_{No}$	19. dB
C/N Required (42 dB post-detection SNR)	14.0 dB	$E/_{No}$ Required ($P_e = 10^{-5}$, QPSK)	9.4 dB
Margin	6.0 dB	Margin	9.6 dB



Comparison of satellite transmission power and
bandwidth for FM and 4 phase shift keying transmission

Figure 4-6

Table 4-24 lists the link margins of various digital systems as provided by Dr. Phillips of the European Broadcasting Union, illustrating the relative power required for a given C/N and bandwidth.

4.2 FM Modulation for TV Broadcasting - Channel Considerations

4.2.1 Single Carrier Per Transponder.

The satellite transponder is an integral part of the overall link which delivers the TV signal from the transmitting station to the demodulator of the receiver earth terminal. Accordingly, transmission channel requirements have been developed by the CCIR, as stated in Table 4-25, to assure using the proper channel parameters relative to bandwidth, noise, gain flatness, and group delay distortion which provide for minimum distortion of the video content of the FM Carrier. As noted in Table 4-25 the gain flatness is maintained within ±0.5 dB and the group envelope delay - specified at ±63 nanoseconds at band edges, assured that all principal video harmonic components up to 4.5 MHz arrive at the proper interval in time to assure defining an edge or a change in detail - without this detail information being delayed to a later or succeeding interval. Figure 4-7 shows typical amplitude and group delay channel response characteristics as specified by INTELSAT in Document B6 28-72E which provides the frequency and time response tolerances which should be met by the transponder channel on TVRO receiver system to minimize distortions due to gain flatness at RF and IF.

In a television system in which only one FM signal is transmitted through the 36 MHz wide transponder, the FM signal is assured a reasonably symmetric channel relative to both gain/amplitude and group delay and in most cases the transponder is operated at or very near saturation.

TABLE 4-24

Approximate propagation margins and receiver characteristics

a) Propagation *					
Frequency		**12 GHz**	**23 GHz**	**42 GHz**	**85 GHz**
Moderate rain (5 mm/hr) for 10 km	dB	1	7	16	33
Fog and cloud for 0.5 km (30 m visibility, 2 gm/m³ at 0°C)	dB	0.1	0.5	1.5	4.0
Oxygen and water vapour at 20° elevation (50% humidity, 7.5 gm/m³, 10 km path)	dB	0.15	2.0	1.0	3.0
Sky temperature at 20° elevation	K	20	150	100	180
Noise margin for all but 0.3% time	dB	1	9	18	40
b) Receiver **					
Dish diameter	m	0.9	0.7	0.5	0.3
Gain on axis	dB	38	42	44	46
Beamwidth at 3 dB	degrees	2	1.5	1.1	0.9
Effective area	dB (m²)	−4.5	−6.5	−9.5	−14
Noise factor	dB	6	8	10	12
G/T	dB/K	6	9	9	9
Noise power in 1 MHz	dB (W)	−138	−136	−134	−132
Relative power required for a given channel width and C/N	dB	−21	−11	0	−23

* The values of rain attenuation exceeded for 0.3% time were obtained by extrapolation from the ATS-6 data given in CCIR Report 564-1 for receiving sites in the UK, France and Netherlands. The attenuation given for the higher frequency bands are somewhat higher than those given in Table XIIA of Draft Report 215-4.

** 625 Line System

TABLE 4-25

Satellite Television Performance Requirements[a]

Transmission Parameter	Performance Requirement
Insertion Gain[b]	±0.5 dB
Insertion Gain Variations	
Short Term (1 second)[b]	±0.2 dB
Long Term (1 hour)[b]	±1.0 dB
Noise	
Random (weighted)[b,c]	56 dB
Impulsive[b]	25 dB
Periodic, Below 1 kHz[d,e]	50 dB
Periodic, 1 kHz to 1.2 MHz[e]	55 dB
Attenuation Frequency[f]	±0.5 dB
Envelope Delay[b]	±63 ns
Differential Gain[b]	1.2 dB
Differential Phase[b]	3 degrees
Linear Distortion	
Field Time[b,d]	±1 percent
Line Time[b]	±1 percent
Short Time[e]	±1 percent
Luminance-Chrominance Inequalities	
Gain[e]	0.5 dB
Delay[e]	±50 ns
Synchronizing Signal	
Nonlinearity[b]	-10 percent
Distortion[b]	+5 percent

a. These requirements are for a CCIR-type satellite hypothetical reference circuit (SHRC).

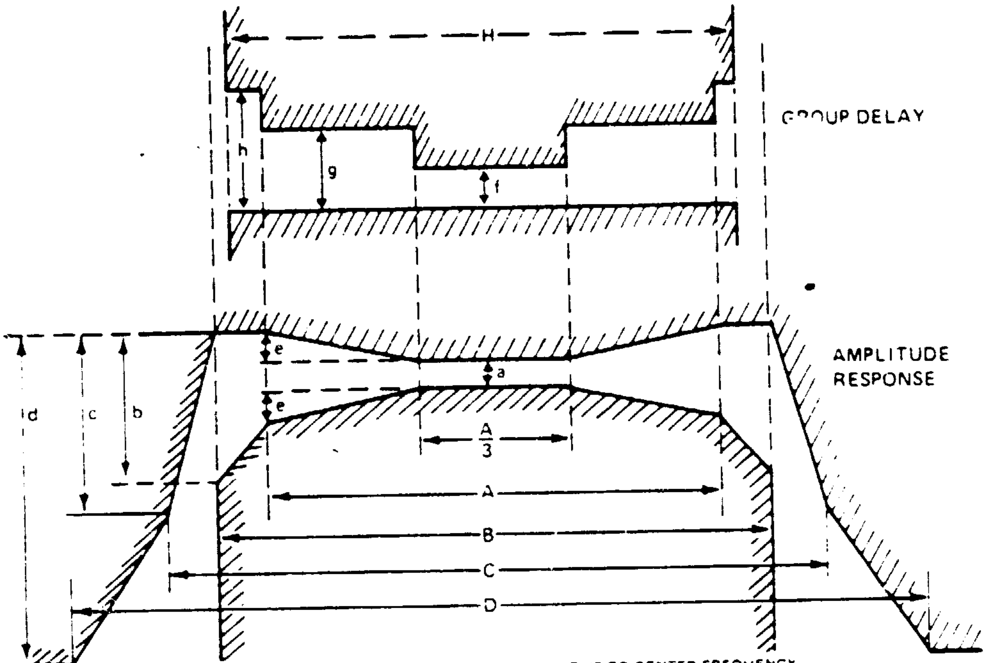
b. Based on CCIR Recommendation 421-2.

c. Present provisional CCIR recommended value for the SHRC given in Recommendation 354-1.

d. Measured after clamping. Clamping is used in satellite links to attenuate the energy-dispersal waveform upon reception.

e. Based on CCIR Recommendation 451-1.

f. Based on CCIR Recommendation 421-2 and Report 407-1.



NOTES
(1) FIGURES ARE SYMMETRICAL RELATIVE TO CENTER FREQUENCY
(2) FIGURES ARE NOT DRAWN TO SCALE
(3) AMPLITUDE SCALE IS LINEAR IN dB
(4) FREQUENCY SCALE IS LINEAR IN MHz

Transmit Equipment
Gain Frequency Characteristics

CARRIER SIZE (MHz)	A (MHz)	B (MHz)	C (MHz)	D (MHz)	a (dB)	b (dB)	c (dB)	d (dB)
1.25	0.9	1.13	1.50	4.0	0.7	1.5	3.0	25
2.5	1.8	2.25	2.75	8.0	0.7	1.5	2.5	25
5.0	3.6	4.50	5.25	13.0	0.5	2.0	3.0	25
7.5	5.4	6.75	7.75	17.0	0.4	2.5	4.0	25
10.0	7.2	9.00	10.25	19.0	0.3	2.5	5.0	25
15.0	10.8	13.50	15.50	25.0	0.3	2.5	5.5	25
17.5	12.6	15.75	18.00	26.5	0.3	2.5	6.5	25
20.0	14.4	18.00	20.50	28.0	0.3	2.5	7.5	25
25.0	18.0	22.50	25.75	34.0	0.3	2.5	8.0	25
36.0	28.8	36.00	45.25	80.0	0.6	2.5	10.0	25

Transmit Equipment
Group Delay Characteristics

CARRIER SIZE (MHz)	A (MHz)	H (MHz)	f (ns)	g (ns)	h (ns)
1.25	0.9	1.13	16	16	20
2.5	1.8	2.1	16	16	20
5.0	3.6	4.1	12	12	20
7.5	5.4	6.2	12	12	20
10.0	7.2	8.3	9	9	18
15.0	10.8	12.4	6	6	15
17.5	12.6	14.2	6	6	15
20.0	14.4	16.6	4	5	15
25.0	18.0	20.7	3	5	15
36.0	28.8	33.1	3	5	[illegible]

FIGURE 4-7. Transmit Amplitude and Group Delay Requirements.

In symmetric - channel single carrier per transponder - channel operation which conforms to the mask of Figure 4-7, and the specifications listed, the receiver becomes the principal place where the quality of the receiver signal must be maximized.

Although an FM system is used and in most conventional receivers there is some form of amplitude limiting,severe amplitude non-flatness can cause AM and FM conversion to occur in the limiters which lead to intermodulation of the video signal.

Phase linearity is commonly discussed in terms of group delay which is defined as the derivative of the phase frequency response. The group delay limits of the receiver should meet the requirements of the mask of Figure 4-7. Non-linear phase results from conventional filtering and must be equalized to provide a group delay characteristic which falls within the mask of Figure 4-7 to yield satisfactory performance. Group delay distortions cause the following degradations of the demodulated signal:

- o Baseband gain/frequency variations
- o Harmonic distortion which produces luminance/chrominance crosstalk
- o Baseband intermodulation which causes unwanted frequency products to occur in the video signal
- o Differential phase distortions

Demodulator linearity is a measure of the accuracy of the transfer function of the demodulator (volts/MHz of deviation) over its deviation range. For good performance this accuracy (linearity) should be within one percent on any portion of the deviation range. Demodulator non-linearity causes harmonic distortion and excessive differential gain of the demodulated signal.

Once the signal is demodulated it must have several operations performed on it before it is a usable signal suitable for distribution. The basic signal processing operations as specified by FACC's Edward Chapman are:

- De-emphasis
- Removal of the subcarrier from the video signal
- Energy dispersal removal from the video signal
- Restoration of DC level to the video signal
- Selection and demodulation of the audio subcarrier
- De-emphasis and filtering of the demodulated audio signal

In FM systems triangulation of the noise spectrum occurs during the demodulation process. This causes the noise spectrum to increase in level with an increase in modulating frequency. This results in a decreasing signal-to-noise ratio at increasing baseband frequency. To overcome this effect, a de-emphasizing network is utilized in the receiver and a matching pre-emphasizing network in the transmitter. Pre-emphasis shapes the frequency response of the video signal and causes the highest frequency component of the video signal to be 13.2 dB (voltage ratio of 4.6)higher than the lowest frequency component.

The weighted S/N improvement of a pre-emphasized video signal over a flat video signal is approximately 2.5 dB for 525 line transmission.

Another factor of pre-emphasis used in video transmission is the improvement in color information by the reduction in distortion of the chrominance signal by the luminance signal. By reducing the relative level of the luminance signal to the chrominance signal the amount of chrominance-to-luminance distortion caused by non-linearities in the system is reduced.

Removal of the subcarrier from the video is required to eliminate the possibility of subcarrier to chrominance intermodulation which could produce spurious products that fail within the video passband. Although the frequency of the subcarrier is high enough that it would probably not cause degradation of the picture it is best to remove the subcarrier as quickly as possible after demodulation to avoid potential intermodulation problems.

All video signals transmitted through a satellite are required to have an energy dispersal waveform. This waveform is simply a triangular waveform (whose inflection points are synchronized with the vertical blanking interval) summed in with the video signal prior to modulation. The energy dispersal waveform causes the carrier to be modulated typically 1.0 MHz peak-to-peak with video and 2.0 MHz peak-to-peak when video is removed. The deviation caused by the dispersal waveform insures that the radiated power from the satellite at any one RF frequency is less than a certain maximum allowable level to minimize the probability of interference with terrestrial microwave systems and, in some cases, adjacent satellites, and to reduce intermodulation in half transponder video transmission. After the video signal is demodulated the triangular waveform must be removed and this is commonly done by clamping the video signal to the sync tips. In addition to removing the triangular waveform, clamping also provides DC restoration of the video signal.

The video associated audio is transmitted on a subcarrier which is summed in with the video signal. The subcarrier must be filtered from the video signal and demodulated to produce the audio signal. Since this is also FM modulation, the audio signal must be de-emphasized to correct for pre-emphasis (pre-emphasized modulation provides an unweighted S/N improvement of approximately 12 dB over flat modulation for the 75 μsec pre-emphasis network and [illegible] kHz audio format used in U.S. domestic video transmission).

4.2.2 Two Carriers Per Transponder

It is an attractive economic feature in satellite usage to transmit two FM TV (video + sound) signals side by side through a single satellite transponder - using a lower FM deviation for both FM signals. Consider a system which places two FM TV carriers side by side and each occupying a 17 MHz bandwidth in a 36 MHz standard transponder channel.

In order to maintain picture quality for both carriers, it is necessary to reduce the drive to the satellite TWTA by both carriers (see Figure 4-8) whereby the two carriers together provide a TWTA output approximately 5 dB below saturation. This reduces intermodulation distortion productivity both of the amplified carriers, but it does not reduce the EIRP for each carrier.

Another aspect of two carriers per transponder is the need to equalize each half of the transponder channel to essentially provide symmetrical group delay for each FM carrier and to limit the group delay at the edge of each 17 MHz band to less than 30 nanoseconds (see Figure 4-7) which then prevents delaying high frequency picture information into the next picture element.

4.2.3 Vidiplex Systems

Utilizing a newly-developed satellite television transmission technique, Vidiplex, four channels of television programming were sent from Los Angeles, California, to Juneau, Alaska, through a single transponder on the Satcom satellite. According to RCA, who managed the demonstration, this had never been done anywhere in the world for public viewing.*

Vidiplex, a trademark of Thomson-CSF, is an adaptation and extension of the STRAP technique (for simultaneous transmission and reception of alternating pictures). Vidiplex, a technique developed by CBS Labs and manufactured by Thomson-CSF, produces a technical pairing of two television signals which can then be transmitted within the same spectrum of a single television channel.

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* Satellite Communications, April 1979.

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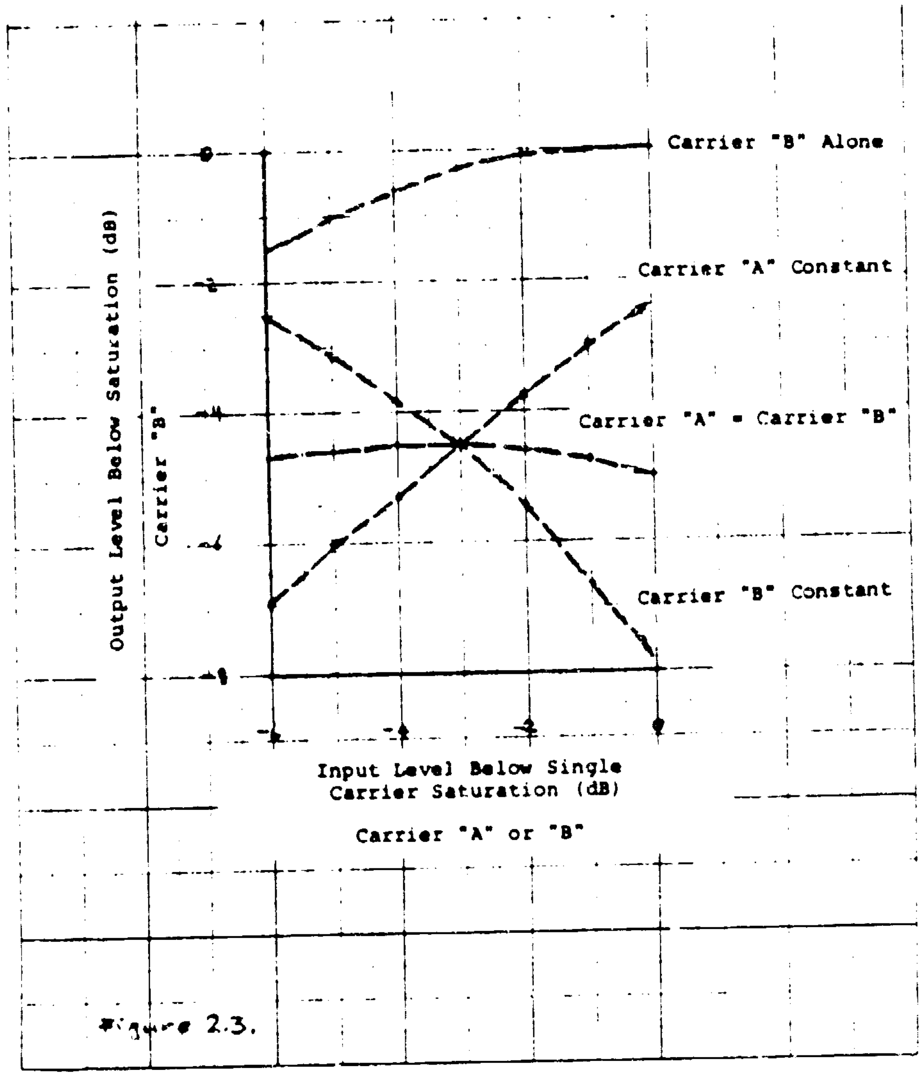


Two Input/Output Characteristics

Figure 4-8

For an earlier two-signal-one transponder experiment, RCA developed an alternate line delay, a device that takes every other line from the picture transmission, shifting, those lines slightly to prevent colors from bleeding together, because of the corresponding intermodulation in the transmission system.

For the Juneau demonstration, RCA Alascom combined two Vidiplex units to establish what was actually a dual-Vidiplex system. Four television signals were grouped into pairs, with each pair run through a frame synchronizer, then into two Vidiplex encoders. Each encoder signal was fed to a satellite uplink, and the two paired signals were transmitted on one transponder. Through reduced bandwidth techniques, RCA places two carriers in the same bandwidth normally occupied by only one.

At the receiving end, two reduced bandwidth satellite receivers, each equipped with a Thomson-CSF noise reducer, fed the two Vidiplex decoders. The outputs, flowing through the alternate line delay device, were then fed into the standard VHF modulators to a local CATV system. Video and audio were brought together at the cable carrier.

4.2.4 Slow Scan TV.

A variety of slow scan TV picture transmission systems have been developed over the last two decades; however, the present trend is to use conventional CCTV cameras, monitors, and other system components in conjunction with "scan conversion" devices which reduce the bandwidth of a CCTV camera output from a nominal five megaHertz to approximately one kiloHertz for transmission over voice grade circuits. This is a compression ratio of 5000 to 1, and is generally achieved by a) stretching out the signal in time from 30 pictures per second to perhaps 1 picture in 100 seconds, and b) sacrificing some resolution in the final image.

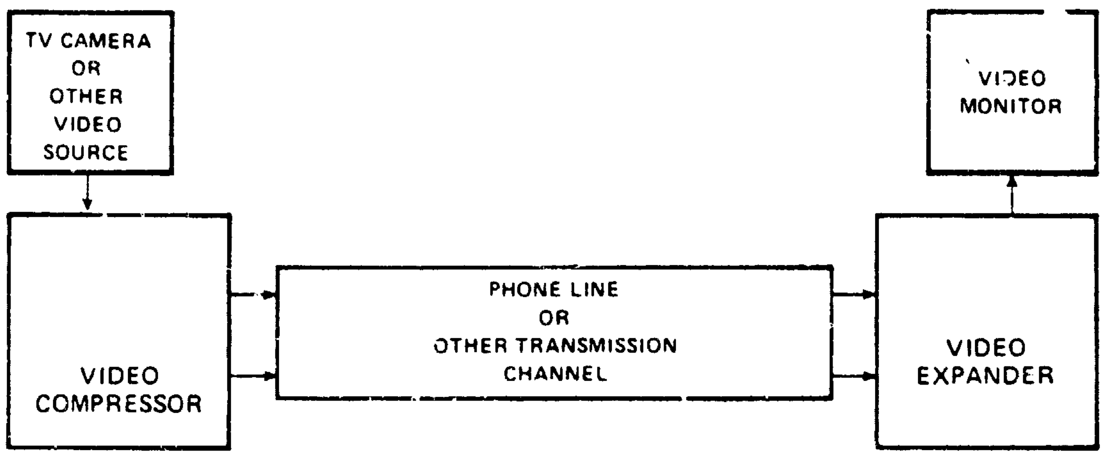
Time is the essential factor in slow scan TV communications, and the amount of time required to transmit a single picture is primarily determined by two factors: bandwidth of the communications link, and resolution of the reproduced image. The dial-up phone network provides a basic limitation to bandwidth, and, although the useful frequency range of a dial-up circuit may be approximately 300 to 2500 Hertz, it is usually necessary to transmit a DC component in the slow scan TV signal. This is usually accomplished by amplitude or frequency modulation of an audio tone, with the result that the effective bandwidth of the transmitted data is only on the order of one kiloHertz, or about 2000 picture elements per second. Under these conditions, a few approximations are as follows:

128 x 128	picture elements	=	8 seconds
256 x 256	picture elements	=	32 seconds
256 x 512	picture elements	=	64 seconds
512 x 512	picture elements	=	128 seconds
512 x 1024	picture elements	=	256 seconds

In general, 128 x 128 pictures are too coarse to be useful except in very limited situations, 256 x 256 is acceptable in many instances, while 256 x 512 or higher resolution provides excellent imagery. Key considerations are viewer distance from the TV screen and type of graphic material to be reproduced. In general, the guidelines of conventional TV production may be followed when 256 x 512 resolution is available, while lower resolution will require correspondingly tighter camera shots.

In some instances, wider band communications circuits may be available and scan converters with a faster picture transmission time used. For example, an AM broadcast circuit (100 to 5000 Hertz) would halve the time required for a given resolution, while an FM quality circuit (30 to 15,000 Hertz) can be used to reduce image transmission time by a factor of eight, with room enough left over for simultaneous voice channel. At present, two mid-Western schools are using the sub-carrier channels of their FM stations for distribution of slow scan TV programming, and United Press International will use satellite transmission of 8 kiloHertz slow scan TV pictures to cable companies.

Note: Narrow band video systems are manufactured by Colorado Video, Inc. Box 928, Boulder, Colorado 80306



TYPICAL COMMUNICATION SYSTEM

Figure 4-9A

video transceiver 280

general description

The Model 280 is designed to provide narrow band video communications over standard voice grade telephone circuits. Three basic functions are provided:

1. A "frame freeze" capability which captures a single image that may be assessed for quality before transmission
2. Conversion of the frozen picture to a "slow scan" television signal suitable for transmission over audio channels
3. Reception of slow scan TV Signals and reconversion to a still image on a normal TV monitor.

In the transmission mode, the 280 accepts a conventional CCTV input signal which is digitized on command and fed to a solid state digital memory. The output of the memory is then displayed on a TV monitor which indicates the exact quality of the image to be transmitted. Once a transmit command is given, the memory is read out slowly from left to right, with a white cursor on the TV monitor screen showing the degree of picture completion. Two sending speeds are available: 35 seconds for a single field picture with 256 x 256 memory elements, and 74 seconds for a full frame picture with 256 x 512 elements, dot interlaced.

In the receiving mode, the 280 accepts properly formatted slow scan TV input signals and reconstructs a conventional TV still picture, using the same memory which provided frame freeze for transmission. Image retention is indefinite unless deliberately erased or power to the 280 is lost.

Features of the Model 280 include:

- Completely solid state design
- Operation in moving environments
- Remote control
- Plug-in circuit cards for simplified maintenance
- Real time monitoring of A/D operation
- "Gen-lock" to other video sources for systems operation
- Optional operation at 625 line, 220 VAC, 50 Hertz

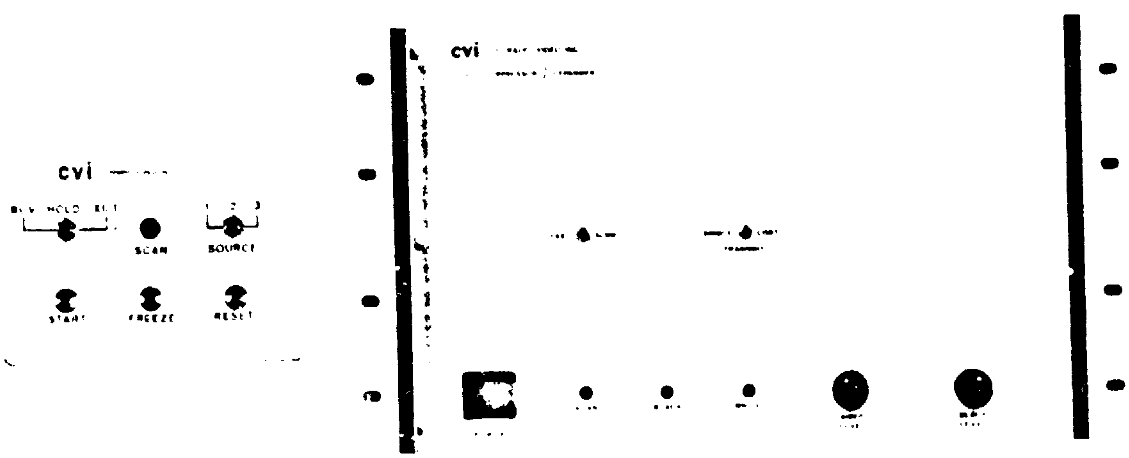


FIGURE 4-9B.

4.3 Digital Modulation for TV Broadcast.

4.3.1 Digital Representation of Video.

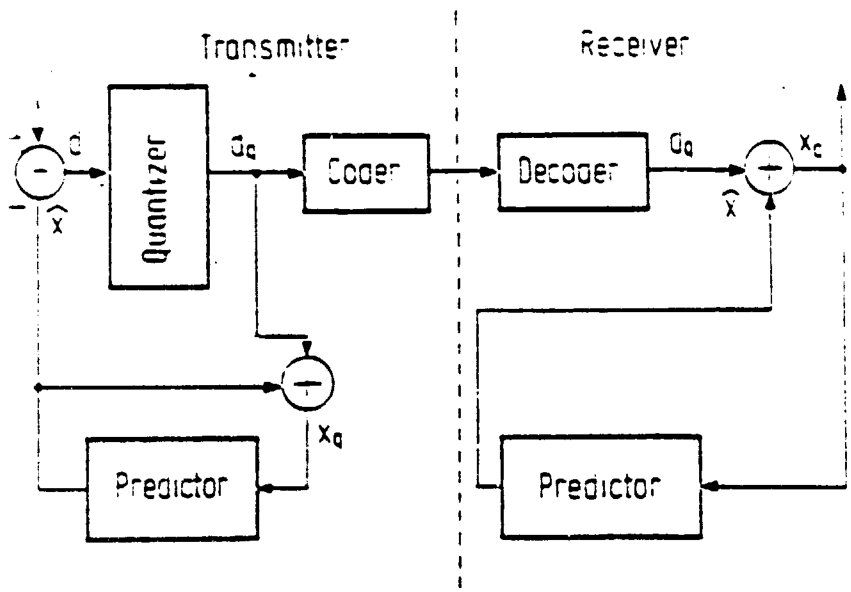
In order to provide a digital representation of an NTSC video signal (4.2 MHz video bandwidth) it is possible to sample at the Nyquist rate of 8.4 megasamples, and then use 10-bit words for each sample, thereby resulting in a PCM bit stream of 84 Mbps. However, this requires a carrier spectrum bandwidth of 84 MHz if quadriphase modulation is used, and it is a major effort in Japan, Europe, and the USA to reduce the bit rate to one suitable for transmission through a 36 MHz channel for NTSC color, or a 6 MHz channel for, example, video conferencing.

Many techniques have been developed to reduce video data rates; see Figure 4-10.

In these techniques, the use of differential PCM techniques (Figure 4-11), has been successful to reduce the data rate to as low as 22 Mbps (NEC). The use of Hadamard Transform techniques can reduce this data rate to as low as 6.3 Mbps (T2 carrier) and special DCPC and frame storage has been used to reduce the digital representation of a black and white or color TV video signal to as low as 1.5 Mbps (T1 carrier). These latter rates are used for video conference.

4.3.2 Digital Representation of Voice.

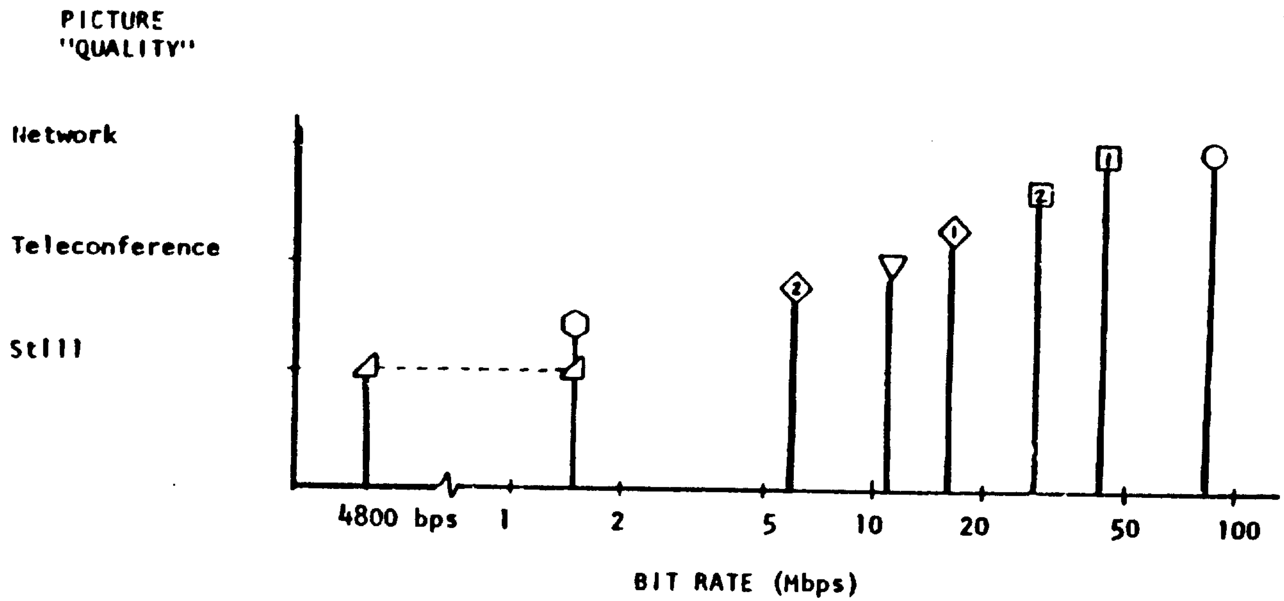
Not only will the amount of data to be transmitted increase with each succeeding year, but also how the data is used will change, bringing about new methods of doing business, new methods for education, practice of medicine, etc. Hence, the satellite communications community must not only meet new needs demanded each year and continue the development of technology for both space and ground installations now on a world-wide basis, but also,



Block diagram for DPCM coding and decoding

Figure 4-10

Figure 4-11
ACHIEVED BIT RATES FOR DIGITAL TELEVISION
WITH VARYING PICTURE QUALITY



Quality levels are discussed in section 3.1.3.

All systems shown are 525 line, system M.

Code:

- ○ PCM, 6 Mbps, color, full resolution.
- □1 DPCM, 43 Mbps, color, [Gatfield, 1977].
- □2 DPCM, 29 Mbps, color, reduced vertical resolution, [Golding, 1972].
- ▽ Hadamard Transform, 11 Mbps, black and white, reduced [George and Hoffman, 1977].
- ◇1 Hadamard/Slant Transform, 16 Mbps, color [Ohira, 1977].
- ◇2 Hadamard/Slant Transform, 6 Mbps, color, [Ohira, 1977].
- ⬡ DPCM, 1.5 Mbps, black and white, reduced temporal and spatial resolution [Haskell, 1977].
- ◺ DPCM, 4800-1.5 Mbps, color, full resolution, frame storage required, transmittal rate matches channel bandwidth.

develop communication technology designed to provide optimum use of the radio spectrum; i.e., maximize the amount of information transmitted through an available bandwidth.

Total bits per unit of bandwidth for a 3.1 kHz voice	=	Baseband bits per second representative of voice in 3.1 kHz BW	x	Bits per Hertz degree of modulation technique used to represent digitized voice

In the transmission of the human voice, a voice channel requiring only 1000 bits per second from a vocoder (as compared to the Spade standard of 64 Kbps) in a modulation system using two bits per Hertz will require only 2 kHz of radio frequency bandwidth for the vocoder transmission, as compared to 128 kHz of bandwidth for the Spade system using the same modulation system. This comparison must of course be measured against useful voice quality for each system.

Tables 4-26 and 4-27 list the various techniques which are used to digitize the human voice or audio signal. Note that, depending on the quality required of the system, the digitized human voice can be represented at bit rates from a few hundred bits to 64 Kbps.

4.3.3 Proposed German Digital TV-System

Experimenters in the Federal Republic of Germany have been very active in testing or designing digital TV through a satellite system. Figure 4-12 shows the experimental system tried via the Symphonie satellite.

Figures 4-13 and 4-14 show a digital TV system being designed for use with a digital TV satellite (such as TV-SAT).

Note that the luminance and the color-difference signals are digitized directly and then multiplexed into a single digital bit stream which is then passed through a data reduction system, a channel coder, and then transmitted

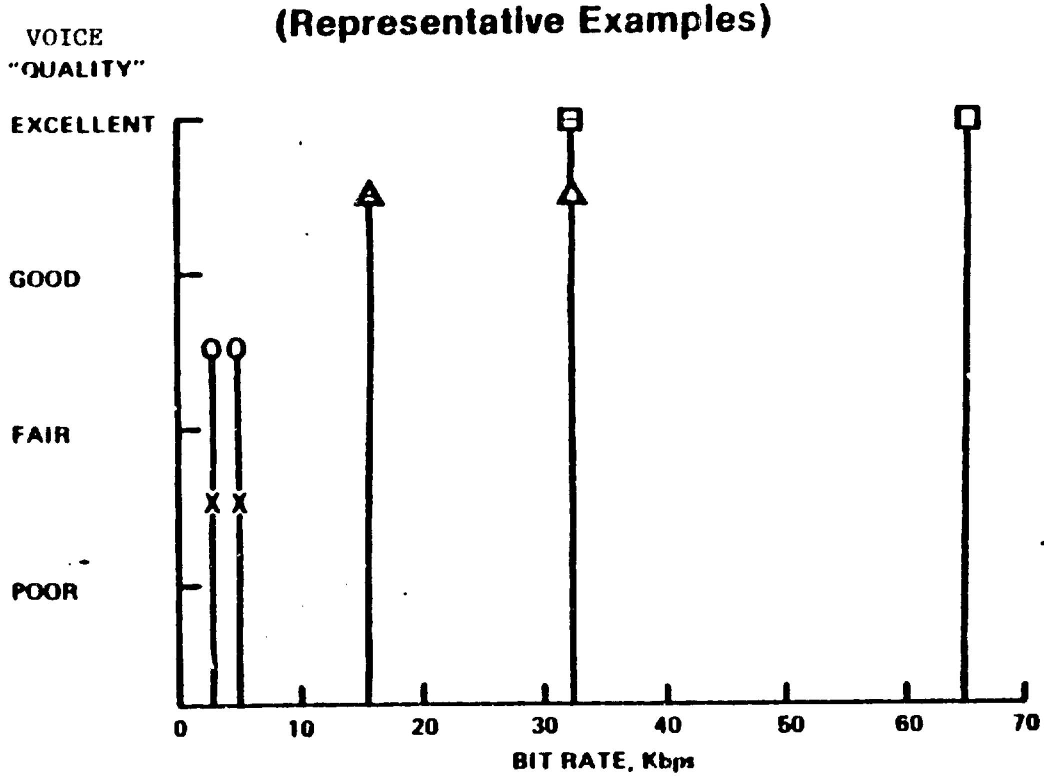
TABLE 4- 26

TYPICAL DIGITAL REPRESENTATION OF VOICE

TYPE INFORMATION	BASEBAND DIGITAL TECHNIQUES	NUMBER OF BITS/SECOND REQUIRED TO REPRESENT INFORMATION
Synthesized-Voice Coding for 3.1 kHz Voice BW	Linear Predictive Coding	400-1200 b/s
	Channel Vocoder Using FFT	2400-4800 b/s
	Cepstrum Homomorphic Filtered Vocoder	2400-4800 b/s
	Formant Vocoders	600-1200 b/s
	Voice Excited Vocoder	7200-9600 b/s
Digital Voice Coding (High to Medium Quality Voice)	Adaptive Predictive Coding	7200 b/s
	Forward Error Control PCM*	10,000 b/s
	Adaptive Delta Modulation	8000-16,000 b/s
	Non-Adaptive Delta Modulation	10,000-32,000 b/s
	DPCM (Differential PCM)	30,000-40,000 b/s
	PCM	54,000-64,000 b/s
High Quality Sound 0-15,000 Hz	PCM Sampling Rate 35 kHz 13-Bit Accuracy/Sample	450,000 b/s

TABLE 4-27

ACHIEVED BIT RATES FOR DIGITAL VOICE
(Representative Examples)



CODE:

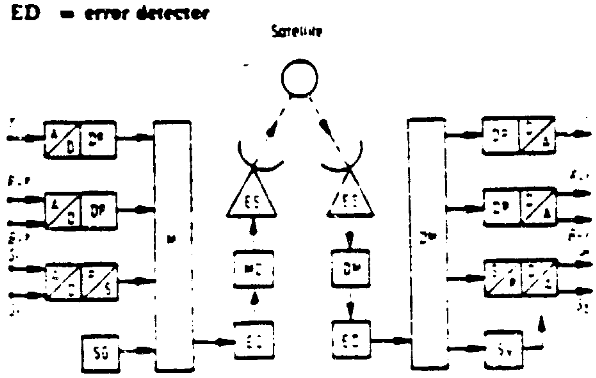
- □ PCM, 64 Kbps. (PRECISION MONOLITHICS, SIGNETICS)
- ⊟ PCM WITH SPEECH INTERPOLATION, 32 Kbps. (SIT SIEMANS (ITALY), SAT (FRANCE), NEC (JAPAN))
- △ CVSD, 32 Kbps. (HARRIS, MOTOROLA, PHILLIPS (NETHERLANDS) TRT (FRANCE))
- ▲ CVSD WITH SPEECH INTERPOLATION, 16 Kbps. (COMSAT EXPERIMENTAL)
- O LINEAR PREDICTIVE CODER, 2.4 OR 4.8 Kbps. (TIME AND SPACE PROCESSING, INTERNATIONAL COMMUNICATION SCIENCES, GTE SYLVANIA, ITT)
- X CHANNEL VOCODER, 2.4 OR 4.8 Kbps. (E-SYSTEMS, PHILLIPS (NETHERLANDS), ERICSSON (SWEDEN), MARCONI (UK))

REFERENCE -
COMSAT LABS
Dr. J. Campanella

NASA HQ EC78 1919 (1)
4 17 78

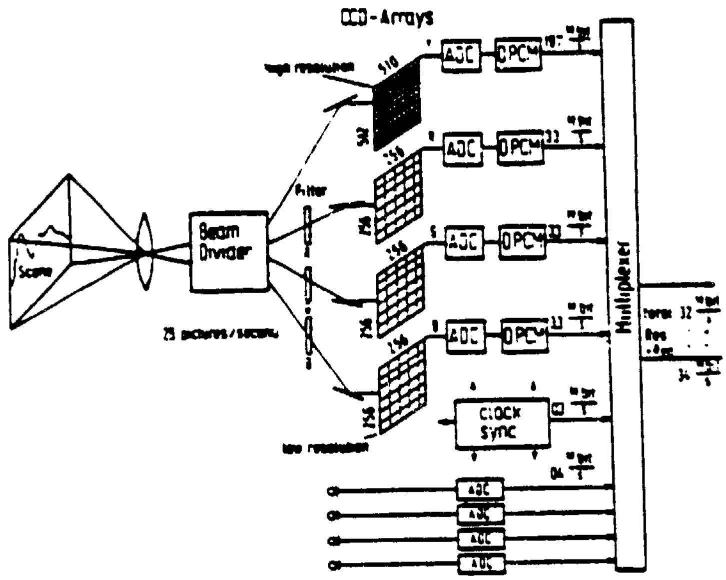
Digital TV satellite transmission system.

A/D = analogue-digital converter
D/A = digital-analogue converter
DP = DPCM processing unit
P/S = parallel-serial converter
S/P = serial-parallel converter
M = multiplexer
EC = error correcting coder
ED = error detector
DM = demultiplexer
SG = sync-pattern generator
Sy = synchronisation unit
MD = modulator (4-PSK)
DM = demodulator (4-PSK)
ES = earth station
Y = luminance signal
$R-Y$, $B-Y$ = chrominance signals
S_1, S_2 = sound signals



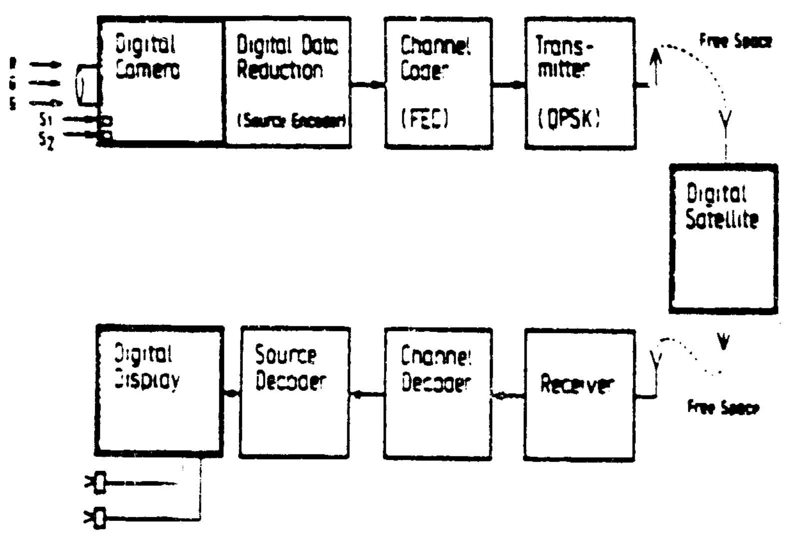
Blockdiagram of the German experimental digital television-system tried via SYMPHONIE

FIGURE 4-12



Proposed block diagram of a digital color TV camera

FIGURE 4-13



Completely digital TV-Sat System

Figure 4-14

to the satellite. The received digitally modulated carrier is then demodulated, decoded, and then demultiplexed and applied to the TV color reproducer.

This system differs from the standard system which provides digitizing the analog video signal after it is produced by combining the luminance and a color subcarrier (3,58 Mbps) formed with two color-difference signals.

Table 4-28 provides a comparison of the carrier power required for an analog FM-TV signal, a digital TV signal in a standard transponder, and a digital TV signal in a regenerative transponder on board the satellite. Note the drastic reduction in all power levels required of the digital systems.

4.3.4 Digital TV Broadcast Proposals from Great Britain.

The 1977 WARC-BS (Geneva) Plan provides in most cases for each country in I.T.U. Region 1 to operate in five channels, each with a usable bandwidth of 27 MHz. The channel spacing is 19.18 MHz and, in general, the channels for a given country have center frequencies spaced at about 77 MHz. The basis of the plan is the use of FM television signals with about 13-MHz peak-to-peak deviation. For any new television system it would be unattractive to employ more than one RF channel for the same picture. Also, if any new transmission system is used, each signal would not only have to be confined to the 27-MHz channel, but would also have to conform to the power limits and protection ratios prescribed in the Plan in order to protect other television services using the standard FM signals.

If, as seems desirable, a new high-definition standard employs digital transmission, and uses separate luminance and chrominance signals (to avoid cross-color and other band-sharing problems of NTSC, PAL and SECAM), G. Phillips and R. Harvey have addressed the problem that the extent to which the picture quality could be improved is quite limited if it is to be confined to one 27-MHz channel. To illustrate the difficulty, the following represents a possible system, but this may well be based on over-optimistic assumptions regarding inter-

TABLE 4-28

Comparison of the Transmitter Power for the Satellite and Earth Stations for the 3 Systems and Summarization of the General Assumption

	Analog FM-TV	Digital TV with Analog Transponder	Complete Digital TV with Regener. Transponder
TV-Receiver (1) C/N	13 dB	8 dB	8 dB
Satellite (2) P_{Transm}	356 W	94 W	47 W
Earth Station (3)	740 W	195 W	47 W

(1) $(S/N)_{Weighted}$ = 50 dB

G/T = 7 DBI/K
Diameter 1M

BER = 10^{-4} Uncoded

BER = 10^{-8} Coded

(2) G_{Transm} = 40 DBI

F_{Down} = 12 GHz

G/T = 7 DBI/K

(3) Diameter = 1M

F_{Up} = 19 GHz

G = 42 DBI

ference and the economics of the required antenna and decoder for the receiver.

Lines per picture	819
Aspect ratio	4 by 3 (present value)
Picture frequency	30 Hz (interlace with 60 fields/s)
Luminance bandwidth	8 MHz — 10 MHz total video
Chrominance bandwidth	2 MHz
Coding	4 bits/sample (e.g., DPCM)
Bit rate at Nyquist limit	80 Mbit/s

The suggested transmission system is a 16-level signal at 20-MHz clock-rate based on a 4 by 4 matrix of amplitude/phase modulation, but this would be subject to an error rate of 1 in 10^3 at a carrier-to-noise ratio (C/N) of 19 dB. Error correction would be needed and the bit-rate for the error-correcting code could correspond to the saving available during the line and field blanking periods. To ensure that the proposed condition C/N = 19 dB corresponds to 1% of the worst month, the receiver G/T would have to be 5 dB better than that assumed in the Geneva Plan.

4.4 Sound Interactive Satellite System

Table 4-29 is a table from CCIR Document 10-11/11041E illustrating a candidate sound interactive link operating with a 12 GHz broadcast satellite. In this system, an FM bandwidth of 50 KHz is used and a satellite EIRP is used with an earth terminal G/T of 16db to provided an audio frequency signal-to-weighted noise ratio of 41.9 db.

TABLE 4-29

Example of System Parameters for Sound Interactive Satellite Connections according t Doc 10-11/1104/E

Parameters	Example
1. **System**	
Frequency of carrier (MHz)	12000
Type of modulation	FM
Frequency deviation (pre-emphasis 75 s) (kHz)	±25
Audio-frequency bandwidth (kHz)	5
Total radio-frequency bandwidth required (kHz)	60
Carrier-to-noise ratio before demodulation (for 99% of the time in the least favorable month) (edge of beam) (dB)	19
Corresponding audio-frequency signal-to-unweighted noise ratio including de-emphasis (edge of beam) (dB)	51.2
Audio-frequency signal-to-weighted noise ratio (dB)(1)	41.9
2. **Receiving Installation**	
Figure-of-merit, G/T, of receiver (dB)(2)	16
Required flux (edge of beam) (99% of time in most unfavorable month) (dB(W/m^2))	-134.3
Free-space attenuation between isotropic sources 35.786 km apart (dB)	205.1
Additional free-space attenuation for an angle of elevation of 40° (dB)	0.5
Total atmospheric attenuation for 99% of the time in the most unfavorable month (dB)(3)	1.0
Up-path noise (provisional value) (dB)	0.5
Required EIRP from satellite at edge of beam (dBW)	29.3
3. **Satellite Transmitter**	
Antenna beamwidth at -3 dB points (degrees)	1.4
Antenna gain at edge of service area relative to an isotropic source (dB)	38
Loss in feeders, filters, joints, etc. (dB)	1
Required satellite transmitter power (dBW)	
For 6 carriers sharing transponder with video carrier	0.1
For 50 carriers sharing linear transponder	9.3

(1) Assuming weighting filter of Rec. (468-3).
(2) In accordance with the definition in the example shown in the Annex to Draft Report (473-2).
(3) Examples valid for an angle of elevation of about 40° and Rosman, N.C. climatic conditions.

Telecom 79

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NETEC-6/3 Digital Television Terminal

(For Video Conference Use)

The NETEC-6/3 is a low bit rate interframe encoder/decoder which converts standard NTSC color or monochrome television signals into 6 Mbps bit stream with audio signal and control data.

Operation at 3 Mbps is also possible.

Features

- Economical video transmission for long haul teleconferencing
- Digital interframe coding
- 1/15 or 1/30 transmission bit rate compression
- Transmission over parallel 4(2) T1 lines (6.3 or 3.1 Mbps)
- Monochrome/NTSC color television signal
- Audio and control data

Specifications

Video Signal Encoding	
Video input/output	Standard NTSC color or monochrome television signals 1 Vp-p at 75 ohms, unbalanced
Transmission bit rate	6.3/3.1 Mbps
Signal to noise ratio	45 dB unweighted
Audio Signal Encoding	
Bandwidth	50 to 5000 Hz
Sound input/output	Maximum +12 dBm at 600 ohms, balanced
Signal to total distortion ratio	Greater than 35 dB
Dimensions	600(W) x 740(D) x 1515(H) in mm 236(W) x 291(D) x 596(H) in inches

Video Codec Products		
	Application	Bit Rate
NETEC-22H	Broadcast TV	22 to 30 Mbps
HO-DPCM	Broadcast TV ITV	45 Mbps 32 Mbps
NETEC-6/3	Conference TV	3 to 6 Mbps

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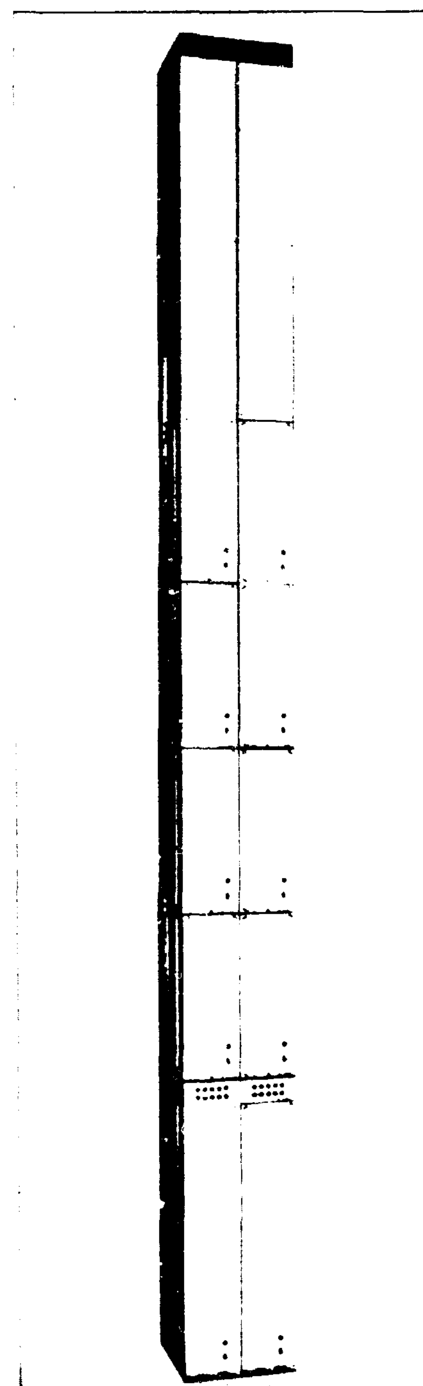
NEC

Optical Analog Transmission Equipment

For simple video transmission or FDM transmission, the analog fiber optic system is recommended. The hybrid transmission system, which can transmit any bit rate below the specific speed, is suitable for data transmission or video analog transmission in pulsed form such as PFM-IM.

Features

- Immunity from noise interface
- No crosstalk
- Compact design and low power consumption
- Low cost
- Analog baseband signal interface with terminal equipment.



Major Parameters

	Direct IM Transmission System	PFM-IM Transmission System	Remarks
Signal	Video signal with audio signal		
Electrical I/O Interface	Video signal 1 Vp-p (75Ω unbalanced) Audio signal 0 dBm (600Ω balanced)		Base band
Light Source	LED	LD	
Photosensor	APD	APD	
Transmission Range	6.1 km	9.8 km	• When S p-p/Nrms of video signal is 54 dB • Optical fiber of 3.5 dB/km is used • Overall system margin of S/N is 3 dB in optical level • S/N of audio signal is 45 dB or more
Power Consumption	Transmitter 6 VA Receiver 6VA	Transmitter 18 VA Receiver 18 VA	

FUJITSU LIMITED

FUJITSU VIDEO DIGITAL TRANSMISSION SYSTEM "FEDIS-SERIES"

FEDIS-SERIES REALIZES AN ECONOMICAL VIDEO TRANSMISSION SYSTEM FOR DIGITAL NETWORK

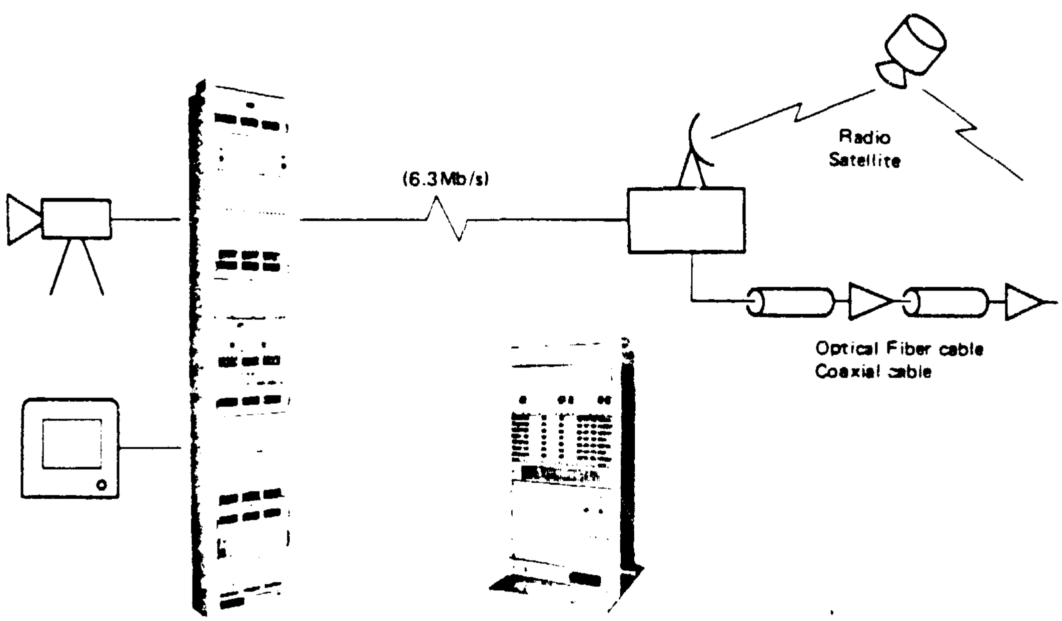
OF POOR QUALITY

FEATURES

- High band compression ratio (FEDIS 1.5 ~ 45)
- Employment of LSI A/D, D/A and Memories, etc permits compact size and assures high reliability
- Voice or data channel in cluded (option)
- OPTICAL FIBER LINK interface available (option)

FEDIS-SERIES

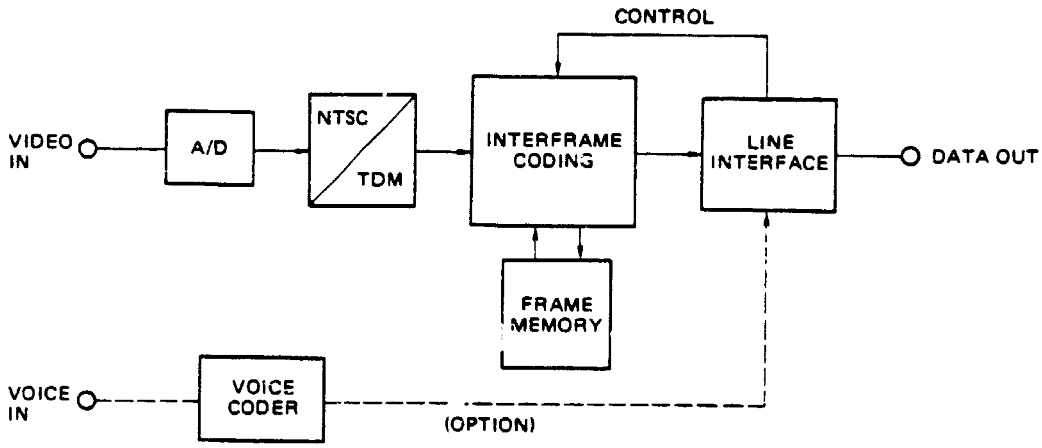
Model	I/O Signal	Encoding	Transmission Speed	Applications
FEDIS-1.5	1MHz/4MHz TV	Interframe coding	1.5Mb/s (DS-1)	Teleconference
FEDIS-6.3	4MHz Color Video	Interframe coding	6.3Mb/s (DS-2)	Teleconference
FEDIS-20	4MHz Color Video	Interframe coding	20Mb/s	ITV CATV
FEDIS-32	4MHz Color Video	Intraframe Coding (DPCM)	32Mb/s	ITV CATV
FEDIS-45	4MHz Color Video	Intraframe Coding (DPCM)	45Mb/s (DS-3)	ITV CATV
FEDIS-100	4MHz Color Video	PCM	75 ~ 100Mb/s	ITV CATV



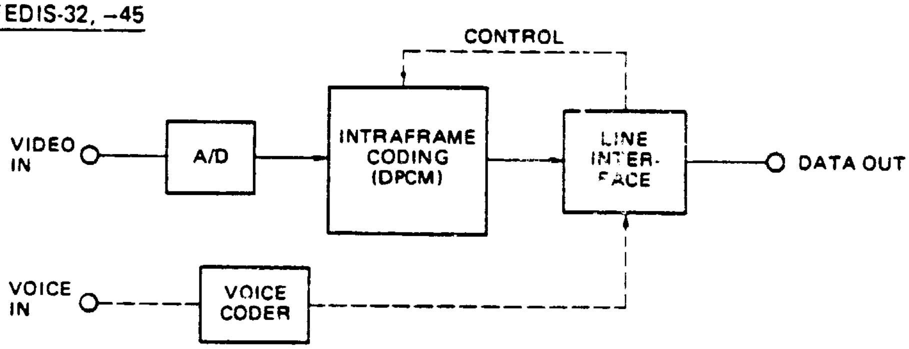
(FEDIS: Fujitsu Efficient Digital Image System)

Basic Configuration of FEDIS SERIES (Transmitting side)

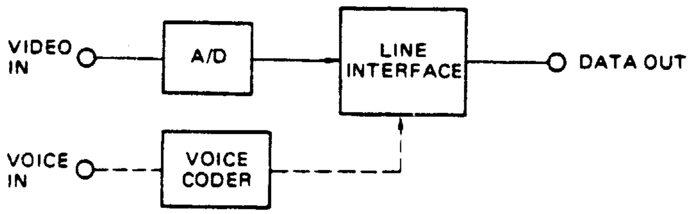
FEDIS-1.5, –6.3, –20



FEDIS-32, –45



FEDIS-100



Technical Note:

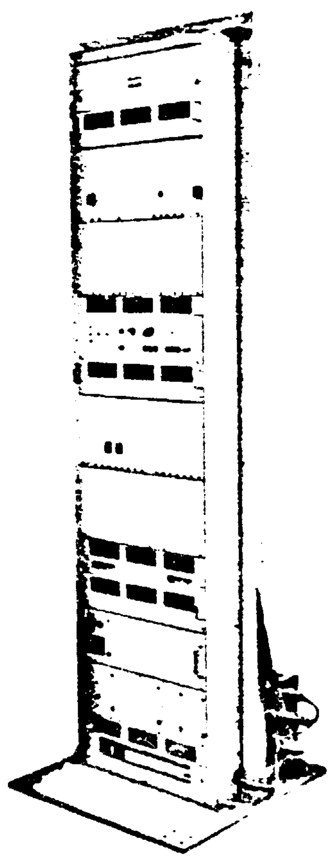
1. Buffer memory, variable length word coder, error correcting coder, multiplexer and line interface including optical fiber cable interface are included in "LINE INTERFACE".
2. Voice coder permits broadcasting sound quality.

FUJITSU

Fujitsu Limited. 6-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100, Japan Telephone: 03-216-3211, Telex: J22833

FUJITSU LIMITED

6.3Mb/s COLOR VIDEO TRANSMISSION CODEC FOR TELECONFERENCE



Fujitsu has developed a color video signal CODEC for teleconferences, using a highly efficient band compression technology. This CODEC attains 1/15 band compression, enabling a 4 MHz color video signal to be placed on the PCM 2nd stage multiplex level (6.3 Mb/s) instead of 100 Mb/s. New dot interlace technology and D PCM coding are used to realize the band compression.

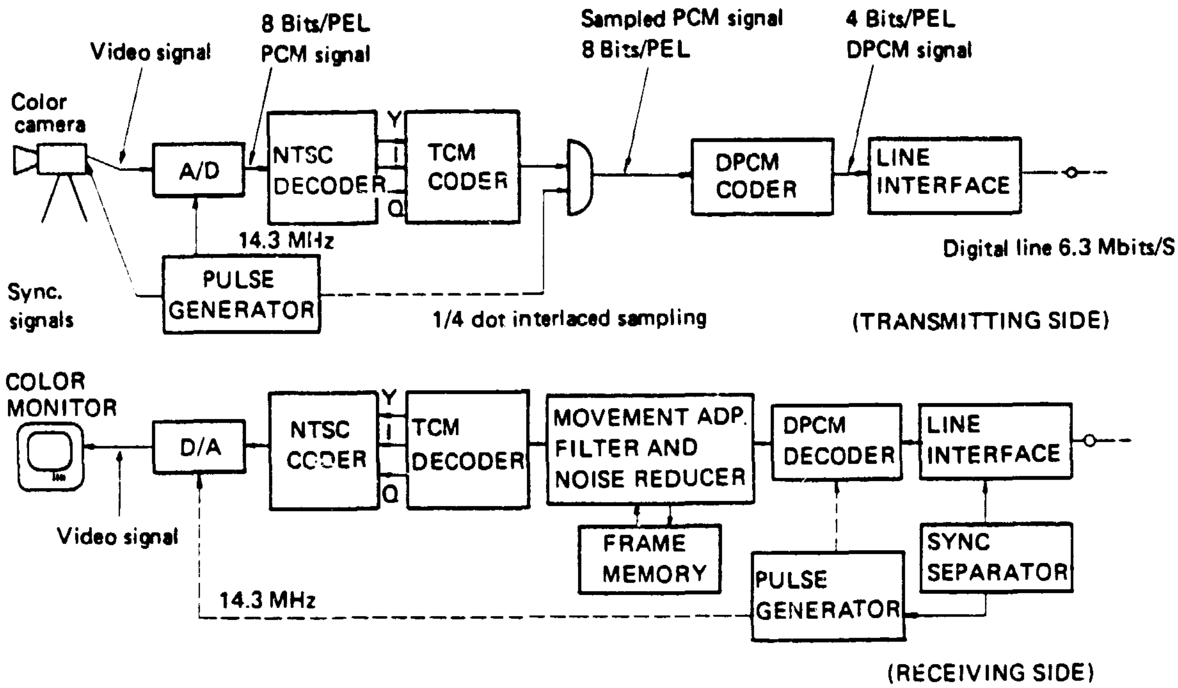
Features of the equipment

- o By use of dot interlace*, 1/4 band compression is attained.
  - * The codec transmits 1/4 of the whole picture elements' information in one field period and a full picture is reproduced with a frame memory in the receiving side.
- o Chrominance signal and luminance signal are split by the digital filter following the high speed CODEC.
- o TCM is used to multiplex the split signals.
- o D PCM to the TCMed signal is used to attain 1/2 band compression.
- o To improve the response performance of a reproduced picture to movement, the moving area is reproduced using the latest frame dot interlaced.

(This equipment was developed under the guidance of NTTPC.)

Block Diagrm of 6.3 Mb/s Color Video Codec

Block Diagram of 6.3 Mbit/s Color Video Codec



Main System Parameters

Input signal	NTSC color video signal (4.2 MHz band) 263-line non interlaced
Sampling frequency	14.3 MHz
A/D, D/A converter	Linear coding, 8 bit/sample
Color signal processing	TCM (Time Compression Multiplexing)
Band compression	1/4 dot interlace, DPCM, 1/15 band compression
Frame memory	957 kbit
Transmission speed	6.312 Mb/s (DS2 level)
Power dissipation	350 W/SYS

FUJITSU

Fujitsu Limited: 6-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo 100, Japan Telephone 03-216-3211, Telex J22833
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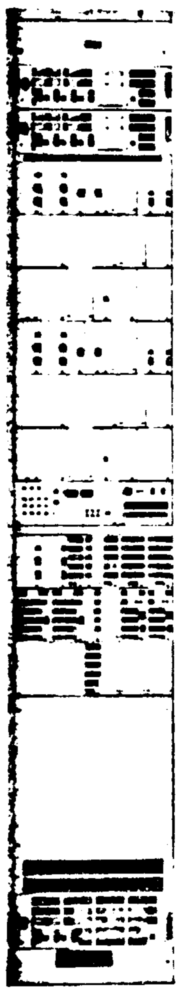
STEREO SOUND PROGRAM TRANSMISSION EQUIPMENT

FUJITSU LIMITED



Fujitsu stereo sound program transmission equipment is used to construct a high performance stereo sound program circuit in a digital transmission system. This equipment provides a 15 kHz stereo program circuit of CCITT J.21 grade. To multiplex the two high performance stereo channels on the limited bit rate PCM first stage multiplex level (1.544 Mb/s), advanced technologies are used in the equipment.

Sophiscated CODEC

13 bit linear coding with a 7-segment digital compander realizes –57 dBmOps noise performance using only 11 bits, leaving one bit for error-correction.

Low noise technique

To obtain transmission quality effectively equal to a 10^{-8} error rate on a 10^{-6} error rate line, a convolutional error-correcting code is applied to the upper 3 bits. Besides this, critical noise produced by excess error rate or burst error, is suppressed by dropping analog output to "no signal level" over these periods.

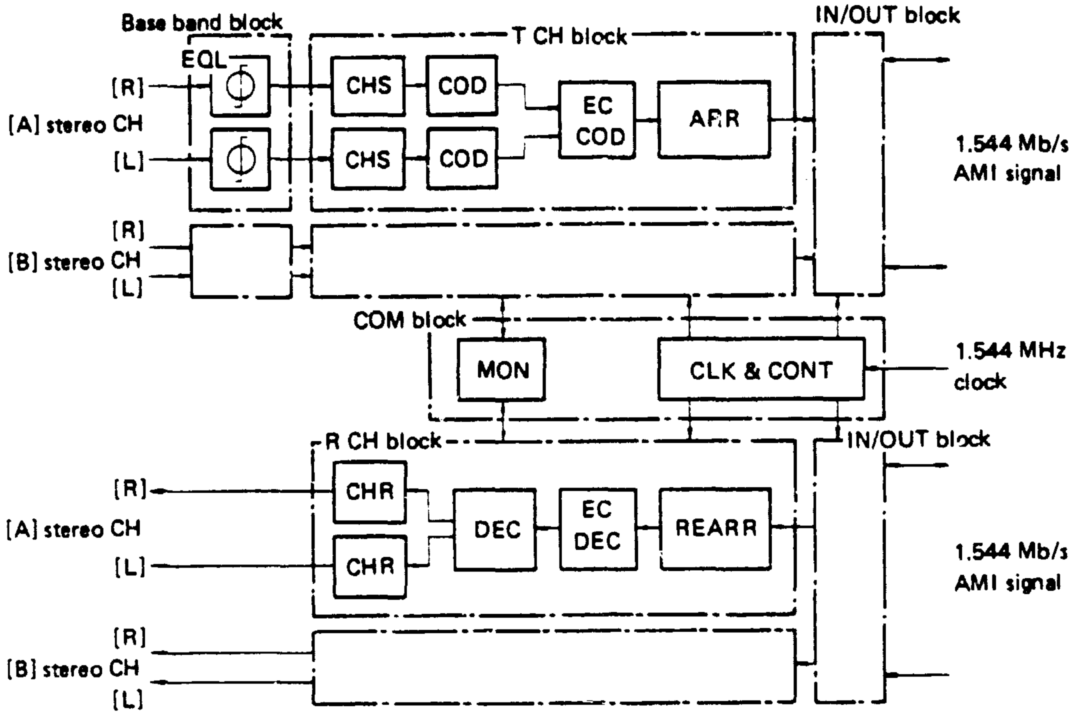
Flexible adaptability to network plan

At PCM level, the self-contained functions of branching control and drop/insert control permit a flexible program signal distribution plan in the network.

(This equipment was developed under the guidance of NTTPC.)

Stereo Sound Program Transmission Equipment

Block diagram of sound program transmission equipment



Main system parameters

Channel capacity	2 stereo CH/1.544 Mb/s
Input signal band	0.04–15 kHz/600Ω balance
Sampling frequency	32 kHz
Encoding	13-bit/sample linear encoding + D/D companding
Companding law	7 segment (13-bit → 11-bit)
Over load	+12 dBm0
Error correcting	Convolutional code
Word configuration	11-bit data + 1 check bit
Countermeasure for burst error	Replacement to silent signal
Line code	1.544 Mb/s AMI
Standard circuit configuration	3 links
Mounting	2 stereo CH/standard rack (2750 mm)
Power	–48 V DC

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5.0 TV BROADCAST SATELLITES

5.1 Introduction

This section will discuss the status and technology of TV broadcast satellites to serve requirements specified by BS-WARC-77 and WARC-79 at UHF, S-band (2.54 GHz) and the new frequencies of 12.2-12.7 GHz in region 11.

These satellites will be primarily directed toward high EIRP designs, e.g., in the 60-65 dbw range at 12 GHz in order to make possible the low cost small earth terminals to be discussed in the next section. However, the discussion will also include lower EIRP TV broadcast satellite in the 50-55 dbw EIRP range as presently in use in Canada via ANIK-B and ANIK-C, and as is presently being planned for use in Australia.

This section will first review salient features of existing TV broadcast satellites design and technology of broadcast satellites which can fulfill the following requirements:

- Have payload weight compatible with Delta and Atlas Centaur class launch vehicles until 1986 (first available dates for new payloads on the Shuttle) and then for Space Shuttle and STS launch.
- Provide the required number of TV channels and contoured antenna beams with the required EIRP while using optimum characteristic and structures for the bus, TWTA, multiple beam antenna, and attitude control and pointing accuracy.
- Maximum communication channel capacity commensurate with maximum payload weight.
- Antenna sidelobe characteristics for closest orbital spacing and minimum interference between TV broadcast satellites.

5.2 TV Broadcast Satellite Design Parameters

Table 5-1 lists the critical design parameters of a TV broadcast satellite which will influence the ability to provide required EIRP and contoured antenna-beam patterns on earth. The costs associated with the principal parameters involved - weight and dc power will be discussed in Section 7.

The initial criterion of a broadcast satellite is the specification of the EIRP into a given area or footprint, and the number of channels required at that EIRP.

The next step is then to determine the antenna gain, number of feeds, and the number, efficiency, and size of power amplifiers required. This will begin to define critical mass and dc power requirements which the overall satellite must meet. These requirements, added to the requirements of the remainder of the transponder (exclusive of power amplifiers already considered) define the basic payload mass and power requirements (including antenna).

The payload mass and dc power requirements can then be used to define a satellite bus which has a structural size, mass, and ability to provide dc power from a solar array or batteries. This will lead to a basic dry mass and size, of a structure to which must be added the mass and weight of hydrazine fuel for attitude control, the apogee kick motor and fuel, and the thrust systems for achieving the transfer orbit. This will lead to a satellite system size and weight.

The satellite system size must be compatible with the room inside of the fairing of a launch vehicle, and must be consistent with the ability of the vehicle to launch its weight.

The pacing critical parameters are:

Satellite total EIRP	Satellite mass (in orbit)
Satellite DC power	Launch vehicle capability - size and weight

TABLE 5-1

Basic Satellite Design Parameters

Parameter	Satellite Experience	Consideration
In-Orbit Mass		Includes satellite mass plus weight of fuel required to sustain attitude control over lifetime, plus weight of dry AKM
Launch Vehicle Payload Mass		Weight of satellite plus all thrust mechanisms required to transfer satellite into orbit
Satellite Size	Spinner vs 3-axis stabilized	Constrained by launch vehicle fairing for expendable launch vehicle. On Shuttle - by the cradle and bay length-cost consideration
DC Power	Related to in-orbit mass (Fig.5- 1)	Constrained by the satellite size - the the size of solar cell array in body stabilized system, by the external surface in a spin stabilized system
RF Power	Related to dc power for satellite bus - Broadcast satellite TWT in the 40-500 watt range	Constrained by efficiency of power amplifier, number of channels and EIRP required, and by power required of satellite bus, receivers, attitude control, and TT&C system
Antenna	Antenna mass related to overall on-orbit satellite dry mass	Provides with power amplifier, the satellite EIRP. Will be a large system in 60 dbw EIRP sat.
Payload including Antennas	% payload mass to in-orbit satellite dry mass critical	Provides basic satellite repeater function
Satellite Sensitivity (G/T)	Needed to assure oper-ability of up-link. Determines earth terminal EIRP	Served by the antenna gain and low noise amplifiers in the transponder

TABLE 5- 1 (Continued)

Basic Satellite Design Parameters

Parameter	Satellite Experinece	Consideration
Attitude Control and Pointing Accuracy	Determines the ability of satellite to maintain a footprint on earth to a ± 0.1 degree accuracy	Provided by attitude control system, including spinner action (spinner) or momentum wheels; requires fuel and sensors to maintain attitude control over satellite lifetime
DC Bus	Critical to end-of-life specification	Determined by solar cells and bus system efficiency during sun exposure; by batteries in eclipse.

5.2.1 Broadcast Satellites vs Communication Satellites

Broadcast satellite design is very different from communication satellite design. The difference is in the number of channels and the per channel EIRP required and serviced. In the COMSTAR and SATCOM satellites, for example, 24 communication channels are provided, with each channel using a TWTA at around the 5-watt level, and producing EIRP's in the 30-dbw range.

The broadcast satellite will have much fewer channels; TV-SAT (Germany), for example, will provide only 4-5 channels, each using a high power TWTA in the 300-400 watt power output range, and a high gain antenna providing a narrow contoured beam, where possible, to illuminate a specific area. In the case of the TV-SAT, no TV broadcast is provided during eclipse.

Table 5-2 lists several of the TV-broadcast satellite characteristics related to antenna beamwidth and RF/DC power now under consideration for several European countries.

Figure 5-1 plots the change in EIRP and dc power for broadcast and commercial satellites showing that commercial communication satellites, while increasing in dc power, have remained in the 30-35 dbw range while increasing the number of channels.

5.2.2 Satellite Mass vs Primary Power

Figure 5-2 relates the satellite in-orbit mass to primary dc power of various present day satellites showing how a unique relationship exists between these two parameters over wide ranges of power and mass. Note that at the 1000 kg level (the present day limitation of the Atlas-Centaur launch vehicle) around 1000-14000 watts are the limit of dc power provided by the solar array.

In the case of Intelsat-V, the satellite is designed to provide an initial dc power of 1400 watts from the solar array, with the provisions of the power being reduced to 1000 watts after a seven year life.

TABLE 5-2

TYPICAL TV-BROADCAST CHARACTERISTICS - EUROPE

Country	Antenna Beamwidth	TWTA Power Per Channel	
		RF Output	DC-Power
Germany	$1.6^{o} \times 0.7^{o}$	230 W	600 W
France	$2.5^{o} \times 1.0^{o}$	350 W	920 W
United Kingdom	$1.8^{o} \times 0.7^{o}$	250 W	650 W
Italy	$2.5^{o} \times 1.0^{o}$	350 W	920 W
Jugoslavia	$1.7^{o} \times 0.7^{o}$	250 W	650 W
North Countries			
East-Region	$2.0^{o} \times 1.0^{o}$	450 W	1180 W
West-Region	$2.2^{o} \times 0.8^{o}$	250 W	650 W

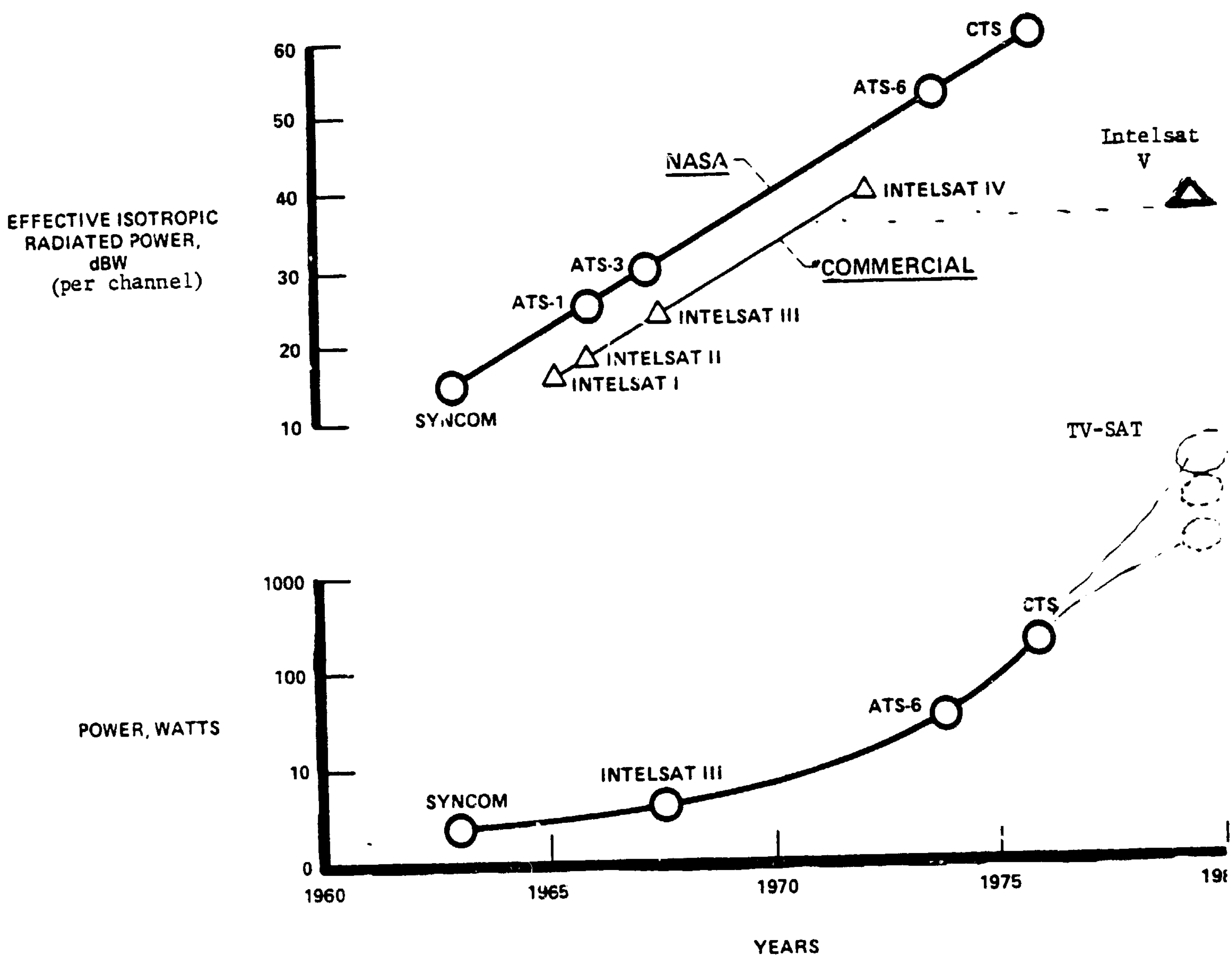
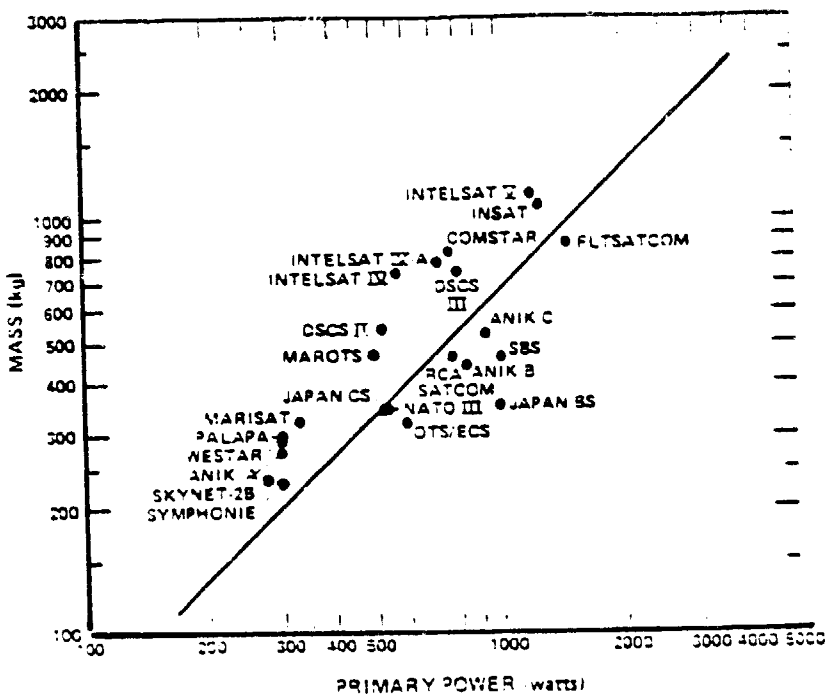

60
50
40
30
20
10
EFFECTIVE ISOTROPIC
RADIATED POWER,
dBW
(per channel)
CTS
ATS-6
NASA
ATS-3
ATS-1
SYNCOM
INTELSAT IV
Intelsat
V
COMMERCIAL
INTELSAT III
INTELSAT II
INTELSAT I
TV-SAT
1000
100
10
0
POWER, WATTS
CTS
ATS-6
INTELSAT III
SYNCOM
1960
1965
1970
1975
YEARS

Figure 5-1



SATELLITE ON ORBIT MASS vs PRIMARY POWER
Figure 5-2

The mass ranges of Figure 5-1 make an excellent introduction to the next section which will discuss the launch mass capabilities of available launch vehicles.

5.3 Launch Vehicle Payload Capabilities in the Expendable Launch Vehicle and the Shuttle Eras.

The space shuttle and its capability of providing low cost launches into low earth orbits (less than 160 miles and requiring an additional launch stage) initially led to almost a discontinuance or early phase-out of the Atlas-Centaur and Delta class launch vehicles, which were the backbone of satellite launches in the 1960-1970 period.

With the slippage of the Space Shuttle and the successful development of both Europe's ARIANE sponsored by ESA and Japan's N-Rocket, the Atlas-Centaur and Delta class rockets are not only being made continuously available with upgrades in load capability, but the Atlas-Centaur upgrade must be considered as a very real answer to the growing economic competitive threat of the ARIANE rocket which is now assured many European payloads and which will carry some Intelsat-V's. The Atlas Centaur development, Circa April 1980, is shown in Figure 5-3. The Ariane developments are shown in Figure 5-4.

In the early 1970's, the Delta 2914 and the Atlas-Centaur handled the satellite payloads having geosynchronous weights of 800 lbs and 2100 lbs respectively as shown in Table 5-3.. The Delta 3910 (sponsored by RCA for use with SATCOM) and the Delta 3914, were also developed in the 1970's and, with the ARIANE and the STS system also in the development stage, broadcast satellite spacecraft system design was limited to payloads in the 800-2100 pound class (300-900 kg) by this launch vehicle availability. Table 5-4 illustrates the on-orbit mass in Kg and the primary power in watts of most of the satellites built and launched or designed for launch during the era of the 1970's showing the upper mass level of one kilogram and the dc power level of 1 KW of these satellites.

Figure 5-5 shows the launch vehicle history and availability during the nest six years as set forth by C. L. Cuccia and R. J. Rusch at the AIAA 8th

Communication Satellite Systems Conference in April 1980, showing the Atlas-Centaur and Delta 3910, the Delta 3920 which will be available in 1982, and the upgraded Atlas-Centaur whose load capability is being increased to almost 5000 pounds.

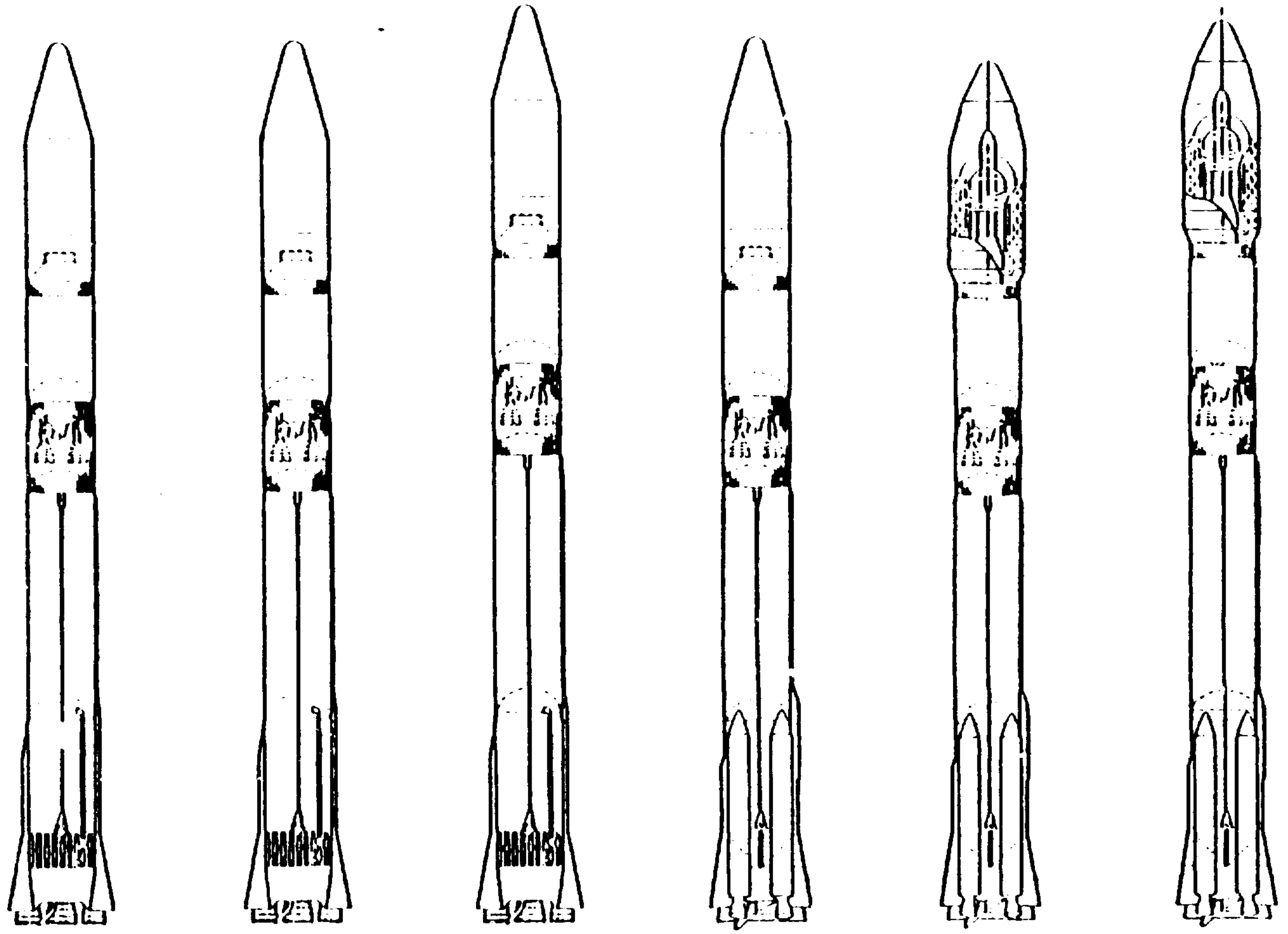
Any new user or designer of a space communication system which requires a launch, simply cannot achieve a reservation on a STS launch until 1986 and must rely on the Delta 3910, Delta 3920, Atlas-Centaur, and the ARIANE vehicles to provide that launch.

Figure 5-3

GROWTH ATLAS/CENTAUR PERFORMANCE AND COST

GENERAL DYNAMICS
Convair Division
Apr 80

(GEOSYNCHRONOUS TRANSFER – 27 DEG INCLINATION)



	AC-60 (CURRENT)	AC-61 (BASELINE)	STRETCHED ATLAS (80")	STRAP-ON SOLIDS (4)	SOLIDS (4) FAIRING (12')	SOLIDS (4) FAIRING (12') STRETCH (80")
PERFORMANCE (LB)	4,500	4,800	5,200	5,900	5,800	6,200 +
ROM COST ($M)						
N/R	0	2	3	15	25	28
ΔREC.	0	0	+0.1	+1.5	+2.5	+2.6

FIGURE 5-3

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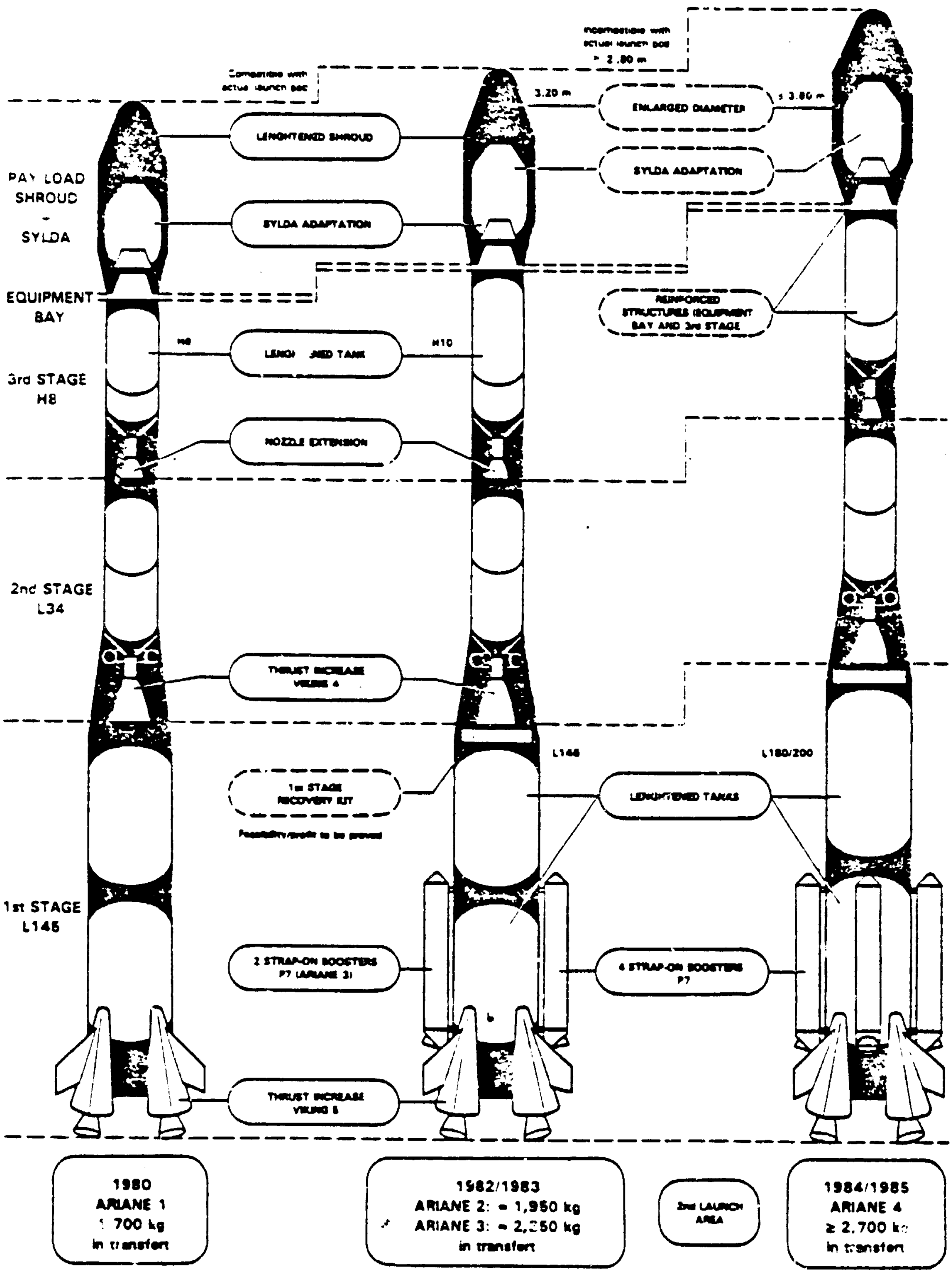


Figure 5-4
ARIANE IMPROVEMENTS

TABLE 5-3

Launch Vehicle Payloads - 1976

Launch Vehicle	Synchronous Transfer Orbit Payload (Lb)	Synchronous Equatorial Orbit Payload (Lb)*
N-Vehicle (Japan)	550	260
Delta 2914	1550	800
Delta 3914	2000	930
Ariane (ESA)*	3300	1830
Atlas-Centaur	4150	2100

* Not tested until 1979

** Assumes AKM

Increase in Launch Vehicle Capability

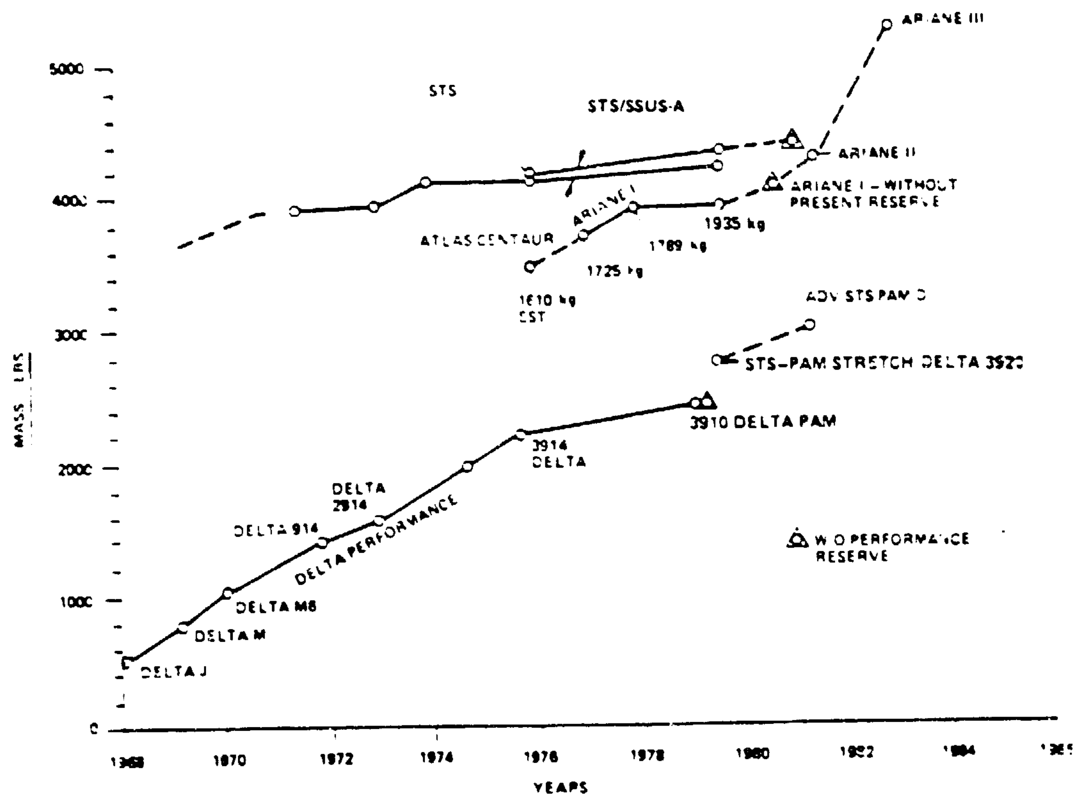


FIGURE 5-5

5.4 Design Aspects of TV-Broadcast Satellites

Table 5-4 lists the various technologies which must be addressed in designing a satellite. They include system oriented technologies, pacing technologies which contribute to the satellite system capacity and constraining technologies which determine the size, weight, and mass of the satellite system which is placed into orbit. The pacing technologies are used to produce the capacity requirements of the overall system once the constraining technologies have determined the size and weight which can be orbited.

All satellite development during the 1970's has been in the direction of increasing and maximizing capacity. INTELSAT-V, for example, represents an increase in capacity of more than 12 times over INTELSAT-III (at the start of the decade) with an increase in in-orbit mass of around 7 times.

The key pacing technologies, therefore, are those related to the satellite structure and to the RF system which encompasses the satellite antennas, the power amplifiers, the low noise receivers and lightweight filters.

Table 5-5 lists important broadcast satellite technology areas which, in effect, reflect these pacing technologies as identified by Dr. Van Trees (Table 5-5), at the AIAA 6th Communication Satellite Systems Conference in Montreal, Canada, in April 1976. These technology areas highlight a number of areas where key new technology developments are recommended to take place during the next three decades. In general, Dr. Van Trees' predictions identify satcom technological developments in the following areas.

- Satcom antennas for improved utilization of the radio spectrum by the use of dual polarization and high isolation spot or contoured multiple beams.

TABLE 5-4

Broadcast Satellite Technologies

System Oriented Technologies

- Means to effectively reduce cost per channel by more efficient utilization of available power and frequency spectrum.
- Development of new modulation and multiple access techniques.
- Exploitation of higher frequency bands.
- Development of more efficient communications hardware.
- Reduction in spacecraft weight through improved structures, energy conversion, storage systems, prime propulsion, and on-board propulsion.

Pacing Technologies

- Satellite Antennas	- Including techniques for multiple beam operation, beam shaping, sidelobe control and polarization purity.
- Power Amplifiers	- Providing means to develop efficient lightweight power amplifiers of both TWT and solid state types at 2, 11, and mm waves allocated to BSS.
- Attitude Control Systems	- For both spinner and three-axis satellites for precision antenna pointing.
- Thermal Control	- Development of materials for thermal control.
- Low Noise Receivers	- Including the use of parametric amplifiers and FET input amplifiers.
- Lightweight Filters	- For minimum guard bands and minimum group delay distortion with sharp attenuation at band edges.
- Batteries	- For lightweight energy storage on-board the satellite.
- High Reliability Parts	- Including all screening and ability to build small lots of devices for very long life.
- Spacecraft DC Power	- Derived from solar cells or nuclear isotope power systems.
- On-board Digital Systems	- Including all on-board control and data management.

Constraining Technologies

- Boosters	- Including rocket type launch vehicles and space shuttle.
- Structures	- Including new materials.
- Propulsion Systems	- Apogee kick motors and nuclear and ion propulsion systems.

TABLE 5-5

IMPORTANT COMMUNICATION SATELLITE TECHNOLOGY AREAS
ACCORDING TO DR. H. VAN TREES

	Technology	Description
a.	High Isolation Hemispheric Coverage Antennas	Hemispheric coverage antennas with 30 to 33 dB pattern and polarization isolation.
b.	Dual Polarization at 14/11 GHz	For reuse of the 11/14 GHz frequency band.
c.	30/20 GHz Technology	Extensive antenna and propagation R&D must be performed.
d.	Multifeed 3° Beamwidth 6/4 GHz Antenna	Further development of 3° beam antennas is necessary.
e.	High Resolution Steerable 6/4 GHz Antenna	Antennas with constituent beams of the order of 1° or less are required.
f.	120 Mbps TDMA	For the proposed 72 MHz channelization.
g.	Forward Error Correction (FEC)	For interference-limited environments using digital communications.
h.	DSI	To increase the bandwidth efficiencies of some digital systems.
i.	Linearized Transponders	For use of more efficient modulation schemes.
j.	Advanced Modulation	To provide highly efficient use of bandwidth.
k.	Intersatellite Link (ISL)	To provide full connectivity between smaller capacity satellites, using either optical or microwave links.

- o Linear power amplification, new modulation and data handling techniques to reduce in-channel system degradation and adjacent channel interference now encountered in digital communications, and to provide for improved utilization of the radio spectrum.

These technologies - as they relate specifically to high EIRP satellites - will be discussed at length in paragraph 5.7. However, the following paragraphs will highlight how these technologies relate specifically to a comparison of communication and broadcast satellites.

5.4.1 Spinner and Body Stabilized 3-Axis Satellites

Spinners and 3-axis satellites are both candidate broadcast satellites for 1000 kilogram in-orbit mass.

Figure 5-6 shows the cross-section of the spinner CS satellite built by FORD Aerospace. Figure 5-7 shows the cross-section of the giant Hughes LEASAT which was described at the AIAA Eight Communication Satellite Conference in Orlando, Florida, in 1980. Figure 5-8 shows the Anik-C with its additional solar cell "Skirt" now used by Hughes to increase solar cell power. As shown, the spinner uses the shell as both part of the body stabilization process, and as a surface for solar cells. Inside is a tray with the payload and bus system. The antenna is despun at one end of the spinner cylinder configuration. Note in general, the enormous space inside of the cylindrical structure which serves to house the AKM or perigee motor and which is not used to house payload.

One of the major problem of the spinner satellite is the transfer of payload heat to space (thermal).

Figures 5-9 and 5-10 show respectively the Intelsat-V and German TV-SAT structures which are 3-axis stabilized, using momentum wheels and sensors/ hydrazine thrusters (which are also used on spinners). The interior of the box structure which is modular for both types of satellites is used to house the

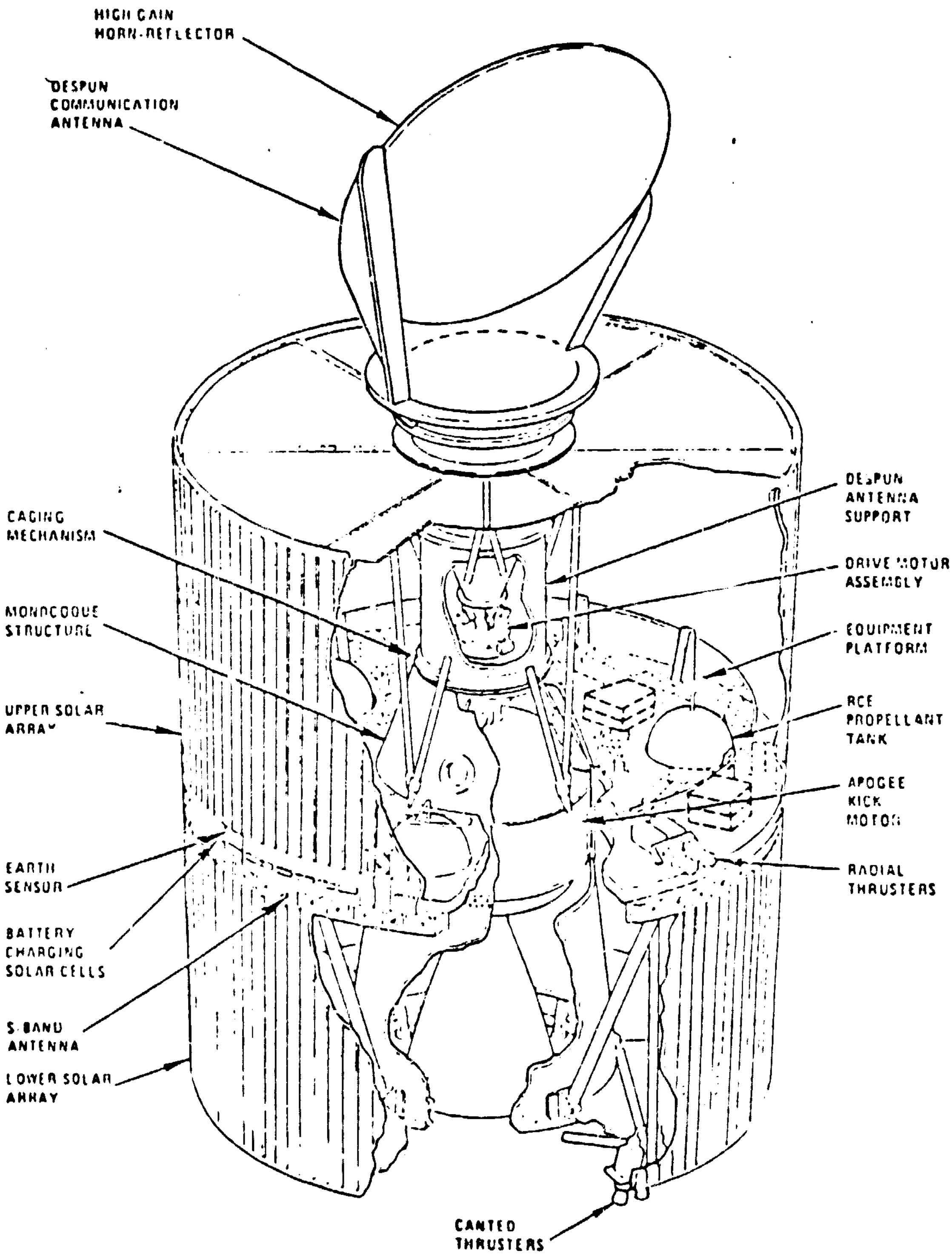


Figure 5-6. CS Satellite Cross-section

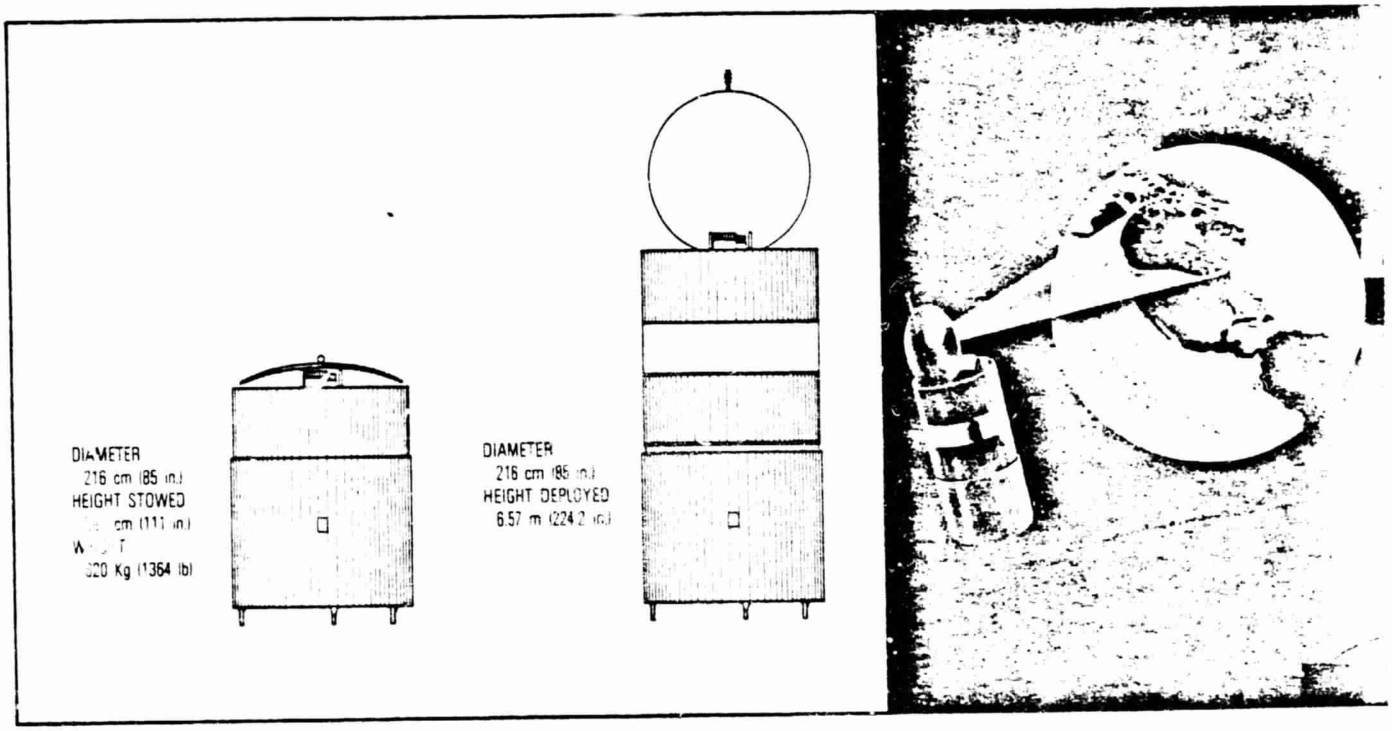


Figure 5-8. ANIK-C Structure showing Solar Cell Skirt

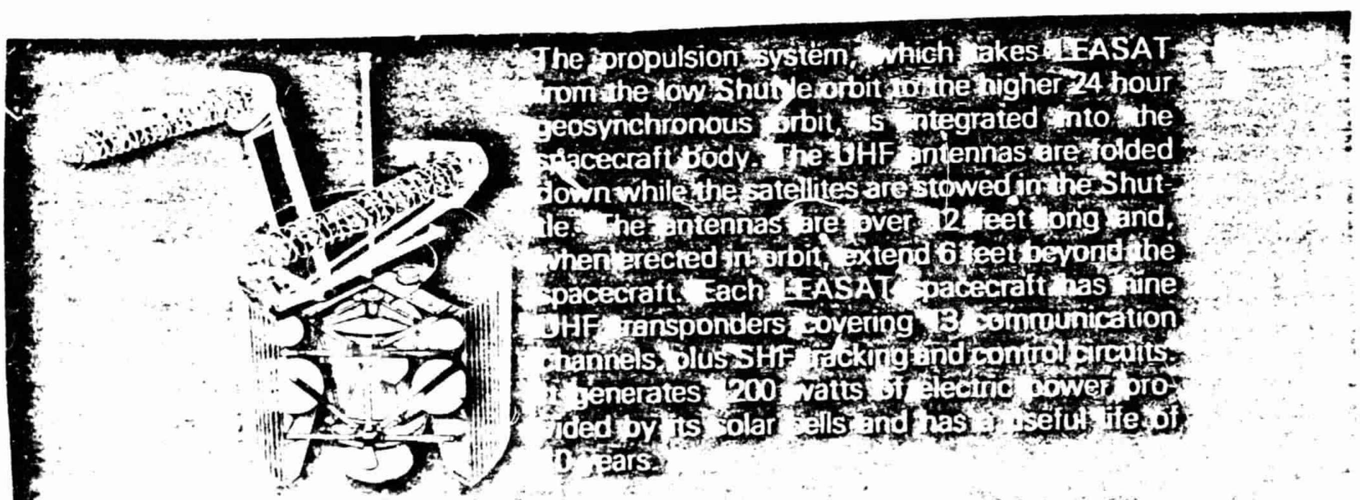
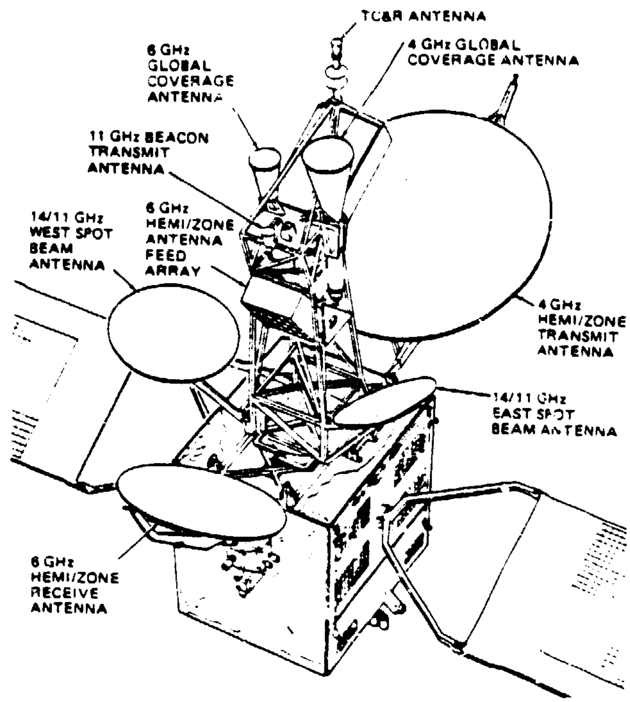


Figure 5-7. LEASAT Cross-section



INTELSAT V Antenna Configuration

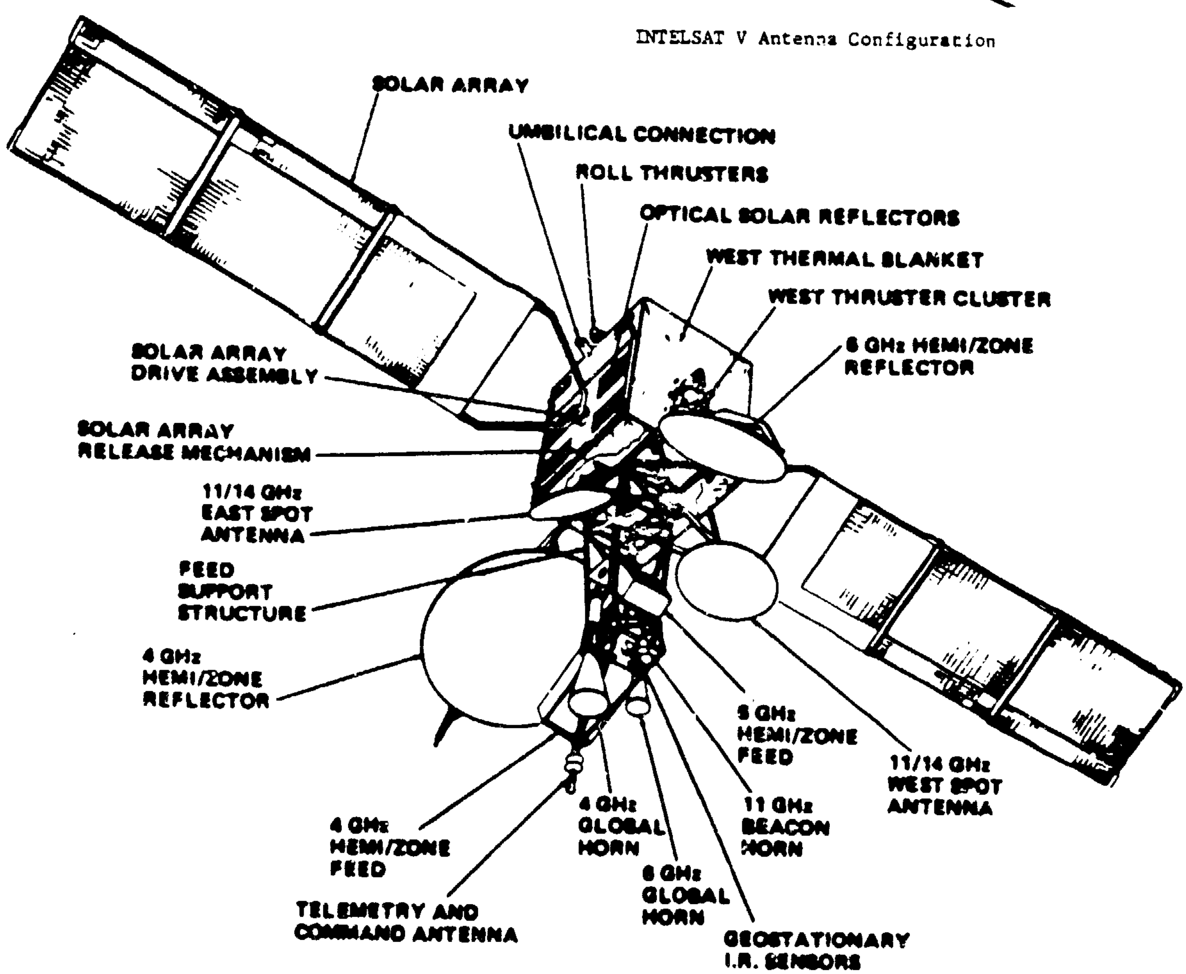
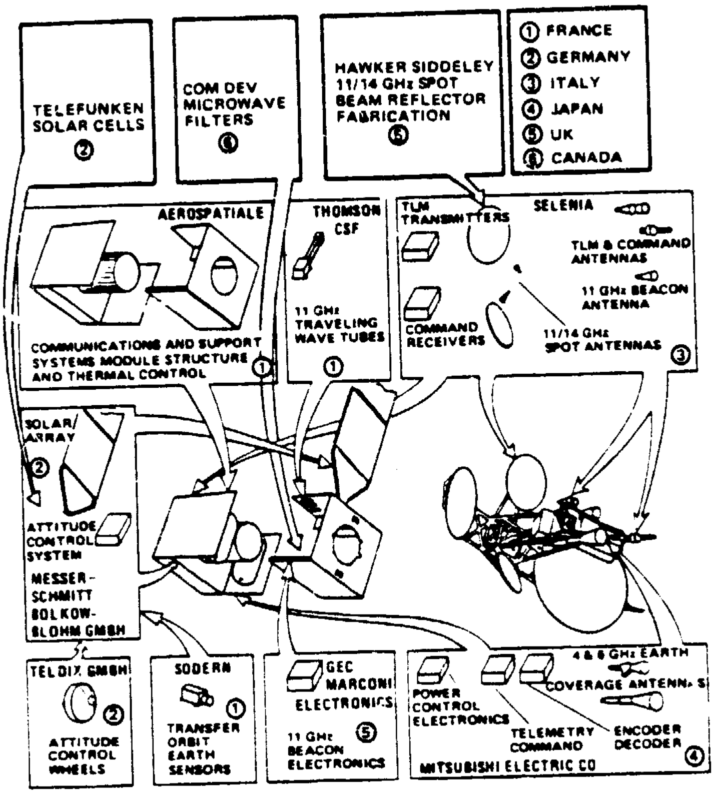
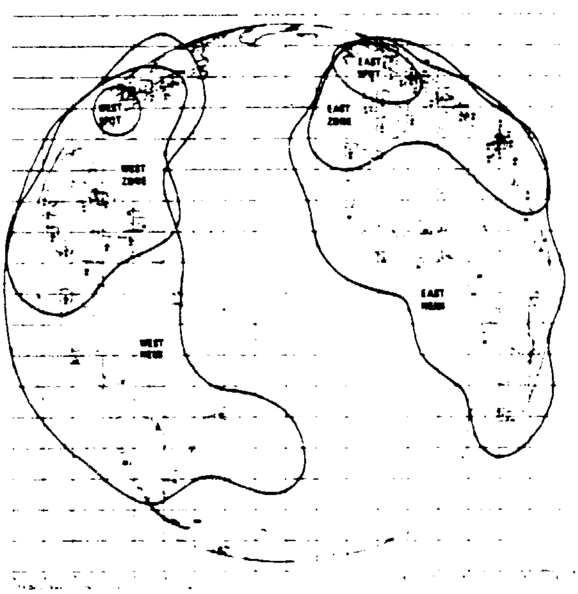


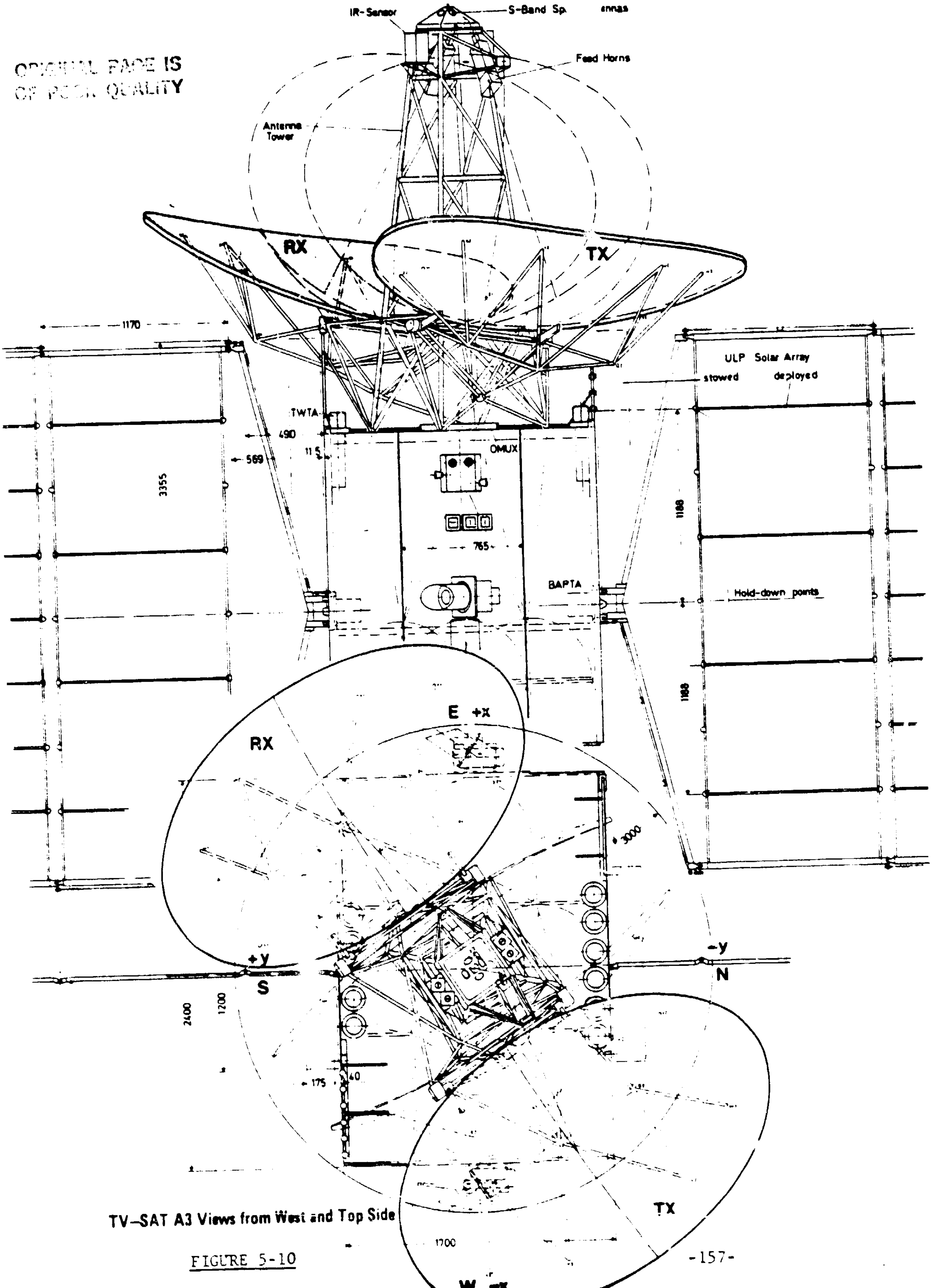
Figure 5-9a. Intelsat-V Structure





INTELSAT V Atlantic Ocean Coverages

Figure 5.9b.



TV–SAT A3 Views from West and Top Side

FIGURE 5-10

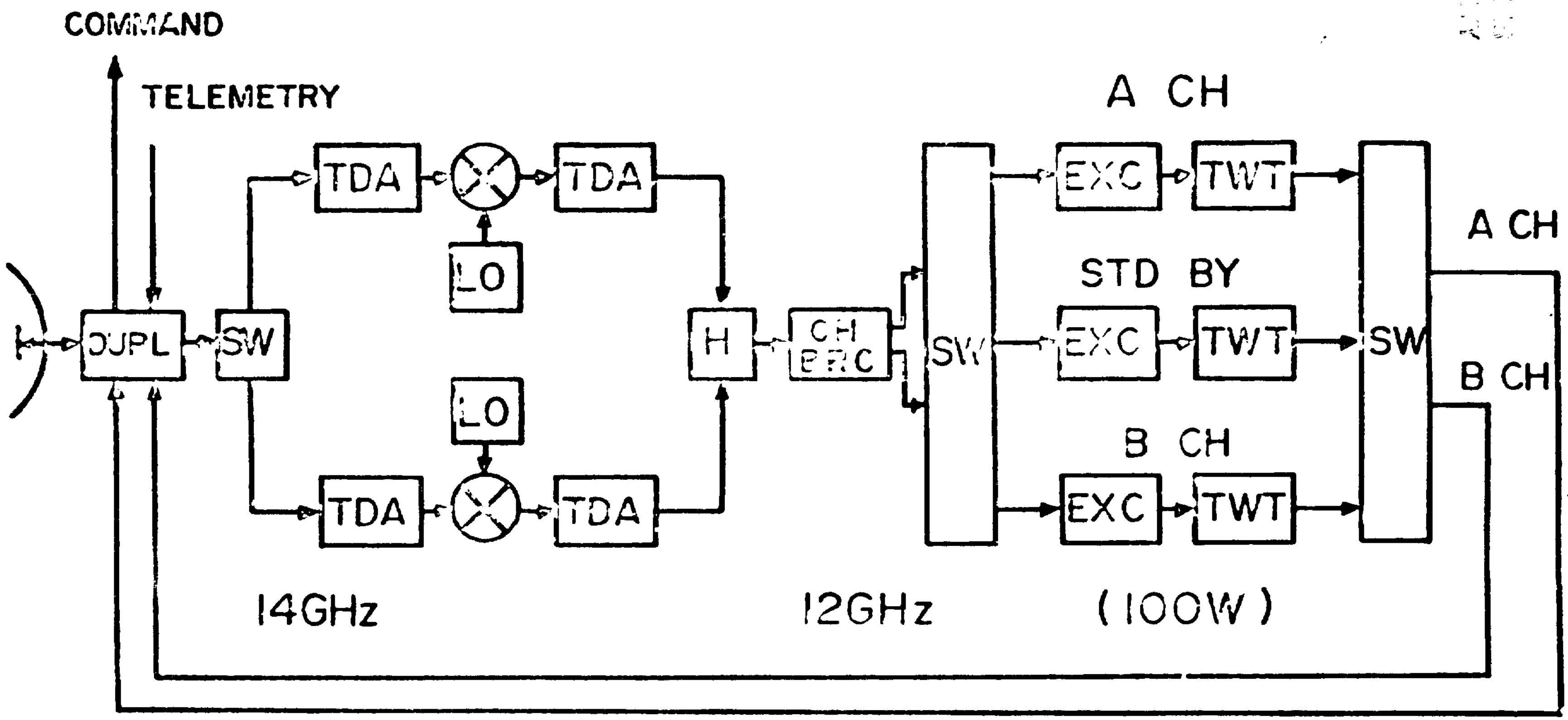
satellite transponder and bus electronics. One side of the satellite box is used as a platform to support an antenna complex. The solar cells are made into arrays which are unfurled from the satellite box.

The spinner thermal, despun-antenna, and solar cell area optimization are virtually non-existent on a 3-axis body stabilized system which must in turn cope with thermal problems of a compact box full of electronic equipment but which must include all body stabilization elements which do not have the benefits of a large cylindrical spinning mass to contribute to the stabilization process.

Both satellite types are now in use and merits relative to specific requirements must be made before judgements can be made as to the relative suitability of one or the other structural system.

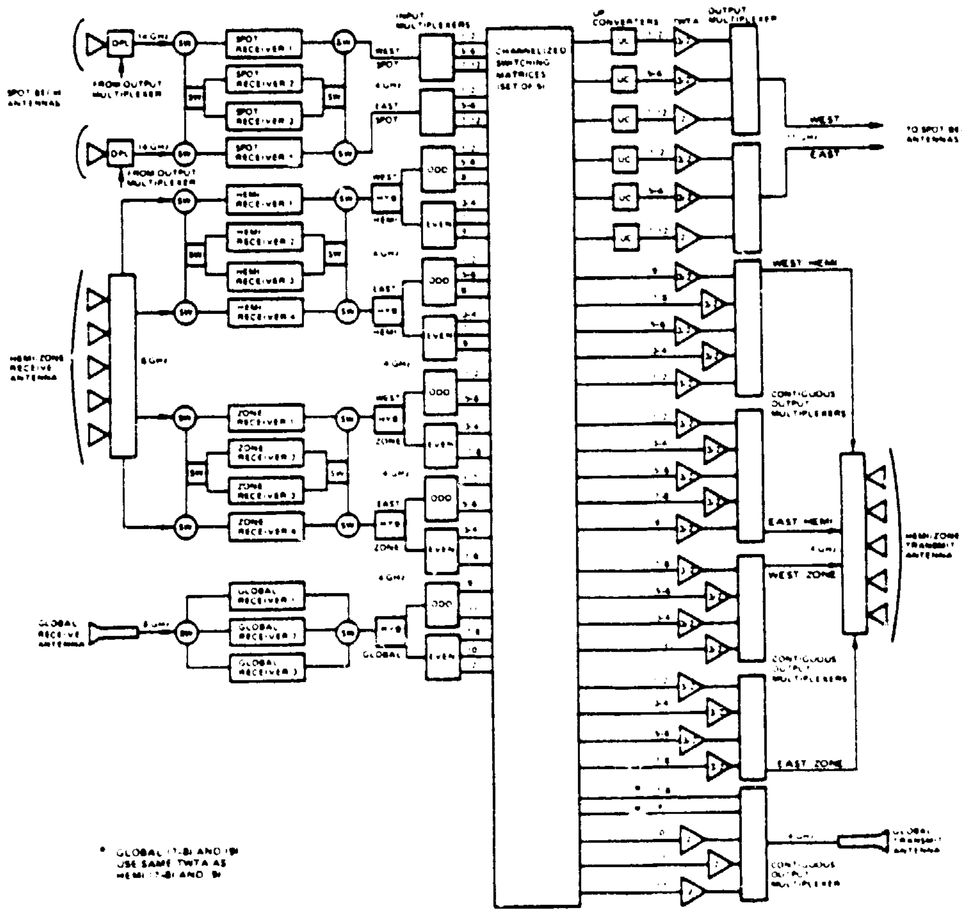
5.4.2 <u>The Transponders</u>

Figures 5-11 and 5-12 show respectively the transponders of the Japan BSE and Intelsat-V illustrating the different circuit configurations between the fairly simple (four-channel) configuration of a broadcast satellite and a complex multiple channel (24-30 channels for Intelsat-V) satellite used for commercial satellite communications. Actually the difference is equalized by the use of very high power TWTA (40-750 watts) as compared to the low power (4.5-20 watts) typical of a communication satellite. From the transponder standpoint the differences between spinner and body stabilized satellites are more properly described in terms of related thermal problems rather than basic electrical circuit problems.



CONFIGURATION OF 14/12 GHz COMMUNICATIONS TRANSPONDER

Figure 5-11. BSE Transponder



Communications Subsystem Simplified Block Diagram

Figure 5-12. Intelsat-V Transponder

5.4.3 Antennas and Pointing Error

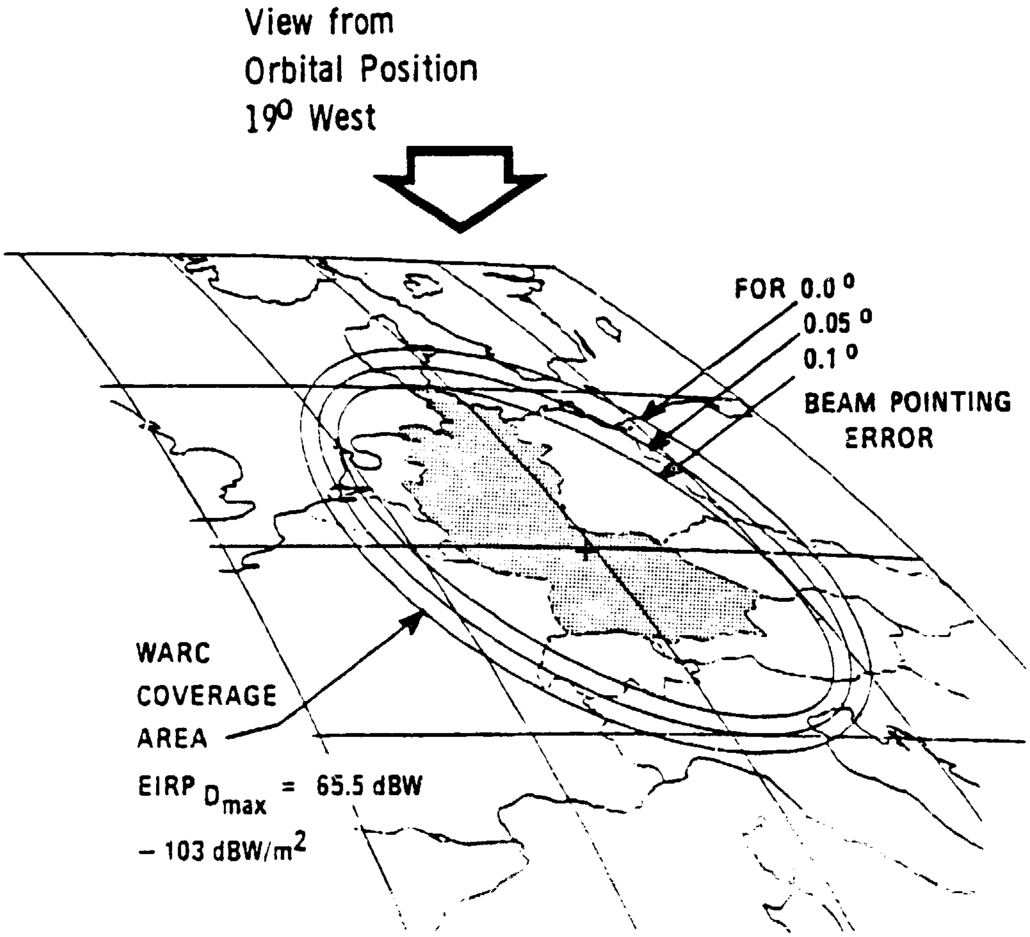
A major design requirement of a broadcast satellite is providing a footprint on earth from an EIRP of around 60-65 dbw, in a specified contour or region, and maintaining the satellite pointing accuracy to the point where the footprint does not significantly move due to pointing motion (error) of the satellite.

This requires large high gain antennas to provide such high EIRP operating with high power TWTA or solid state devices. For example, if a 400 watt TWTA (26 dbw) is used, an antenna gain of at least 40 dB is required (assuming 1-2 db filter and connector losses between the tube and the antenna feed, and any feed network losses experienced). This will require an antenna at least 4 to 5 feet in diameter which is the size of the Intelsat-V 4-GHz reflector. This is a very large antenna for a communication satellite and requires a spacecraft at least as big as the Intelsat bus to carry it - and other antennas.

Figure 5-13 shows area coverage defined by WARC-77 for the FRG and includes the shift in pattern with respect to beam pointing errors as large as 0.1^{o}. For many communication satellites, such charge or shift is not that serious. Table 5-6 lists the beam pointing accuracies of several existing satellites showing that many of these satellites are specified to a much more tolerant beam pointing accuracy. However, because TV broadcast of one country can shift across the borders of a neighboring country and violate its sovereign rights, present beam pointing accuracies are now specified at ± 0.1 degree - all axes, and this point will be described in more detail in Paragraph 5.6. The following paragraph will provide some of the WARC history involved.

5.4.3.1 Satellite Stationkeeping (Doc. USSG IWP 4/1-12 - Verbatim)

The degree to which satellite stationkeeping is maintained determines how far a satellite is permitted to drift from its nominal orbital position. This



Antenna Coverage Area for the FRG as Defined by WARC 1977

Figure 5-13

TABLE 5-6

Antenna Pointing Accuracy Summary

COMSTAR	$\pm 0.26^\circ$	N-S Axis	Spinner
	$\pm 0.20^\circ$	E-W axis	
Intelsat IV	$\pm 0.35^\circ$	Each Axis	Spinner
Intelsat IVA	$\pm 0.25^\circ$	N-S Axis	Spinner
	$\pm 0.20^\circ$	E-W Axis	
Intelsat V	± 0.15	Roll	3-Axis
	± 0.14	Pitch	
	± 0.41	Roll	
ANIK-A	$\pm 0.1^\circ$	All Axes	Spinner
SATCOM	$\pm 0.2^\circ$	All Axes	3-Axis
Japan CS	$\pm 0.3^\circ$	(3σ)	Spinner
Japan BSE	$\pm 0.2^\circ$	(3σ)	3-Axis
ESA OTS-II	$\pm 0.17^\circ$	Pitch & Roll	3-Axis
	$\pm 0.5^\circ$	Yaw (3σ)	
Symphonie	$\pm 0.5^\circ$	All Axes	3-Axis

has the effect of introducing an uncertainty into the orbital separation between satellites in adjacent systems, which will influence the amount of mutual interference produced by these systems.

Until WARC 79, satellite stationkeeping tolerances were specified in the ITU Radio Regulations in paragraphs 470VC, 470VD, and 470VE. Under these provisions satellites were required to have the capability of maintaining their longitude to within ±1 degree, and to try to operationally maintain position to ±0.5 degrees. These limitations did not have to be followed if no unacceptable interference was caused to any other satellite network whose satellite complied with the limits. The Radio Regulations set no standards for latitude stationkeeping. The Final Acts of WARC 79 reduced the longitudinal tolerance to ±1 degree, with the exception that the ±1 degree requirement remains in force for those systems notified to the IFRB prior to the date of entry into force of the Final Acts, January 1982. No latitude tolerance was imposed at WARC 79.

The benefits of tighter stationkeeping tolerances must be weighted against those technical considerations which are involved in meeting them. Stationkeeping is maintained by means of orbital correction maneuvers; tighter tolerances require that these maneuvers be performed more frequently. Although tighter tolerances require no extra fuel, they do have operational implications. More frequent corrections will require more careful monitoring of satellite position and a higher workload for satellite control personnel. In addition, more computer processing time will be required to compute correction parameters. This can lead to increased expense and perhaps the need for more complex computer installations, particularly if a system has several satellites which must be controlled concurrently.

For satellite systems implemented in the near term, longitude stationkeeping within ±0.1 degree poses no problems. Several existing systems, including Canada's

ANIK series, Western Union's Westar series, and Indonesia's Palapa series, are currently operating within the new longitude tolerance of ±0.1 degree; this standard is thus clearly operationally feasible. It is, however, unclear that further tightening of the standard beyond this point would yield sufficient additional interference protection to justify the added operational expense and complexity. For example, if two adjacent satellites have a nominal separation of 5 degrees and each has a tolerance of ±0.1 degree, the increase in interference is less than 0.5 dB with both satellites at their worst case locations (4.8 degree separation) assuming that the ground station antenna sidelobes follow CCIR Rec. 465.1 (32-25 log θ). Further, the imposition of restrictions on latitude stationkeeping produces essentially no further interference protection, but would affect satellite control operations.

5.5 Design Aspects of Present TV Broadcast Satellites

As design considerations are directed toward new TV broadcast satellites compatible with present expendable launch vehicles and the future use of the Space Transportation System, it is of interest to review pertinent design aspects of many satellites presently developed or in development, which furnish not only considerable design experience and guidance but which also provide technological developments which apply in all areas of satellite design.

The primary aspect of TV broadcast satellite design must center around the satellite mass and available dc power, and be concerned with achieving the highest possible percent of mass for the communications payload (Figure 5-14), and then using the maximum amount of available dc power to develop EIRP in one or more antenna beams. Note in Figure 5-14 that the 3-axis satellite - with increasing dry mass for the spacecraft - provides a higher payload percentage of the dry in-orbit mass than the spinners - and particularly than the giant spinners which must include the perigee motor in its mass.

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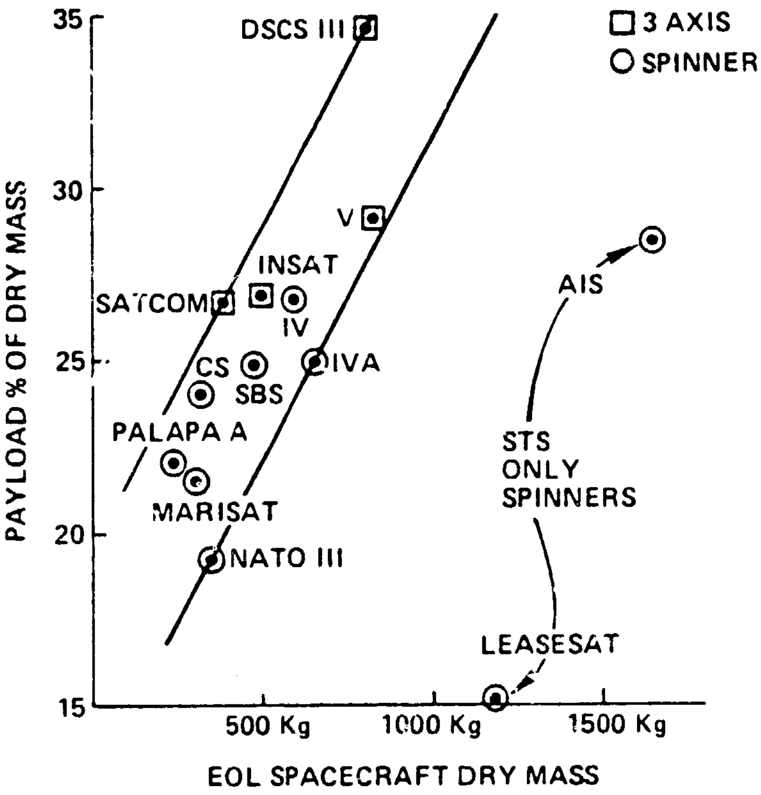

Figure 5-14

This paragraph will then explore the mass ratios for existing and in-development satellites to establish the present percentage total mass ratios for the antennas, transponders, attitude control systems (ACS) for both spinner and 3-axis stabilized satellites, and for both broadcast satellites and communication (FSS) satellites.

5.5.1 Typical BSS and FSS Communication Satellite Mass and Power Breakdowns

Table 5-7 lists the in-orbit weights and primary power for many existing broadcast and communications satellites. Note that these satellites are all under 1000 Kg in mass and that the primary power ranges from 300 watts for ANIK-A to almost 1000 watts for Intelsat-V. The 11-GHz satellites have EIRP's from 30 to 60 dbw and the antenna gains and TWT powers used to develop these EIRP's are listed in Table 5-8.

Tables 5-9 through 5-13 list pertinent subsystem weights and powers* for both 3-axis (Satcom and Intelsat-V) and spinners (Intelsat-IVA, SBS, CS-2, and COMSTAR) showing the following general mass/power ratios now typical of communication satellites which distribute television (SATCOM 1 is entirely devoted to television distribution, primarily for CATV and networks). Note that no exact correlation can be made for mass ratios.

The ratio of antenna mass to total dry mass varies from 3.3% to 9.2%, except for SBS which is almost 25%.

The transponder mass ratio varies from 18 to 25 percent of the total dry mass and is more orderly in its variation.

Structure percentage on Intelsat-IVA and Intelsat-V are very close in percentage, while structure weight percentage in SBS and CS-2 are small but reasonably in the same range.

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* The author expresses with thanks, guidance from an FACC memorandum due to Mrs. C. Majors of FACC.

TABLE 5-7

Typical Communication Satellites

Satellite	Bandwidth Per Satellite (MHz)	Weight in Orbit (Kg)	Frequency	Primary Power (Watts)	EIRP Range
Intelsat-IV	432	700	4/6	570	30-35 dBW
Intelsat-IVA	432	790	4/6	600	30-35 dBW
Westar	432	330	4/6	330	30-35 dBW
RCA Satcom	864	461	4/6	-	30-35 dBW
Comstar	864	750	4/6	610	30-35 dBW
Palapa	432	300	4/6	307	30-35 dBW
Anik-A	432	297	4/6	320	30-35 dBW
Symphonie	320	230	4/6	780	-
CTS	170	350	11/14	918	60 dBW
SIRIO	150	188	11/18	-	30-35 dBW
Japan CS	170	317	11/14	530	36 dBW
Intelsat-V	1600	1000	4/6, 11/14	967	30-35 dBW

TABLE 5-8

PRESENT SATELLITE ANTENNAS AT 11 GHz FOR FIXED AND BROADCAST SATELLITE SERVICES

Satellite	Description	Gain	Beamwidth	Driving TWT Power
CTS	Two parabolic reflectors with a single feed each	Tx = 36.9 dB Rx = 37.9 dB	Beamwidth of 2.5° to -3 dB points	200 watts, 20 watts
Japan Broadcast Satellite - BSE	Center fed reflector 3.4 x 5.2 feed with three feed horns	Tx = 37 dB	Beamwidth 1.3° x 2.3° to -4.0 dB points, not to exceed 28 dB in Korea, Russia	100 watts
Orbiting Test Satellite - OTS	Six antennas including two redundant receive dishes giving full European coverage and driving two spot beam antennas for Eurobeam A. Eurobeam B is a narrow band channel using antennas with elliptical beamwidth.	Eurobeam A Rx = 25 dB Tx = 33.8 dB	Eurobeam A Rx = 7.5° x 4.25° Tx = 2.5° Circular Eurobeam B Rx, Tx = 5° x 3.5°	20 watts
INTELSAT V	East Beam 980 mm diameter contoured surface	Rx, Tx = 33 dB	Shaped Beam	10 watts
	West Beam 1200 mm diameter parabolic dish	Rx, Tx = 36 dB	Spot Beam	10 watts
SIRIO	Reflector 30 x 300 mm to give elliptical spot	Tx = 20 dB Rx = 20.1 dB	6.5° azimuthal 4.6° vertical plane	10 watts
Anik B	Four spot beams covering Canada	Tx = 37.12 dB Rx = 33.5 dB (edge)	1.5°/beam	20 watts
SBS	72 inches diameter	Tx = 33 dB peak Rx = 30 dB edge	Covers U.S. with 8 horn array	23 watts

Orbital Load Summary (watts)

Subsystem	Solstice	Equinox	
		Sunlight	Eclipse
Communications	788.8	788.8	788.8
Telemetry, command and ranging	43.5	43.5	43.5
Attitude control (including solar array drive)	52.4	41.2	41.2
Propulsion (excluding electro-thermal thruster)	0.8	0.8	0.8
Electrical power subsystem	10.0	10.0	10.0
Harness loss	10.0	10.0	9.0
Thermal control	67.5	109.5	35.5
Total bus no. 1 & no. 2 load	973.0	1003.8	928.6
Battery charge (7th year)	28.7	97.5	–
Total array load	1001.7	1101.3	–
System power margin	108.3	83.4	–
10% array margin	111.0	118.5	–
Solar array capacity	1221.0	1303.2	–

TABLE 5-9. Intelsat-V Power

TABLE 5-10 . INTELSAT V Mass Summary

Subsystem	Current Baseline Mass (kg)	
	Centaur Launch	STS Launch
Structure	139.4	139.4
Adapter	18.9	18.9
Propulsion	35.6	35.6
Electrical power	135.7	135.7
Communication transponder	183.4	183.4
Communications antenna	57.6	57.6
Telemetry, command, and ranging	25.7	25.7
Attitude determination and control	74.2	74.2
Thermal control	28.7	28.7
Electrical integration	41.5	41.5
Total	740.7	740.7
Margin	(4.6%) 33.8	(6.6%) 49.2
Total spacecraft	774.5	789.9
Apogee motor	924.1	924.1
Propulsion fuel	170.7	183.0
Launch total	1869.3	1897.0

Table 5-11

Domestic Satellites for Television Distribution

Mass and Power Distribution

	Satellite			
	COMSTAR		SATCOM	
Characteristics	24 Channel Spinner		24 Channel 3-axis Stabilized	
Total Deg Mass/Power	670/610		855/463	
Subsystem	Mass (kg)	% Dry S/C	Mass (kg)	% Dry S/C
Antenna	61	9.2	51.6	6.8
Transponder	139.4	20.9	176	20.7
Power	125.6	18.8	181.6	21.2
Attitude Control	45.2	6.8	55	6.5
Solar Array	70.1		--	
Thermal	28	4.2	21.7	2.5
	Power (watts)	% Total	Power (watts)	% Total
Communication	495	86	429	92
TT&C	17.5	3	10	2.3
Attitude	24	4	14	3.7

TABLE 5-12

SPACECRAFT	SBS		CS-II	
	KG	%	KG	%
ANTENNA	116.1	24.9%	10.1	3.3%
TRANSPONDER			66.1	21.6%
TOTAL PAYLOAD	116.1	24.9%	76.2	24.9%
STRUCTURE	45.7	9.8%	39.5	12.9%
TT&C	26.8	5.7%	26.3	8.6%
REACTION CONTROL	13.2	2.8%	9.6	3.1%
POWER	163.8	35.1%	72.8	23.8%
ATTITUDE CONTROL	23.6	5.1%	19.3	6.3%
THERMAL	20.0	4.3%	16.1	5.3%
ELECTRICAL INTEG.	23.6	5.1%	14.0	4.6%
BALANCE WEIGHT	5.4	1.2%	4.5	1.5%
AKM (DRY)	29.0	6.2%	27.3	8.9%
TOTAL BUS	351.1	75.1%	229.4	75.1%
DRY SPACECRAFT	467.2	100.0%	305.6	100.0%

Table 5-13

SPACECRAFT	INTELSAT-IVA		INTELSAT-V	
	KG	% OF DRY	KG	% OF DRY
ANTENNA	42.2	6.5%	66.7	8.3%
TRANSPONDER	121.1	18.5%	167.8	20.8%
TOTAL COMMUNICATIONS	163.3	25.0%	234.5	29.1%
STRUCTURE	153.9	23.6%	170.4	21.1%
TT&C	24.4	3.7%	25.8	3.2%
REACTION CONTROL	15.1	2.3%	31.9	4.0%
POWER	129.3	19.8%	143.9	17.8%
ATTITUDE CONTROL	46.6	7.1%	70.2	8.7%
THERMAL	30.4	4.7%	27.8	3.4%
ELECTRICAL INTEGRATION	24.6	3.8%	40.5	5.0%
BALANCE WEIGHT	6.2	1.0%	2.2	0.3%
AKM (DRY)	56.8	8.7%	61.7	7.6%
TOTAL BUS	487.3	75.0%	574.4	70.9%
DRY SPACECRAFT	653.1	100.0%	807.7	100.0%

Attitude control equipment is in the 6-8% mass percentage of in-orbit total mass but does not include the fuel mass (170 Kg for Intelsat-V) which is required for stationkeeping.

The attitude determination and control subsystems of body stabilized satellites are distinctly heavier than those of corresponding spin-stabilized satellites. The difference may be largely accounted for by the difference between the body-stabilized satellites' heavy momentum wheels plus their associated electronics and the lighter Despin Motor Assembly of the spinner.

One would expect that body-stabilized satellites would use more propellant for attitude control than would comparable spinning satellites. This proves to be the case; as an example, Intelsat-V uses 9.7% of its on-orbit fuel for attitude control where Intelsat-IVA uses only 1.4%. The total amount of on-orbit propellant needed, however, appears not to be a function of the method of stabilization since a small fraction is used for attitude control. In plotting the relationship between the satellites' lifetimes and the propellant needed as a fraction of the mass to be stationkept, the spinners show no obvious advantage.

5.5.2 ATS-6 2.670 GHz Characteristics (Table 5-14)

The ATS-6 experimental satellite was launched into geostationary orbit on May 30, 1974, and positioned at 94° W longitude. The spacecraft was used in a wide variety of applications and scientific experiments including communications experiments at frequencies from 40 MHz to 30 GHz.

A major ATS-6 mission activity during the first year of operations was the Health, Education, and Telecommunications Experiment (HET). Sponsored jointly by NASA, the Department of Health, Education and Welfare, the Veterans Administration and the Federation of Rocky Mountain States, HET featured daily broadcasts of quality color television in wideband FM format to small receiving systems located at schools, hospitals, and other institutions in Alaska, the Rocky Mountain States, and Appalachia.

The ATS-6 configuration used for the HET experiment is shown in Figure 5-15. The TV-FM signals from earth stations were received at C-band on the Earth Coverage Horn (ECH). The signals are then amplified, down-converted to IF where they are further amplified, filtered and limited. The signals are then converted to the 2.560 or 2.670 GHz band for final high power amplification and fed to the 9.1 meter paraboloid satellite antenna from its prime focus.

The HET system parameter summary is given in Table 5-16. Note the 3 dB beam contour of 0.90. This was innovative and set the stage for later narrow-beam satellite designs for TV broadcast.

It is not possible to delineate meaningful mass/power subsystem ratios for ATS-6 due to the multiple function nature of the spacecraft. It is significant, however, that ATS-6 pioneered in precision attitude control using signals provided from earth stations.

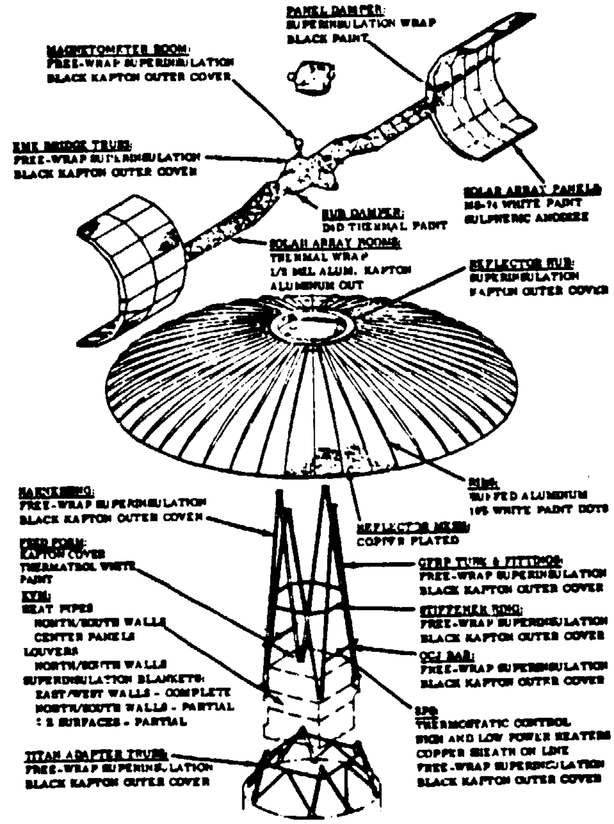


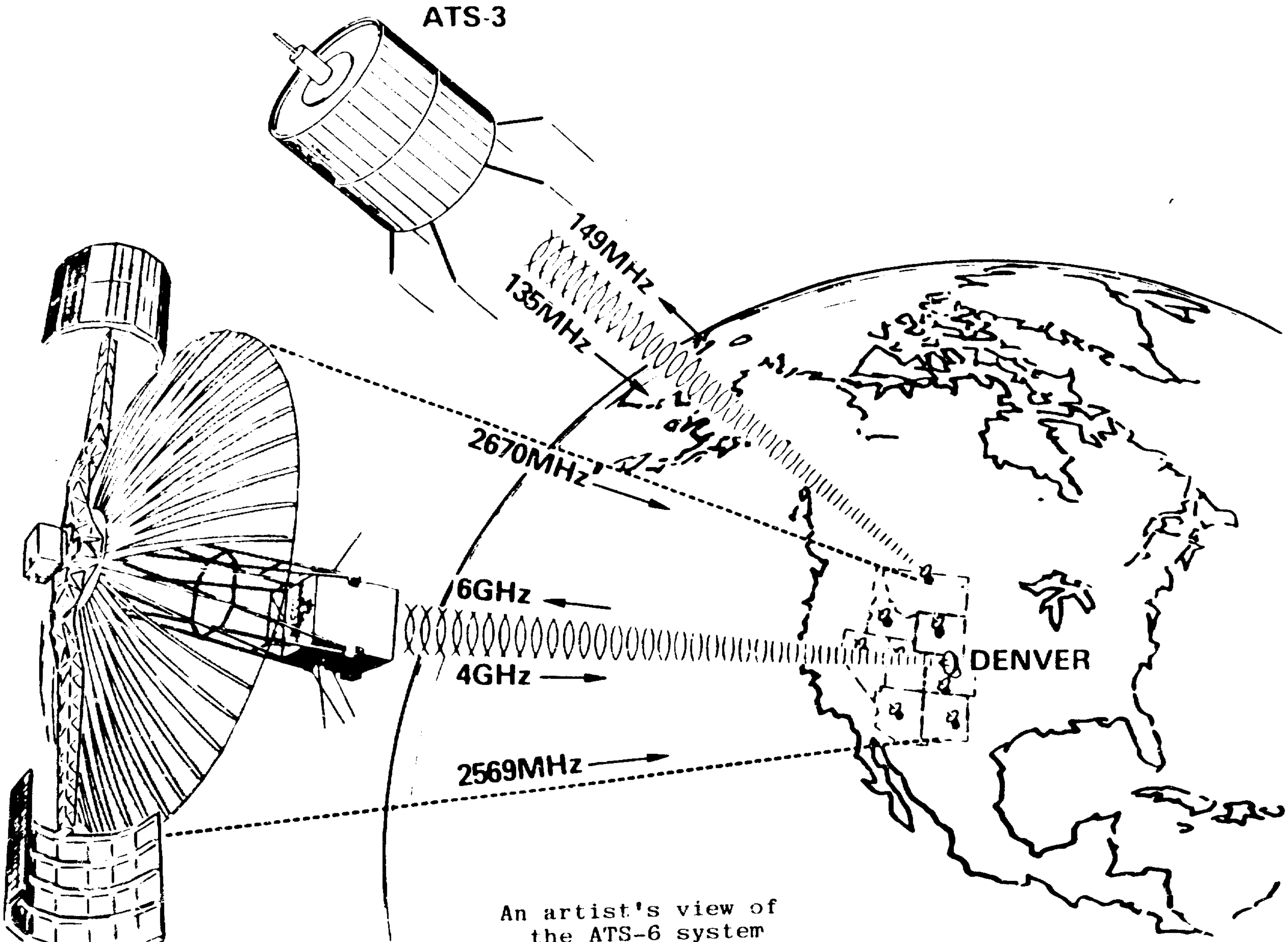
TABLE 5-14. Thermal Control Subsystem Elements

TABLE 5-15

COMMUNICATION SUBSYSTEM IN-ORBIT PERFORMANCE COMPLIANCE

Receive Frequency (MHz)	Antenna/ Near Peak Gain * (dB)	Field-of-View (FOV) (Deg)	Required G/T (dB/°K) Peak	Required G/T (dB/°K) FOV	In-Orbit G/T * (dB/°K) Near Peak
[illegible]	PFF/44.4	0.4	13.5	10.5	16
[illegible]	ECH/18.4	30	-17	[illegible]	-14
[illegible]	Off-Axis PFF/40.[illegible]	1.0	8.5	—	10.4
1[illegible]	Fan PFF/[illegible]	7.5 x 1.0	-2.0	-4.0	-2.0

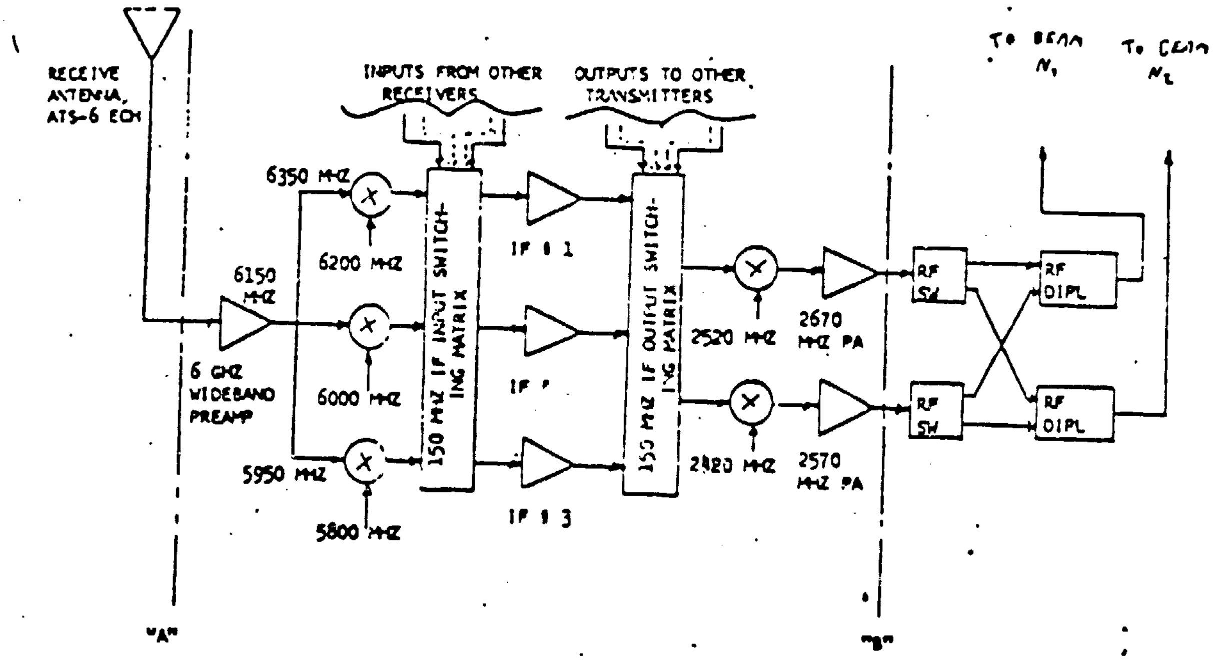
Transmit Frequency (MHz)	Antenna/ Near Peak Gain * (dB)	Field-of-View (FOV) (Deg)	Required EIRP (dBw) Peak	Required EIRP (dBw) FOV	In-Orbit EIRP * (dBw) Near Peak
[illegible]	PFF/40.1	0.8	44.2	43.5	40.7
[illegible]	ECH/17.1	30 x 13	[illegible]	[illegible]	[illegible]
[illegible]	Off-Axis PFF/[illegible]	1.0	[illegible]	—	[illegible]
[illegible]	Fan PFF [illegible]	7.5 : 1.0	[illegible]	[illegible]	[illegible]
[illegible]	PFF/[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



An artist's view of
the ATS-6 system

Figure 5-15A

(Doc. USSG BC/826 (Rev. 1))



SIMPLIFIED BLOCK DIAGRAM
OF THE ATS-6 HET SYSTEM

Figure 5-15B

(Doc. USSG BC/826 (Rev. 1))

TABLE 5-16

ATS-6 HET SYSTEM PARAMETER SUMMARY

	Receiver Center Frequency MHz (1)	Receive Antenna	Repeater Type	Repeater Bandwidth MHz (3 db)	Transmit Center Frequency MHz	Transmit Antenna(2)	Repeater EIRP, dBW, Peak	3db Contour of beam "foot print"
Repeater Channel 1	5950 6150 6350	ATS-6 Earth Coverage Horn 17° HPBW	Hard limiting dual conversion, no spectrum inversion	40	2569.2	ATS-6 30' reflector, S-Band beams N_1 or N_2	+53.2 either beam	≤0.9°
Repeater Channel 2	(same)	(same)	(same)	30	2670	(same)	+53.0 either beam	(same)

NOTES: (1) Selected by command
(2) Either channel can drive either beam; both channels can drive either beam simultaneously; channel power cannot be divided between the two beams; all functions selected by command. See Figure for typical S_1 and S_2 "footprints". The S_1 and S_2 elements create S-Band beams N_1 and N_2 respectively.

5.5.3 CTS-HERMES (11/14 GHz)

The characteristics of the CTS-Hermes are too well known to be repeated here. Figure 5-16 and Tables 5-17 through 19 list key system and mass properties.

CTS must be regarded as the satellite which not only pioneered the 11/14 GHz frequencies with 60 dbw EIRP, but was the first satellite to commit its payload to large high power TWT at a power level never before achieved in space.

CTS had two LITTON 200-watt TWTA with high efficiency (50% by using 10 depressed collectors) and two 20 watt Thomson-CSF TWTA. It was virtually a flying TWTA laboratory and certainly did much to establish the credibility of high power satellites as the answer to low cost TVRO earth terminals. CTS is now followed by ANIK-B and ANIK-C and CANADA is providing most of the TV-broadcast operations technology at the outset of the 1980's; with the demise of BSE and the retirement of CTS, these two Canadian satellites are the only TV broadcast (direct-to-user) systems in operation in the world today outside of USSR.

5.5.4 BSE - Japan's Broadcast Satellite (11/14 GHz) for Experimental Purposes

Japan's Broadcast Satellite for Experimental Purposes (BSE) pioneered the direct-to-user broadcast satellite concept in Region 3 and sparked earth terminal developments discussed in Section 6 and Section 7. BSE is no longer in operation but its brief history of operation (see Tables 5-20 through 5-22).

According to Table 5-21, the antenna and communication system (transponder) account for 2% and 18% of the satellite mass respectively, while the communications system uses almost 90% of the spacecraft dc bus power.

The low percentage of antenna mass ratio is typical of a single beam broadcast system using essentially a simple 3-horn offset fed antenna system (Figure 5-17) to place a large contoured footprint. Thus the mass is primarily directed toward providing a high level of RF power.

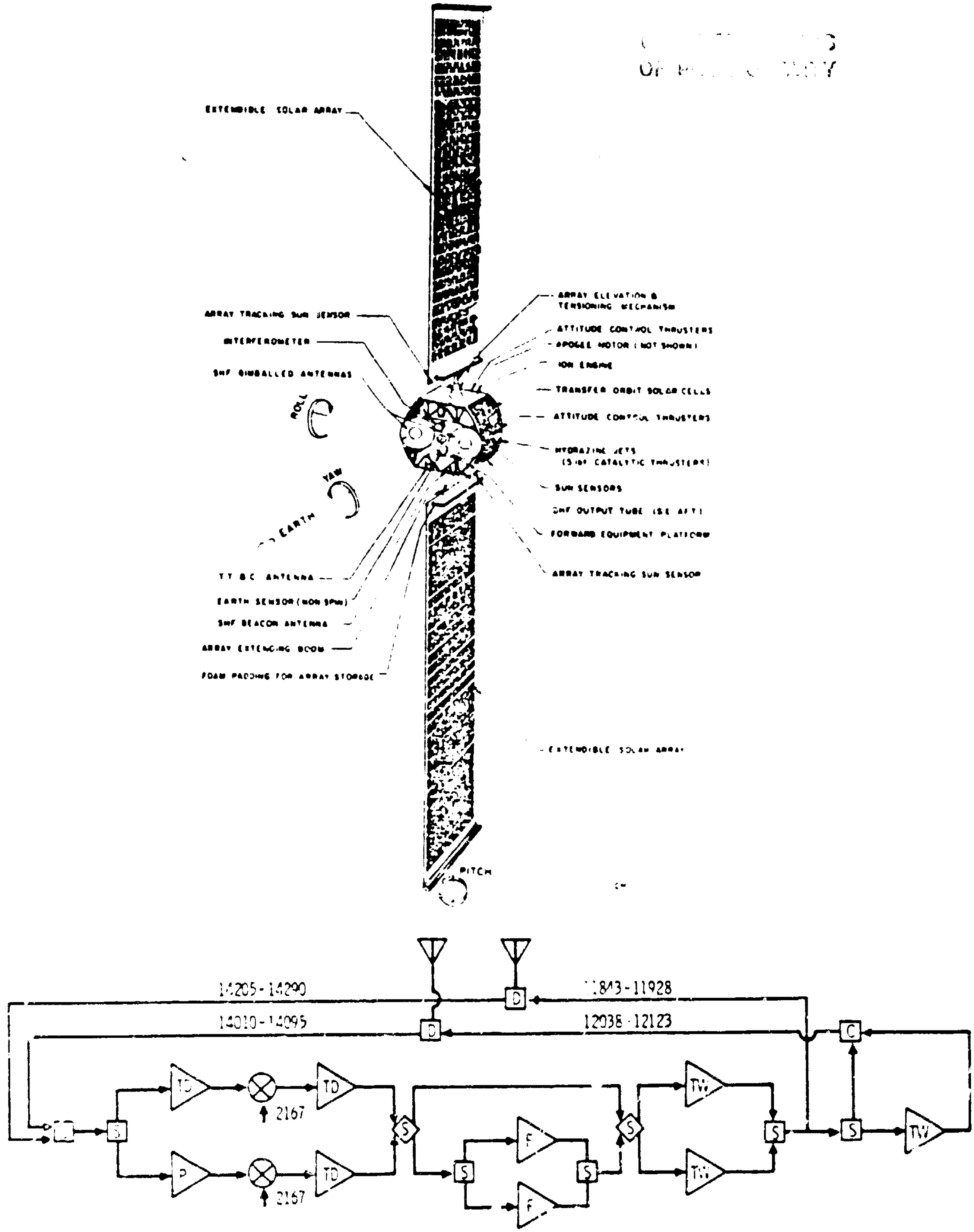


Figure 5-16. CTS Spacecraft

TABLE 5-17. UPLINK PARAMETERS

Applicant: CTS	Frequency: 14 GHz Elevation: 45° Type of Service: Analog Voice/TV
System Parameters	
Earth Station:	
Transmit power (400 Watts)	26.0 dBW
Feed line losses	2.0 dB
Carrier power at feed	24.0 dBW
Transmit antenna:	
Gain	48.4 dB
Aperture size	8.0 ft.
Overall efficiency	54.0 %
Beam size	0.6°
EIRP per carrier	72.4 dBW
EIRP stability	± 0.5 dB
Losses:	
Path loss at subsatellite point	206.4 dB
Path loss correction for elevation angle	0.3 dB
Atmospheric attenuation	0.3 dB
Receive antenna:	
Off-axis loss	0.1 dB
Pointing loss	0.2 dB
Polarization loss	0.0 dB
Net losses	207.3 dB
Rain attenuation, highest average value for: 0.01% of any year	4.3 dB
Spacecraft:	
Receive antenna:	
On-axis gain	37.7 dB
Aperture size	2.33 ft.
Overall efficiency	54.0 %
Signal to CTS Receiver*	-97.2 dBW
Receiver Noise (2315°K, 30 MHz)	-120.2 dBW
Carrier-to-Noise Ratio (clear weather)	23.0 dB
Threshold Requirement	12.0 dB
Signal Margin	11.0 dB

* The transponder gain to saturate the 200W TWT (23 dB) is 23 dB + 97.2 dB = 120.2 dB.

C-3

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TABLE 5-18 DOWNLINK PARAMETERS

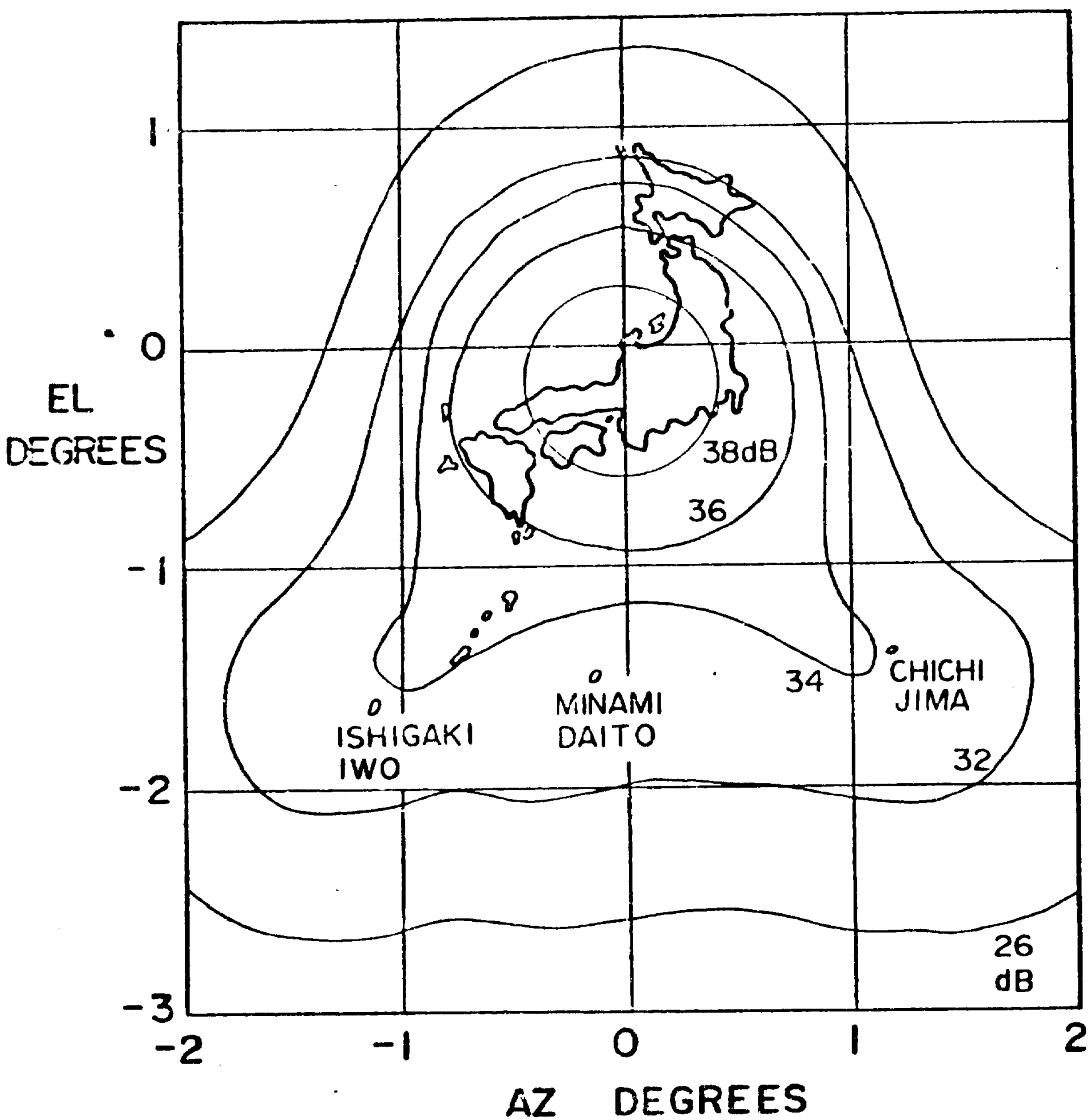
Applicant: CTS	Frequency: 12 GHz Elevation: 45° Type of Service: Analog Voice/TV
System Parameters	
Spacecraft:	
Transmitter power at saturation	23.0 dBW
Multiple carrier output backoff	- - dB
Feed line losses	2.0 dB
Carrier power at antenna feed	21.0 dBW
Transmit antenna:	
On-axis gain	36.2 dB
Aperture size	2.33 ft.
Overall efficiency	54.0 %
Beam Size	2.5°
EIRP per carrier	57.3 dBW
Losses:	
Path loss at subsatellite point	205.1 dB
Path loss correction for elevation angle	0.4 dB
Atmospheric attenuation	0.3 dB
Receive antenna:	
Off-axis loss	3.0 dB
Pointing loss	0.6 dB
Polarization loss	0.0 dB
Net losses in clear weather	209.4 dB
Rain attenuation, highest average value for: 0.1% of any year	12.0 dB
Earth Station:	
Receive antenna:	
On-axis gain	47.1 dB
Aperture size (dia.)	8.0 ft.
Overall efficiency	54.0 %
Beam size	0.7°
Signal power to receiver (EIRP - Losses + Receiver antenna gain)	-106.0 dBW

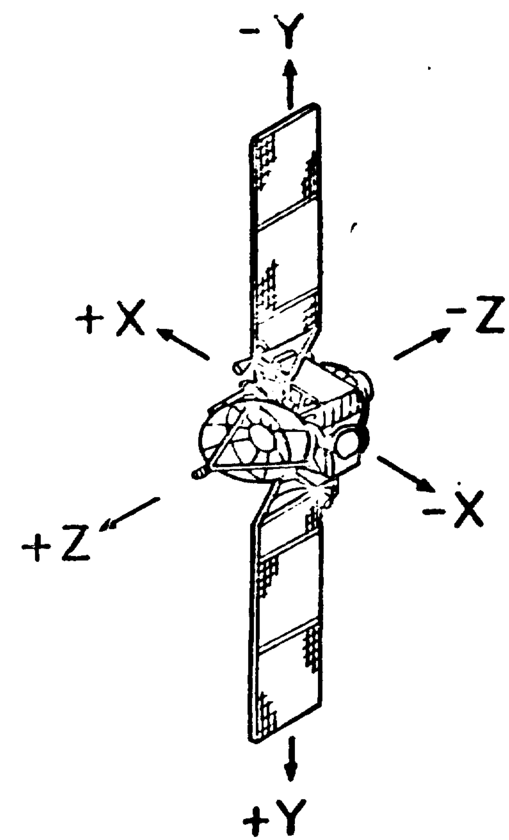
TABLE 5-19. Mass Power Budget of CTS.

System	Weight, kg	Weight, lbm
Telemetry, Tracking, and Command System	14.6	32.2
Super-High-Frequency Communications	67.2	147.9
Power Conditioning	21.5	47.3
Batteries	14.9	32.7
Body Solar Array	3.2	7.1
Flexible Solar Array Blankets	13.8	30.3
Flexible Solar Array Structure including Slip Rings and Deployment and Acceleration Mechanism	46.3	101.8
Wiring Harness and Electrical Integration	15.5	34.0
Attitude Control System	24.7	54.3
Basic Structure	55.1	121.2
Thermal Control	12.7	28.0
Reaction Control System (RCS) Hardware	18.0	39.5
RCS Fuel	25.1	55.2
Balance Weights	3.2	7.1
Apogee Motor and Fuel	341.0	750.2
Spacecraft Pad Weight	676.8	1488.9
Spacecraft Usable Weight in Synchronous Orbit	347.1	763.6
Lift-off Margin	+7.6	+16.7

	Operational mode		
	Spinning phase	Synchronous sunlight	Synchronous eclipse
	Power, W		
Transmitter Experiment Package	1.2	585.2	6.7
SHF Antennas, peak	-----	12.9	-----
Transponder	-----	98.0	-----
SHF Beacon	-----	18.0	-----
Telemetry, Tracking, and Command transmitter	12.7	12.7	12.7
Encoder and Transfer-Orbit Electronics	1.7	1.3	1.3
Receivers	5.0	5.0	5.0
Decoder	.7	.7	.7
Solar Array Mechanical Assembly	-----	8.8	3.4
Solar Array Technology Experiment	-----	5.0	5.0
Power Control Unit[a]	3.1	7.7	5.0
Essential Housekeeping Converter[a]	26.1	28.2	27.6
Main Housekeeping Converter[a]	4.6	8.5	5.6
Momentum Wheel Converter[a]	-----	6.3	4.8
Experiments Power Converter[a]	-----	18.1	-----
Power Switching Unit	.2	.3	.3
Batteries at C/20[b]	[c]10.4	[d]21.9	-----
Electrical Integration Assembly	4.9	4.9	4.9
Spacecraft Wiring Harness[a]	.7	1.5	1.2
Nonspinning Earth Sensor Assembly	-----	2.5	2.5
Spinning Earth Sensor Assembly	2.2	-----	-----
Sun Sensor Assembly	.5	.5	.5
Three-Axis Rate Gyro	-----	13.4	-----
Attitude Control Electronics Assembly	1.1	5.5	5.5
Momentum Wheel Assembly	-----	5.4	5.4
Heaters[e]	19.4	105.5	-----
Reaction Control System	13.0	18.5	11.90

SATELLITE BEAM





LAUNCH VEHICLE

NASA THOR DELTA 2914

TABLE 5-20. BSE

TABLE 5-21

BSE Spacecraft Weight and Power Summary

	Weight (Kg)	Ave. Power (Watts)
Structure/Mechanical	76.2	-
Thermal Control	21.6	29.5
Electrical Power	73.4	11.3
Attitude Control	26.6	22.4
Secondary Propulsion	47.7	-
Apogee Kick Motor	341.0	-
Tracking Telemetry & Command	11.6	29.5
Antenna	7.0	-
Communication	62.7	626.4
Ballast	2.2	-
Total	670.0	719.1
Dry In-Orbit	352	

TABLE 5-22

BS LINK BUDGET

UP LINK : FROM CENTRAL EARTH STATION

DOWN LINK : TO INDIVIDUAL RECEIVER

	DOWN LINK 12 GHz	UP LINK 14 GHz
	SATELLITE	EARTH STATION
TRANSMIT POWER	20.0 dBW	21.6 dBW
LOSS	1.5 dB	2.8 dB
ANTENNA GAIN	37.0 dB	61.0 dB
EIRP (ON AXIS)	55.5 dBW	79.8 dBW
PATH LOSS	205.6 dB	207.1 dB
SATELLITE POINTING ERROR	0.5 dB	0.7 dB
E.S. POINTING ERROR	0.4 dB	—
E.S. TRACKING ERROR	—	0.2 dB
ATMOSPHERIC LOSS	1.0 dB	1.4 dB
RAIN LOSS	0.0 dB	0.0 dB
TOTAL LOSS	207.5 dB	209.4 dB
	EARTH STATION	SATELLITE
ANTENNA GAIN	43.5 dB	41.5 dB
NOISE TEMPERATURE	28.2 dBK	31.6 dBK
G/T	15.3 dB/K	9.9 dB/K
C/T	-136.7 dBW/K	-119.7 dBW/K
K	-228.6 dBW/K-Hz	-228.6 dBW/K-H
B (23MHz)	73.6 dBHz	73.6 dBHz
C/N	18.3 dB	35.3 dB
SATELLITE I.M.	38.7 dB	
SYSTEM C/N	18.1 dB	
THRESHOLD MARGIN	8.1 dB	
RAIN LOSS	1.0 dB	10.0 dB
NOISE INCREASE	0.4 dB	0.0 dB
C/N	16.9 dB	25.3 dB
SYSTEM C/N	16.2 dB	
THRESHOLD MARGIN	6.2 dB	
FM IMPROVEMENT	18.3 dB	
WEIGHTING with CCIR EMPH	12.[illegible] dB	
RECEIVE TV S/N	47.[illegible] dB	

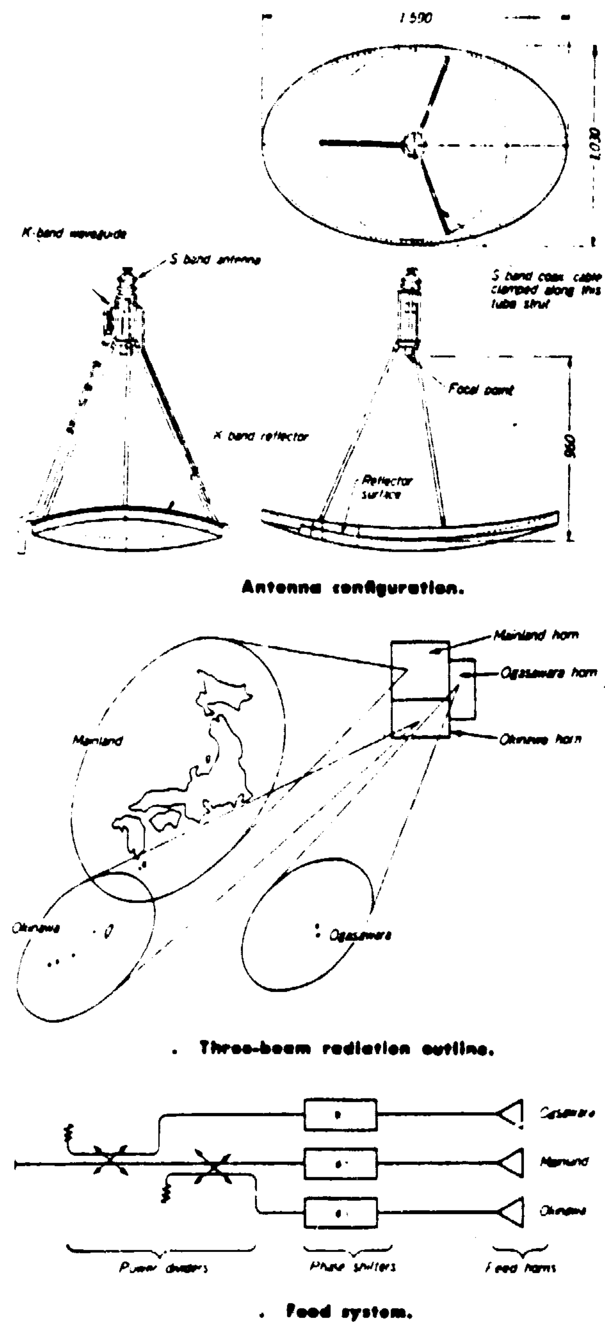


Figure 5-17. BSE Antenna System

5.5.5 India's INSAT for TV Broadcast (2.54 GHz)

India's INSAT is a multiple function satellite, providing not only TV broadcast at 2.6 GHz, but also telephony and TV at C-band, data collection at UHF and radiometer cloud photography. (Figure 5-18).

Table 5-23 lists mass and percentage of dry mass ratio for various INSAT subsystems. Note that all antennas require only 3.5% of the total dry mass while the transponder for all functions (Figure 5-19) uses 15% of the dry mass.

An interesting aspect of INSAT design is the high ACS and reaction control system to account for the unusual unbalanced configuration which accounts for radiometer radiation from one spacecraft face.

5.5.6 USSR's STATSIONAR-T

Figure 5-20 shows the basic STATSIONAR-T spacecraft which illustrates the array of 96 helical antennas used to beam TV into Siberia at 715 MHz. (See Figure 5-21).

Little has been published relative to the design of this satellite, but it is known that the satellite weighs almost 2000 Kg, its solar cells furnish around 1.5 KW, and it uses a single transponder to drive a 200 watt Klystron bolted to the structure to provide RF drive to the antenna.

Because of the limited channel capability of this spacecraft, antenna and transponder mass ratios are not applicable as a comparison to other spacecraft.

SYSTEM OVERVIEW

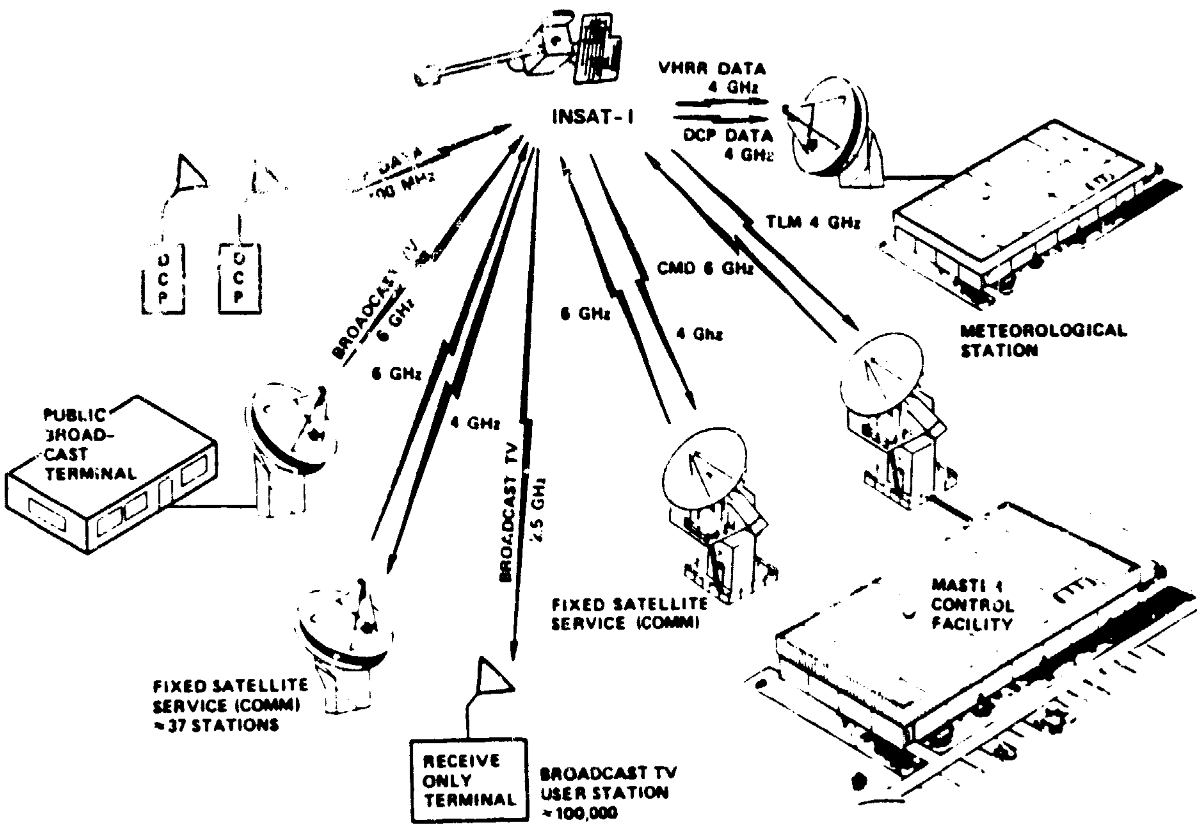


FIGURE 5-18

TABLE 5-23

SPACECRAFT	INSAT	
	KG	%
ANTENNA	17.5	3.5%
TRANSPONDER	75.5	15.0%
TOTAL PAYLOAD	130.2	25.9%
STRUCTURE	85.0	16.9%
TT&C	22.5	4.5%
REACTION CONTROL	60.2	12.0%
POWER	92.0	18.3%
ATTITUDE CONTROL	64.7	12.9%
THERMAL	27.1	5.4%
ELECTRICAL INTEG.	21.3	4.2%
BALANCE WEIGHT	0.0	0.0%
AKM (DRY)	Biprop.	
TOTAL BUS	372.8	74.1%
DRY SPACECRAFT	503.0	100.0%

SATELLITE SIMPLIFIED BLOCK DIAGRAM

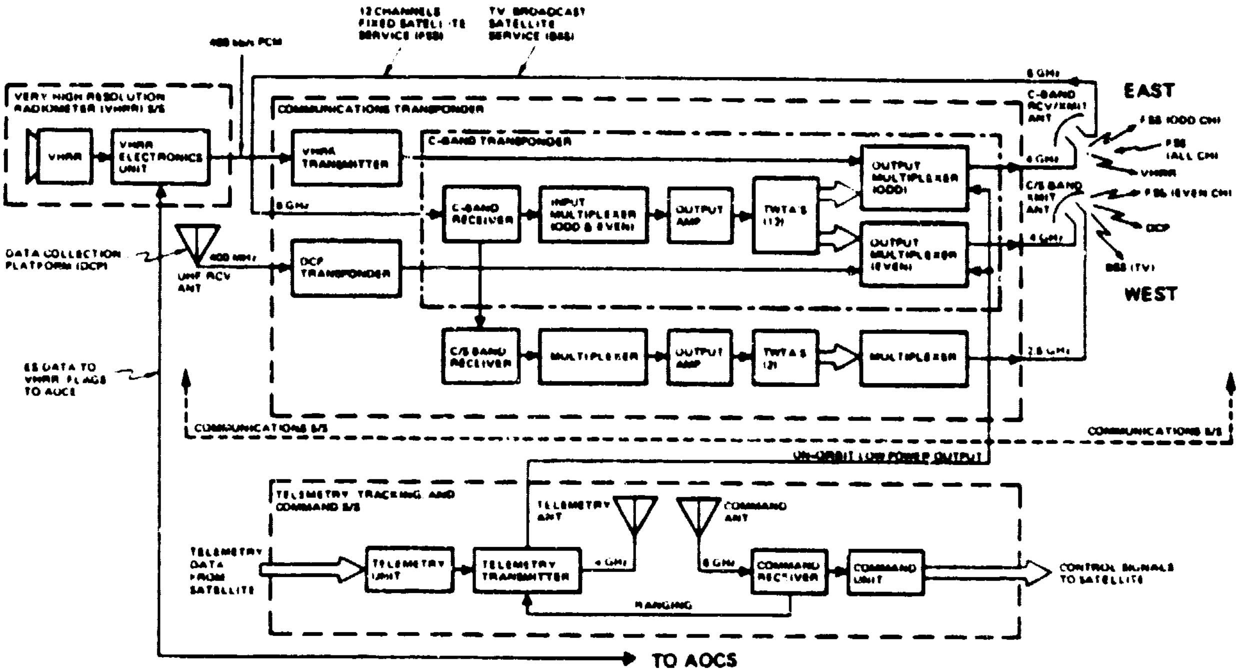


FIGURE 5-19

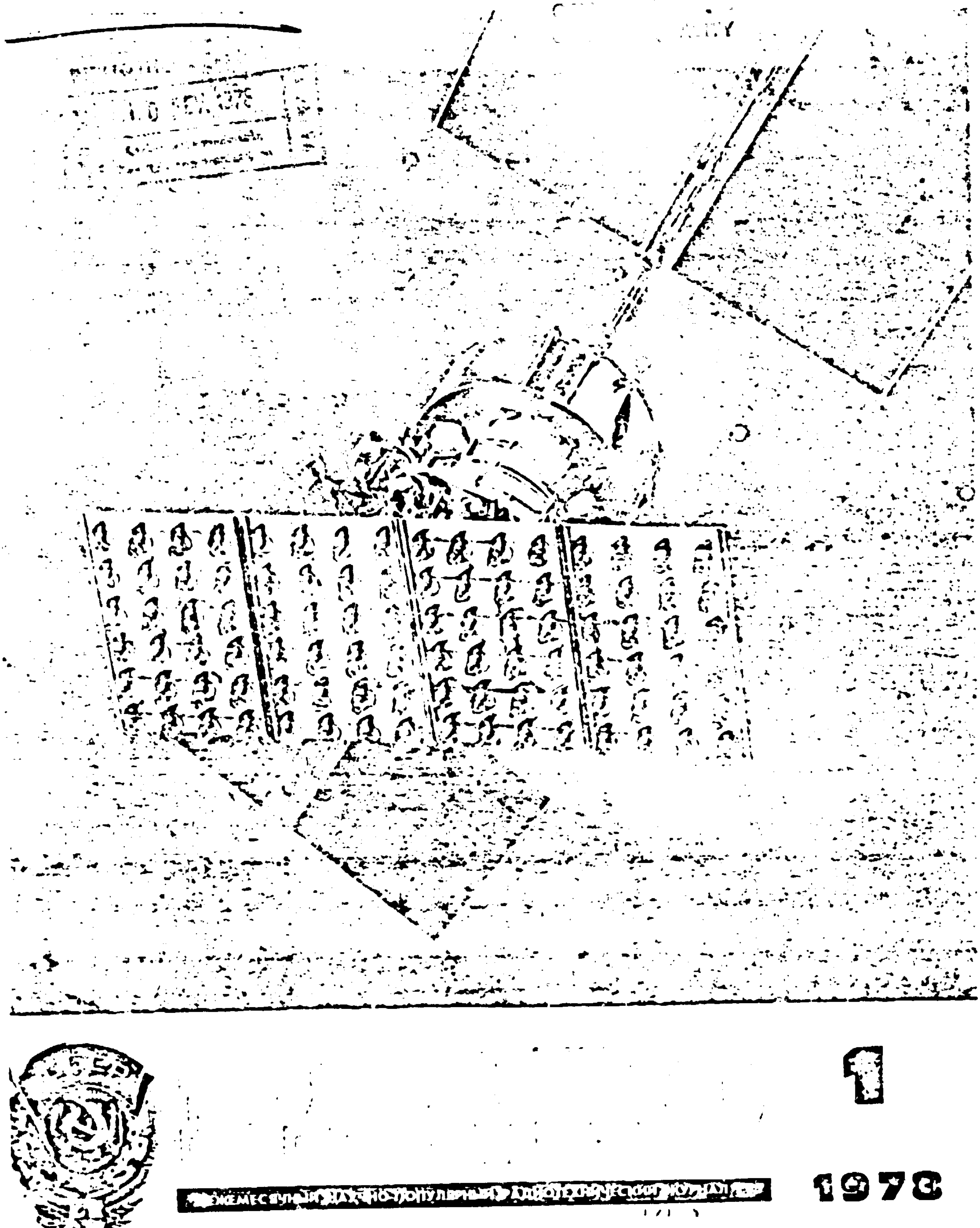


Figure 5-20
STATSIONAR-T

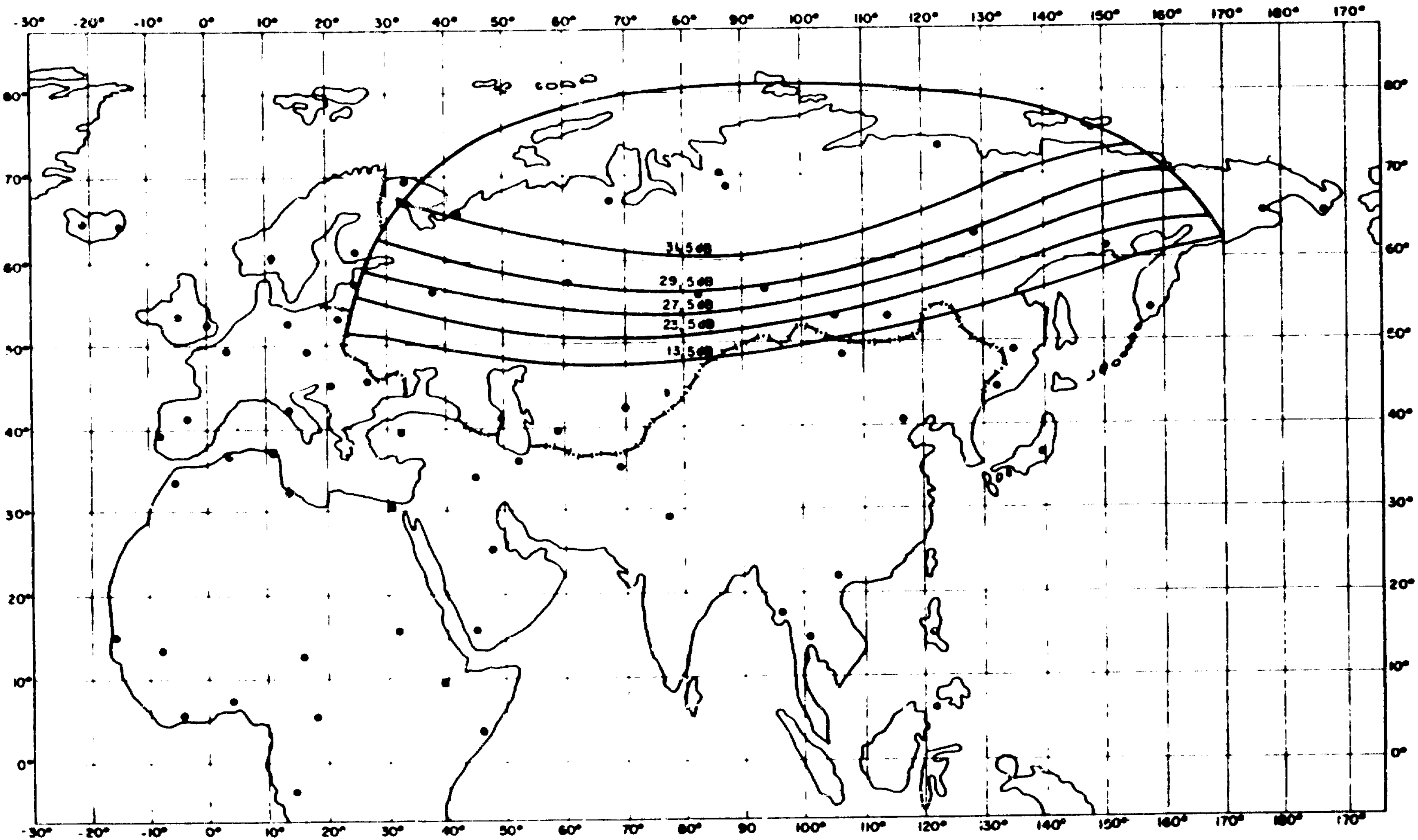


Figure 5-21
Coverage area of the Russian
broadcasting-satellite

5.5.7 German TV-SAT Design (Figure 5-22)

The most important part of the German TV-SAT program is the satellite. It has to use new technologies never flown before in commercial communication satellites, e.g., output amplifiers of some hundreds of Watts, ultra-lightweight solar generators or ion thrusters.

The preoperational TV-SAT is limited to an overall launch weight of 1700 kg., the layout of the structure, however, will allow launch weights up to 2000 kg. The thermal control of the three modules is decoupled to the most possible extent. This means that other payloads with lower or higher heat generation will not influence the design of the service and propulsion modules. The main spacecraft data are summarized in Table 5-24. Weight and power margins are not extremely high but for the moment very comfortable.

The German authorities began in 1971 financing the development of hardware components for a direct broadcasting satellite. Some of the key items included:

- Traveling wave tubes of 200 to 450 watts
- Total repeater chains
- CFC-antenna dishes as large as 2m in diameter
- Feed system of the transmitting antenna
- Ultra-lightweight solar generator
- Double-gimbaled momentum wheel
- High-precision infrared Earth sensor
- Digital reprogrammable attitude and orbit measurement and control system
- Digital TM/TC system
- RF-sensor
- Liquid apogee thrust system
- Bearing and power transmission assembly for high power

Table 5-24 lists the TV-SAT-A3 mass breakdown. Note that the antenna mass is 6-7% of the dry mass but that the repeater (transponder) mass is only 14 percent of the dry mass. Thus TV-SAT has traded transponder mass for more sophisticated antenna mass to provide for the narrow beam required to illuminate the FRG (See Figure 5-13) and to provide mass margins for the structure providing the exceptionally high dc power level of 2.5 KW.

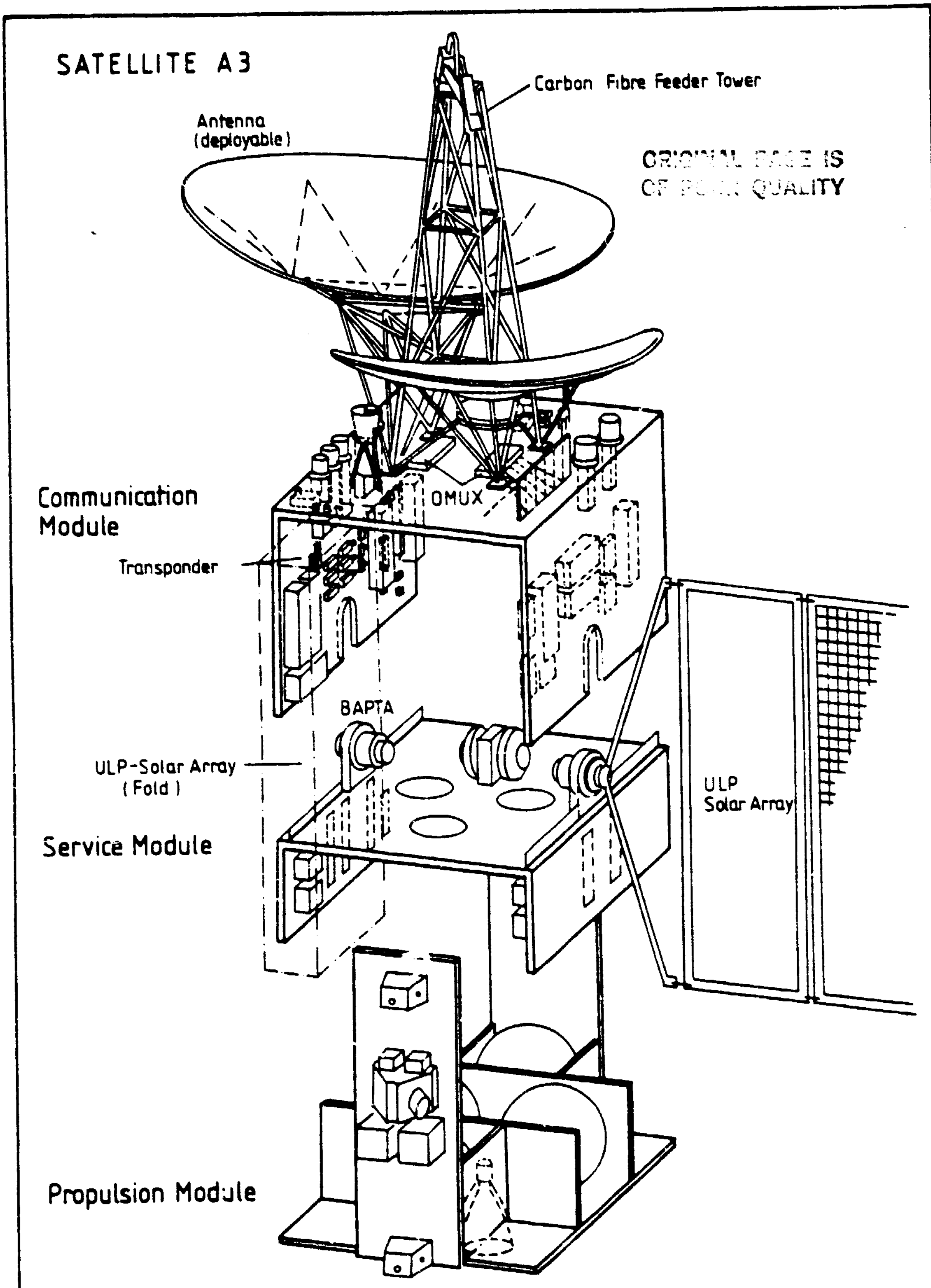


Figure 5-22	Explosion View of German TV SAT	Sept. 1979

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MASS

Antenna	56,7 kg
Repeater	110,7 kg
Power Subsystem	59,5 kg
Solar Array	93,5 kg
Drive Assembly	14,4 kg
Data System	24,9 kg
AMCS	48,5 kg
UPS	91,5 kg
RITA	32,6 kg
Structure	144,7 kg
Thermal Control	63,1 kg
Bus Harness, EK, Pyro	26,4 kg
Balance Miscellaneous	20,0 kg
Total Nominal Dry Mass	786,5 kg
Propellant Mass 5 years	822,7 kg
Resultant Transfer Orbit Mass	1609,2 kg
Maximal Transfer Orbit Mass (with special TV-SAT Adapter)	1711,7 kg
Margin	102,5 kg = 11,5%

POWER

Maximum required, EOL	2533 W
Installed, EOL	2849 W
Margin	316 W = 12,4%

OTHERS

Spacecraft Reliability	(5 years)	0,837
Payland Reliability	(5 years)	0,924
Bus Reliability	(5 years)	0,906
Total length with extended arrays		19,25 m

Table 5-24	Main Spacecraft TV-SAT-A3 Data (Version ARIANE)	Sept 1979

5.6 TV Broadcast Satellite Technologies

This section will discuss the principal TV broadcast satellite technologies which will make possible the optimum design of the candidate satellite discussed in Paragraph 5.7.

5.6.1 Basic Weight Considerations - The Use of Ultra-lightweight Materials.

Spacecraft and satellites have evolved from the typically heavy aluminum structures first used on SKYNET I and NATO II to wide-spread use of reinforced plastic composite materials on the satellites of today. Figure 5-23 shows the technical progression up to INTELSAT V and future projections.

The next generation after the all metal designs used a substantial amount of fiberglass reinforced plastics for secondary structures and bonded honeycomb sandwich panels (solar arrays, antennas, and equipment platforms).

The structural advantage of using graphite composite materials is shown in Figure 5-24. Graphite materials can be selected that have specific strengths much higher than any metal and one graphite composite has a specific stiffness like berylium. Besides their structural advantages, graphite composites have a low thermal coefficient of expansion (Table 5-25), making them ideal for dimensionally stable spacecraft component requirements. Because of this, graphite composite materials were first used in antenna structures.

The Voyager spacecraft antenna is a 12-ft (3.66 m) diameter graphite sandwich reflector and is the largest graphite antenna built and weighs slightly over 100 lbs (45.4 kg). The Japanese ECS satellite was the first to use graphite and Kevlar (R) materials in primary structure. There is extensive use of graphite on INTELSAT V (Figure 5-25) including solar array structure, antenna module truss, antenna reflectors and feeds, waveguide, and multiplexer.

For future satellite there will be even more extensive use of graphite. The primary spacecraft structure will be graphite or a combination of graphite

TECHNICAL EVOLUTION OF SATELLITE MATERIALS

SKYNET I NATO II	Aluminum structures
SMS	Fiberglass and honeycomb sandwich structures
VIKING NATO III VOYAGER CS, ETS II, ECS	Graphite composite antennas
ECS	Graphite composite and Kevlar composite primary structures
INTELSAT V	Extensive use of graphite in structures and RF components
Future	Low cost graphite materials Lower cost composite manufacturing Graphite and graphite/berrylium Primary structures

FIGURE 5-23

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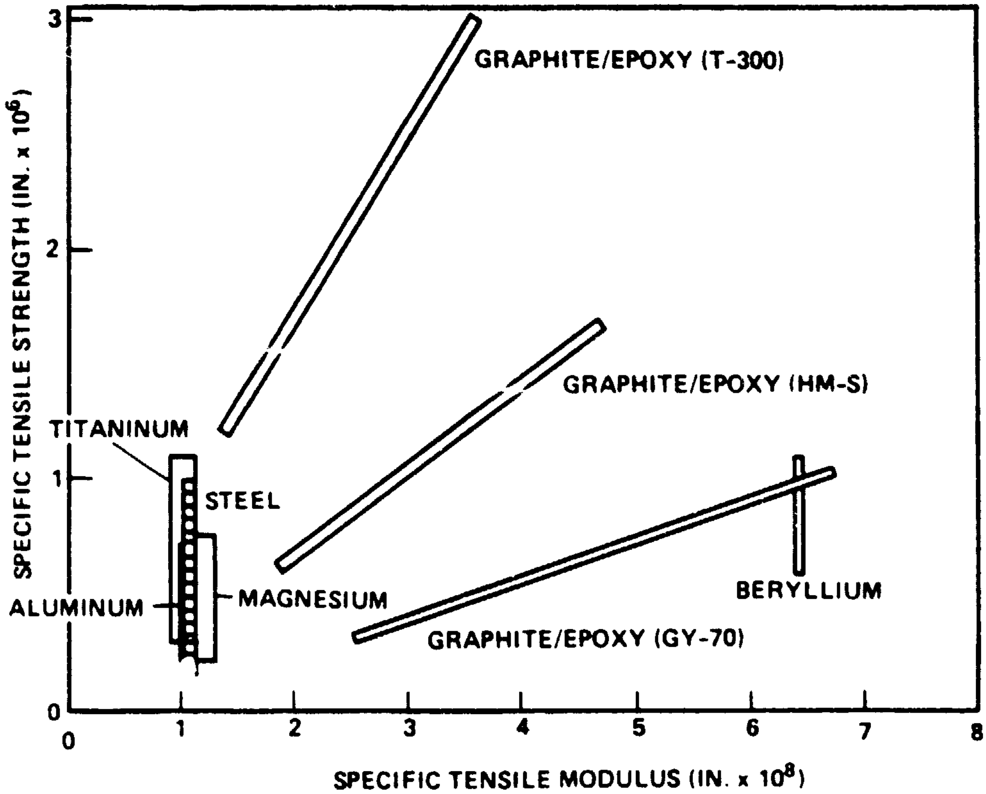
STRUCTURAL EFFICIENCY OF GRAPHITE EPOXY COMPOSITES COMPARED TO METALS



NOTE: FOR LAMINATES UPPER END OF BAR IS UNIDIRECTIONAL & LOWER END IS QUASI ISOTROPIC

FIGURE 5-24

Table 5-25

DIMENSIONAL STABILITY OF GRAPHITE EPOXY COMPOSITES COMPARED TO METALS

Material System	E (MSI)	F_{TU} (KSI)	α In./In./°F X 10^{-6}	P (lb/in^3)
Graphite	42.5	079.8	00.60	0.060
Epoxy	14.9	028.1	00.05	
Beryllium	42.0	044.0	[illegible]. 40	0.066
Aluminum	10.5	60.0	13.0	0.100
Titanium	16.0	160.0	04.8	0.160
Steel	29.0	270.0	06.30	0.283
Invar	20.5	065.0	00.70	0.291

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GRAPHITE COMPOSITE USAGE ON INTELSAT V

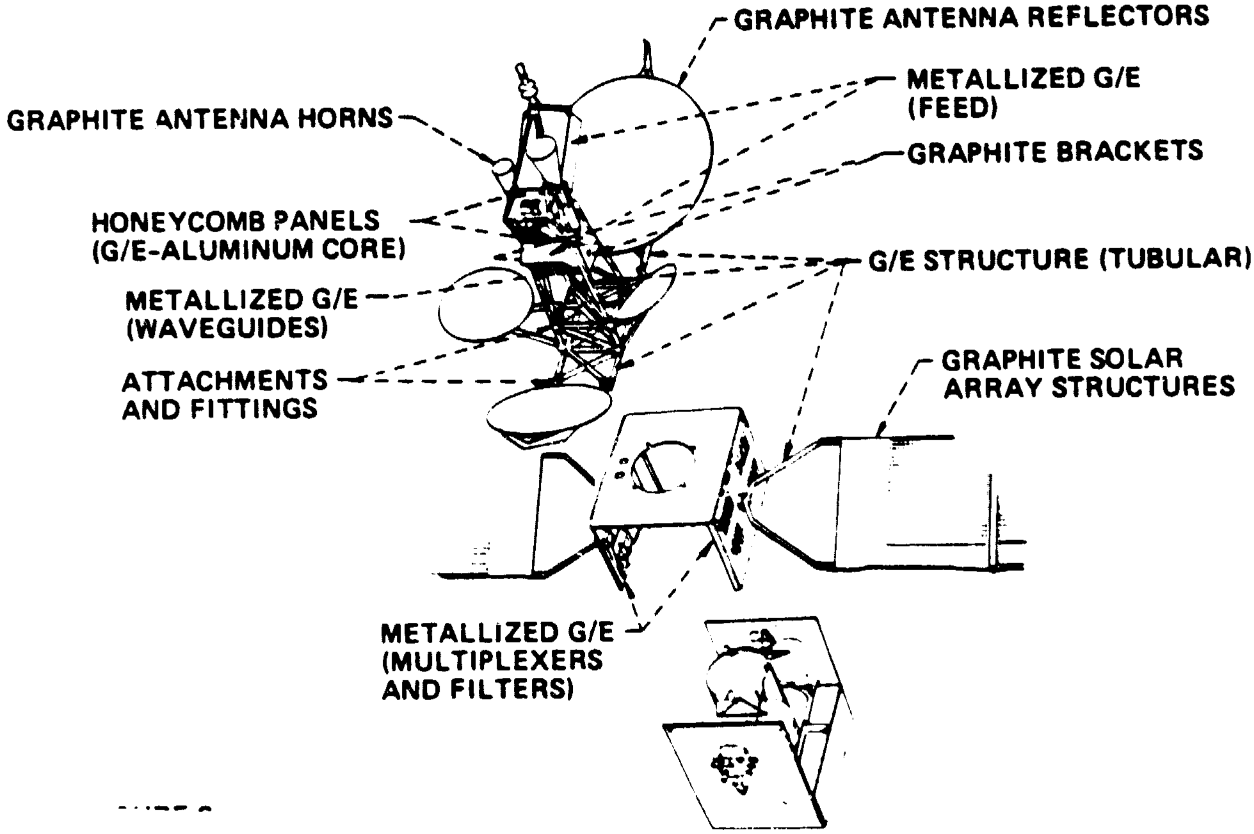

FIGURE 5-25

and berylium. Lower cost graphite fibers will be used. A significant emphasis will be placed on the lowering of manufacturing costs, particularly by using faster curing resin systems and automated manufacturing equipment.

5.6.2 The Technology of Spacecraft G/T and EIRP

Since the earliest days of satellite communications, the spaceborne active-repeater has provided the basic functions of, (1) receiving an up-link signal arriving at one antenna in one frequency band, (2) converting this signal to a second frequency, usually in the down-link frequency band, and (3) providing significant amplifier gain to produce from the down-link antenna sufficient effective radiated power to various earth terminals to make possible the demodulation of one or more channels of information of specified quality from the receivers in these terminals.

In the 1960's and early 1970's, the 4/6 and 7/8 GHz frequencies were in primary use, and the single frequency conversion transponder of Figure 26a was used until the advent of CTS which was the first to use the 11/14 GHz frequencies. As the frequencies above 10 GHz became of interest for satellite communications, the dual conversion transponder, shown in Figure 5-26b became widely used; although CTS provided single conversion from 14 to 11 GHz, satellites such as Intelsat-V and Japan CS converted from their Ku-band and K-band frequencies to C-band as an intermediate frequency and the European OTS satellite converted from 14 GHz to around 800 MHz and then back to 11 GHz.

Figure 5-26c illustrates an on-board regenerative repeater in which the incoming digital modulated carrier is demodulated, regenerated, and remodulated to reduce up-link noise and intersymbol interference contributions to the digital link. Figures 5-26d and 5-26e show, respectively, a multiple-beam transponder system using either RF matrix switching route TDMA modulated carrier bursts, or

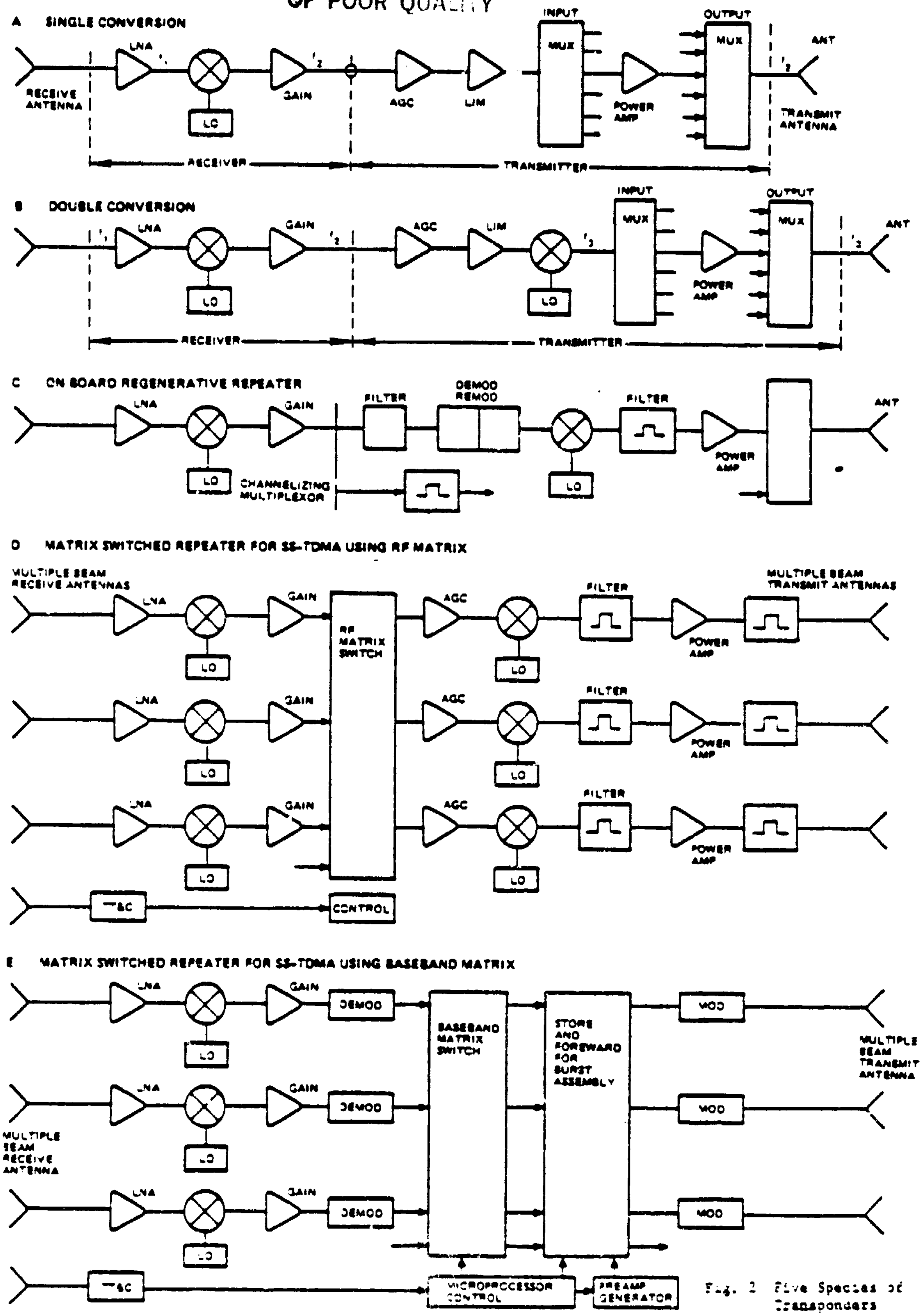

Fig. 2 Five Species of Transponders

Figure 5-26. Various Types of Transponders baseband matrix switching and signal processing to route TDMA bursts of baseband data to remodulators for transmission to proper down-link.

Table 5-26 lists the principal components which have been used to build satellite transponders and includes the basic switch and modulators which in the 1968-1978 era have been used for demod-mod and matrix switching functions. The candidate components of the 1978-1988 era have also been listed and show how the FET is a viable candidate for each of these device functions.

The TV broadcast satellite will use a transponder of the types shown in Figures 5-26a and 5-26b as long as FM carriers are used. When the era of TV broadcast by digitally modulated carriers using burst transmission arrives, then transponders using on-board regeneration and matrix switches for routing can be used.

In the design of the satellite system several parameters must be accounted for in determining satellite sensitivity (G/T) or satellite radiated power (EIRP). They are listed in Table 5-27.

Figures 5-27 and 5-28 show two types of broadcast satellite transponders including the antenna. Figure 5-28 highlights the high TWTA power level (250 and 450 watts) characteristic of this complex transponder system designed to serve as a baseline to FRG designs. The emphasis on the high power amplifiers and high gain antennas to provide high EIRP in the 60-65 dbw range is what distinguishes this type of repeater system from a communication satellite system.

There are five critical technology areas for broadcast satellites to meet the sensitivity and EIRP requirments in addition to providing stability of spacecraft motion. They are LNA, antennas, filters, attitude control, and dc power (batteries and solar cell arrays). These technologies will be discussed in the following paragraphs.

TABLE 5-26

CANDIDATE TRANSPONDER COMPONENTS

Devices	1968 - 1978	1978 - 1988
LNA	Mixers TDA	TDA Paramps FET Amps Mixers Josephson Tunneling
Receiver Gain	TWT Transistors	FET Amps
Oscillators Mixers	Multipliers Schottky Diode	FET Oscillator FET Mixer
AGC	Transistors PIN Diode	Dual Gate FET PIN Diode
Limiters	TDA PIN Diode	FET Limiter
Power Amps	TWTA Impatt Amp	FET Power Amp TWTA Impatt Amp
Switches	PIN Diode Schottky Diode	FET (Single & Dual Gate) PIN Diode
PSK Modulators	Schottky Diode	Schottky Diode FET (Single & Dual Gate)

TABLE 5-27

Parameter of Satellite G/T and EIRP

Satellite G/T	Key Parameters
	o Antenna gain (receive) (G)
	o Antenna noise (earth temperature) $T_A(^oK)$
	o Feed and filter loss in noise temperature between LNA and antenna $(T_L{}^o)$
	o LNA receiver noise temperature and gain - T_R

$$G/T = \frac{G(db)}{\left(T_A + T_L + T_R\right)(db)}$$

for small values of feed and filter loss.

Satellite EIRP	
	o Transmit Antenna gain (G)
	o Output channel filter and feed loss (L)
	o Power amplifier output power level P_o (not necessarily at saturation)

$$EIRP = G + P_o - L$$

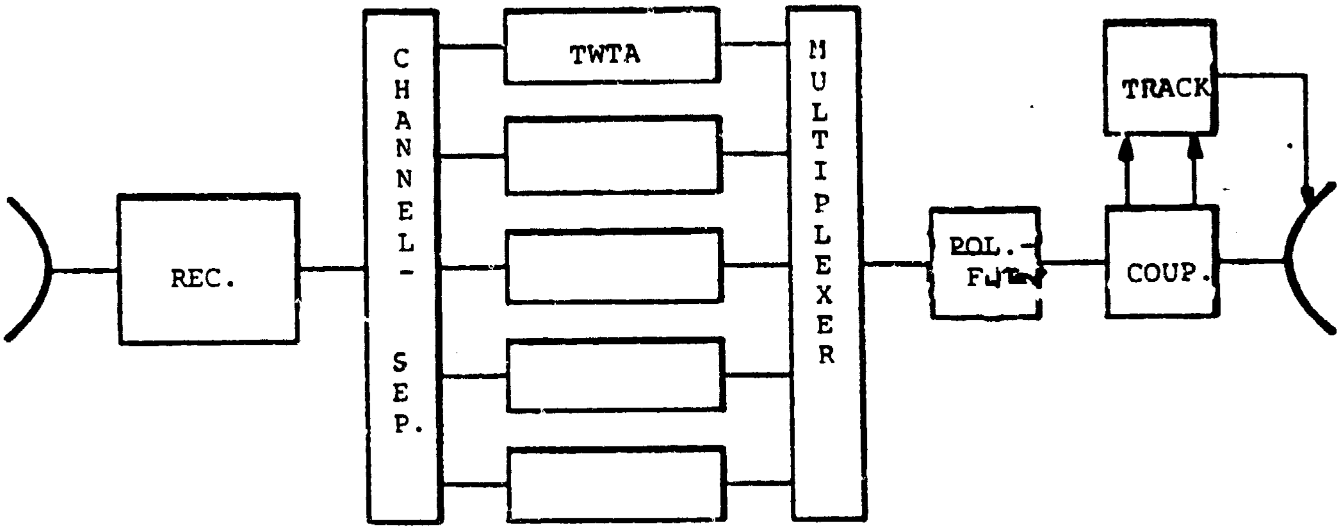

Figure 5-27. Blockdiagram of a direct broadcasting satellite payload

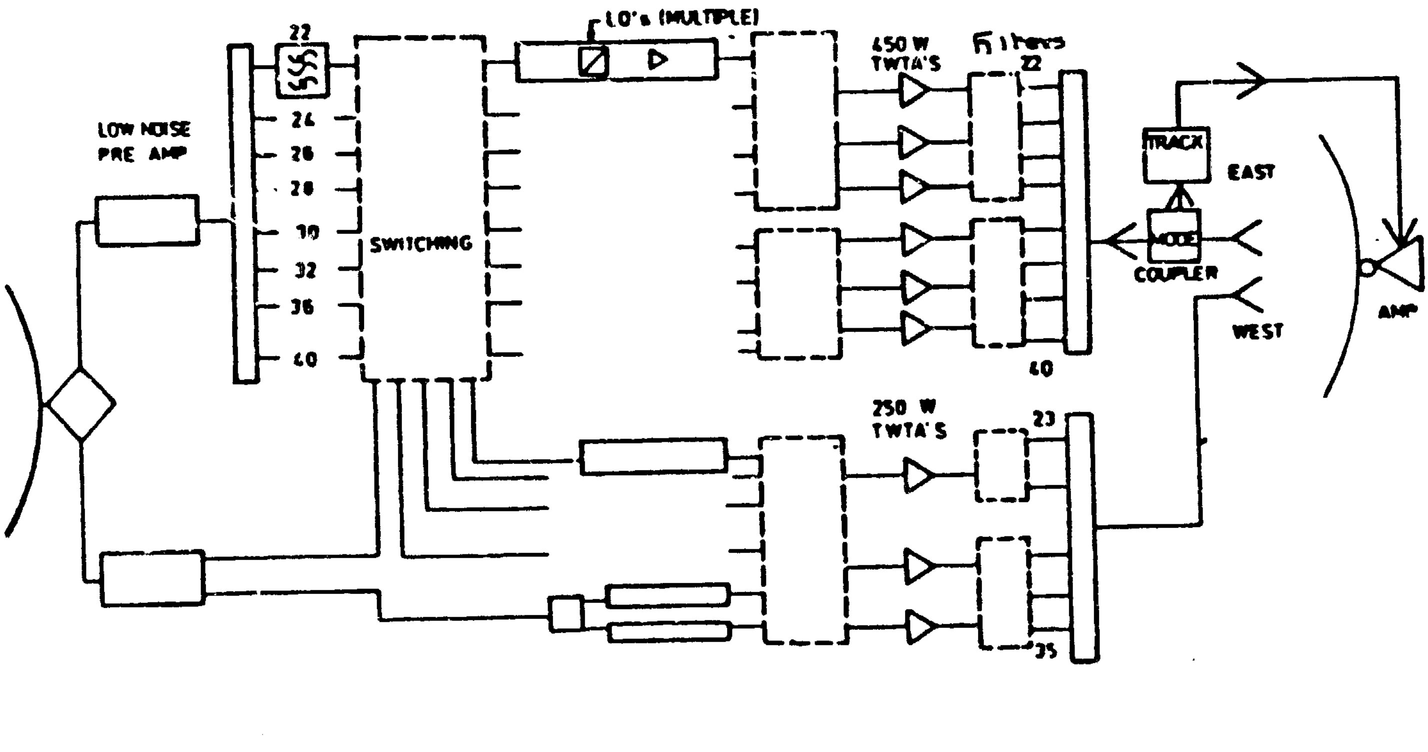

Figure 5-28. Satellite payload of a multi-national direct broadcasting satellite payload

5.6.3 Satellite Receiver Technology

Four types of low noise receiver front ends are in use in communication satellites today: (Table 5-28).

- o Tunnel diode amplifiers
- o Mixer - low-noise post amplifier complexes
- o Parametric amplifiers
- o FET amplifiers

The tunnel diode amplifier with its 4-6 dB noise figure in the 6 and 16 GHz frequency ranges is widely used in Intelsat satellites and in Symphonie, and has proven to be stable low noise amplifier. Table 5-28 lists many of the amplifier characteristics now achieved in principal communication bands.

Mixer technology is providing mixers with conversion losses in the 3.5-6 dB range at frequencies from 2 to 60 GHz. Such a mixer operating into a post low noise amplifier having a noise figure of, say, 5 dB will provide an overall noise figure of 9-11 dB. The mixer - post amplifier combination was used at 30 GHz for the Japan CS to provide a 10.5 dB noise figure based on a 6 dB mixer operating into a wide band 3-5 GHz FET amplifier with a 4.5 dB noise figure. This was designed in 1974 when tunnel diode amplifier technology at this frequency was determined not to have sufficient reliability and 30 GHz paramps had not been qualified for space.

For a long time the parametric amplifier was looked upon as a "Peck's bad boy" whose need to be constantly tweaked during the days of using klystron pumps mitigated against its consideration as a space device. However, the use of the stable long-life Gunn oscillator pump and the advent of computer aided design gave rise to a paramp which can now be reliably operated in spacecraft. Table 5-29 lists the principal space satcom paramps which have been developed in Japan, Europe and U.S. A 14-GHz paramp in CTS has amassed more than 10,000 hours of

TABLE 5-28

NOISE PERFORMANCE OF CANDIDATE SPACECRAFT LNA

TYPE AMPLIFIER	NOISE TEMPERATURES (°K)/ FACTORS (dB)			
	FREQUENCY (GHz)			
	6	8	14.25	28
UNCOOLED PARAMP	50°K 75°K	75°K- 100°K	75°K 200°K	250°K- 400°K
TDA	3.7	4.0	6.0	8.0
FET	1.5	2.5	3.0	6.0
MIXER (CONVERSION LOSS)	3.5	4.0	4.5	5.0

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TABLE 5-29

DEVELOPMENTS IN SPACECRAFT PARAMP TECHNOLOGY

Frequency	Company	Location	Noise Temperature	User
2.2 GHz	LNR	USA	38°K	NASA, TDRSS
3.5-4.25 GHz	AIL	USA	100-150°K	NASA for Use Aboard Space Shuttle
14.5 GHz	GTE Telecommunications	Italy	250°K	Used in CTS
	AIL	USA	130°K	NASA
	Micromega	USA	250°K	NASA
	LNR	USA	75°K	NASA, TDRSS
30 GHz	Fujitsu Labs	Japan	4.5 dB NF	Experimental
	LNR	USA	3.5 dB NF	Experimental
36 GHz	AIL	USA	3.3 dB NF	Experimental
60 GHz	AIL	USA	5.0 dB NF	Experimental

continuous operation without loss of noise temperature or undergoing any bandwidth gain change. A 14-GHz paramp will be used in TDRSS, and Fujitsu in Japan has developed a 30 GHz satcom paramp which is a candidate front end low noise amplifier for future Japan satcoms to have input frequencies at the band.

Perhaps the most useful development for low noise front ends of communication satellites is the FET amplifier which does not require the pump power of a paramp and gives a noise figure almost as low as that of an uncooled paramp, particularly if it can be cooled to some temperature from $100^{\circ}K$ to $-40^{\circ}C$. At present, noise figures of around 2 dB at 4 GHz, and 4 dB at 14 GHz and 6 dB at 18 GHz are being obtained with half-micron gate FET's and noise figures as low as 1-1.5 dB have been achieved* by cooling these FET amplifiers to temperatures as low as $100^{\circ}K$. Figure 5-29 provides a graph of noise figure versus frequency for various manufacturers.

Low noise amplifiers of both the FET and paramp variety are used for earth terminal showing again the wide variety of amplifiers presented to the world marketplace by Japanese, U.S., and European manufacturers, illustrating that low noise amplifiers, whether in space or on the ground, is truly a worldwide technology with Japan emerging as the principal device manufacturer. (Table 5-30).

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* at 12 GHz

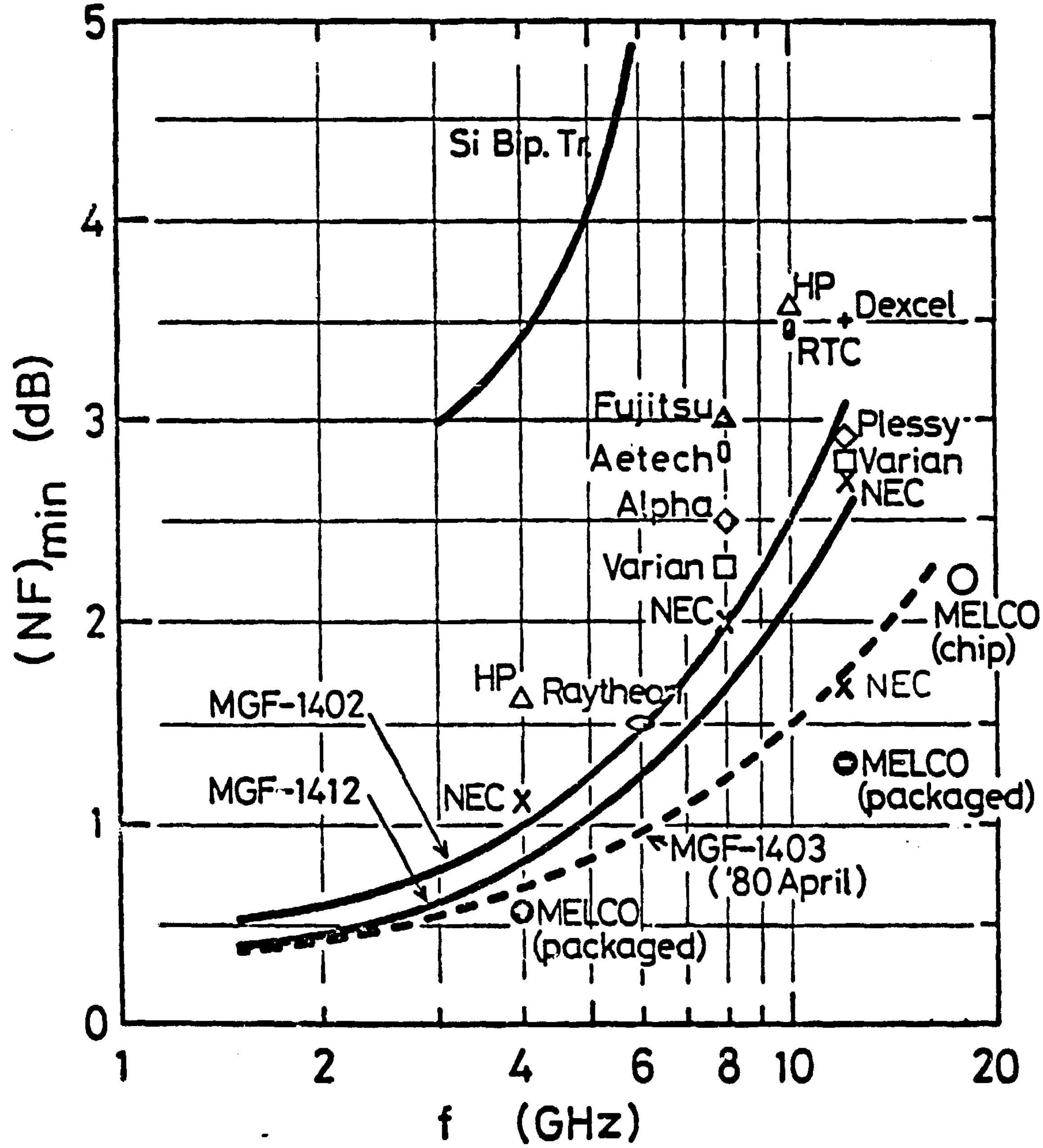

FIGURE 5-29A. Comparison of Performance (Low Noise GaAs FET) (Mitsubishi)

Mitsubishi

Jan, 1930

Nippon Electric 1980

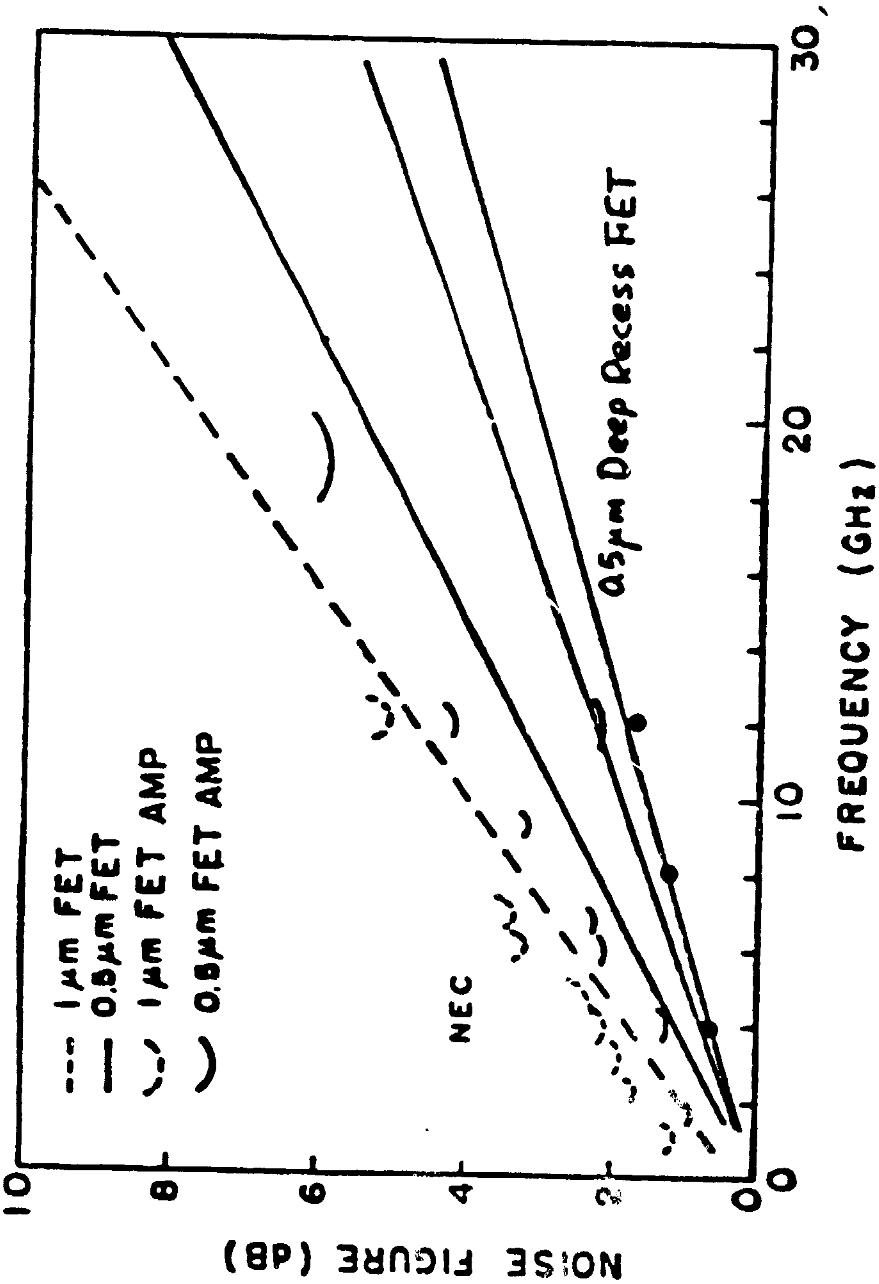

FIGURE 5-29B. NEC Low Noise FET Performance.

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TABLE 5-30

NOISE PERFORMANCE OF CANDIDATE SPACECRAFT LNA AT 14.25 GHz

Type Amplifier	Noise Temperatures (°K)/ Factors (dB)
Uncooled Paramp	75°K (LNR) 200°K
FET	3.0 dB
TDA	6.0 dB
Mixer (Conversion Loss)	3.5-5.0 dB

STATUS OF SPACECRAFT PARAMP TECHNOLOGY AT 14.25 GHz

Source and Location of Development	Noise Temperature	User
LNR - USA	75°K	NASA, TDRSS
AIL - USA	130°K	NASA
GTE Telecommunications - Italy	250°K	Used in CTS
Micromega - USA	250°K	NASA

STATUS OF FET AMPLIFIER TECHNOLOGY AT 14.25 GHz

Source and Location	Noise Figure
Comsat/Watkins Johnson - USA	3.5 dB
SPAR - Canada (OTS)	4.8 dB
AVANTEK	3.0 dB
NEC	3.0 dB

5.6.4 Satellite Filter Technology

Filter multiplexers are required to channelize the available total frequency bands used by the transponder. The major tradeoff in filter design in a mm-wave satcom is one of channel bandwidth versus guardband bandwidth which determines the filter loss and therefore the reduction in amplifier power presented to the antenna. Table 5-31 lists the channel bandwidths and guard-bands of principal satcoms now in use. Note the stringent guard-band requirements - around 4 MHz guardband between 40 MHz channels - for the Intelsat and U.S. domestic satcoms, as compared to the large guardbands typical of European and Japanese satellites. This represents a major gap in technological filter competence between the U.S. technology on the European and Japanese technologies with the U.S. presently enjoying a significant lead.

Several developments for 4 GHz and 11 GHz input/output for the multiplexers took place in the 1973-1975 period which greatly impacted on spacecraft filter design and manufacture, i.e.: (Table 5-32).

- The development of the dual-mode ellyptic filter by Atia and Williams at Comsat Laboratories, which provided channel characteristics in small lightweight filters using only a few cavities to replace the large Tschbychev waveguide filters using as many as 14 sections.
- The development of filters using graphite epoxy material by O'Donovan and Kalianteris of the then RCA Limited in Canada (now COM-DEV), for the 24-channel SATCOM which greatly reduced filter weight for the Tschebchev filters and made possible meeting the weight limitations of the RCA satcoms.
- The development of linear phase filters by GEC-Marconi for OTS based on design by Dr. David Rhodes of Leeds University (UK) and MDL (USA).

TABLE 5-31

TYPICAL EXAMPLE OF CHANNEL BANDWIDTH

System	Frequency Band (GHz)	Useable Channel Bandwidths (MHz)	Minimum Guard Band in Terms of O/O Channel BW (%)
DSCS-2	3/8	7, 50, 100	20-30
NATO-3	7/8	17/50/85	20-30
INTELSAT IV	4/6	36	10
INTELSAT IVA	4/6	36	10
INTELSAT V	4/6, 11/14	34,36,41,72,77,241	8.3 to 11
ANIK	4/6	34	11
Westar	4/6	36	10
RCA Satcom*	4/6	36	11
Japan CS	20/30	200	50-60
ATT Comstar*	4/6	40	17.6
OTS (ESA	11/14	5, 40, 120	100
Symphonie	4/6	80	32
CTS	11/14	85	-

* Dual linear polarization

TABLE 5-32

ADVANCES IN FILTER TECHNOLOGY ART

1960-1974	<u>Tschebychev Filters for Channelization</u>
	Intelsat IV specs gave most significant requirements 12 Channels
	• 40 MHz BW each in 500 MHz range • Useful channel bandwidth - 36 MHz • 4 MHz channel separation
	Equalizers required
	Filters and equalizers, heavy and large size
1974 - On	<u>Development of New Types of Filters - New Materials</u>
	New filter type: Dual-Mode Elliptic
	• Reduction in required filter sections • Excellent adjacent channel isolation • Used in Intelsat IV-A
	Linear Phase
	• Reduces equalization requirements • Used in Japan CS at C-band
	Lightweight filter materials
	• Aluminum • Graphite epoxy
	Development of contiguous band dual-mode filter multiplexers

- o The development of dual mode ellyptic filters for 11 GHz by O'Donovan and Kalianteris of COMDEV in Canada for CTS and Anik F4.
- o The development of 4 GHz dual-mode contiguous band filters in graphite epoxy by J. Bowes of Ford Aerospace and Dr. S. Cohn, Consultant, for use in Intelsat-V.
- o The development of a 7-channel directional multiplexer at 18 GHz by J. Bowes of Ford Aerospace for Japan in using cylindrical TE_{111} mode coupled cavities.

Table 5-33 lists the state-of-art of filters and multiplexers in communication satellites at 4 and 11 GHz due to Dr. C. Kudsia of COMDEV Canada*; these authors also provided the material selection tradeoffs listed in Table 5-34, and described the ANIK-C Ku-band filter multiplexer shown in Figure 5-30 and described in Table 5-35; these filters illustrate a level of sophistication virtually undreamed over only 5 years ago.

Table 5-36 lists the filters now used in major satcom transponders and the name and location of the filter developers. The technology gaps between Europe, Japan and the U.S.A. is narrow and virtually non-existent. This started with technology exchanges between the U.S. and Europe already in effect, i.e., the MDL (U.S.) and GEC-Marconi (UK) cross-licencing agreement on linear phase filters, the subcontract by Hughes to AEG Telefunken on Intelsat IVA filters and the training of French filter engineers in dual mode ellyptic filter techniques at Comsat Labs.

* Kudsia & O'Donovan, AIAA 8th Satellite Communications Conference Orlando, Florida, 1980.

TABLE 5-33

MICROWAVE FILTERS & MULTIPLEXERS IN COMMUNICATIONS SATELLITES: STATE-OF-THE-ART

	FREQUENCY BAND	CONFIGURATION	PROGRAM	MULTIPLEXER SUPPLIER
Output Multiplexing Networks	4 GHz	4-Pole dual-mode elliptic function TE_{111} filters in INVAR on curved manifold	INTELSAT IV-A	Hughes Aircraft Co. (HAC)
		GFRP* 6-Pole dual-mode quazi-elliptic TE_{111} filters combined contiguously on a straight manifold	INTELSAT V	Ford Aerospace & Communications Corp. (FACC)
		6-Pole dual-mode quazi-elliptic TE_{111} filters in INVAR on curved manifold	ANIK-D PALAPA-B	COM DEV LTD. COM DEV LTD.
	11/12 GHz	4-Pole dual-mode elliptic function TE_{113} filters in INVAR	ANIK-B INTELSAT V	COM DEV LTD. COM DEV LTD.
		6-Pole dual-mode quazi-elliptic TE_{113} filters in INVAR	ANIK-C	COM DEV LTD.
		6-Pole Canonical dual-mode elliptic function TE_{113} filters in INVAR	SBS	HAC
Input Channelizing Filters	4 GHz	8-Pole dual-mode quazi-elliptic TE_{111} filters in INVAR	INTELSAT IV-A	HAC
		8-Pole dual-mode quazi-elliptic TE_{111} filters in GFRP*	INTELSAT V ANIK-D	FACC Spar Aerospace Ltd.
		6-Pole Canonical dual-mode elliptic function TE_{111} filters in INVAR	PALAPA-B	COM DEV LTD.
	11/12 GHz	8-Pole dual-mode quazi-elliptic TE_{113} filters in INVAR in cascade with 2-pole dual-mode allpass TE_{113} equalizer	ANIK-C	COM DEV LTD.
		6-Pole Canonical dual-mode elliptic function TE_{113} filters in INVAR in cascade with 4-pole dual-mode allpass TE_{113} equalizer.	SBS	HAC

* Graphite Fiber Reinforced Plastic.

TABLE 5-34

MATERIAL SELECTION TRADEOFFS FOR MICROWAVE FILTER NETWORKS

Operating temperature range 0°C to 50°C

Allowance for misalignment & manufacturing tolerances in TOTAL ELFD = ±.25 MHz at 4 GHz; ±.5 MHz at 12 GHz; ±.75 MHz at 20 GHz

MATERIAL	COEFFICIENT OF THERMAL EXPANSION (α) RAW MATERIAL ppm/°C	EFFECTIVE 'α' FOR A FINISHED FILTER * ppm/°C	SPECIFIC GRAVITY	NORMALIZED** WEIGHT OF A FINISHED RF FILTER	TOTAL ELFD IN MHz					
					CENTER FREQUENCY IN GHz					
					.3	1	2	4	12	20
Magnesium	29.8	35	1.74	1	.5	1.15	2	3.8	11	18.3
Aluminum	22.4	25	2.7	1.2	.45	.9	1.5	2.8	8	13.3
Stainless Steel	5.3	6	7.9	1.45	.3	.4	.55	.85	2.3	3.8
Invar	1.6	2 to 2.5	8.05	1.5	.27	.3	.4	.5	1.2	2
GFRP***	1.5	2 to 3.0	1.35	1.1	.27	.3	.4	.55	1.4	2.25

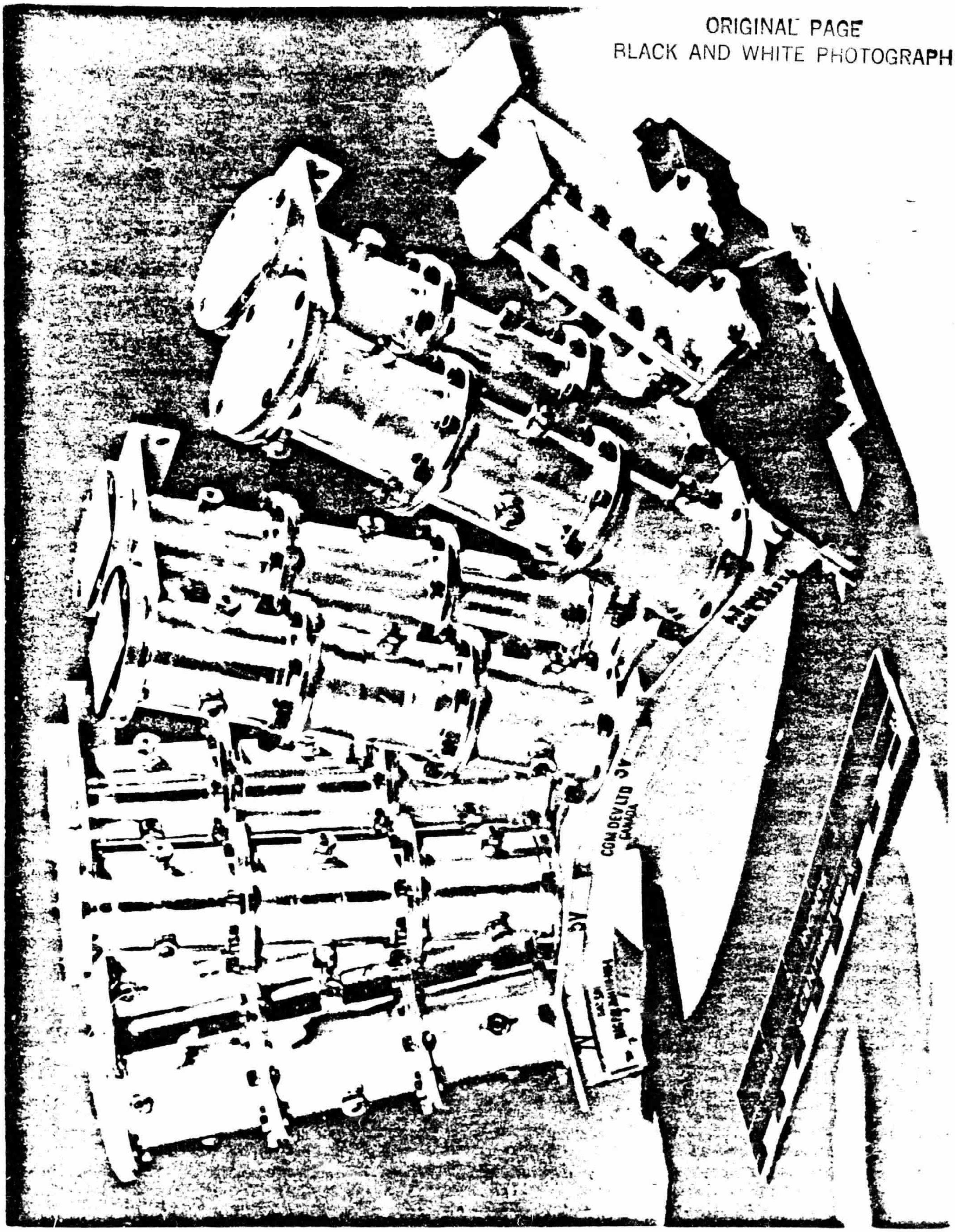
* Coefficient of thermal expansion in a finished filter is always greater than that of the raw material. This discrepancy is due to manufacturing processes, non-ideal shapes of resonant cavities, and use of tuning elements in the finished filter.

** This is based on using 20 mil average thickness for Invar and steel units, 40 to 45 mil average thickness for Al & Mg, and 50 mil thickness for GFRP. Other hardware like screws, bushings, plating etc., is the same for all units.

*** GRFP temperarure data does not take into account long term "creep" effects which will result in a slightly larger allowance for ELFD. At 4 GHz, available data [1] indicates an ELFD of .365 MHz due to long term "creep" over a 10 year life span.

FILTER REALIZATION & STRUCTURE TRADEOFFS

FILTER STRUCTURE	PREFERRED OPERATING FREQUENCY BAND (GHz)	PRACTICAL UNLOADED Q	AVAILABLE BANDWIDTH	SALIENT CHARACTERISTICS
Standard Waveguide	2 - 90	See Fig. 1	<10%	Simplest but bulky structure. Single-mode operation. Poor isolation response beyond 1.5 x f_o. Restricted to all-pole response functions.
Circular/Square Waveguide	2 - 90	See Fig. 1	<10%	Simple construction & permits dual-mode operation. No restriction on response functions under dual-mode operation. Poor isolation beyond 1.5 x f_o. Greater incidence of spurious.
Evanescent Mode Structure	.2 - 12	Typically half of standard WG structure	<15%	Simple construction but sensitive to temperature. Superior wideband isolation characteristics. Provides a practical Q vs size tradeoff.
Inter-Digital (ID) Structure	.1 - 14	See Fig. 2	<70%	Simple construction but bulky to realize high Qs. No restriction on bandwidth. Superior wideband isolation characteristics.
Coax Cavity Structure	.1 - 8	See Fig. 3	<5%	High Q structure but bandwidth limitations. Construction can be difficult depending upon requirements of response functions and weight.
Dielectric Loaded Resonator Filters	.1 - 4	Typically half of ID structure	<25% in ID structure	Compact structure but lower Qs. Sensitive to temperature. Requires superior dielectric materials. Construction can be difficult.



ANIK-C FLIGHT UNIT 12 GHz DUAL O/P MUX

Figure 5-30

TABLE 5-35 INPUT MULTIPLEXER FILTER TRADEOFFS FOR ANIK-C SATELLITE USING LONGITUDINAL DUAL-MODE TE_{113} FILTER & EQUALIZER

CRITICAL PERFORMANCE REQUIREMENTS*

Frequency Band	:	11.7 to 12.2 GHz
Usable Channel Bandwidth	:	$f_o \pm 27$ MHz
Insertion Loss Variation	:	<1.2 dB over $f_o \pm 27$ MHz
Isolation	:	≥25 dB at $f_o \pm 36$ MHz ≥45 dB at $f_o \pm 50$ MHz and beyond
Amplitude Slope	:	≤.01 dB/MHz over $f_o \pm 13$ MHz
Group Delay	:	≤2 ns at $f_o \pm 18$ MHz ≤5 ns at $f_o \pm 21$ MHz ≤1.5 ns ripple
Assumed equivalent linear frequency drift	:	± 1 MHz
Assumed average Unloaded Q of Waveguide Cavities	:	11,000

FILTER CONFIGURATION	ISOLATION AT ±36 (dB)	LOSS VARIATION OVER ±27 (dB)	GAIN-SLOPE OVER ±13 (dB/MHz)	GROUP DELAY (ns)		
				±18	±21	RIPPLE
10-pole linear phase filter with two pairs of real-axis zeros	15	.65	.006	1	3	.5
	20	.8	.007	1	4	1
	25	1.4	.013	1.8	5.5	1
10-pole linear phase filter with one pair of transmission zeros & one pair of real-axis zeros	20	.8	.011	3.5	8	0
	25	1	.016	7	11	0
	30	1.25	.016	7	12.5	0
8-pole filter with one pair of transmission zeros & 2-pole allpass equalizer	25	.75	.003	.7	3	.5

* These requirements are for the whole transponder prior to the TWTAs.

INPUT MULTIPLEXER FILTER TRADEOFFS FOR SBS SATELLITE USING CANONICAL DUAL-MODE TE_{113} FILTER & EQUALIZER

CRITICAL PERFORMANCE REQUIREMENTS*

Frequency Band	:	11.7 to 12.2 GHz
Usable Channel Bandwidth	:	$f_o \pm 21.5$ MHz
Insertion Loss Variation	:	<1.0 dB over $f_o \pm 21.5$ MHz
Isolation	:	≥15 dB at $f_o \pm 27.7$ MHz ≥35 dB at $f_o \pm 31$ MHz and beyond
Amplitude Slope	:	≤.084 dB/MHz over $f_o \pm 15$ MHz
Group Delay	:	<2 ns at $f_o \pm 15$ MHz <5 ns at $f_o \pm 17$ MHz ≤11 ns at $f_o \pm 19$ MHz ≤27 ns at $f_o \pm 21.5$ MHz ≤1.2 ns ripple
Assumed equivalent linear frequency Drift	:	± 1 MHz
Assumed average Unloaded Q of Waveguide Cavities	:	11,000

FILTER CONFIGURATION	ISOLATION (dB) AT ±27.7	ISOLATION (dB) AT ±31	LOSS VARIATION OVER ± 21.5 (dB)	GAIN-SLOPE OVER ± 15 (dB/MHz)	GROUP DELAY (ns)				
					±15	±17	±19	±21.5	RIPPLE
8-pole filter with one pair of transmission zeros & two pairs of real-axis zeros	8.5	28	.65	.04	1	3.5	9	20	1
	10	30	.7	.04	1.2	4	9.5	25	1
	15	≥35	1.1	.045	2.0	6.0	12.5	35	1
8-pole filter with two pairs of transmission zeros & one pair of real-axis zeros	15	≥35	1.1	.055	6.5	[illegible]	17	40	0
	20	≥35	1.2	.06	7	11	18.5	43	0
	25	≥35	1.35	.065	7.5	12	20	48	0
6-pole elliptic function filter with two pairs of transmission zeros plus 2-pole allpass equalizer	15	≥35	.9	.016	1	3.5	10	29	1.1

TABLE 5-36

FILTERS FOR USE IN SPACECRAFT TRANSPONDERS

Frequency (GHz)	Multiplexer Type	Company	Location	User
8	Linear Phase	Marconi	U.K.	OTS
2	Tschebychev	Ford	USA	ATS-6
	Tschebychev	AIL	USA	NASA
3.7 - 4.2	Tschebychev	Hughes	USA	Westar, Anik, INTELSAT IV
	Tschebychev	TRW	USA	INTELSAT III
	Tschebychev	MDL	USA	JCS
	Tschebychev	Thomson-CSF	France	Symphonie
	Tschebychev	RCA Ltd.. COMDEV	Canada	RCA Satcom (graphite epoxy)
	Tschebychev	NEC	Japan	JCS
	Dual Mode	Hughes	USA	INTELSAT IVA
	Dual Mode	Telefunken AEG	W. Germany	INTELSAT IVA
	Dual Mode	NEC	Japan	INTELSAT IVA
	Dual Mode Contiguous Multiplexer	Ford Aerospace	USA	INTELSAT V
5.9 - 6.4	Multiplexer	Siemens	W. Germany	Symphonie
7.25-7.75	Tschebychev	Ford Aerospace	USA	NATO III
	Tschebychev	RCA	USA	Tacsat
	Tschebychev	Marconi	U.K.	Skynet
	Tschebychev/ Dual Mode	Wavecom	USA	DSCS II
	Tschebychev	G.E.	USA	DSCS III
11.7-12.2	Tschebychev	Thomson-CSF	France	OTS
	Tschebychev	Erickson	Sweden	OTS
	Ellyptic	COMDEV	Canada	INTELSAT V
	Ellyptic	COMDEV	Canada	Anik F4
	Ellyptic/Dual Mode	TRW/Wavecom	USA	TDRSS
	Tschebychev	RCA Ltd. (now SPAR)	Canada	CTS
	Tschebychev	G.E.	USA	Japan BSE
17.7-20.2	Tschebychev	Ford Aerospace	USA	Japan CS
	Tschebychev (single band)	NEC	Japan	Japan CS
	Tschebychev	Comsat Labs	USA	ATS-6
	Linear Phase	MDL	USA	Experimental for Ford Aerospace
27 - 30	Tschebychev	Ford Aerospace	USA	Japan CS
34	Tschebychev	Lincoln Labs	USA	LES 8-9
	Tschebychev	RRL/MOPT	Japan	ECS prototype
	Tschebychev	NEC	Japan	ECS
Above 30	Tschebychev	Fujitsu	Japan	Guided mm-wave system

5.6.5 Satellite Power Amplifier Technology

The power amplifier for transponders, with the antenna gain, provides the spacecraft EIRP and represents a key component in the down-link. Historically, the traveling wave tube amplifier, with its excellent history of life and reliability in space, has served this power amplifier function. A decade ago, the principal suppliers were Hughes for the early Intelsat systems and Watkins-Johnson and Eimac for the IDCSP satellites and Watkins-Johnson for many NASA/JPL deep space probes.

The early U.S. domination of the 2 and 4 GHz space TWT technology led the European Space Agency's predecessor, ESRO, to fund 11 GHz TWT programs at the 20 watt level, a decision which has had far reaching consequences in establishing Europe as a major TWT supplier for space satcoms, and in particular, those addressing the 11/14 GHz frequencies. Also, in the early 1970's, the Japanese National Space Agency, NASDA, funded NEC to develop space TWT for 4 and 19 GHz for ultimate use in the Japan CS and ETS-IV, thereby creating another important space TWT technology base in the world. The USSR entered the space TWT development arena in the 1960's, producing 50 watt 4 GHz TWT for the Molnyas satellites and in the early 1970's, a 300 watt space klystron at 716 MHz for Statsionar-T.

Today, the space TWT technology is world-wide and Table 5-37 lists many of the space TWT which are manufactured all over the world, including the Russian UHF space klystron and the array of 11 GHz TWT from 10 to 700 watts which are manufactured in Europe for the European OTS/ECS and H-sat and the U.S. TDRSS and SBS systems. The development of these TWT has also brought about the development of reliable high efficiency and light-weight power supplies and high efficiency multiple collector techniques which have achieved dc-to-rf efficiencies in the 40-50% range.

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TABLE 5-37

SPACE TWT SUPPLIERS

Frequency (GHz)	Power Level (watts)	Company	Country	User
2	50, 100	Watkins Johnson	USA	NASA
3.7 - 4.2	0.5	Hughes	USA	INTELSAT IV
	4.5	Hughes	USA	INTELSAT IV, IVA
	4.5	NEC	Japan	JCS
	8	Hughes	USA	INTELSAT V
	10	Telefunken AEG	W. Germany	Anik
	10	Hughes	USA	ATS-6
	13	Telefunken AEG	W. Germany	Symphonie
7.25-7.75	17	Hughes	USA	Skynet
	20	Hughes	USA	NATO III
	20	Hughes	USA	DSCS III, Tacsat
11.7-12.2 (Nominal)	1	Hughes	USA	Classified
	10	Hughes	USA	SIRIO
	10	Thomson-CSF	France	INTELSAT V
	20	Thomson-CSF	France	OTS, CTS
	20	Telefunken AEG	W. Germany	OTS, Anik
	25	Telefunken AEG	W. Germany	SBS
	30	Telefunken AEG	W. Germany	TDRSS
	100 *	Hughes	USA	Japan BSE
	150	Thomson-CSF	France	H-SAT
	200	Litton	USA	CTS
	450	Telefunken AEG	W. Germany	H-SAT
	700	Telefunken AEG	W. Germany	TV - German
	700	Siemens	W. Germany	TV - German
14	1.5, 20	Hughes	USA	Skynet
	50	Hughes	USA	Shuttle
17.7-20.2	2.5	Hughes	USA	ATS-6
	4	Hughes	USA	JCS
	4	NEC	Japan	JCS
	10	Hughes	USA	ATT (Exp)
30	2.5	Hughes	USA	ATS-6
	20	Watkins Johnson	USA	RADC
43	10	Hughes	USA	Classified
	100	Hughes	USA	NASA
60	13, 50	Hughes	USA	Classified
84	200	Hughes	USA	NASA

* In 1980, NEC announced the development of a 100-watt Space TWT for 12 GHz.

This disbursement of space TWT technology on a world-wide basis displayed in Table 5-37, which lists the various suppliers and the power levels according to frequency range, indicates that at 11 GHz, the European domination of this art is evident, despite contributions of space TWT by Hughes to Italy's Sirio, and Japan's BSE, and by Litton to Canada's CTS. It is Thomson-CSF and Telefunken AEG in Europe who, through R&D contracts for CTS, OTS, Comsat Labs and H-Sat, now dominate the U.S. market of 11 GHz space TWT for SBS, TDRSS, and ANIK F4. With the growing interest in 11/14 GHz, due to WARC-77, this European technological superiority is significant.

Table 5-38 provides more detail of the space TWT suppliers for the 11.7-12.2 GHz band, and since this Table was compiled in winter 1979-1980, NEC - Japan, announced development of a 100 watt TWTA for space.

Table 5-39 lists the salient features of the Thomson-CSF 10 watt, 20 watt, and 150 watt TWT; Tables 5-40 and 5-41 and Figure 5-31 provide details on the AEG Telefunken space TWTA at various frequencies, with Figure 5-31 indicating the excellent efficiencies (45-50%) achieved for both the 200 watt and 450 watt TWTA.

Figure 5-32 shows a chart due to R. Strauss of Comsat Labs relating power level for both helix and coupled cavity TWTA at 11 GHz and 20 GHz down-links showing the capability up to one kilowatt TWT or Klystron at these frequencies.

Figure 5-33 shows a plot of maximum RF power versus frequencies for Klystron, helix TWT and coupled cavity TWT showing that at around 250 watts at 12 GHz, the helix TWT technology advances to its limit based on the ability to conduct heat from the helix, and for higher saturated power, the coupled cavity TWT or the Klystron must be used.

TABLE 5-38

SPACE TWT SUPPLIERS FOR 11.7-12.2 GHz BAND

Power Level (watts)	Country (of Mfg.)	User
1	USA	Classified
10	USA	SIRIO
10	France	INTELSAT V
20	France	OTS, CTS
20	W. Germany	OTS, ANIK
25	W. Germany	SBS
30	W. Germany	TDRSS
100	USA	Japan BSE
150	France	L-SAT
200	USA	CTS
260	France/W.Germany	TV-SAT
450	W. Germany	L-SAT
700	W. Germany	TV - German
1500 (klystron)	W. Germany	Experimental

TABLE 5-39

CHARACTERISTICS OF THE THOMSON-CSF INTELSAT-V TH-3559 11-GHz/10-W TWT

Gain At Saturation	55 dB
Gain Ripple, Max. in Any 240 MHz Channel	$\pm$ 0.1 dB
3rd Order Intermodulation Products, Relative to Either Carrier (2 Carriers 10 dB Below Saturation)	-17 dB
AM/PM Conversion	6°/dB
Small Signal to Saturation Phase Shift, Typ	40°

THOMSON-CSF CTS/CTS 20-Watt 11-GHz TWT

Characteristics	Double Collector Tube TH 3525	Triple Collector Tube TH 3535
Output Power	Single Mode 20W	3 Modes: 20W, 8W, 4W Constant Drive Power
Phase Shift	40°	30°
Efficiency	40% at 20W	43% at 20W 28% at 8W 18% at 4W
Weight (Including HV Leads)	650 g	450 g

CHARACTERISTICS OF THE THOMSON-CSF H-SAT TH-3579 12-GHz, 100-150-W TWT

Gain at Saturation	50-55 dB
Gain Ripple at Saturation in Any 50-MHz Channel	$\pm$ 0.1 dB
3rd Order Intermodulation Products, Relative to Either Carrier (2 Carriers 9 dB Below Saturation)	-23 dB
AM/PM Conversion	5°/dB
Small Signal to Saturation Phase Shift, Typ	40°

TABLE 5-40

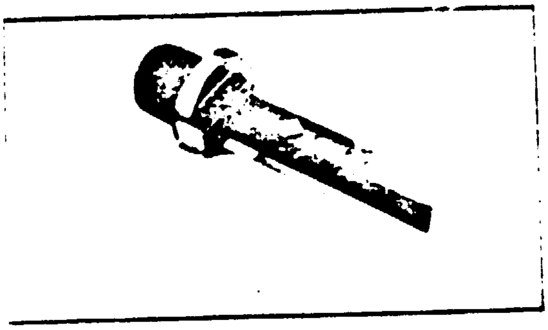
AEG-TELEFUNKEN SPACE TUBES USED IN COMMUNICATIONS SATELLITES

Project	Type	Power	Frequency	Efficiency	Coll.-Stages
OTS	TL 12 022	20 W	10.9 - 11.8 GHz	40%	2
TELESAT	TL 12 025	20 W	11.7 - 12.5 GHz	40%	2
TELESAT	TL 4 010	10 W	3.7 - 4.2 GHz	42%	3
TDRSS	TL 12 030	30 W	11.7 - 12.2 GHz 13.4 - 14.05 GHz	41%	3
SBS	TL 12 026	20 W	11.7 - 12.2 GHz	42.5%	3
ANIK C	TL 12 016	15 W	11.7 - 12.2 GHz	42.5%	3
COMSAT	TL 4 012	12/6 W	3.7 - 4.2 GHz	44/40%	3
DFVLR	TL 12 008	10 W	10.9 - 11.7 GHz	38/40%	2/3
DFVLR	TL 12 024	20 W	10.9 - 11.7 GHz	46/48%	3
DFVLR	YH 1 190	70 W	11.7 - 12.5 GHz	40/33%	2/1
DFVLR	TL 20 030	25 W	19.7 - 20.7 GHz	38%	2
DFVLR	TL 60 010	10 W	60 GHz	---	---

TABLE 5-41

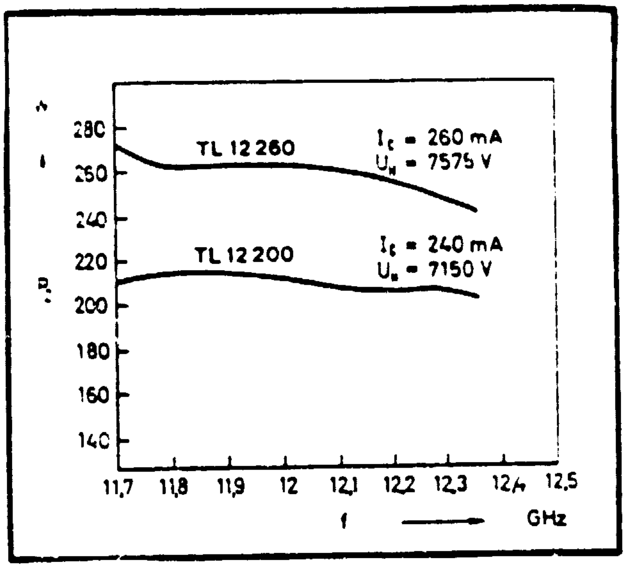
TEST REESULTS OF DIFFERENT DBS-TWT'S MADE BY AEG-TELEFUNKEN

TWT	Unit	TL 12 200	TL 12 450	TL 12 800
Frequency Range	GHz	---	11.7 - 12.5 GHz	---
Output Power	W	200	450	700
Gain	dB	40	50	50
Phase Shift	0	50	45	40
AM-PM Conversion	°/dB	4.5	4.0	4.5
Collector Stages	---	3	5	1 (5)
Efficiency	%	45	50	40 (50)
Weight	kg	2.6	7	9



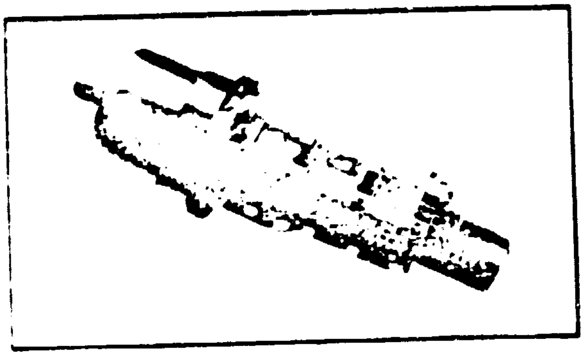
200 W Satellite TWT TL 12200

FIGURE 5-31

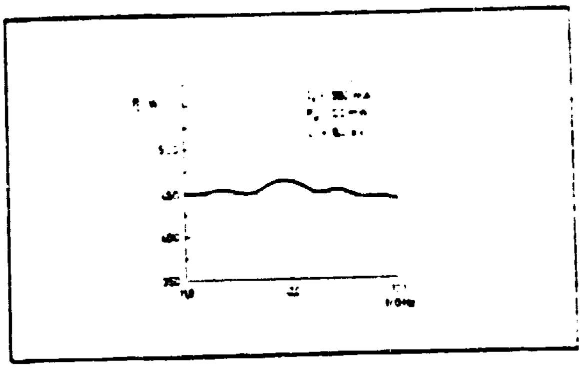


: Output Power P_o versus frequency for the 200 W TWT TL 12200 and the 260 W TWT TL 12260

- Cathode design life of more than seven years
- Specific weight of less than 15 g/W
- Efficiency of 45 % for broadband helix tubes
- Efficiency of 50 % for coupled cavity tubes.



.. 450 W Satellite TWT TL 12450



: Instantaneous bandwidth of satellite TWT TL 12450

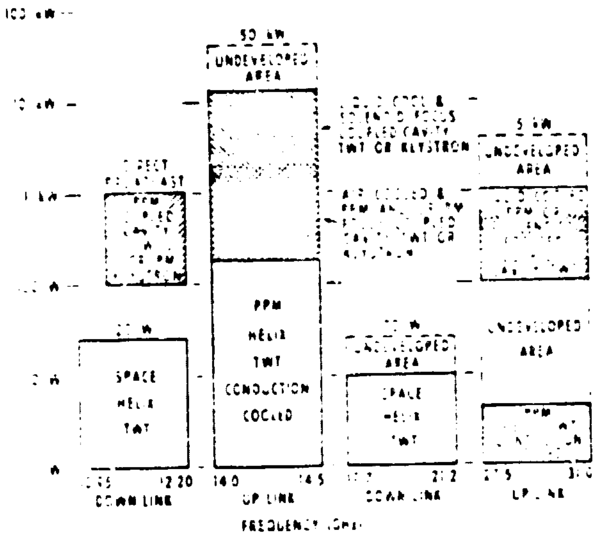


Figure 5-32 Power Tube Amplifier Type Designs at 11-31 GHz for Satellite Communications *

* Due to Robert Strauss, COMSAT Labs.

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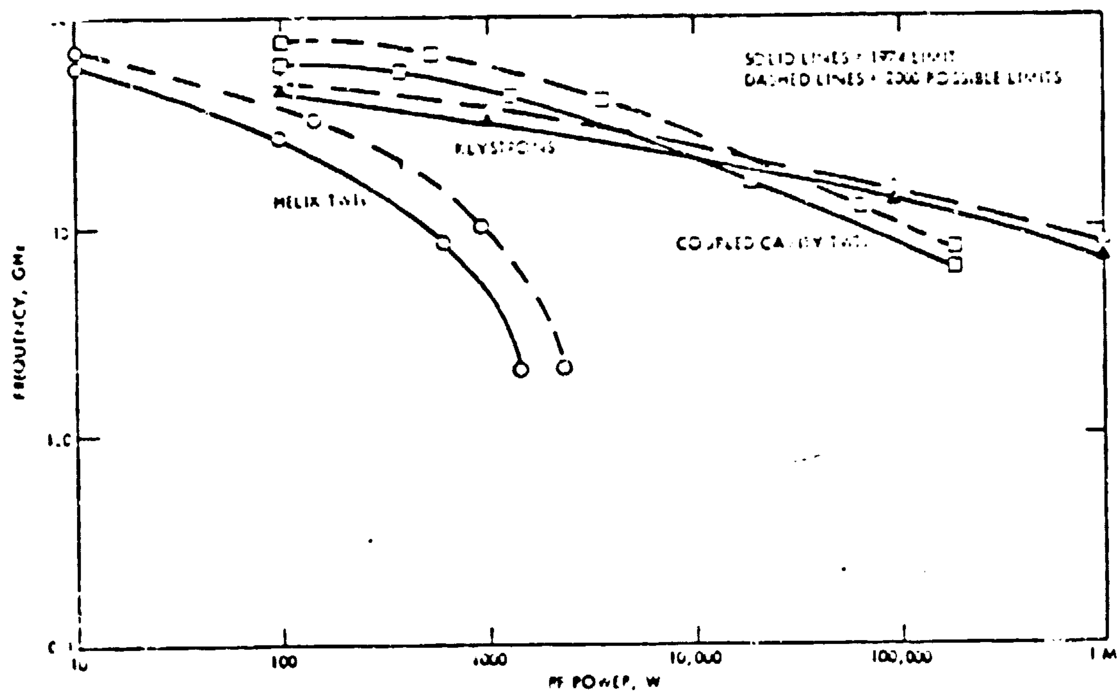

Figure 5-33. Maximum RF Power Versus Frequency

5.6.5.1 Solid State Power Amplifiers for Satcom Use

The luanching of Applications Technology Satellite (ATS-6) inaugurated the first extensive use of solid state power amplifiers for space application. Due to the relative simplicity of solid state power amplifiers, as compared to TWTA with its complex high voltage power supply, a significant improvement in reliability, weight and size was demonstrated.

There are now a large number of different types of solid state amplifiers competing against the TWT for the power amplifier sockets in communication satellite transponders. These include: (see Figure 5-34)

- o Gunn diode amplifiers
- o Impatt amplifiers
- o Trapatt amplifiers
- o Varactor diode up-converters
- o Bipolar amplifiers
- o FET power amplifiers

Table 5-42 lists the power levels generally representative at frequencies where solid state amplifiers of all types have flown in space or have been developed for space applications, i.e., at 20 and 30 GHz on Comstar in the Comsat Labs mm-wave propagation experiment and as output amplifiers at 0.5 watt at 36 GHz on LES-8 and LES-9. Actually, many of these solid state amplifiers are also used in terrestrial radio systems and the 400 mw with the varactor diode up-converter at 20 GHz is particularly significant since it represents an efficient up-conversion from a lower frequency where RF power is easier to generate.

The impatt amplifier is the primary type of power amplifier with the Gunn diode amplifier providing a lower power (and lower noise) function, with capability of operating as a low noise driver to the Impatt amplifier. Actually,

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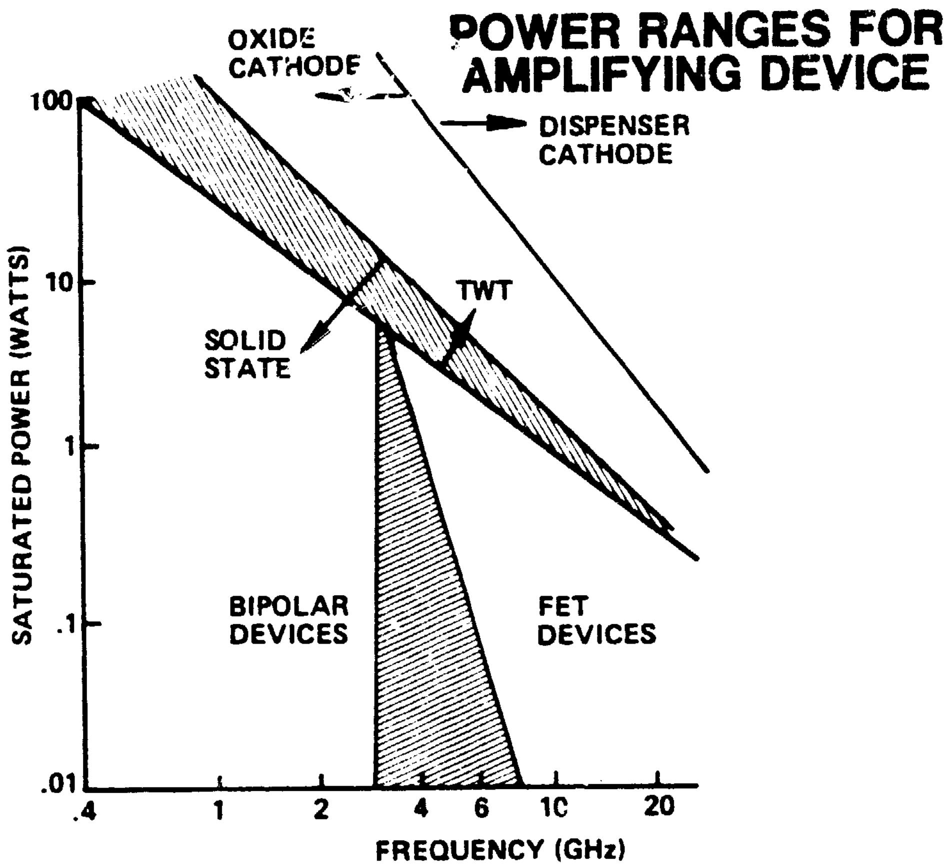
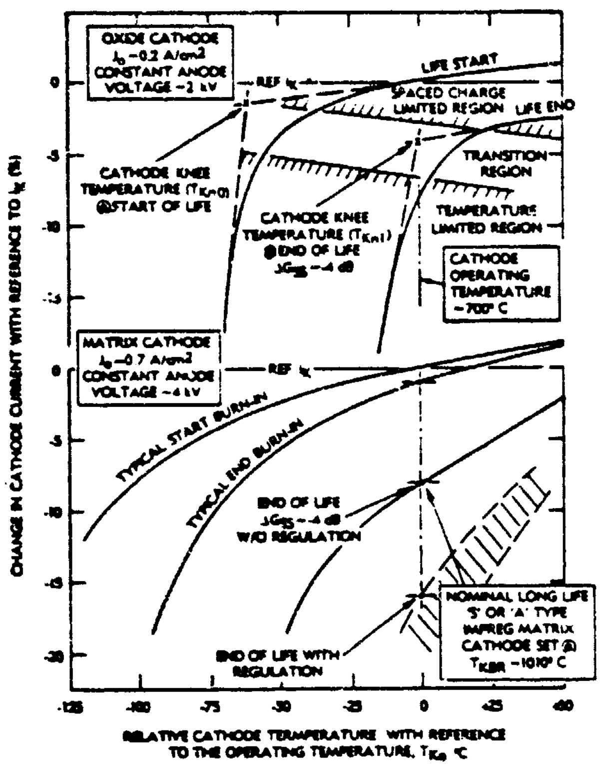


Figure 5-34



Comparison of Oxide and Matrix Cathode
Characteristics as a Function of Cathode
Temperature

(R. Strauss)

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TABLE 5-42

TYPICAL OPERATIONAL AND EXPERIMENTAL SOLID STATE POWER AMPLIFIERS FOR COMMUNICATION APPLICATIONS

Frequency	Bipolar Transistor	Impatt Amplifiers	Power FET Amplifiers
860 MHz	110 Watts - ATS-6	------	------
1270 MHz	1.2 KW - Spaceborne Radar	------	------
1550 MHz	40 Watts - ATS-6	------	------
1685 MHz*	20 Watts - SMS	------	------
2075 MHz	20 Watts - ATS-6	------	------
2300 MHz	24 Watts - Voyager	------	------
4-6 GHz	7 Watts - Terrestrial Radio	1-10 Watts Terrestrial Radio 15.8 Watts - SRI	20 Watts - Fujitsu 10 Watts - Experimental - Ford
7-8 GHz	------	3 Watts - Hewlett Packard 4 Watts - Hughes 12.8 Watts - Varian 280 Watts - Experimental - Hughes (pulsed)	1 Watt - Terrestrial Radio - Japan 4.4 Watts - Westinghouse 6 Watts - Experimental - Ford
11 GHz	------	3-5 Watts - Terrestrial Radio 13 Watts - Experimental - U.K.	100 MW - CTS 2-4 Watts - Experimental
18-20 GHz	------	200 MW - Terrestrial Radio 29 dBm - Comstar	2 Watts - Experimental
30 GHz	------	29 dBm - Comstar	------
35 GHz	------	100 MW - ETS - II 500 MW - LES 8/9 5 Watts - Experimental - TRW	------
55-60 GHz	------	1-1.6 Watts - Hughes/Fujitsu (OSC) 200 MW - Hughes	------

*In 1981, Microwave Power Devices of Hauppauge, New York, announced the development of a 2 kw all solid state transmitter at 1.7 GHz. Previously, this company has delivered 1 kw solid state transmitters for various applications at frequencies from 2 MHz to 1600 MHz.

the Impatt amplifier has many species, or can be considered to be one of many species of a form of semiconductor diode. These species include Read and Avalanche diodes, double drift (DD) and single drift (SD) Impatt diodes (the double drift being more useful at higher millimeter waves) and Impatt diodes operating with hi-lo profiles in what is known as a "surfing mode". Impatt diode amplifier power levels in the 1-12 watt level are now achieved in X-band. J. Raul of TRW has achieved 5 watts in K_a-band and 1 watt has been achieved by Fujitsu at 60 GHz. A single diode hi-lo profile GaAs Impatt diode amplifier, operating in the surfing mode has exhibited power outputs of 15 watts. GaAs Impatt diodes are now developed in Japan with MTBF of more than 10^5 hours at 7.5 GHz.

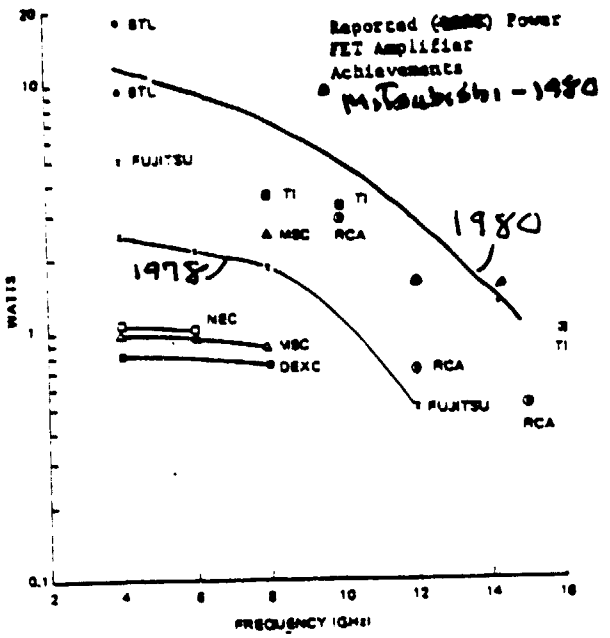
The use of the hi-lo profile technique for increasing Impatt amplifier power and efficiency was reported by P. W. Huish of the U.K. British Post Office at the 7th European Microwave Conference (1977), the development of high efficiency Impatt diodes designed to replace TWT in the 10.7-11.7 GHz band and the achievement of 5 watts. While this complements significant R&D effort at Plessey, Mullard, and other laboratories in the U.K. and Europe, it does not give Europe a role in the competitive race taking place between the U.S. and Japan for technological superiority in this area.

For power amplification at frequencies below C-band, bipolar transistors are used extensively. On the ATS-6 satellite, multiple-stage, parallel power combined solid state amplifiers have been built from UHF up to S-band frequencies. These amplifiers pioneered the way for qualification of a family of bipolar transistors that are still used on current space programs, and they helped establish the concept of multiple parallel output stage design for space applications. The UHF solid state transmitter amplifier (860 MHz) on ATS-6 used 8 parallel combined MSC 2010 bipolar transistors at the output stage. This transmitter amplifier delivers 110 watts, 62 dB gain with overall efficiency of 44%. An interesting feature of the 860 MHz amplifier is the power back-off capability. On command, two or four or six of the output stages can be turned off to reduce the RF output power. The amplifier is operated directly from a regulated spacecraft bus and requires no power conditioning.

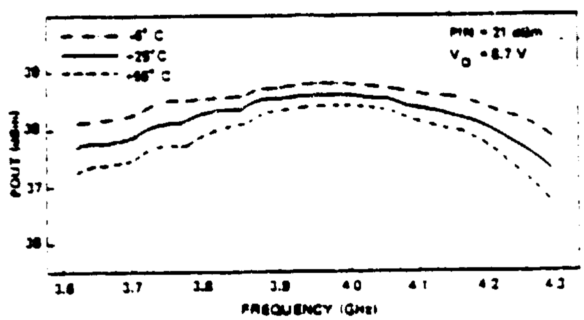
Other L-band and S-band solid state power amplifiers were flown on ATS-6. The L-band amplifier (1550 MHz) delivered 40 watts of RF power by combining eight MSC 3005 transistors at the output stage. This 1550 MHz amplifier provided 55 dB gain with 41% DC-RF power conversion efficiency. For a redundant pair, the amplifiers weighed 10.6 lbs. with overall dimensions of 16" by 15" by 3". By parallel combining four MSC 3005 bipolar transistors at 2075 MHz, a 20-watt S-band amplifier were built for ATS-6. This 20-watt amplifier gave 55 dB gain with 25% efficiency. At 2570 MHz and 2670 MHz, two 17-watt S-band transistor amplifiers were built with the same devices; both amplifiers show 55 dB gain with efficiency of 23.5%. This S-band amplifier weighed 4.6 lbs., with dimensions of 11" by 7" by 4".

The most important solid state amplifier development of the 1970's was the power FET which in 1976 provided up to 10 watts of saturated power at 4 GHz, 6 watts of saturated power at 8 GHz, 0.5-1 watt at 18 GHz, and 225 mw at 22 GHz. Figure 5-35 lists the 1980 status, worldwide, of power FET's in the 4 to 12 GHz range, showing the international competition which is presently underway to supply FET's to terrestrial radio power output stages to replace TWT. Seven manufacturing firms are now developing product capability, with 1 watt FET now developed for the 7 GHz Japanese terrestrial radio system and the Japanese submarine cable system which requires lifetimes up to 20 years.

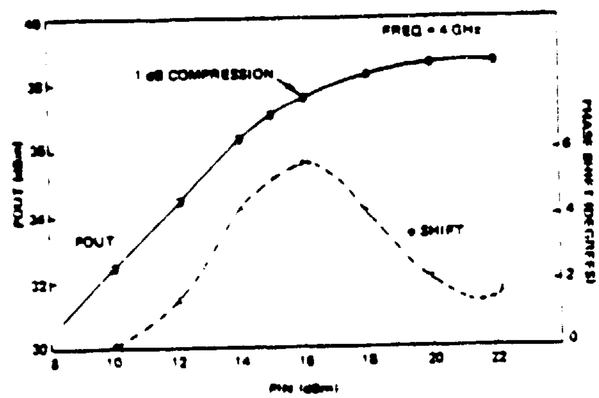
For high efficiency operation, Dr. P. T. Ho built and tested a 5-watt 3.7-4.2 GHz FET amplifier for direct TWTA replacement. This seven-stage, MIC power amplifier provided 50 dB gain with power added efficiency of 35%. The completed amplifier consists of a two-stage pre-driver amplifier, a three-stage drive amplifier, and a two-stage series-parallel combined power amplifier. The



(A)



Ford Aerospace 4 GHz FET Amplifier



Compression and Phase
of Amplifier

(B)

Figure 5-35

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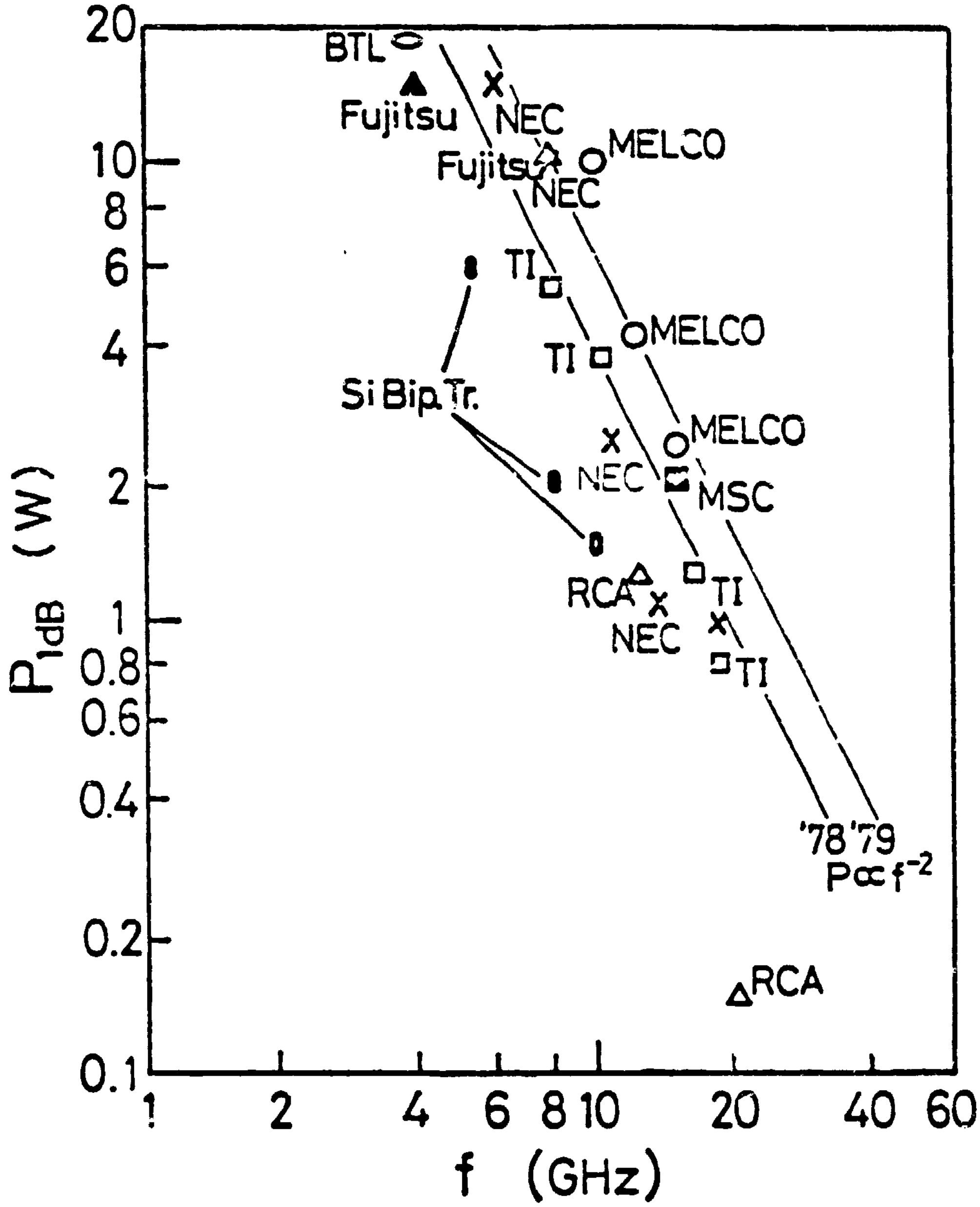
Comparison of Performance (High Power GaAs FET) (c)



Jan. 1980

Figure 5-35C. Power FET Achievements according to Mitsubishi.

amplifier chain is packaged in two separated chassis and mounted on a common platform. (Figure 5-35B).

The RF characteristics of the FET amplifier are superior to that of the TWTA, although efficiency must be traded for linearity, a choice not available with the TWTA. Typically, power output at saturation of two tone intermodulation test of a FET amplifier is 4.5 dB down for one signal saturation. Compared to 5 dB down for the TWTA, the FET amplifier adds 0.5 dB link margin for the communication channel with multiple carriers. For linear power amplification, the TWTA requires 6-8 dB back-off to achieve a carrier to third order intermodulation distortion ratio of 25 dB; and for the FET amplifier, 2-3 dB power back-off achieves same kind linearity. This linear characteristic makes FET amplifier more suitable for multiple carrier and some digital communications system. As far as AM to PM conversion, the typical value for the TWTA is 6-7 degrees/dB, and the FET amplifier runs about 3-4 degrees/dB. In addition to the superior RF performance, FET solid state amplifier offers additional weight and size savings in the spacecraft design. For a 5-watt, C-band transmitter, the FET amplifier weighs about 1.4 pounds with volume equal to 50 cubic inches. For a TWTA, the weight goes up to 3.0 pounds with volume equal to 150 cubic inches.

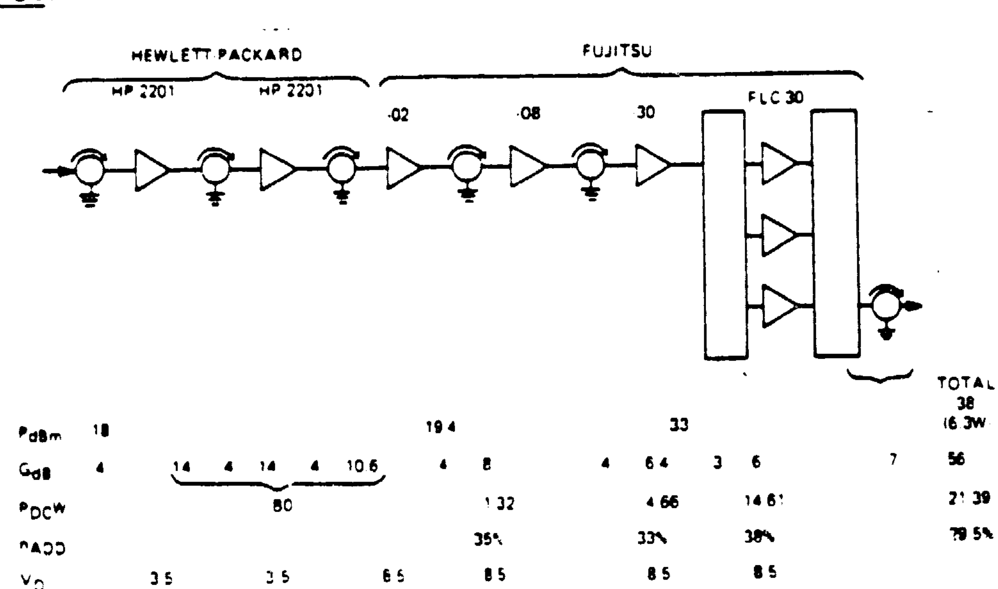
Figure 5-36 shows circuit and specifications of a similar FET amplifier built by RCA for use in SATCOM-IV at C-band. This amplifier, described by F. Drago et.al., at IAF-79 in Munich Germany was the first of the new power amplifiers using FET's to be positively committed to spacecraft use.

Looking into the 1980's, at 12 GHz, the FETA cannot be positively selected for power levels above 20 watts for at least 5 years, and the TWT must be considered the only viable contender for space use for 50-1000 watt power amplifier applications.

FETA Specifications

Item	Specification
1. Frequency Band	3.7–4.2 GHz
2. Instantaneous Bandwidth	3.7–4.2 GHz
3. Output Power	6.0 W saturated; 4.8 W two carriers
4. Amplifier Gain	Power gain >55 dB; small-signal (ss) gain <58 dB
5. Local Gain Slope	0.02 dB/MHz
6. Overall-Gain	±0.5 dB about a slope of 0.5 dB from 3.7 to 4.2 GHz.
7. Group Delay	2.0 ns
8. AM to PM Conversion	10°
9. Input VSWR	1.25:1
10. Output VSWR	1.25:1
11. Noise Figure	10 dB
12. Third-Order IMD	From 15 dB at 6 W to 41 dB with input down 10 dB
13. Overdrive	+20 dBm at input without damage.
14. Spurious and Harmonics	-75 dBm/MHz band; 20 dB below carrier
15. Efficiency	20% at 6 W; 10% at 1.5 W
16. DC Power Supply	+15 to +48 V, ±5%
17. Turn-on, Turn-off	No damage
18. Gain Stability	±0.5 dB over a 24-h period
19. Long-Term Stability	P > 4 W after seven years
20. Operating Temperature	+5 to +50°C

FIGURE 5-36.



Block diagram of FETA.

5.6.6 Spacecraft Antenna Technology

There are six main types of satellite antennas: (see Figures 5-37, -38, -39)

- o Single reflector, single feed
- o Multiple feed offset-fed reflectors
- o Multiple feed lenses
- o Contoured reflector single feed antennas
- o Phased arrays
- o Multiple reflectors

Multiple feed offset reflector antennas are now in use in space in Intelsat-IVA and will be used in Intelsat-V and SBS, and in fact, in most sophisticated commercial communication satellites in the 1980's, which are designed to transmit flux into only selected non-circular areas. Multiple feed lens antennas will be used in DSCS-III at 7/8 GHz. Contoured reflector antennas have been used in the Japan Communication Satellite for Experimental Purposes (CS) and phased arrays will be used in TDRS and are planned for use in a scanning spot beam system designed by Dr. Reudink of Bell Laboratories for BELLSTAR.

The use of reflector-type multifeed antennas to produce shaped beams is attractive because of their design simplicity, inherent bandwidth, ease of construction, light weight, and low cost. If the multibeam feed structures are located at prime focus or in a normal Cassegrain configuration, excessive blockage and consequent high sidelobe levels will result. This can be avoided by use of offset-fed reflector types, such as shown in Figure 5-40, which consist of a section of a larger parabola, whose focal point is located outside of the main antenna beam and a multi-horn feed which is located off axis such that it does not block energy reflected from the reflector. In the multiple horn-fed reflector, each feed element separately illuminates the reflector to generate a component beam in the far field. By properly exciting feed elements simultaneously and summing individual component beams in proper phase, a desired shaped-

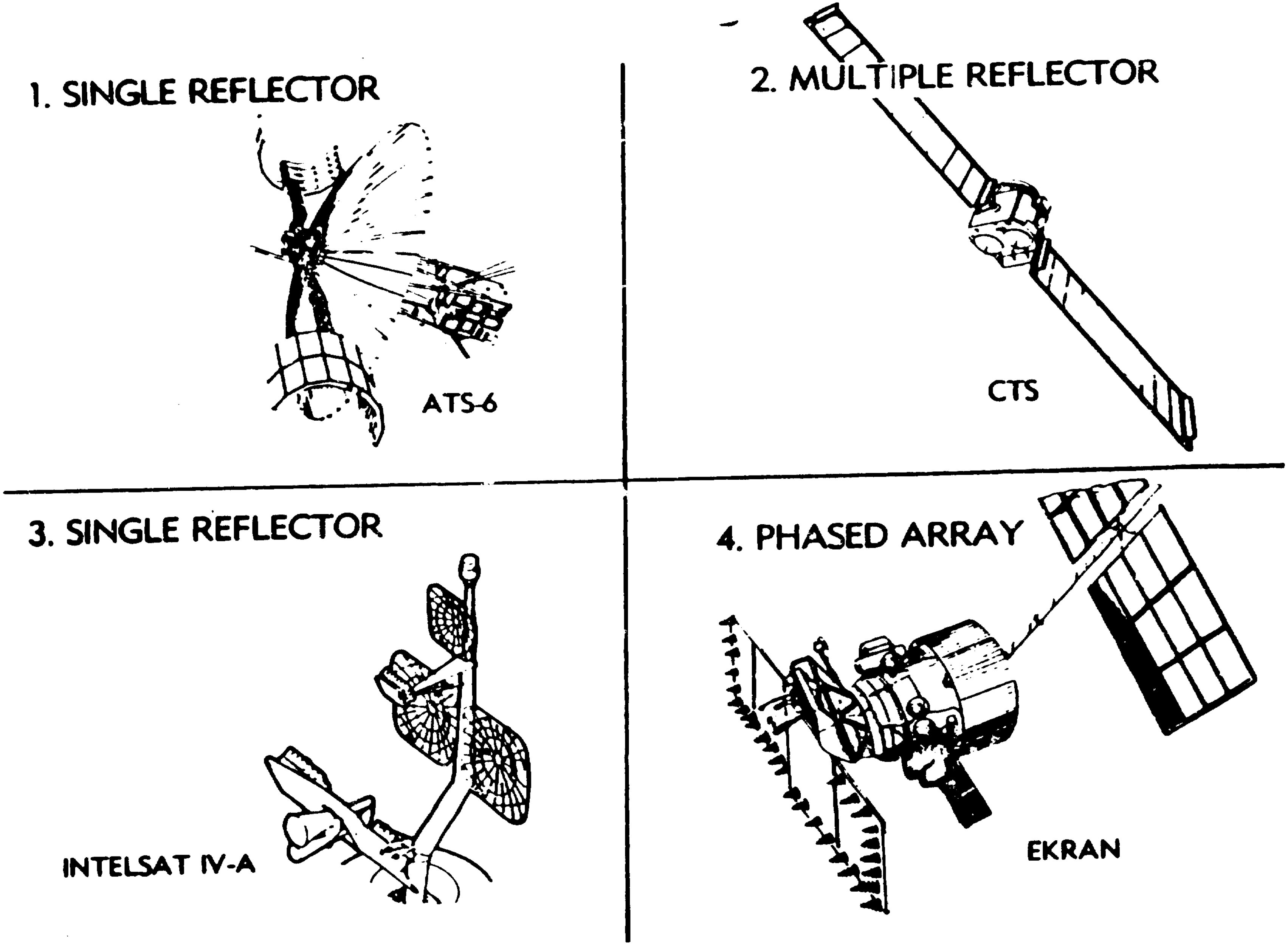
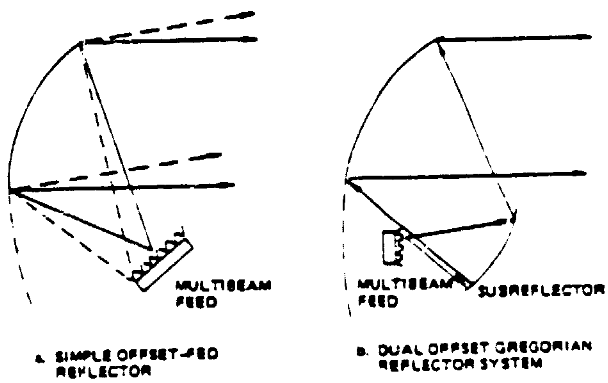


Figure 5-37 (W. Morgan)



Simple and Dual Offset-Fed Multifeed Horn Antennas

Figure 5-38

Figure 5-39. Potential Multiple Beam Antenna Systems

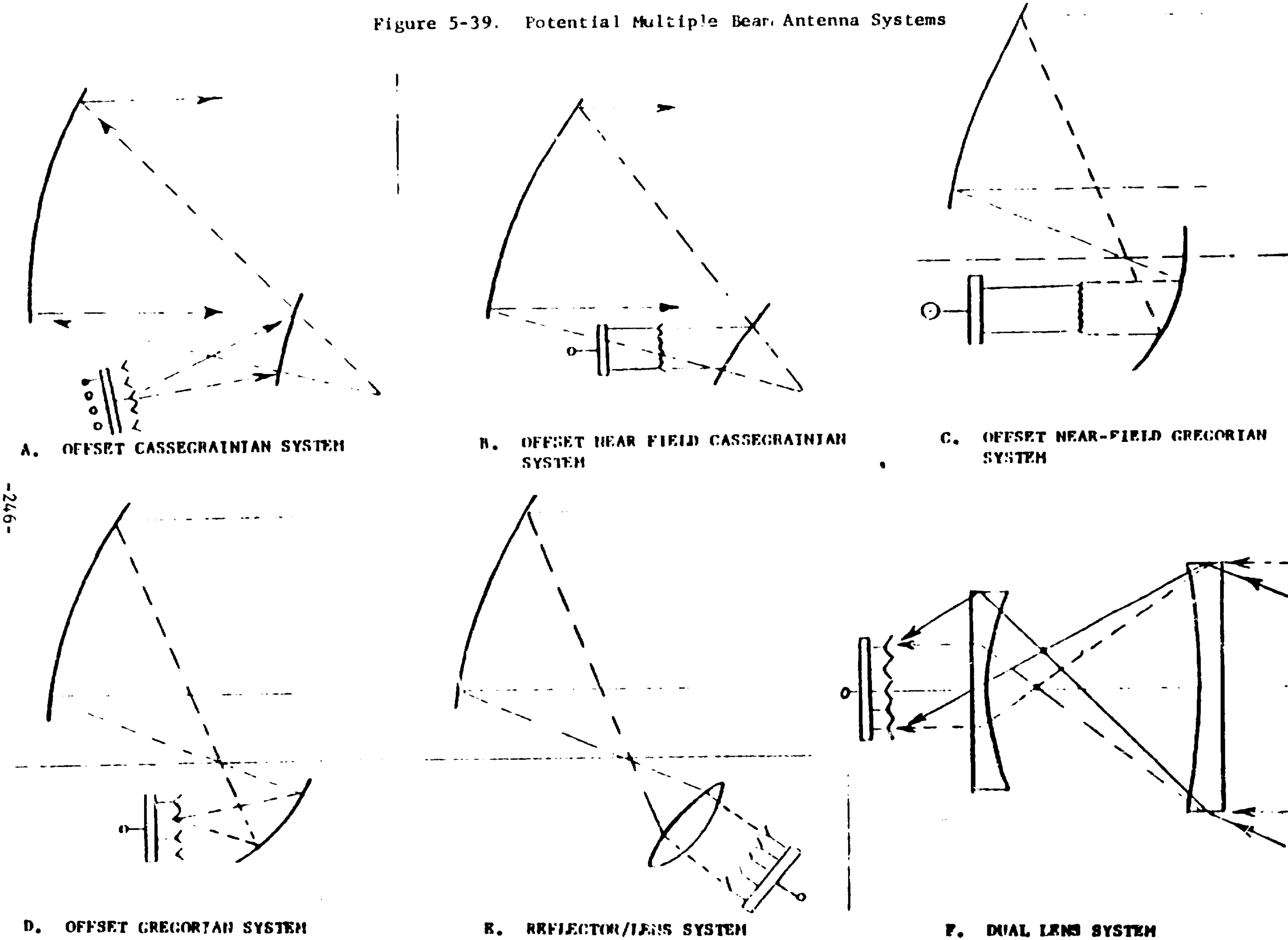


FIGURE 5-39

INTELSAT V ANTENNA MODULE

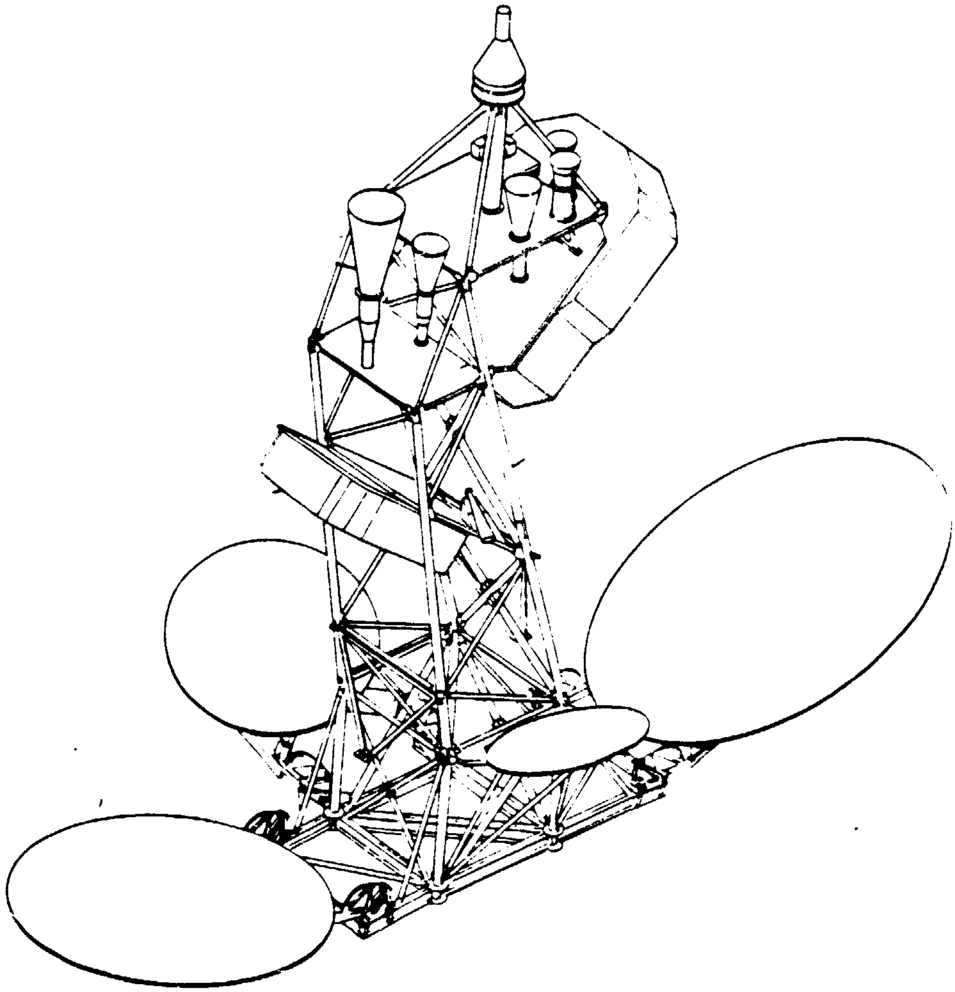


FIGURE 5-40

beam may be achieved to serve a specific ground coverage area. Depending on the feed array element, this system can be operated for any linear or circular polarization. Circular polarization diversity is used since an offset parabolic reflector does not generate a cross-polarized signal when the feed has a perfect CP pattern. Thus, for CP beams, good polarization isolation and axial ratio can be obtained by properly designing the element and array configuration.

5.6.6.1 Antenna Patterns for Fixed Satellite Service and TV Broadcast Satellite Service

As satellite communications developed during the 1970's, the rules and regulations for fixed satellite service and TV broadcast satellite service followed two diverse and very different paths.

TV broadcasting from space - long a dream until implemented by ATS-6, CTS and recently, Japan BSE - followed a planned path which culminated in WARC-77, where countries from Region 1 (Europe, Africa, Siberia) and Region 3 (Southeast Asia, Japan, Australia, Indonesia, etc.) literally structured the 11.7-12.2 and 11.7-12.5 GHz bands by dividing the 11.7-12.2 GHz band into 40 TV channels as shown in Table 5-43, and awarded each country involved, one or more orbital slots, appropriate TV channels, and rather complete details relative to beamwidth, EIRP, etc. These are set forth in the document "World Broadcasting - Satellite Administrative Radio Conference", Geneva, 1977, published by the International Telecommunications Union, Geneva. Region 2 (North and South America) was provided with exclusive positions for broadcast satellite service in the orbital positions between 75°W to 100°W and 140° to 170°W.

In the fixed satellite service, there has been anormous resistance to preplanning due to the interference involved between space and ground systems, the wide variety of international, regional and domestic satellite systems involved using largely satellites with non-homogeneous EIRP levels, and the problems of orbital utilization and crowding, particularly at 4/6 GHz. The philosophy of

TABLE 5-43

1977 BROADCASTING SATELLITE PLAN FOR REGIONS 1 & 3

System Characteristics

Frequency Band	11.7-12.5 GHz in Region 1 11.7-12.2 GHz in Region 3 (and 2)
Channel Spacing	19.18 MHz
RF Channel Bandwidth	27 MHz for both 525 and 625 line systems
Number of Channels	40
Guard Bands - Lower Band Edge	14 MHz
Guard Bands - Upper Band Edge	11 MHz
Polarization	Circular (RH and LH)
Modulation	FM
C/N Objective	14 dB (99% worst month)
C/I Objective (Co-channel)	-31 dB
C/I Objective (Adjacent channel)	-15 dB
PFD (Individual Reception)	-103 dBw/m^2, wanted at edge of coverage
PFD (Community Reception)	-111 dBw/m^2
Signal Processing	CCIR pre-emphasis
Energy Dispersal	600 kHz, pk-pk

Satellite Characteristics

EIRP per Beam (dBw)	Ranges 61.1 to 68
Transmit Beamwidth	Varies depending on country and channel
Pointing Accuracy	$\pm 0.1^\circ$ N-S and E-W
Station-keeping	$\pm 0.1^\circ$ N-S and E-W
Spacing Between Satellites	6 degrees

Earth Stations

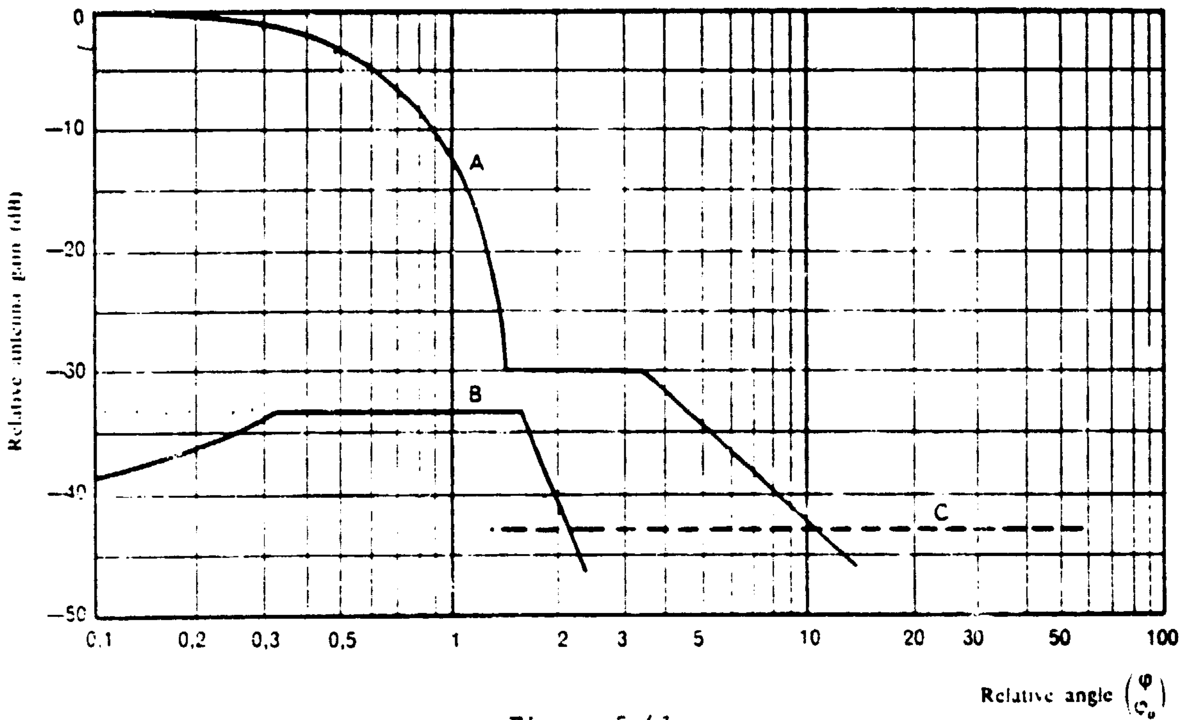
G/T (individual reception)	6 dB/k
G/T (community reception)	14 dB/k
Antenna Beamwidth - individual reception	2°
Antenna Diameter - community reception	1°

fixed satellite service has been to rely on technological developments, coordination and negotiation to allow for increased utilization of the orbital arc and the frequency bands in use, rather than a fixed plan to solve the problems of interference between networks and users.

The following paragraphs will discuss the various determinations of antenna radiation pattern (sidelobe) criteria which have culminated the almost decade-long antenna development during the 1970's in the broadcast satellite service.

5.6.6.1.1 <u>Satellite Antenna Pattern Regulations for TV-Broadcast Satellites</u>

The original pattern envelope for a satellite broadcast antenna recommended by the CCIR in May 1976 had a 25-dB plateau for near-in copolarized sidelobes. In 1977, WARC-77 adopted a 30 dB plateau, shown in Figure 5-41. However, in order to meet the goal of providing each administration with 5 channels and appropriate orbital and polarization assignments, it was necessary to obtain better adjacent region isolation and better sidelobe performance from the spacecraft antenna. A center-fed antenna will produce sidelobes 22-23 dB down with a $D/\lambda \cong 16$ and 25 dB down with $D/\lambda \cong 50$ at 12 GHz, but 30 dB sidelobes with $16 \leq D/\lambda \leq 80$ will require an offset feed. For a front-fed antenna, even though an optimum aperture distribution is used, the blockage by the feed and support structures present RF shadowing to the reflector and act as scatterers. The diffraction pattern of the feed support structure is very broad and low and is out of phase with the primary illumination. With a small aperture antenna, the feed occupies a significant fraction of the aperture, and the resulting loss of gain and increased sidelobe levels make a -30 dB sidelobe envelope difficult to achieve. An offset-fed configuration can circumvent blockage problems and achieve the -30 dB level.



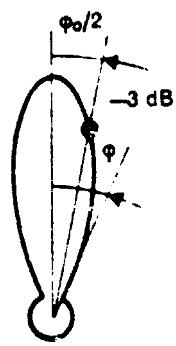


Figure 5-41

Reference patterns for co-polar and cross-polar components for satellite transmitting antenna

Curve A: Co-polar component

Curve B: Cross-polar component

Curve C: Minus the on-axis gain.

The cross-polarized response specification is also severe, but can be achieved if feed design is kept simple. This means using single-purpose feeds which are designed for transmit or receive only. Since the cross-polarized response depends heavily on the feed characteristics, if the feed is used exclusively for transmitting and does not have to be part of a multi-function feed, i.e., transmit/receive, then cross-polarized response in the range of -35 to -40 dB can be expected across the main beam.

The spacecraft antenna reference pattern of the Figure is for an essentially circular antenna beam and is predicated on the antenna illuminating a country with circular boundaries. In this ideal case, the 3 dB down points of the antenna beam exactly centered on the country in question will intersect the boundaries of that country.

The angle parameter θ_o in Figure 5-41 is for the angle across <u>an entire pattern cross-section</u> at the 3 dB power reduction points in the antenna beam, while the angle θ is measured from the center of the beam out toward beam edge. Thus, the 3 dB power reduction points in Figure 5-41 occur for θ/θ_o equal to 0.5 and the drop-off in radiated power from 3 dB to 30 dB will occur in the region between $\theta/\theta_o = 0.5$ and $\theta/\theta_o = 1$. Actually, the 3 dB beamwidth for θ_o is not necessarily optimum for antenna efficiency and gain, even for a country having a perfectly circular boundary. In 1969, J. W. Duncan pointed out that in the case of circular or pencil beams, maximum gain and therefore, optimum antenna efficiency, is realized when the angle θ_o corresponds to the -4.3 dB level of the normalized power pattern.

The problem with the pencil or circular beam antenna which provides the implementation of Figure 5-41 is that few, if any, countries on the face of the earth have circular boundaries and any attempt to illuminate circular patterns on each of a group of contiguous countries or regions will produce an overlapping of patterns resulting in significant radiated power densities into each adjacent country which could result in considerable interference both within and beyond each nation's boundaries.

WARC-79 must face the political situation that in some cases, the broadcasters using TV broadcast satellites would welcome the increased coverage provided by the use of simple antennas. However, when considerations of interference above are used, WARC-77 clearly stated that limiting interfering power flux density at the edge of a service area is -103 dBw/m^2 for service areas in Regions 1 and 3, and -105 dBw/m^2 for service areas in Region 2. In addition, the protection ratio for a broadcasting satellite signal against an interfering terrestrial service (except AM multichannel TV) is 35 dB for carrier differences up to 10 MHz.

In order to achieve this discrimination against interference, the multiple beam satellite antenna becomes an invaluable tool for shaping the transmitted down-link beam into its unique service area. In the technical recommendations to WARC-79 from WARC-SPM, this point was clearly made by illustrating how a multiple-horn offset-fed antenna could be used to greatly improve on the circular/ellyptical antenna beam pattern recommended by WARC-77. This illustration involved a 21-horn offset reflector (8 ft), designed for 11 GHz to serve a very irregular boundary shape which is long in one direction and relatively narrow in other direction and represents a very small country in the world. Figure 5-42 shows the basic contours obtained; Figures 5-43 and 5-44 show the improvement in pattern.

5.6.6.1.2 Fixed Service Satellites and TV-Broadcast Satellites - Orbit and Spectrum Considerations

The growth of two different services, fixed satellite service and TV broadcast satellite service, during the 1980's will require careful consideration

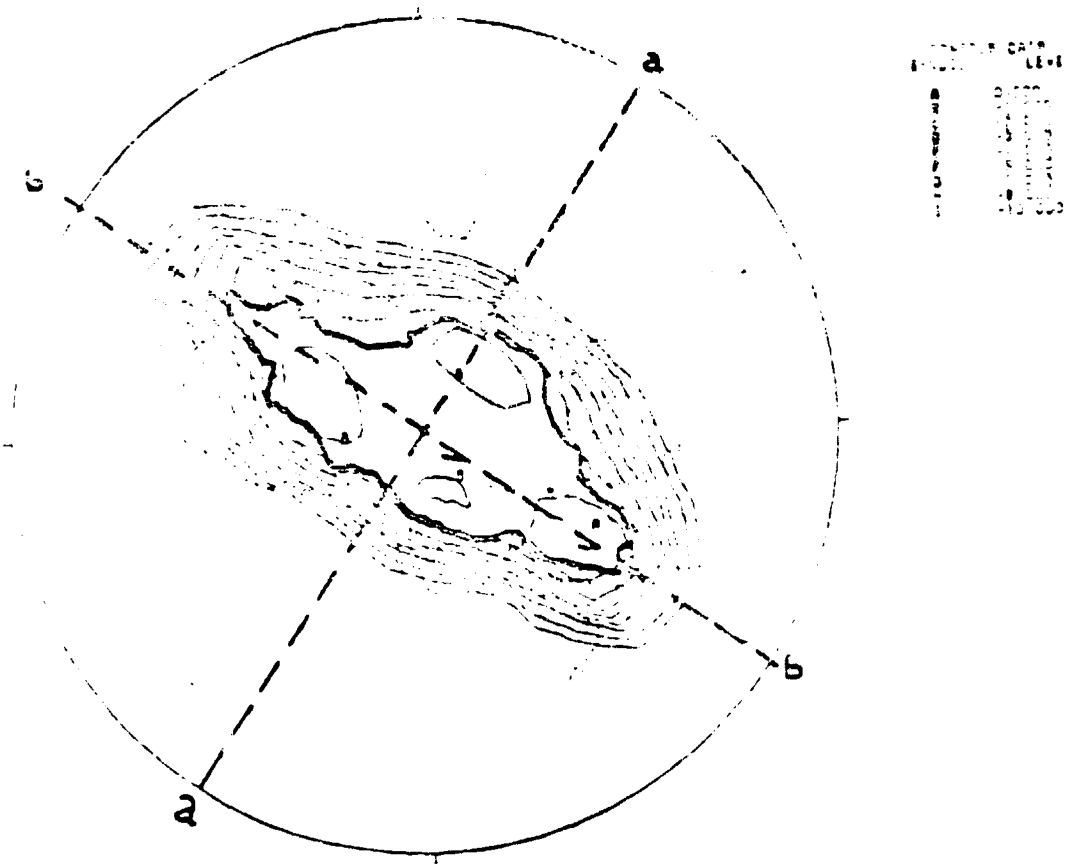


Figure 5-42

Computer derived shaped beam pattern at [illegible] GHz
for a [illegible]-horn offset-fed parabolic reflector system

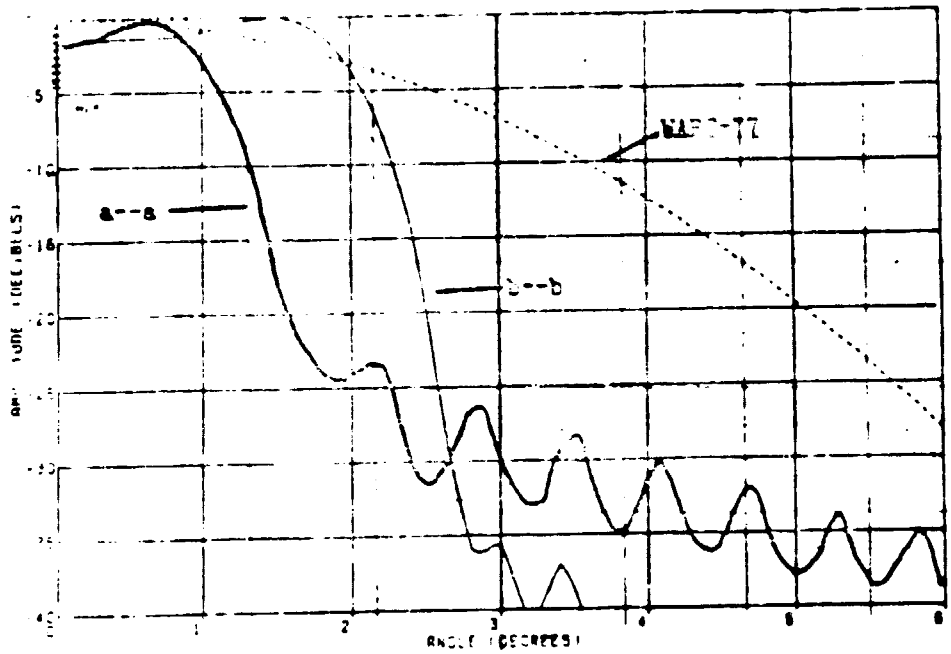


Figure 5-43

Copolar antenna beam amplitude pattern

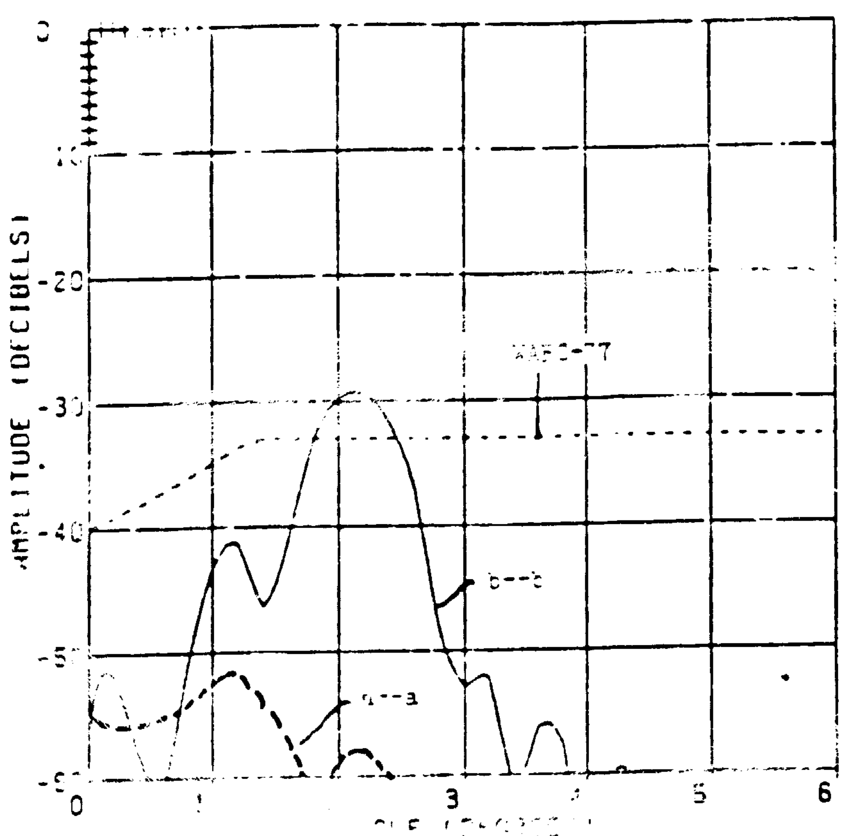


Figure 5-44

Cross Polar Antenna Beam Amplitude Pattern by WARC-79 of how the radio spectrum is to be shared by both services. This is due to the fact that the TV-broadcast satellite is designed to have much higher EIRP than its fixed service satellite counterpart in order to serve primarily small receive-only terminals. The coexistence of satellites using identical frequency bands, particularly in the down-link, can give rise to severe interference which can virtually paralyze the fixed services.

The CCIR XIVth Plenary Assembly in Kyoto, 1978, in its Document 10-11/112E made a perceptive analysis of this problem when it discussed the effect on orbit utilization when dissimilar (inhomogeneous) satellites for both TV-broadcast and for television distribution in the fixed service are colocated in the orbit and which use the same frequency band for down-link. The broadcasting satellites would normally have higher power EIRP than the fixed service satellites, and the protection of the latter would become a critical and difficult problem. Figure 5-45 has been developed to relate antenna discrimination angle to copolarized protection ratio for various fixed satellite earth station antenna sizes for the case when the broadcasting satellite EIRP is 64 dBw for individual reception and 53 dBw for community reception; and the fixed service satellite EIRP is 45 dBw which is a fairly high value. Assuming fixed satellite receiving earth station sidelobe patterns conforming to the $32-25 \log_{10}\theta$ equation, it is evident from Figure 5-45 that the greater the discrepancy between satellite EIRP's the less efficient is the orbit utilization. For example, with a 30 dB protection ratio for the fixed service having an antenna diameter of 4.5 meters, the required angle of discrimination (orbit spacing) when sharing with a broadcasting satellite for community reception, is 5.4°. However, when shared with a higher power satellite designed for individual reception, the required angle is 14.3°.

Thus, one solution is to assign different frequency bands to the broadcast and fixed service satellites, which was already done in Regions 1 and 3 in

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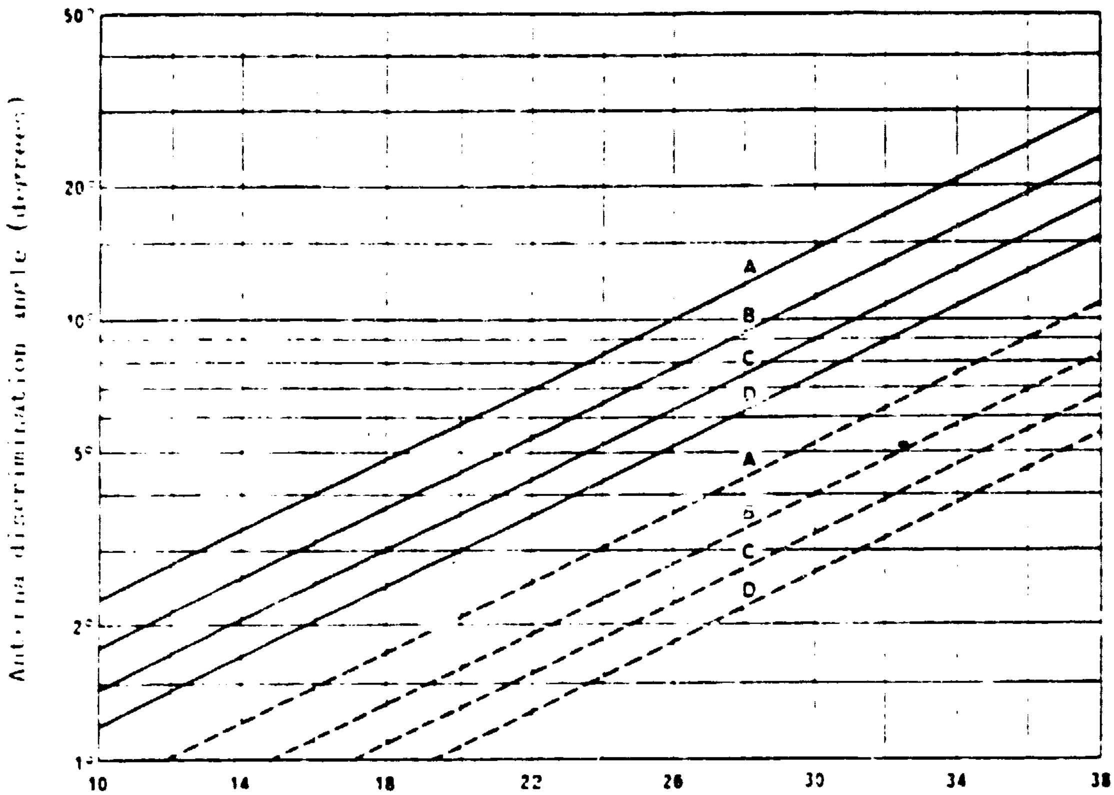

Figure 5-45

Protection ratio versus antenna discrimination angle for fixed-satellite system frequency sharing with broadcast-satellite systems

—— Fixed-Satellite Sharing with Individual Reception Broadcast-Satellite

- - - - Fixed-Satellite Sharing with Community Reception Broadcast-Satellite

Curves	Fixed-satellite earth station antenna
A	Diameter, 4.5 m (beamwidth, 0.37°; Gain, [illegible] dB
B	Diameter, 6.0 m (beamwidth, 0.28°; Gain, 54.7 dB
C	Diameter, 8.0 m (beamwidth, [illegible]°; Gain, [illegible] dB
D	Diameter, 10.[illegible] m (beamwidth, 0.17°; Gain, [illegible] dB

From CCIR Working Document, Attributed to Dr. H. Akima, U.S. NTIA, Boulder, Colorado

Ku-Band, but not in Region 2. In this region, the 11.7 to 12.2 GHz band is now assigned to both. The U.S. position at WARC-79 was to assign this band to exclusively domestic fixed satellite down-link and to allocate the 12.2-12.7 band to TV-broadcast in Region 2.

5.6.6.1.3 Antenna Sidelobe Performance versus Satellite Spacing

W. Morgan has developed the curve in Figure 5-46, showing how the two above formulae can be related to antenna diameter, satellite spacing in degrees and sidelobe performance expressed in terms of decibels below the desired signal rather than the conventional dB. This curve calls attention to the increased interference seen by smaller antennas (4.5 meters) to satellites spaced only 4° apart and points up the basic reason why antennas smaller than 9 meters were not allowed by the FCC until Dec. 15, 1976, when a new ruling permitted 4.5-meter video receive-only antennas in the 4 GHz band which meet the CCIR regulations.

This spacing of 4° presents no problem for larger earth terminals with diameters greater than 9 meters (having a half-power beamwidth of 0.6 degrees) but the advent of the wide spread use of the 4.5 meter with its 1.2° half-power beamwidth can introduce interference problems arising from an earth terminal pointed toward one satellite which also receives significant power flux from an adjacent satellite. Figure 5-47, due to Dr. J. McElroy of NASA, shows this interference while making the following assumptions: (a) coverage is to be provided for all 50 states, this limits the usable segment of the arc to the 40 degrees from 100 to 140 degrees W. Longitude; (b) a C/I of -27 dB is assumed; (c) the CCIR sidelobe envelopes are the basis for the C/I calculation; (d) each satellite is identical (for a given frequency band) and the 4/6 GHz and 12/14 GHz band satellites carry 24 transponders, while the 18/30 GHz band satellites

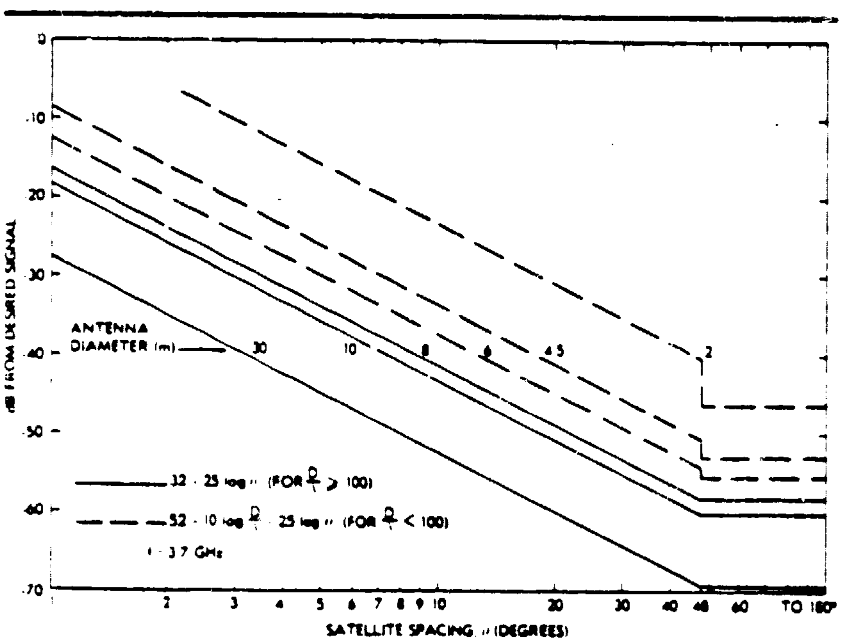

Figure 5-46. **Earth Station Sidelobe Interference Levels**

Figure 5-47

THE ADVERSE EFFECT OF SMALL EARTH STATION ANTENNA DIAMETERS ON UTILIZATION OF THE GEOSTATIONARY ARC BY THE UNITED STATES

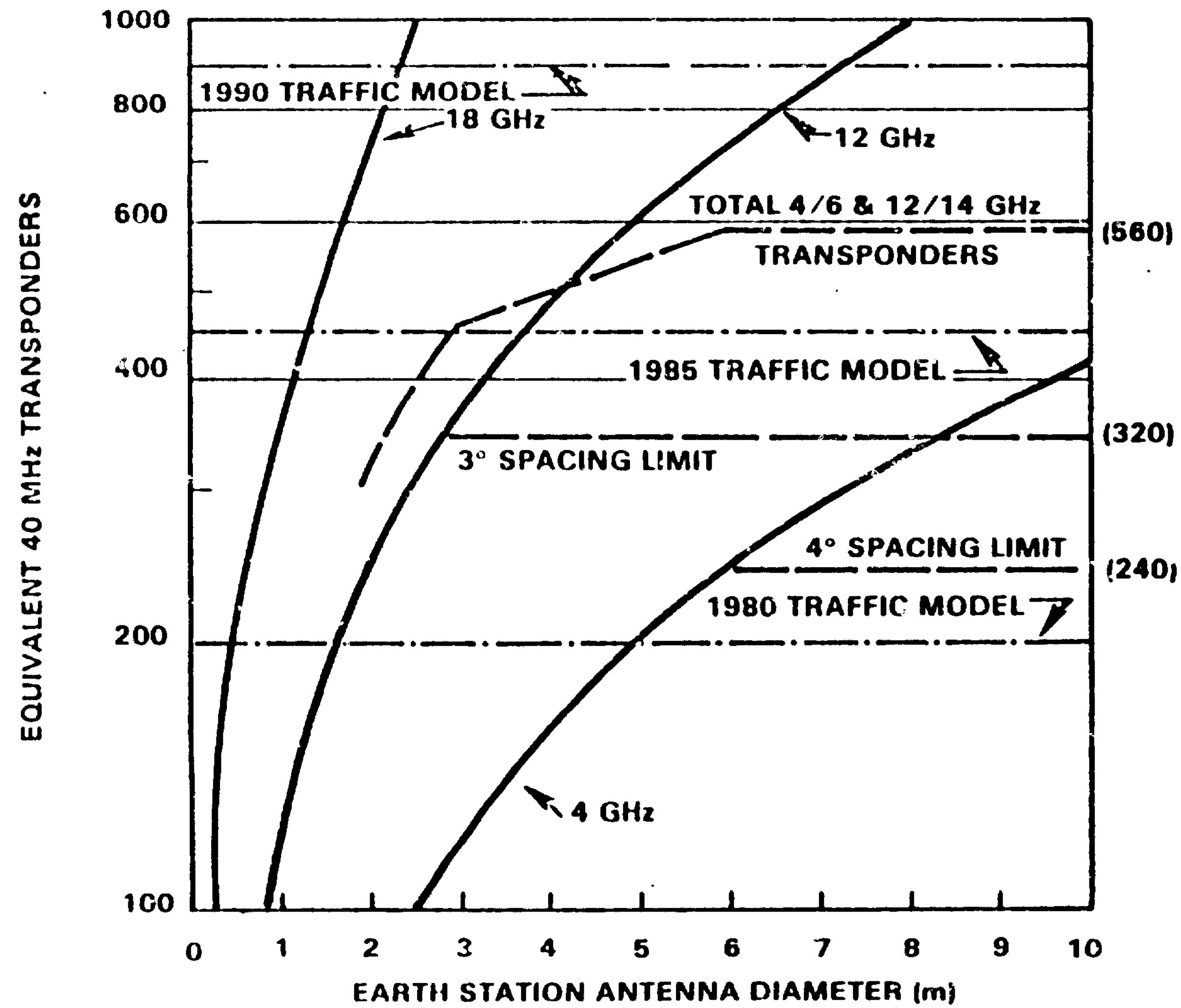

FIGURE 5-47

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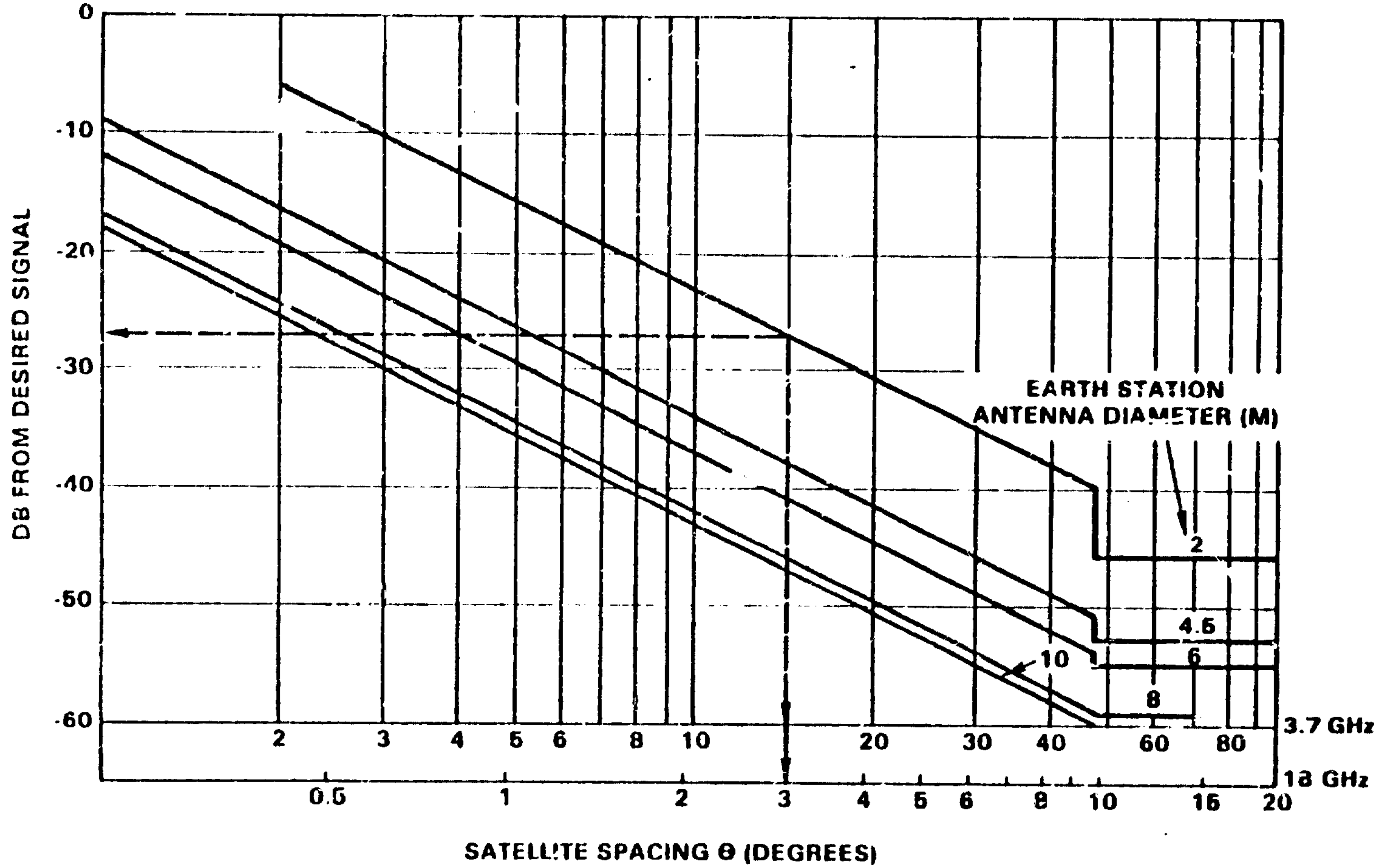
carry 60 transponders; and (e) the interfering satellite has the same service area. The ordinate is the number of equivalent 40 MHz bandwidth transponders, and the abscissa is the diameter of the earth station antenna. The criterion used is one which limits the interference received by the earth station antenna from adjacent satellites and therefore the satellite spacing.

Three solid curves show the maximum number of transponders for the 4, 12 and 18 GHz down-links. Three horizontal lines show the 1980, 1985 and 1990 traffic models from a previous chart. Two other dashed horizontal lines show the current spacing required for satellites in the 4/6 and 12/14 GHz bands, 4 and 3 degrees, respectively. Thus, if this requirement is obeyed, then the upper segment of the two curves for these bands is inaccessible. A composite curve is shown for the total of the 4/6 and 12/14 GHz transponders which obeys this constraint. It can be seen that the total is somewhat above the 1985 traffic model.

Yet another factor in the evolution of the earth terminal technology is the move to higher frequencies to avoid the orbit crowding and interference now being faced at 4/6 GHz, to take advantage of the use of smaller antenna systems (i.e., SBS system for data at 11/14 GHz which is designed to use 5.5 meter antennas for roof-top mounting and 7.7 meter antennas for ground mounting), or the use of 1-meter antennas at 12 GHz for TV satellite broadcasting, or to use the large bandwidth of up to 2.5 GHz at 20/30 GHz for high data rate heavy trunking or direct-to-user applications. The move to higher frequencies can also permit closer satellite spacing than used at 4/6 GHz. Figure 5-48 due to J. McElroy, et al, shows the minimal orbital arc separation required to maintain a specified level of interference suppression for various earth terminal diameters and frequencies.

Figure 5-48

EFFECT OF INCREASED FREQUENCY ON EARTH STATION SIDELOBE INTERFERENCE LEVELS AND PERMISSIBLE SATELLITE SPACING



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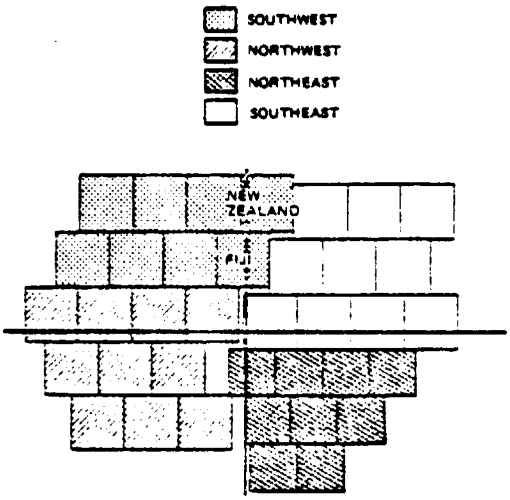
5.6.6.1.4 Offset-Fed Reflector Shaped-Beam Satellite Antennas

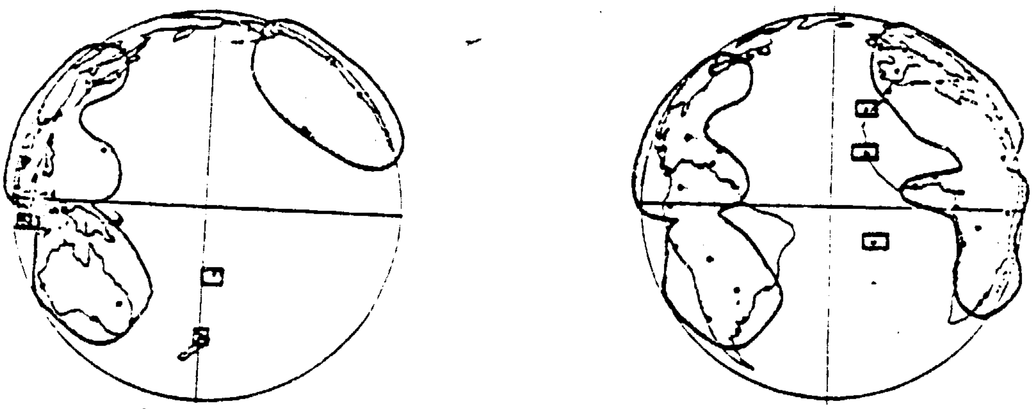
The first major use of multiple horn offset-fed reflectors was made by F. Taormina, et al, for INTELSAT-IVA. On this spacecraft, 53-inch transmit and 35-inch receive [illegible]-square reflectors are constructed of metallic mesh on an open web frame to minimize solar torque effects. The feed horn arrays are cantilevered from the mast and are offset from the reflectors. The receive antenna provides coverage over each hemispheric area with a single beam, while the transmit antenna system provides coverage with a northern and southern beam for each hemisphere. In addition, the odd-channel transmit antenna provides a combined hemispheric beam (on command) if required, while the even-channel antenna provides coverage of the northern sectors only. The feed system for the odd-channel antenna consists of 37 horns having integrated polarizers and energized with a transverse electromagnetic mode (TEM) squarax transmission line power division network. The physical arrangement of the feed horns in the aperture plane is shown in Figure 5-49. There are 19 feed horns for east coverage and 18 hours for west coverage. Two of the west horns are on or off switchable to accommodate differences between Pacific and Atlantic coverage requirements. The north and south feed clusters have separate input terminals for spot and hemispheric operation. The antenna servicing the even channels is illuminated by those horns providing spot beam coverage to the north-east (nine horns) and north-west (ten horns) regions only.

The INTELSAT-V requirements are similar to those of INTELSAT-IVA except that polarization diversity was also required to provide simultaneous coverage of two overlapping regions in each hemisphere. A footprint configuration common to the Atlantic, Pacific and Indian Ocean theaters was desired, with a minimum amount of switching in the feed ne[illegible] to accommodate differences between areas. Offset reflectors, as designed by Dr. C. C. Han, are being utilized for both the 4/6 GHz and 11/14 GHz bands, with separate structures for receive and transmit



PHYSICAL ARRANGEMENT OF FEED HORNS IN APERTURE PLANE

INTELSAT IV-A Odd-Channel Transmit Antenna Feed System



INTELSAT IV-A Shaped Beam Coverage

Figure 5-49

Horn Arrangement for Odd-Channel Transmit Feed System of Intelsat IVA and the Beam Coverage in Both the Atlantic and Pacific Basin (see Figure 5-50). Tight control of individual shaped beams is necessary to maintain low sidelobes (for isolation to the overlapping cross-polarized beam). This beam shaping is accomplished by illuminating the offset reflector from a multitude of individual feed horns (up to 85 for the two hemispheric beams), each with controlled amplitude and phase as determined by optimization to achieve the patterns shown in Figure 5-51.

The effort in developing offset fed multiple beam antennas at 4 GHz has led to substantial investigation of the use of this new antenna technology at higher frequencies. A. Rudge and N. Williams of ERA, U.K., using a specification provided by the European Space Agency have developed a multibeam antenna for 30 GHz using a multiple feed with a 0.8 meter reflector to produce three beams. In the United States, investigations at Bell Telephone Laboratories, multiple-beam offset antennas have been built for operation up to 100 GHz using a 60.96 cm diameter reflector.

In order to illustrate the advances achieved in offset multiple beam reflector antennas for beam shaping areas having complex contours, a 21-horn offset reflector (8 ft.) was designed for 11 GHz to serve a very irregular boundary shape which is long in one direction and relatively narrow in other directions and represents a very small country in the Indian Ocean region. Figure 5-42 shows the basic contours obtained including the contour level where drop-off to 10 dB below peak gain occurs. Figures 5-43 and 5-44 show both the actual copolar and crosspolar pattern amplitude drop-off provided by the 21-horn offset reflector system as compared with the recommended reference pattern of Figure 5-41 (see dotted line) for the long and narrow directions. Note that the shaped beam copolar patterns greatly improve on the WARC-77 reference pattern with improved crosspolar performance.

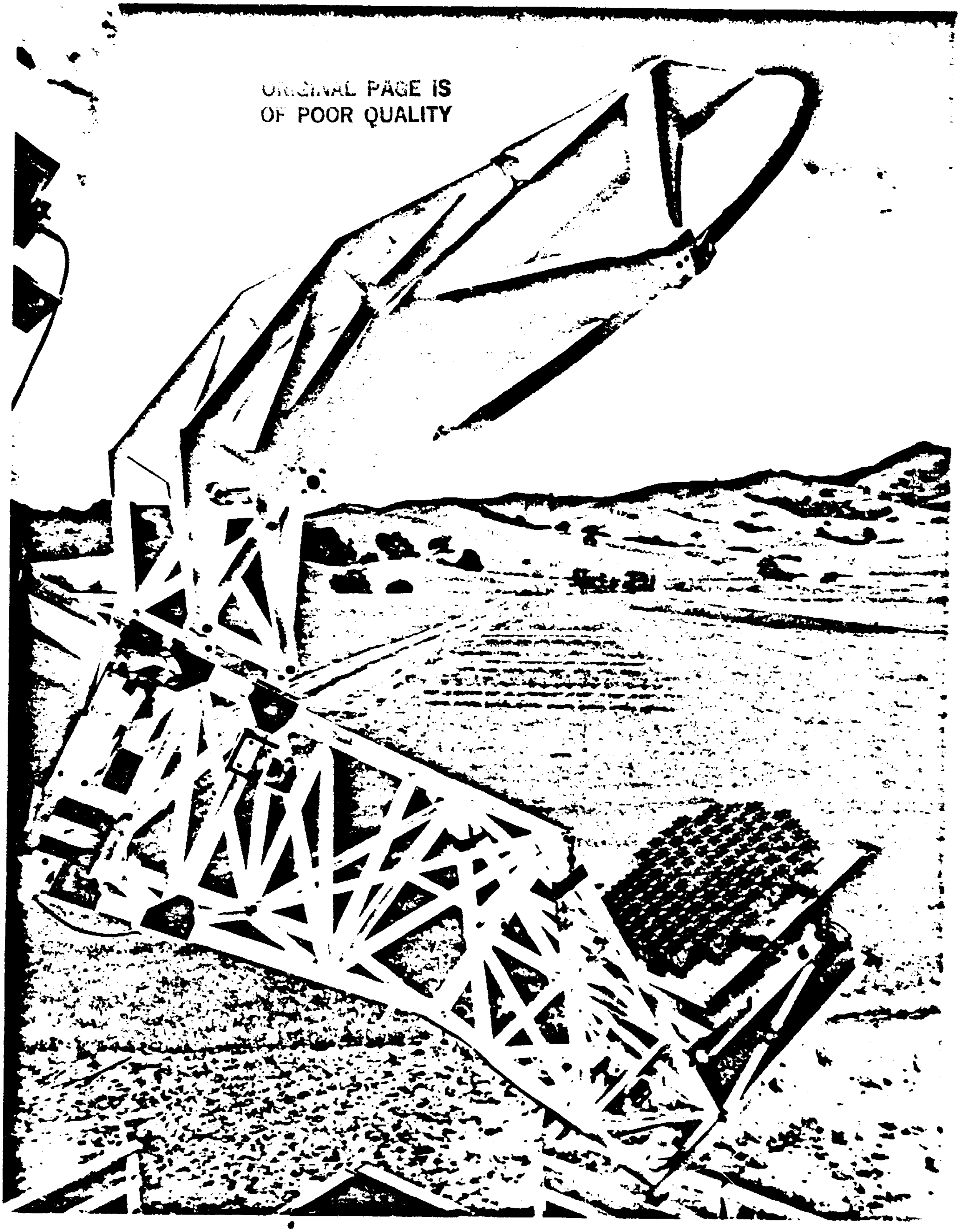
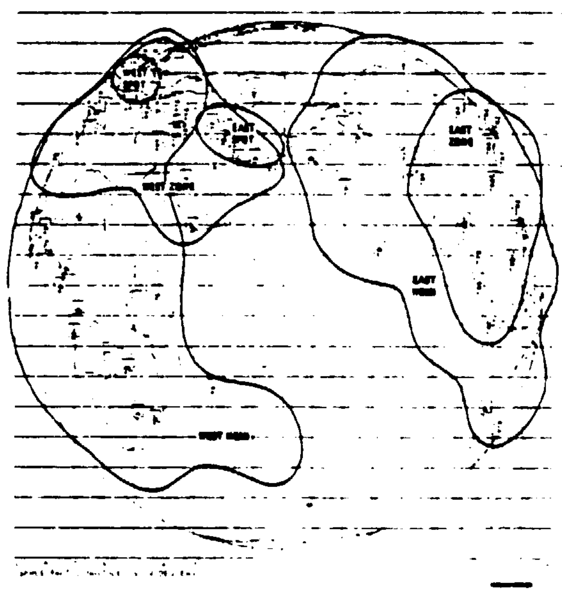


Figure 5-50. 4 GHz Offset-Fed Reflector System for INTELSAT V



Intelsat V Indian Ocean Coverage

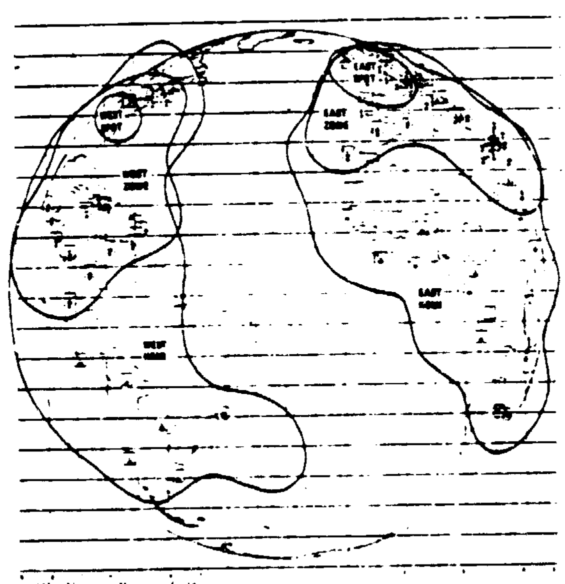
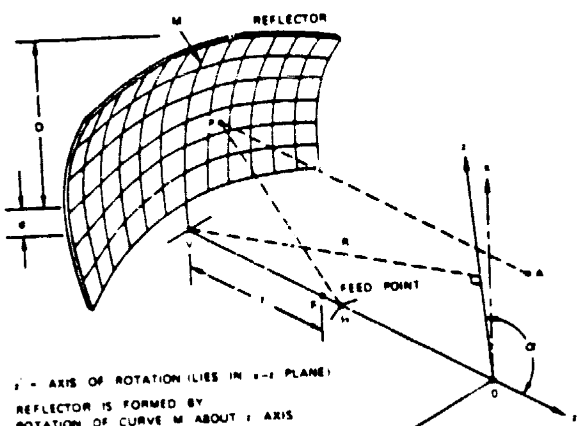


Figure 5-51. Intelsat V Atlantic Ocean Coverage

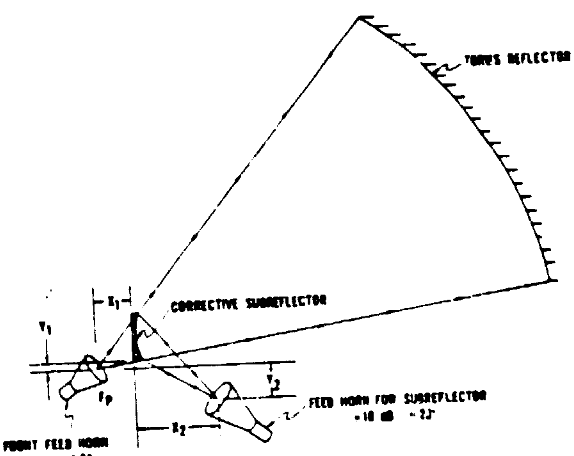
Still another advance in multiple beam antenna is the Torus antenna (Figure 5-52) developed at Comsat Labs which allows the use of individual feed systems to access different portions of the earth from different sections of the Torus.

The reflector technology has been given significant attention during th 1970's. According to NASA's Dr. McElroy "high gain spacecraft antennas have relied almost exclusively on reflector technology in the past. Reflectors have enjoyed the longest and most intensive development and have the most mature analytical foundation. Several data points illustrating the current status of reflector technology are shown in the chart on the facing page. ATS-6, which has a 9.1 meter diameter reflector composed of 48 aluminum ribs with a gold-plated dacron-woven mesh surface, remains the largest aperture antenna flown in space to date. The reflector weighs 82 kg and suffers approximately 2 dB gain loss at C-band under worst case thermal distortion conditions. General Dynamics, as part of a U.S. Air Force technology development program, has produced a fully qualified graphite fiber reinforced plastic (GFRP) reflector, 2.4 meters in diameter. The reflector has a surface accuracy of 7×10^{-5} meters due to manufacturing tolerances, degrades to 13×10^{-5} meters under worst case thermal distortion and has approximately 1 dB gain loss at the operating frequency of 94 GHz under worst case conditions. At 750 wavelengths aperture this represents the largest aperture/surface quality reflector qualified for space flight use today. Two additional representative data points for flight qualified antennas are shown together with one non-flight unit by Harris which was carried to an advanced stage of development. The ultimate reflector surface accuracy attainable with current technology, expressed as a function of reflector diameter, can be approximated by the 4×10^{-5} curve shown in Figure 5-53.

A MULTIPLE-BEAM TORUS REFLECTOR ANTENNA FOR 20/30-GHz
SATELLITE COMMUNICATIONS SYSTEMS



Torus Antenna Geometry



Front Feed and Subreflector
Configurations

FIGURE 5-52

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SPACECRAFT REFLECTOR TECHNOLOGY STATUS (1978) (DR. McELROY)

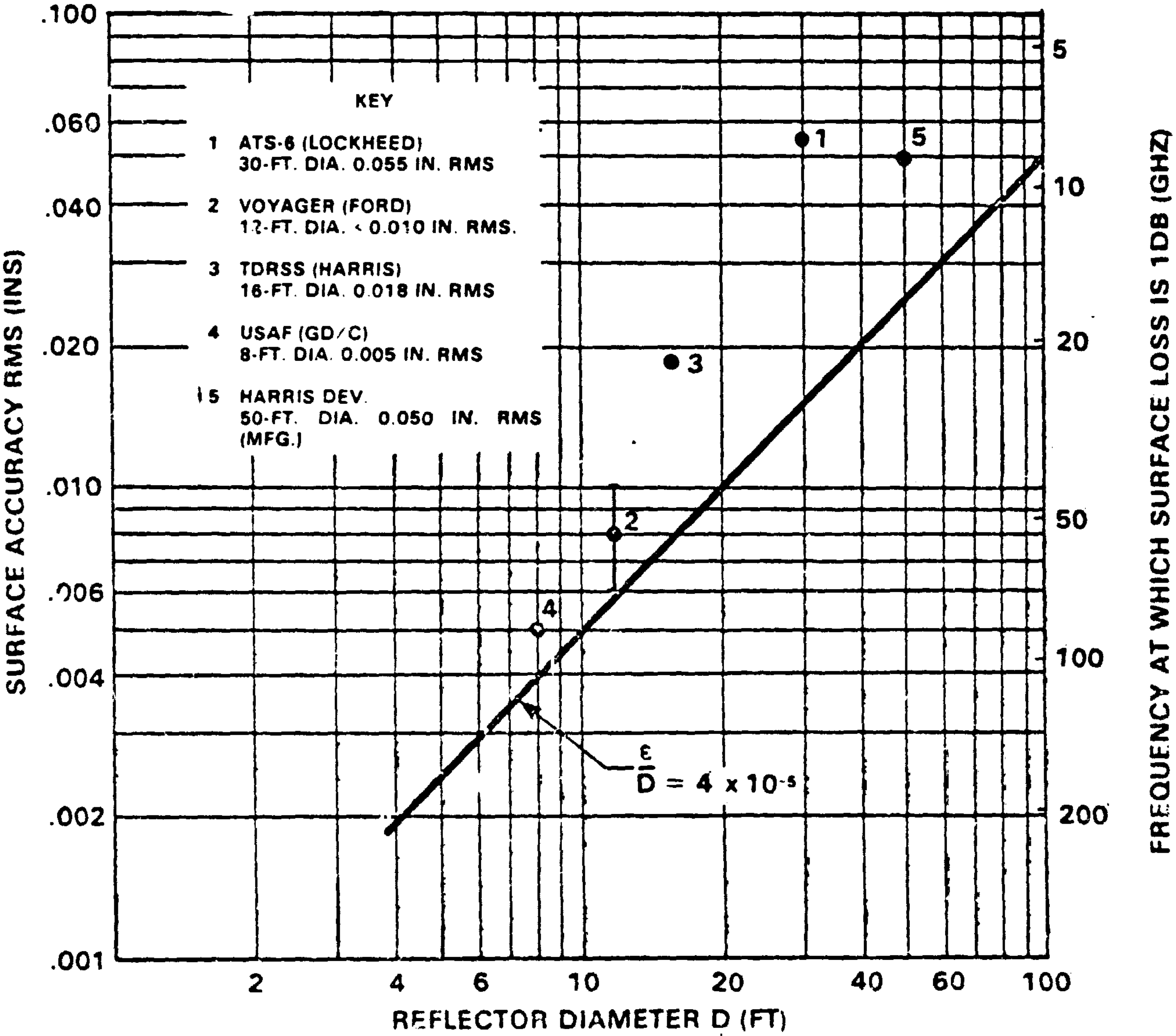

FIGURE 5-53

5.6.6.1.5 Shaped-Reflector Shaped-Beam Antennas

A very important new technology for producing shaped beams from a spacecraft is one which involves shaping or contouring an antenna reflector surface which is illuminated by a single (or multiple) offset feed horn and using the antenna reflector contouring to change the phases of the various rays produced by the antenna to produce a focused beam into the particular earth pattern or footprint. An important realization of this type of antenna (Figure 5-54) is used in the Japan Communication Satellite (CS). This satellite produces antenna beams at 4, 6, 20 and 30 GHz with the 20 and 30 GHz beams contoured to fit the Japanese islands as indicated in Figure 5-55. The four-frequency antenna system consisted of a cylindrical cone horn reflector with a reflector plate specifically contoured to provide a pattern at 20/30 GHz which confined the principal antenna gain of 33 dB to a beam shaped configuration with a beamwidth of around 2° by 3° around the islands of Japan. The initial electrical design concept for this antenna was developed by M. Kudo, et al.

5.6.6.1.6 World-Wide Antenna Experience

At the close of the 1970's, satellite antenna experience has matured in many parts of the world. Tables 5-44 and 5-45 list the various participants in the development of satellite antennas and include the satellites which have furnished this experience.

5.6.6.1.7 Driving the Off-Set Reflector Multiple Beam Antenna - The Beam Forming Network (BFN)

The multiple beam antenna using an off-set reflector is the principal candidate for producing complex-contour footprints for beyond the capability of a contoured reflector system such as is used on the CS. It is not possible to consider the multiple beam with many offset feeds without also considering both the mechanism by which the feeds produce the contoured footprint, and the beam

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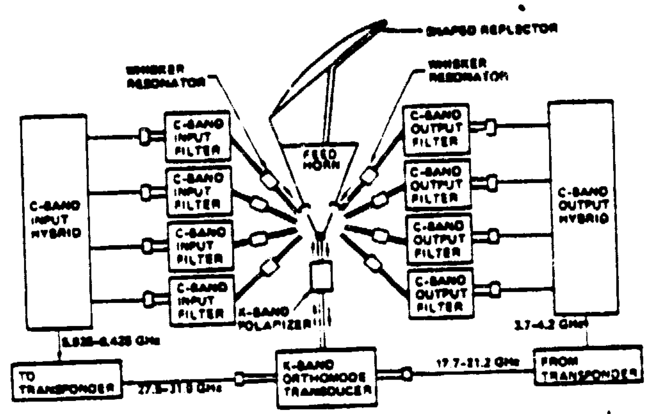
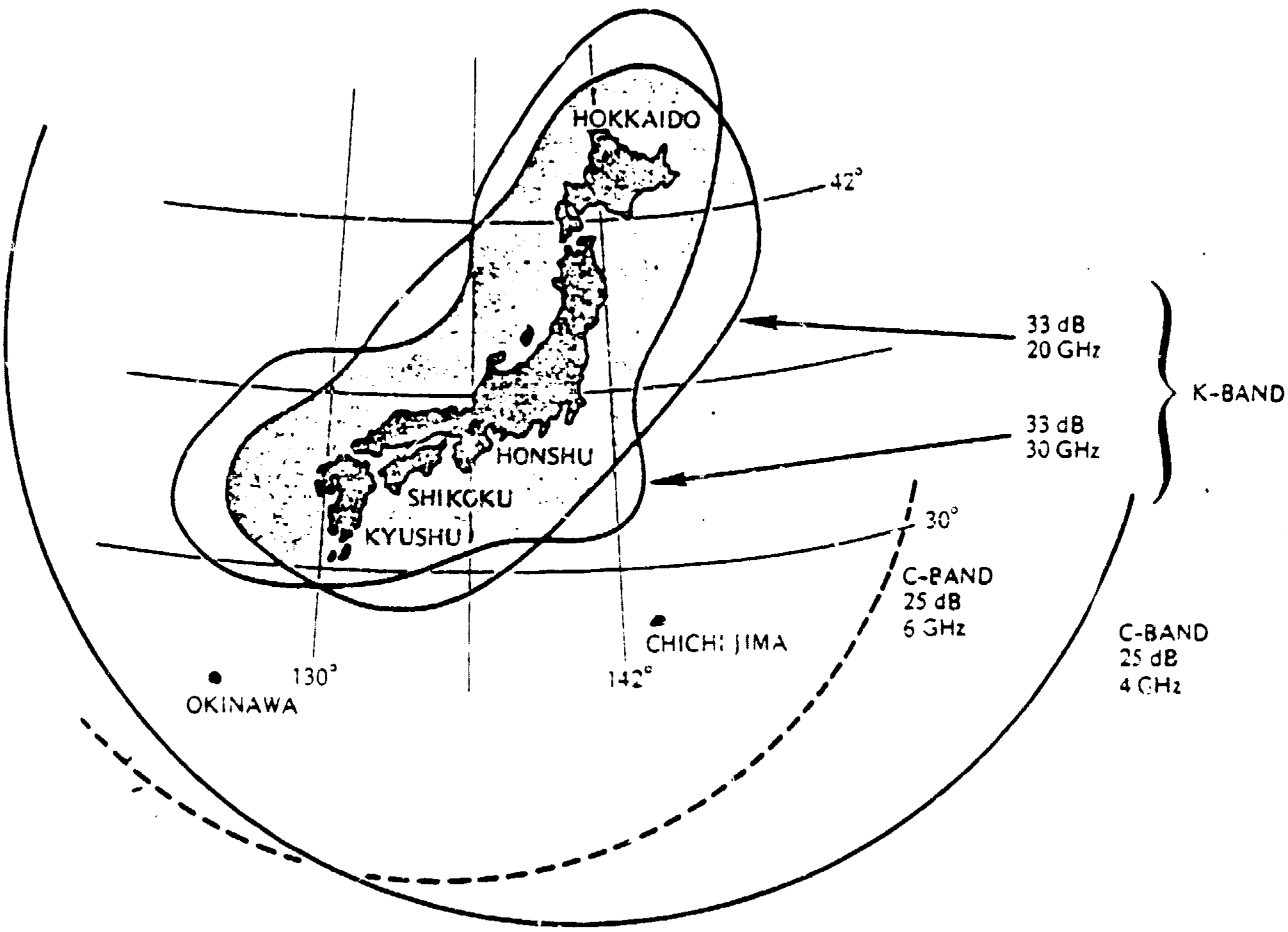


Four Frequency Antenna and Feeder Systems Using Shaped Reflector for 4, 6, 20 and 30 GHz

Figure 5-54



Antenna Pattern Contours at 4, 6, 20 and 30 GHz, for the Antenna System of Figure 17 a, Showing the Shaping Produced at 20 and 30 GHz

Figure 5-55

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TABLE 5-44

WORLDWIDE SATELLITE ANTENNA EXPERIENCE

Frequency	Company	Location	Application
4/6 GHz	Hughes Ac.	USA	Intelsats II, IV, IVA, Anik, Palapa, Westar, Comstar
	TRW	USA	Intelsat III
	Ford Aerospace	USA	Intelsat V
	RCA	USA	Satcom
	Aerospatiale	France	Symphonie
	Selenia	Italy	Intelsat IV
	Mitsubishi/NTT-ECL	Japan	JCS
11/14 GHz	GE	USA	J-BSE
	Hughes Ac.	USA	SBS
	Ford Aerospace	USA	Intelsat V
	TRW	USA	TDRSS
	RCA	USA	Anik F4
	Selenia	Italy	OTS, Sirio
	Toshiba	Japan	J-BSE
20/30 GHz	Martin Marietta	USA	ATS-5
	Ford Aerospace	USA	JCS, ETS-II, ECS
	Comsat Labs	USA	Comstar
	CNES	France	H-SAT
	ERA	U.K.	H-SAT
	CSLT	Italy	H-SAT
	Ticra Aps	Denmark	H-SAT

TABLE 5-45

SPACECRAFT ANTENNA MANUFACTURERS (WORLD-WIDE)

Type	Company	Location	Satellite Used (Partial)
Offset Reflector	Ford Aerospace	USA	NASA Satellite, INTELSAT V, JCS
	Hughes	USA	INTELSAT IV, IVA, Anik, Westar, Comstar
	Bell Telephone Labs	USA	Experimental K-Band Antennas
	RCA	USA	Satcom Nimbus, Tiros
	G.E.	USA	BSE, Landsat
	TRW	USA	INTELSAT III, TDRSS
	Fairchild	USA	ATS-6
	Lockheed	USA	ATS-6
	Ball Bros.	USA	Classified
	RCA Ltd./SPAR	Canada	CTS
	Selenia	Italy	INTELSAT V, OTS
	Siemens	Germany	Azur
	MBB	Germany	Symphonie
	Hawker Siddeley	UK	INTELSAT V
	Marconi	UK	Marots
	Thomson-CSF	France	Terrestrial Radio
	Mitsubishi	Japan	JCS Prototype
	Toshiba	Japan	BSE Prototype
	NEC	Japan	Experimental plus Major Ground Antenna Manufacturer
Lens Antennas	Lincoln Labs	USA	Prototype 7/8 GHz Antenna
	G.E.	USA	DSCS III
	Hughes	USA	Contract DCA, 7/8 GHz
	Ford Aerospace	USA	Contract to Comsat Labs, 6/4 GHz
Helical	Hughes	USA	Marisat
Horn	Ford Aerospace	USA	NATO-III
Electronically Despun Cross Pole Antenna	Ford Aerospace	USA	SMS GOES B,C

forming network (BFN) which is used to excite or interconnect the feeds.

Multiple beam off-set fed reflector antennas have a unique ability to meet the ever increasing demands on satellite antenna systems, by being able to accomplish such functions as: 1) improving EIRP over prescribed areas through pattern shaping; 2) allowing frequency reuse by both spatial and polarization diversity; and 3) reducing interference outside desired coverage areas, to meet new WARC requirements on both copolar and cross-polarized energy. Solutions to these problems generally result in larger, more complex antenna structures and systems, which become an overriding factor in the design of the entire satellite.

The multiple beam antenna (MBA) systems are capable of creating multiple simultaneous beams, each of which may be shaped from a number of smaller constituent beams by the principle of superposition. This principle is illustrated in Figure 5-56, showing a set of three adjacent constituent beams added together in space to produce a single broader beam with a relatively flat top and steep "skirts". This allows more uniform coverage of the desired area, and more rapid decay of energy outside this area, to reduce interference while also improving efficiency. The antenna designer would prefer to use the narrowest possible constituent beams spaced as closely as possible together; this leads to very large antenna structures and numbers of constituent beams, each of which must be individually formed and fed. A natural limitation occurs in the allowable spacing of feed horns, based on their minimum size; this generally occurs at a spacing of about 0.6 beamwidths.

Table 5-46 denotes the approximate number of beams which would be required for earth coverage from synchronous altitude (18^o) for various beam spacings, assuming a 1^o constituent beamwidth (requiring a 17-ft diameter aperture at 4 GHz). The crossover level in each case is also shown; this determines the amount of ripple in the composite pattern between beams. The large numbers of beams result

C - 4

in complex large and heavy beam forming networks (BFN's).

An example of the use of this MBA technique is the Intelsat-V communications antenna which consists of separate offset-fed reflectors for transmit (4 GHz) and receive (6 GHz) (Figure 5-57), as pictured in Figure 5-58. The transmit reflector is 8 ft in diameter, and is fed by an array of 78 contiguous feed horns, each excited with both senses of circular polarization to produce four separate beams, as shown in Figure 5-57. Two of these beams cover hemispheric regions of existing ground stations, while the other two are cross-polarized zone beams for high-traffic areas. The combination provides four times frequency reuse, with a minimum of 27 dB isolation between beams. In addition, two movable spot beams are included, operating at 11 and 14 GHz.

A calculated contour plot of the west-zone receive beam is shown in Figure 5-57, depicting relative locations of the 18 constituent beams used. Each has a beamwidth of about 2°, and all are excited with nearly equal amplitudes, except the edge beams, whose relative amplitudes are shown. Contours up to 30 dB below the beam peak are shown, representing loci where 27 dB isolation from the -3 dB edge-of-coverage contour is provided. This -30 dB contour is thus the nearest edge of another co-polarized beam operable in the same band, and with the desired minimum isolation for frequency reuse. The spacing between edges of such beams is generally at least one full constituent beamwidth, thus placing an upper limit on the number of multiple beams achievable within a given area for a given size antenna.

Excitation of the 78 individual Intelsat-V feed horns with the proper amplitudes and phases is accomplished with an air-suspended stripline BFN shown in Figure 5-59. This network consists of a cascade of hybrid-ring power dividers, with interconnecting line lengths adjusted for phase control.

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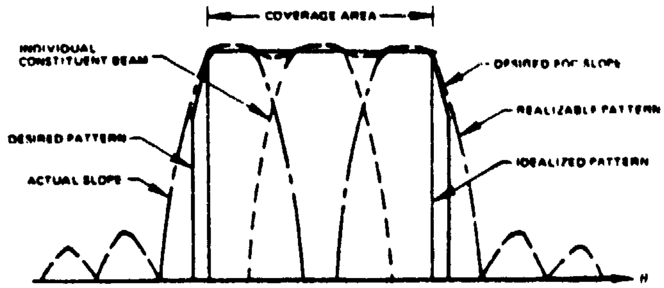


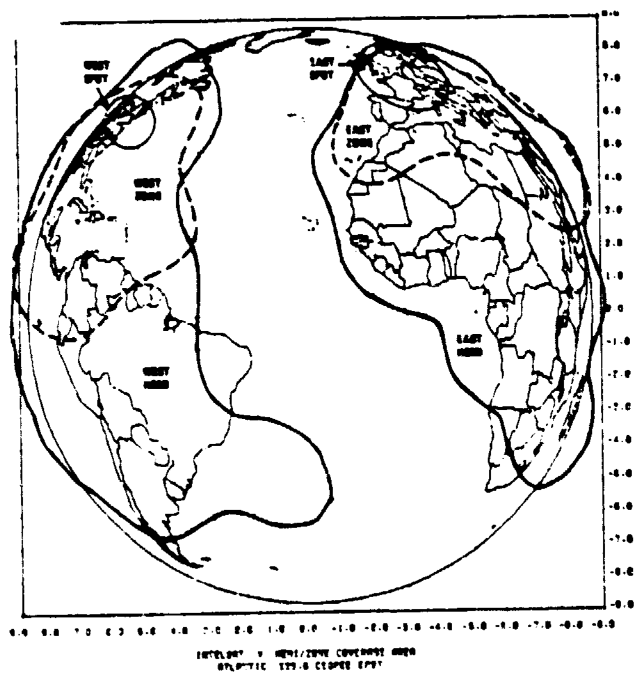
Superimposed coverage patterns.

Figure 5-56

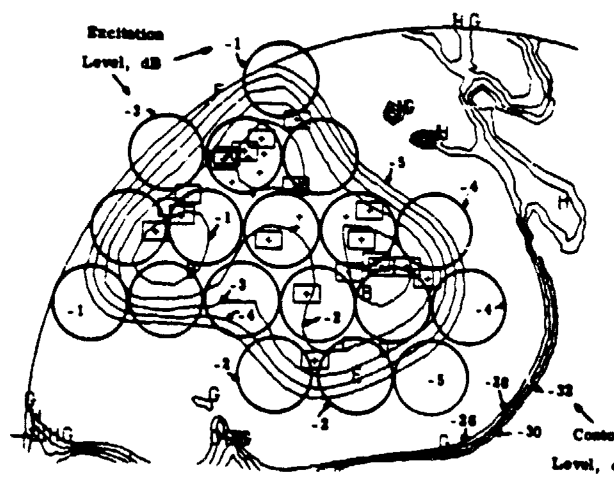
MBA 1° Beams Required for Earth Coverage

Beam Spacing	0.6	0.8	1.0	1.2
Number of Beams	800	470	300	217
Crossover level, dB	-1.1	-1.9	-3.0	-4.3

Table 5-46

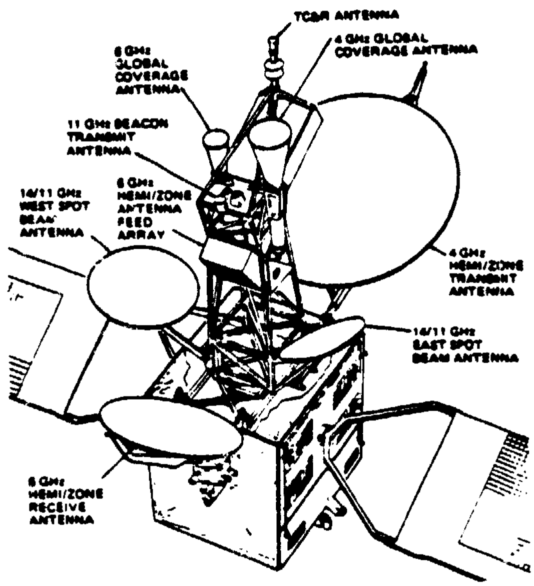


INTELSAT V Atlantic Ocean coverage.

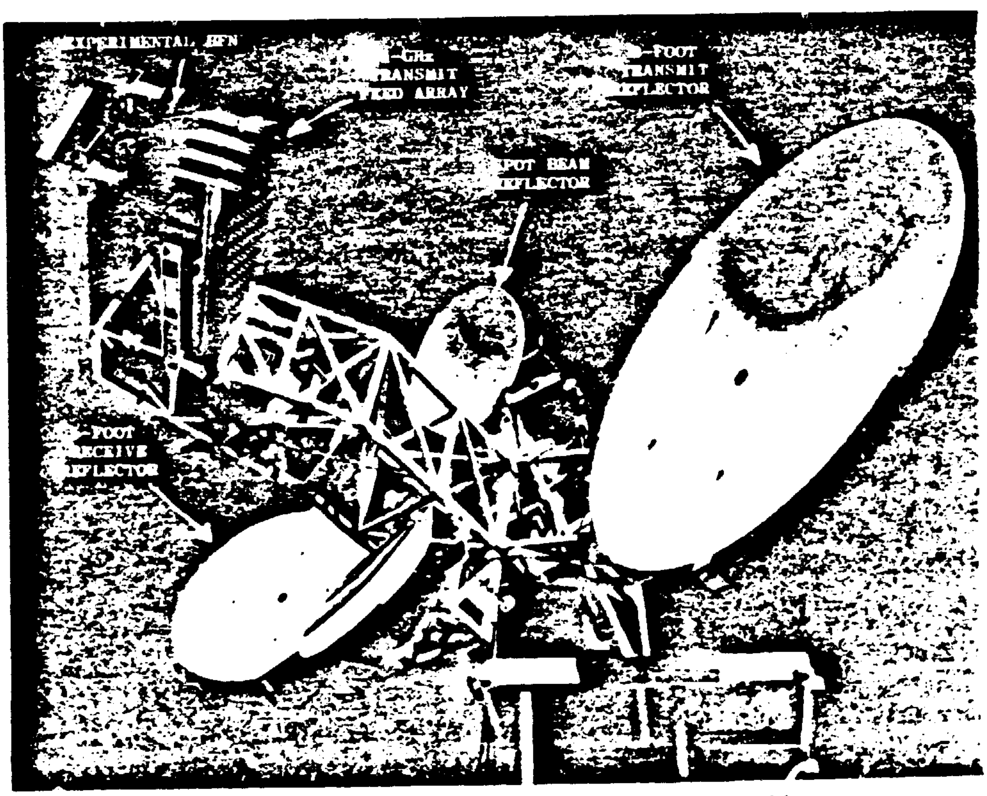


Calculated INTELSAT V west zone receive beam contours.

Figure 5-57

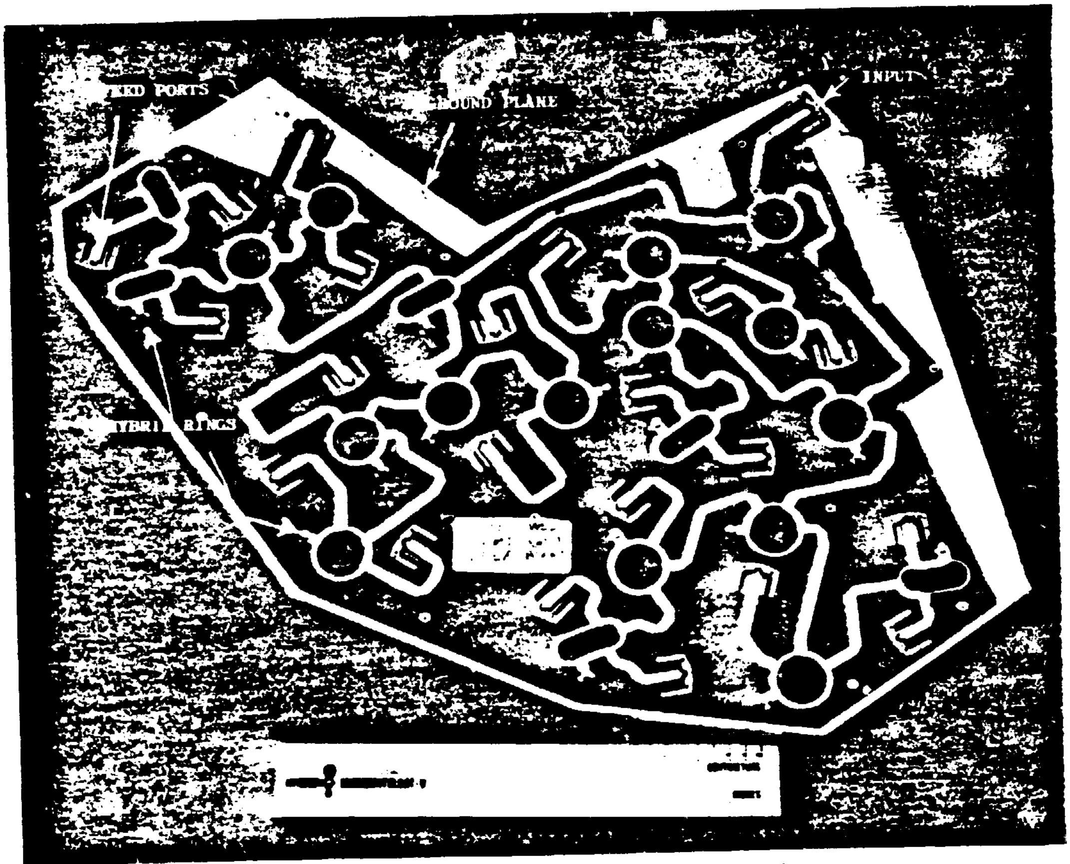


INTELSAT V antenna configuration.



INTELSAT V communication antennas (engineering model).

Figure 5-58



INTELSAT V west-hemi transmit feed network.

Figure 5-59

Future broadcast satellites will undoubtedly require even more complex antennas, including such features as reconfigurability - the ability to adjust beam shapes on command, to meet changing user requirements or to avoid interference.

To explore some of the detailed requirements of future systems, consider a six-beam reconfigurable case*. For 1° constituent beams, an antenna system with perhaps 256 beams is usable, by eliminating coverage in unused areas such as over oceans. Reconfigurability could be implemented by a BFN composed of a matrix of cascaded variable power dividers (VPD's). Full flexibility for each of the six beams would require six BFN's with 255 VPD's in each, cascaded in eight levels, plus 256 six-way switches (one at each feed element to select the beam to which it is assigned), plus 256 phasers to control excitation phases, as pictured in Figure 5-60. This would entail a total of 1530 VPD's and 1536 switches and phasers; if each weighed only an ounce the total BFN would be over 200 lbs, including interconnections. In addition, its losses would represent a considerable waste of power, as projected in Table 5-47. Naturally, these losses as well as the size and weight of the BFN can be reduced by simplifying the design, at the expense of some system flexibility. However, it appears attractive to look at an alternate form for the BFN - an active BFN, similar in principle to a phased array with separate amplifiers at each antenna element.

The receiving portion of the MBA should preferably be a separate structure to avoid diplexing at each feed element, and to reduce filtering requirements by providing at least 50 dB of spatial isolation. The form of the receive portion of an active MBA is pictured in Figure 5-61; it is similar to the transmit, with low-noise preamplifiers in place of power types. Characteristics of available preamplifiers are listed in Table VI for the bands of interest. GaAs FET's

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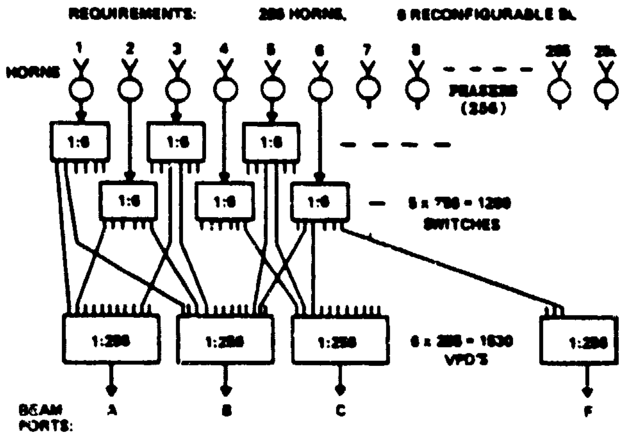
* Dr. W. Matthews, C. L. Cuccia, M. Rubin, FACC.



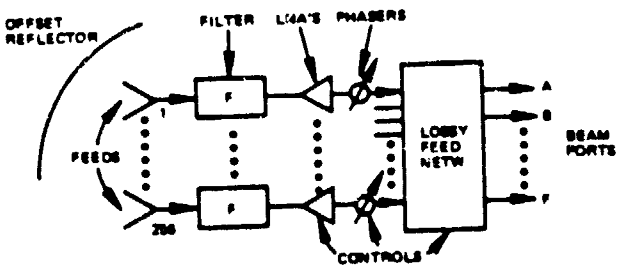
Completely flexible six-beam BFN.

Figure 5-60

PROJECTED 256-BEAM BFN LOSSES

Band, GHz	4/6	11/14	20/30
VPD loss (8), dB	1.6	2.4	3.6
Switch losses, dB	0.5	0.8	1.2
Phaser loss, dB	0.4	0.5	0.8
Connection loss, B	0.5	0.8	1.2
Total loss, dB	3.0	4.5	6.8

TABLE 5-47



Active receive MBA.

Figure 5-61

are usable in all bands, but the 30 GHz band may use direct mixers with slightly poorer noise, to allow the BFN to be built at C or X band.

The receive BFN could incorporate 256 preamplifiers, one at each feed element, or powers from pairs could be combined to reduce the number of amplifiers to 128. Their power consumption is so low that size and weight considerations would probably prevail, as well as the flexibility of individual element phase control.

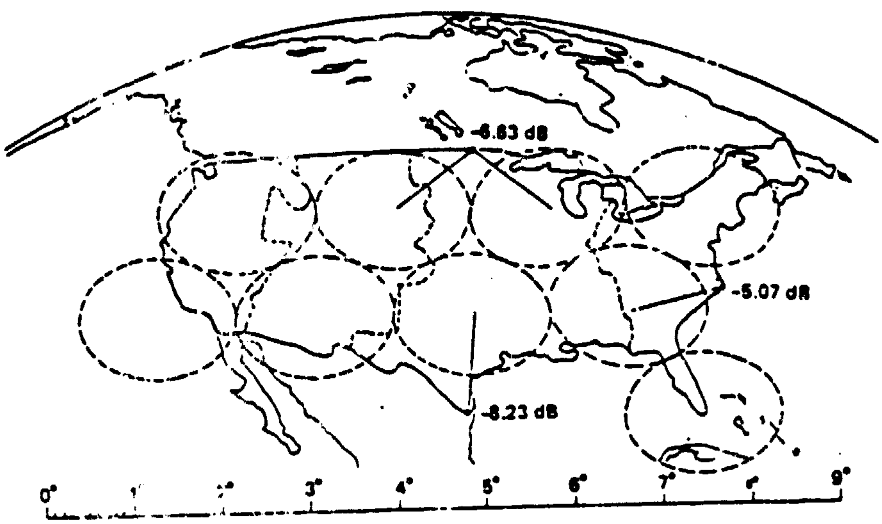
Filtering to suppress the transmit signals to an acceptable level should require only 60-dB rejection. Filters of the same type as transmit will be usable, with 3 of 4 sections. Phasers and VPD's will also be similar, with slightly higher losses. The same linearity and stability requirements will apply, especially if any signal cancellation techniques are to be used for interference suppression.

5.6.6.1.8 The Multiple Beam Footprints on Earth - Introduction to Pointing Accuracy

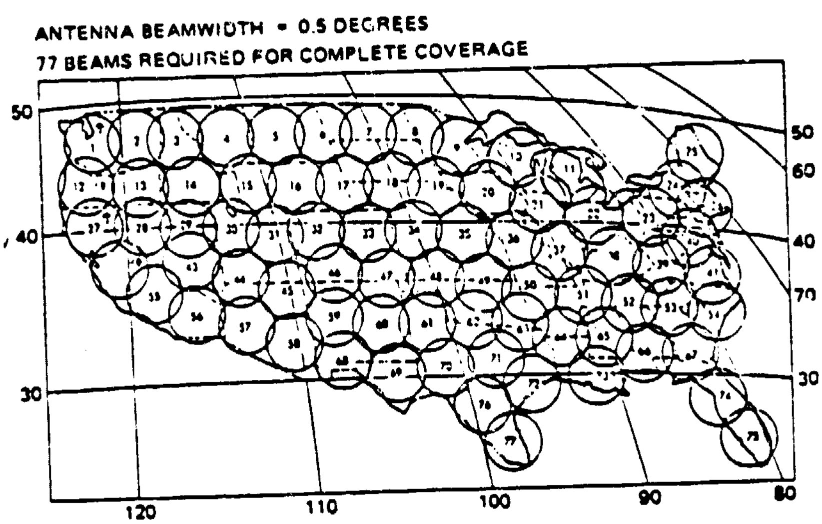
Each of the horns of a multiple beam antenna produces an essentially circular spot beam; the super position of these beams then - in a simplistic approach - produces the desired overall contour.

Figure 5-62 shows how nine circular 1.5-degree beams can cover the United States - or how 77 0.5-degree beams can accomplish the same coverage (with far less illumination ripple). Figure 5-63 shows essentially one of the 0.5-degree beams illuminating the Washington DC area with its boresight axis centered into Maryland. Figure 5-63 also shows how the beam power drops off as a function as a distance away from boresight axis.

Actually, the shape of the earth makes a circular spot illumination impossible except onto the equator from a point directly over-head. Figure 5-64 shows how



Multiple Spot Beam Coverage of the U.S. by Nine 1.5° Circular Beams



Multiple Beam Coverage of the U.S. by 77 0.5° Circular Beams

Spot Beam Illumination of the U.S. by the ATS-6 0.34° Spot Beam Moved to Six Positions

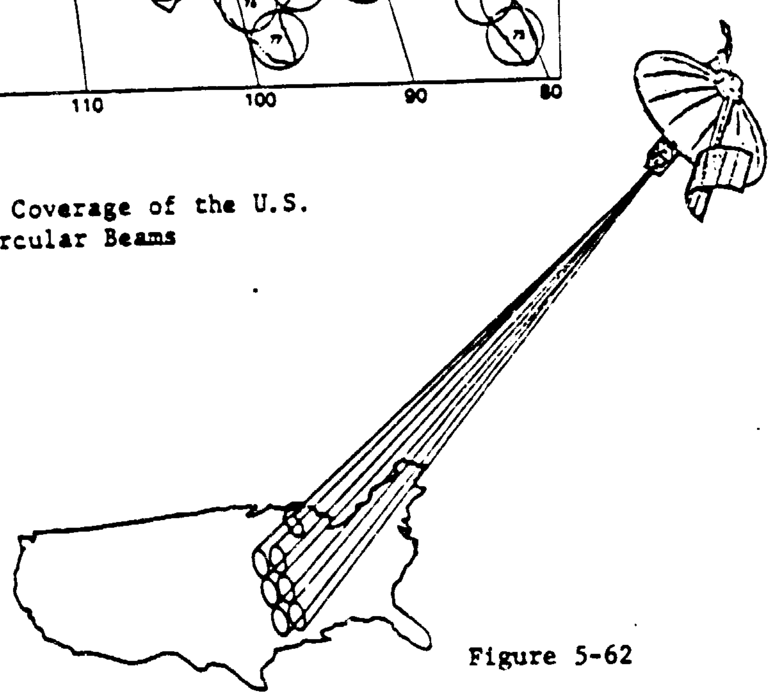
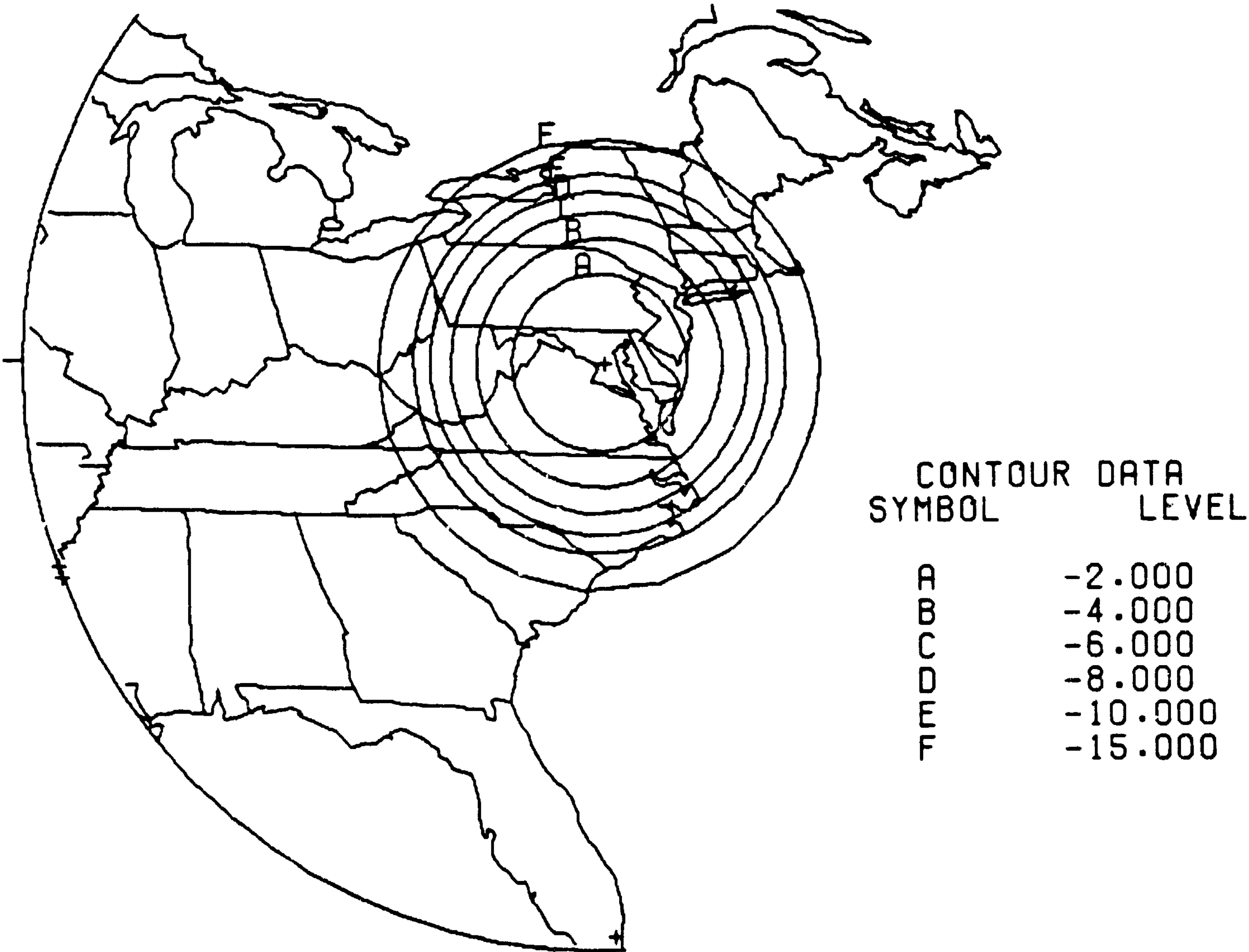


Figure 5-62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SYMBOL LEVEL
A -2.000
B -4.000
C -6.000
D -8.000
E -10.000
F -15.000

Figure 5-63

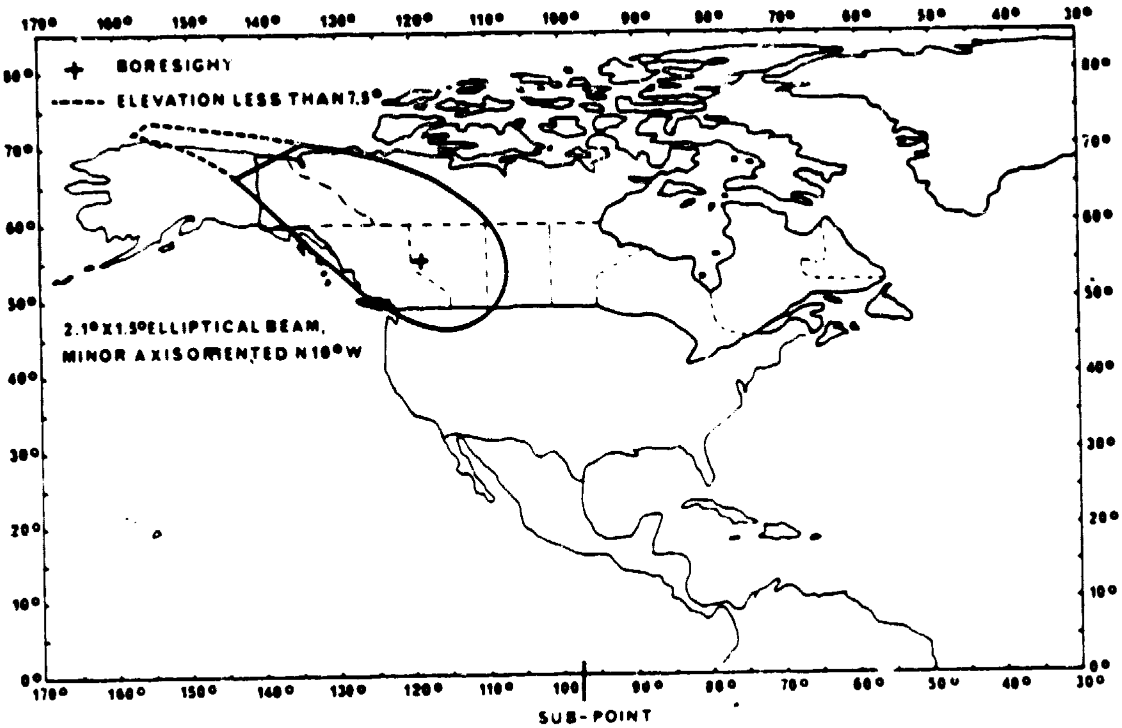


Figure 5-64. Example of coverage pattern

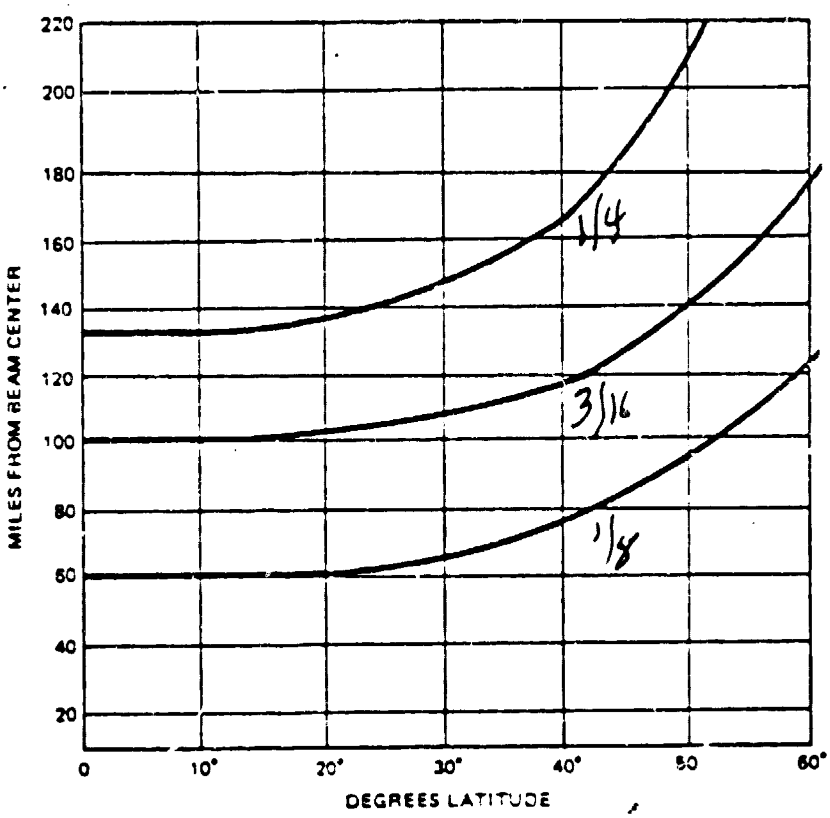


Figure 5-65
Distance North from Beam Center to the 20-dB Power Reduction Point of an Antenna Having the Beam Pattern
The Distance East or West Will be the Same as the Distance at 0° Latitude

a contour will elongate away from the direction of boresight, with the distance elongating according to the nominal curves of Figure 5-65 for three beamwidths as a function of latitude.

Table 5-48 shows the width in miles of a satellite footprint (circular) at the equator from a satellite directly overhead. Note that a spot beam with a 0.5 degree 3-degree beamwidth will have an illumination width of 190 miles.

Table 5-49 shows that a shift of 0.1 degree of the boresight axis will result in a shift of the footprint by 38 miles. This may be trivial for a very wide footprint, but for a set of narrow beam footprint designed to provide a rapid power-flux-density fall-off to a neighboring contoured beam, this movement may be enough to produce major interference into the edge of the neighboring area.

TABLE 5-48

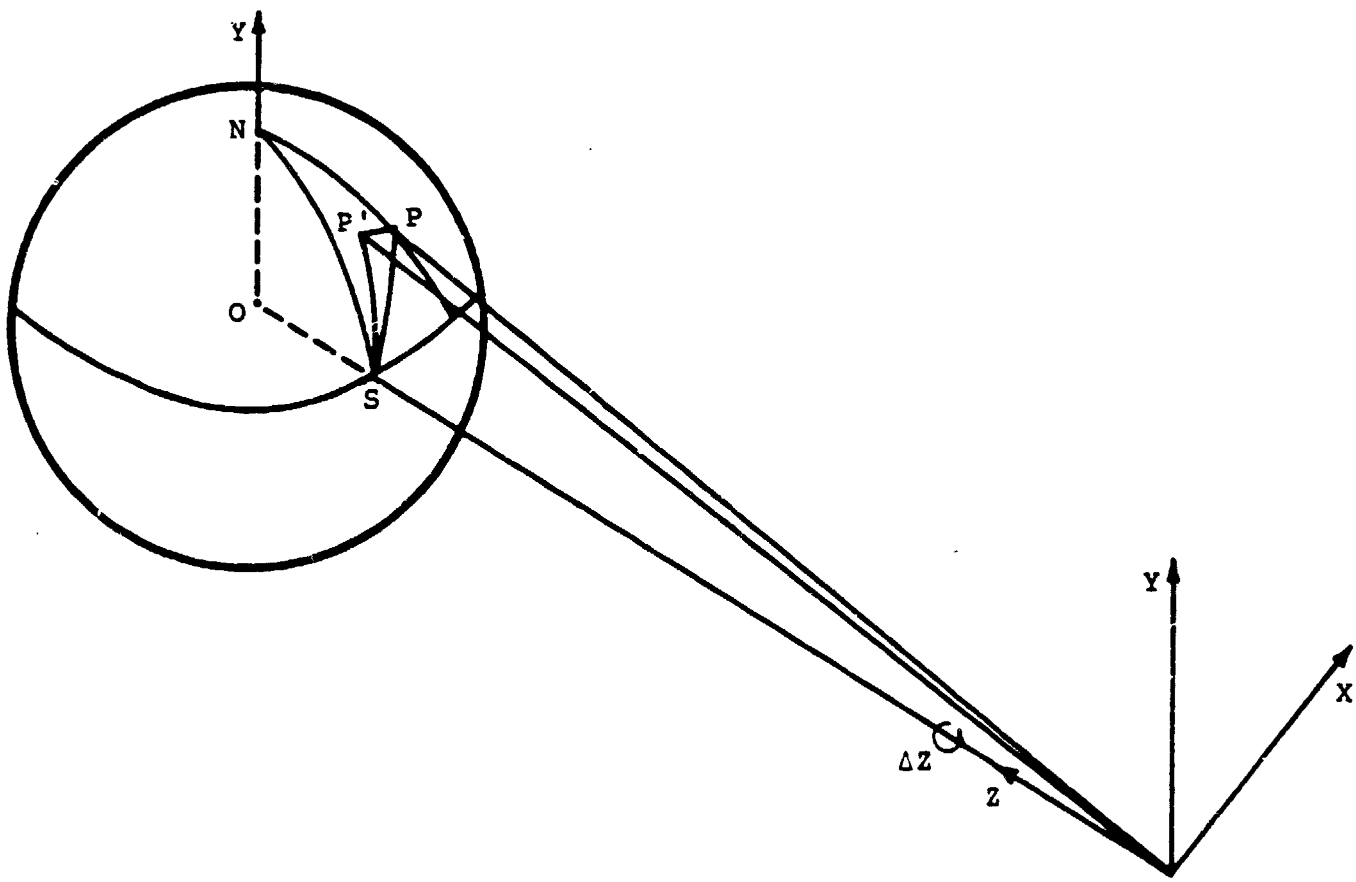
Width of a Satellite Footprint at the Equator from a Satellite Directly Overhead

Circular Spot Beam 3-dB Beamwidth	Width in Miles of Circular Footprint
4°	1536 miles
3°	1152 miles
2°	768 miles
1°	384 miles
0.5°	190 miles
0.4°	153.4 miles
0.3°	115.2 miles
0.2°	76.8 miles
0.1°	40 miles

TABLE 5-49

Boresight of a satellite spot beam in miles on earth due to a beam pointing error - of a satellite positioned directly over the equator

Beam Pointing Error	Motion in Miles of Beam Boresight
2^{o}	768 miles
1.5^{c}	576 miles
1^{o}	384 miles
0.5^{o}	192 miles
0.25^{o}	95 miles
0.2^{o}	76.7 miles
0.15^{o}	57.6 miles
0.1^{o}	38.4 miles
0.05^{o}	19.2 miles



Pointing error due to yaw axis error

Figure 5-66

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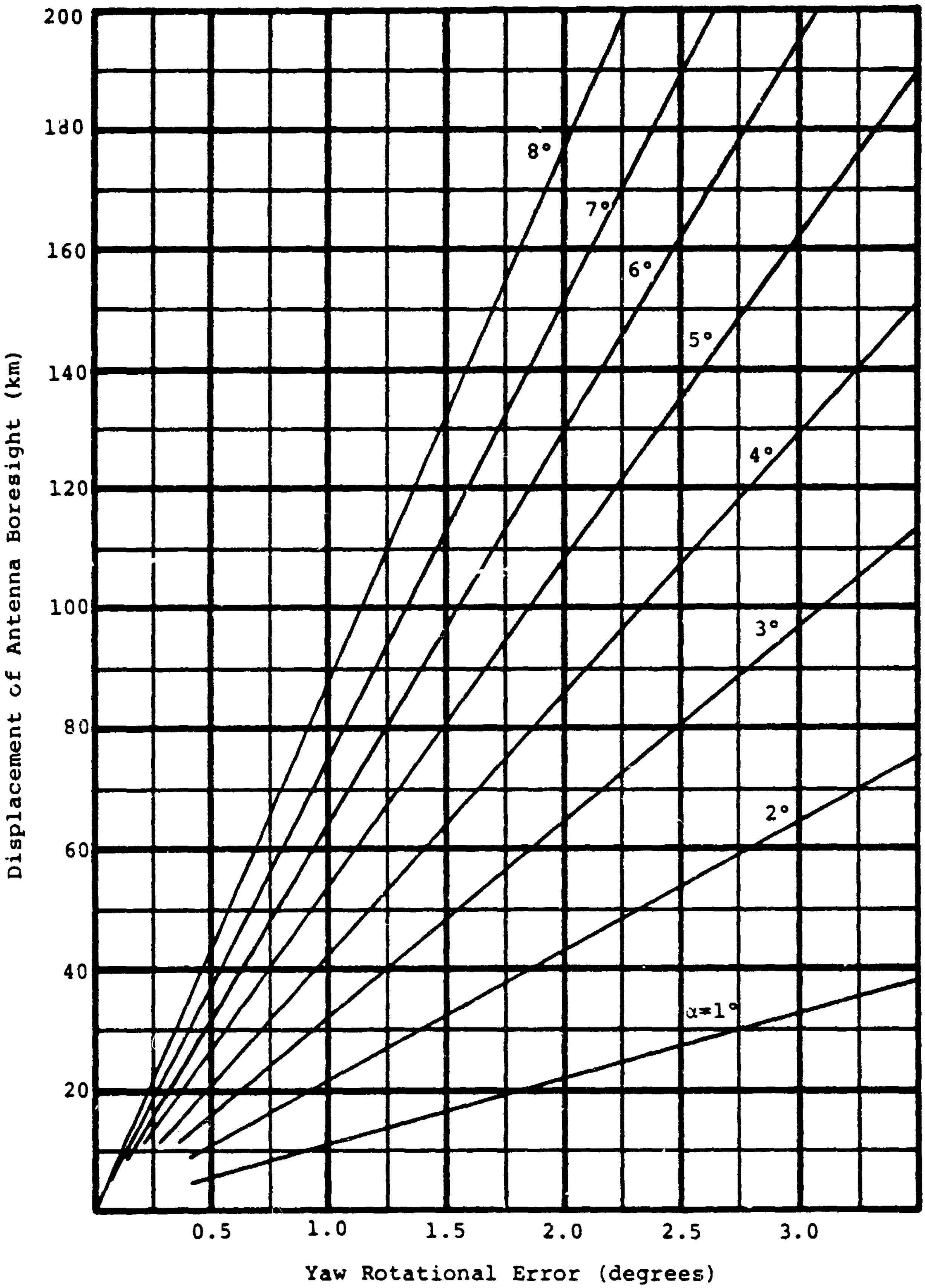


Figure 5-67. Displacement of boresight vs yaw rotational error

5.6.7 Satellite Attitude Control Technology

Having explored the extent of beam motion as a result of a shift in boresight axis, it is now important to consider the primary parameter for maintaining satellite position to minimize such a shift; i.e., the satellite pointing accuracy which is based on a technology which has expanded over the years as much as even the technology of antennas or amplifiers.

According to USSG IWP 4/1-12 (8 April 1980), prior to WARC-79, satellite antenna pointing tolerance was specified in the Radio Regulations in paragraph 470VF. It was specified, relative to the nominal pointing direction, as 10% of the half power beamwidth, or 0.5 degrees, whichever was greater. For beams which are not rotationally symmetric about the axis of maximum radiation, the tolerance in any place containing this axis was related to the half power beamwidth of that plane. The limitation did not apply to global coverage beams (since pointing is not critical), and was not required to be applied if no unacceptable interference was caused to other systems. The Final Acts of WARC-79 retain the provision of 10% of the half power beamwidth, but reduce the minimum tolerance to 0.3 degrees from 0.5 degrees. No tolerance has been established by the Radio Regulations or by WARC-79 concerning the maximum amount that a beam is permitted to rotate about its axis from its nominal orientation.

Several independent factors contribute to satellite antenna mispointing. In addition to the attitude control of the satellite, thermal distortion of the antenna system and solar radiation pressure affect the pointing independently. In addition, variations in pointing occur over varying periods of time. There are time invariant biases; long period errors due to diurnal orbit variations; short period errors such as jitter and nutation; and transient errors such as those produced during maneuvers. At any given time these effects may combine to increase mispointing, or they may cancel each other out. When determining the overall pointing error which a satellite can maintain, the mathematical method which is used to combine these individual effects will strongly affect the predicted results. These effects can be effectively eliminated by the use of a cooperative groundbased tracking beacon system, in which the satellite antenna is moved in order to precisely track a beacon signal transmitted from the ground, regardless of the satellite attitude. However, such a system adds to system cost.

In the absence of a tracking beacon, other pointing control techniques such as earth-sensor or star-sensor systems can be employed. Because of the effects listed above, the pointing accuracy of satellites so equipped is limited to 0.1 to 0.2 degrees. Tracking beacon systems, such as that which will be used on the Satellite Business Systems (SBS), Palapa B, and Westar B satellites, are able to maintain pointing to within 0.05 degrees; however, requiring the use of such systems on all future satellites would add to their cost and complexity, and in most cases would not provide significantly more interference protection than non-beacon systems. Current domestic/regional satellite antennas, for example, have typical edge of coverage gain slopes of 3 to 5 dB/degree. Thus, if pointing is maintained to within 0.2 degrees, less than 1 dB of gain variation will be observed. The improvements in interference protection to be gained by tightening the tolerance beyond 0.1 to 0.2 degrees are small compared to the higher associated costs.

Beam rotation due to satellite yaw errors, for which no tolerance exists, has a negligible effect on orbit utilization. As an example, consider an elliptical beam with characteristics as defined by the Final Acts of WARC-77. For such a beam, assuming a 3 to 1 ratio or major to minor axis, the gain variation produced by a 1 degree rotation is less than 0.15 dB near the 3 dB contour. For more circular beams, the variation is considerably less. Thus there is no need to impose beam rotation tolerances.

Several satellite design and operational factors which can influence orbit utilization have been discussed, and suggestions have been made as to how tightly they should be controlled such that their interfering effects can be reduced without adding significantly to overall system cost and complexity. The tolerance levels required to achieve the desired goals for stationkeeping and pointing tolerance do not differ greatly from those which must be imposed in any event in order to provide adequate communications system performance. Tigi r tolerances on stationkeeping and pointing than those mandated by WARC-79 are achievable using current technologies, but care must be taken to avoid imposing unreasonably strict requirements which produce little added benefit in increased interference protection.

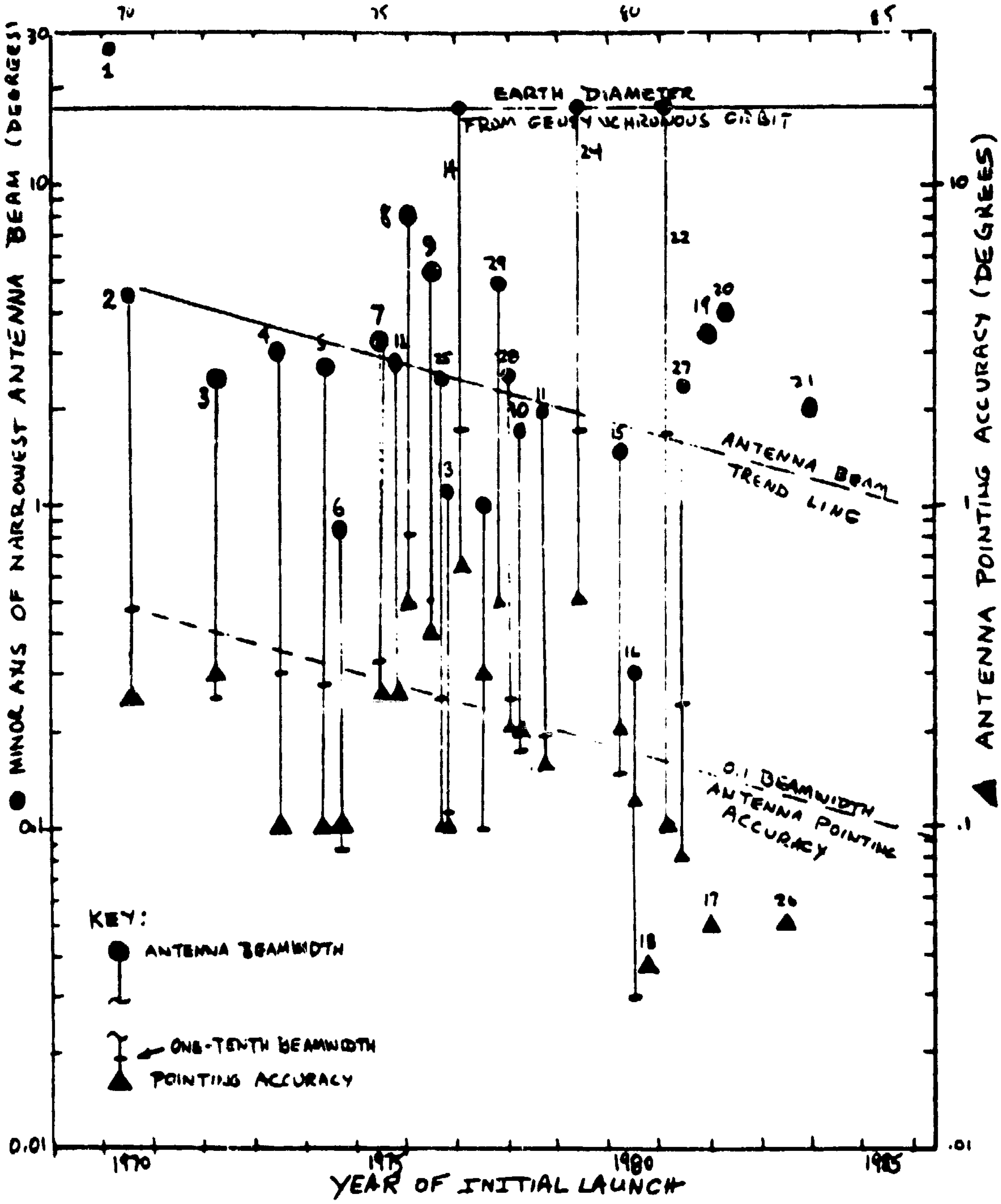
Figure 5-68 shows a chart according to Walter Morgan, which relates antenna pointing accuracy to year of launch, to minor axis of narrowed antenna beam. Here the antenna beamwidths (dots) and the pointing accuracies (triangles) of 29 spacecraft are compared. A vertical line connects these parameters and a horizontal mark is placed at the 0.1° beamwidth point.

Note that while manufacturers and users have claimed 0.1 degree since 1973, a 0.1 degree pointing accuracy is met by only one-third of all spacecraft shown.

5.6.7.1 <u>3-Axis and Spin Stabilized Satellites</u>

The most well known technique of stabilizing a satellite is spin stabilization, which was proposed by Dr. Harold Rosen of Hughes in the early 1960's and first used on Syncom 1. All succeeding Intelsat satellites up to Intelsat IVA are spin stabilized. Intelsat V is 3-axis stabilized.

Spin stabilized satellites are a predominant U.S. capability, although the European Meteosat, which is a spinner, used this technique with great success. Table 5-49 lists the two types of spin stabilized spacecraft, including the single spinner with the rotating antenna on electronically despun antenna or the dual spinner with the despun antenna. The satellites using spin stabilization



1- DCSC-I	11- ANIK-B	21- SATCOL
2- INTELSAT IV	12- SATCOM	22- MAROTS
3- DSCS-II	13- LES-8 & -9	23- CS (SAKURA)
4- ANIK-A	14- MARISAT	24- FLTSATCOM
5- WESTAR	15- INTELSAT V	25- CTS (HERMES)
6- ATS-6	16- TDRS/AW	26- TVBS (Germany)
7- COMSTAR	17- LO-4 (H-SAT)	27- DSCS-III
8- SYMPHONIE	18- SBS	28- OTS
9- NATO III	19- ECS (ESA)	29- SIRIO
10- BSE (YURI)	20- INSAT	

Figure 5-68 (W. Morgan)

TABLE 5-49

WORLDWIDE ACTIVITY IN THE ATTITUDE CONTROL SYSTEMS FOR SPIN STABILIZED SATELLITES

Type	Characteristics	Satellites Used	Comments
Single Spinner	Antenna spins with satellite. Uses momentum of spinning body and antenna for stabilization - requires correction for procession based on position signal from earth and sun sensors.	SMS GOES METEOSAT IDCSP	Using special sensors and sensor logic for control: - Spin type sun sensor - Blipper earth sensor Uses thrusters for precession correction: - Hydrazine - Dry gas - Bi-propellant
Dual Spinner	Antenna is despun and faces earth while body spins. Uses momentum of the body for stabilization Requires thruster correction for procession based on signals from earth and sun sensors	NATO III INTELSAT IVA INTELSAT IV JAPAN CS INTELSAT III ANIK WESTAR PALAPA	Uses spin type earth sensors and spin type sun sensors. Uses mechanical despin drive motor: - Ball Bros. - Ford Aerospace - Hughes Uses thrusters for precession correctives: - Hydrazine - Dry gas - Bi-propellant

are the principal communication satellites in orbit today.

For many years, 3-axis stabilized satellites were a unique U.S. technology but awareness of the rise of such satellites for space platforms led the Europeans to also concentrate on this art to develop what is today a significant 3-axis attitude control capability which is almost at the level of that in the U.S. Table 5-50 lists the important 3-axis stabilized satellites launched in the 1967-1974 time period showing the number of European satellites using this technique including Symphonie.

In this study, the analysis of satellite technology is limited to 3-axis stabilization because of the size of the satellite which must be designed to include the capability of supporting large antennas and of maximizing the percentage of payload mass to dry S/C mass.

The technologies involved in 3-axis stabilization relative to user and country or origin of manufacture are listed in Tables 5-51 and 5-52. Here, it is evident that Europe has developed a significant capability - almost equal to the U.S. - as far as hardware is concerned.

Germany has developed special competence in reaction wheels and both France and Germany have shown competence in momentum wheels. Ford Aerospace and Communications Corporation is presently using the German MBB/Teldix attitude control system on Intelsat V. This German group had already developed attitude control equipment for Symphonie which has an excellent history of stable operation in space.

All attitude control systems for communication satellites using either spin or 3-axis attitude stabilization require various sensors and gyros to perform the stabilization. Table 5-53 lists the various types of sensors and gyros used in space and the manufacturers from whom they can be procured. This list indicates the significant European competence which has been developed in this

TABLE 5-50

IMPORTANT THREE-AXIS STABILIZED SATELLITES LAUNCHED IN 1967-1974

Spacecraft	Launch Date	Mission/Comments
OGO-4	July 28, 1967	Exceeded expected lifetime; stabilized without gas by dumping stored momentum from reaction wheels.
OGO-5	March 4, 1968	Demonstrated excellent three-axis stabilization in intended highly elliptical (180/91, 260 miles) orbit; achieved 52 months operational life.
OAO-2	December 7, 1968	Three-axis gyro stabilization in addition to OAO-1 ADCS. Demonstrated 30 arc-seconds pointing accuracy.
Nimbus 3	April 14, 1969	Demonstrated 36 month life; first day and night weather measurements.
Azur 1	November 8, 1969	German satellite, stabilized by elliptical bar magnets.
ITOS 1	January 23, 1970	Improved TIROS meteorological satellite; three-axis stabilized to 1°; exceeded design life.
Nimbus 4	April 8, 1970	Still operational.
PEOPLE 1	December 12, 1970	French; gravity gradient stabilized.
TD-1A	March 12, 1972	French scientific satellite in polar orbit; inertia wheels and gas jets.
Landsat A	July 23, 1972	Earth Resources Technology Satellite-1; still operational (45 months -- vs. 12 months design life.)
OAO-3	August 21, 1972	4,900 lb. spacecraft named Copernicus. Achieved 0.1 arc-sec pointing accuracy.
TIP-1	September 2, 1972	Transit navigational satellite with passive sensors, momentum wheels and gravity gradient.
NOAA-2	October 15, 1972	ITOS-D; operated 25 months (12 months design life).
Nimbus 5	December 11, 1972	Still operational.
Aeros 1	December 16, 1972	German
Transit	October 30, 1973	Gravity gradient stabilized; no other sensors.
NOAA-3	November 11, 1973	ITOS-F
UK-X4	March 9, 1974	United Kingdom satellite called Miranda; ACDS designed to demonstrate 3 arc-min. accuracy with only gas jets, horizon and star sensors.

TABLE 5-51

IMPORTANT THREE-AXIS STABILIZED SATELLITES LAUNCHED IN 1967-1974 (Continued)

Spacecraft	Launch Date	Mission/Comments
ATS-6	May 30, 1974	Large (3090 lbs and 26 ft. high) communications satellite with 30 ft diameter antenna reflector; still operational.
Timation 3	July 14, 1974	Gravity gradient and momentum wheel stabilization.
Aeros 2	July 16, 1974	German
ANS	August 30, 1974	Dutch satellite; First Scout launched satellite to be three-axis stabilized.
NOAA-4	November 15, 1974	ITOS-G with momentum fly wheel stabilization; still operational.
Symphonie 1	December 19, 1974	French/German communication satellite using momentum fly wheel stabilization.

TABLE 5-52

WORLDWIDE ACTIVITY IN ATTITUDE CONTROL SYSTEMS FOR BODY STABILIZED COMMUNICATION SATELLITES
(ZERO MOMENTUM)

Characteristics	Actuator	Function	Typical Use	Typical Manufacturer	Manufacturing Company
	Reaction wheel	To correct errors in satellite pointing	LANDSAT Japan BSE NIMBUS	Teldix Bendix Sperry	Germany U.S. U.S.
Body has no residual momentum	Thruster - Hydrazine (most used) - Dry gas - Bi-propellant - Ion propulsion	Unloads reaction wheel to do gross corrections	Virtually all satellites	Aerojet-General Thiocal Martin Marietta SEP	U.S. U.S. U.S. France
	Magnetic torque including magnetometer	Unloads reaction wheel without using thrusters	RCA SATCOM ESRO II	RCA MATRA - Cruzet } Magnetometer - Time-Zero } Magnetometer - Develear } Magnetometer	U.S. France France U.S. U.S.

TABLE 5-53

WORLDWIDE ACTIVITY IN ATTITUDE CONTROL SYSTEMS FOR BODY STABILIZED COMMUNICATION SATELLITES
(MOMENTUM BIAS SYSTEM)

Characteristics	Actuator	Function	Typical Use	Typical Manufacturer	Manufacturing Company
Form of dual spinner Uses momentum wheels to stabilize	Fixed momentum wheels	To correct errors in pointing	INTELSAT V Symphonie OTS	Teldix Bendix Sperry Matra Aerospatiale	Germany U.S. U.S. France France
Momentum bias can be used to avoid using star trackers and rate integration gyros	3-axis orthogonal momentum wheels	Corrects error in satellite pointing	TD-1	Matra	France
	Gimbaled momentum wheels	Corrects errors in satellite pointing	LES 8, 9	Lincoln Labs	U.S.
	Reaction wheels	Corrects errors in satellite pointing	LANDSAT Japan BSE NIMBUS	Teldix Bendix Sperry	Germany U.S. U.S.
	Thrusters	Unloads reaction wheel or momentum wheel	Virtually all satellites	Aerojet-General Thiocal Martin Marietta SEP	U.S. U.S. U.S. France
	Magnetic Torquing	Unload momentum wheels	RCA SATCOM ESRO II	RCA MATRA - Cruzet - Time-Zero - Develear Magnet-ometer	U.S. France France U.S. U.S.
	Nutation Damper	Provides passive attitude correction	ESRO-II METEOSAT	Aerospatiale Matra	France France

TABLE 5-54

WORLDWIDE ACTIVITY IN SENSORS USED FOR ATTITUDE CONTROL SYSTEMS

Type Sensor	Vendor	Country
Earth Horizon Sensor	Marconi	U.K.
	Lockheed	USA
	Barnes	USA
	TRW	USA
	Quantic	USA
	Sodern	France
	Galileo	Italy
Slipper Spinning Earth Sensor	Lockheed	USA
	Barnes	USA
	Sodern	France
Sun Sensor	Ball Bros.	USA
	Atcol	USA
	Sodern	France
	Matra	France
	Bendix	USA
	Minneapolis Honeywell	USA
Star Tracker for Yaw Axis Reference	Ball Bros.	USA
	Kollsman	USA
	Cole-Morgan	USA
	Northrup	USA
Star Mapper Sensor	Ball Bros	USA
	Matra	France
	Bendix	USA
	Minneapolis Honeywell	USA
Rate Gyro and Rate Integration Gyro (For determining position from a known position)	Minneapolis Honeywell	USA
	Nortronics	USA
	Singer-Kearfott	USA

area. One area, not shown, is the logic circuits to operate with these sensors; here, Japan has developed a significant competence in competition with the U.S. and Europe.

There are many who believe that the era of the spin stabilized satellite is nearing an end with the increased number of 3-axis satellites being designed in Europe (OTS, ECS, H-Sat), U.S. (Satcom, IDRSS, Intelsat V) and Japan (BSE, ETS-III). However, Hughes has capitalized on its spin-stabilized satellite experience with drastic reduction of non-recurring costs by winning new contracts for SBS, ANIK C, Anik D, GOES D, E, and F, Palapa B and Bellstar, and Marisat, and is building a giant spinner, LEASAT, which is compatible with Shuttle launch thereby adapting spin-stabilized satellites to the Shuttle era.

5.6.7.2 Pitch Roll and Yaw

In order to understand attitude control technology for both spin stabilized and 3-axis satellites, it is necessary to understand the parameters which are used to define pointing accuracy; i.e., pitch, roll, and yaw of a spacecraft. Figures 5-69, 5-70, and 5-71 show respectively, these parameters which are defined in Table 5-55 and illustrated in Figure 5-72. (Due to W. Morgan).

Table 5-56 is a listing of the antenna pointing control parameters attributed to several spacecraft - both spinners and 3-axis.

5.6.7.3 The Attitude Control Subsystem

The attitude control subsystem provides active stabilization for the spacecraft (Figures, 5-73, 5-74, 5-75). In transfer orbit, the spacecraft is spin-stabilized by means of active nutation control electronics, which operates the propulsion subsystem. Attitude determination is derived from earth sensors and sun sensor data which is processed by the attitude determination and control electronics (Table 5-57).

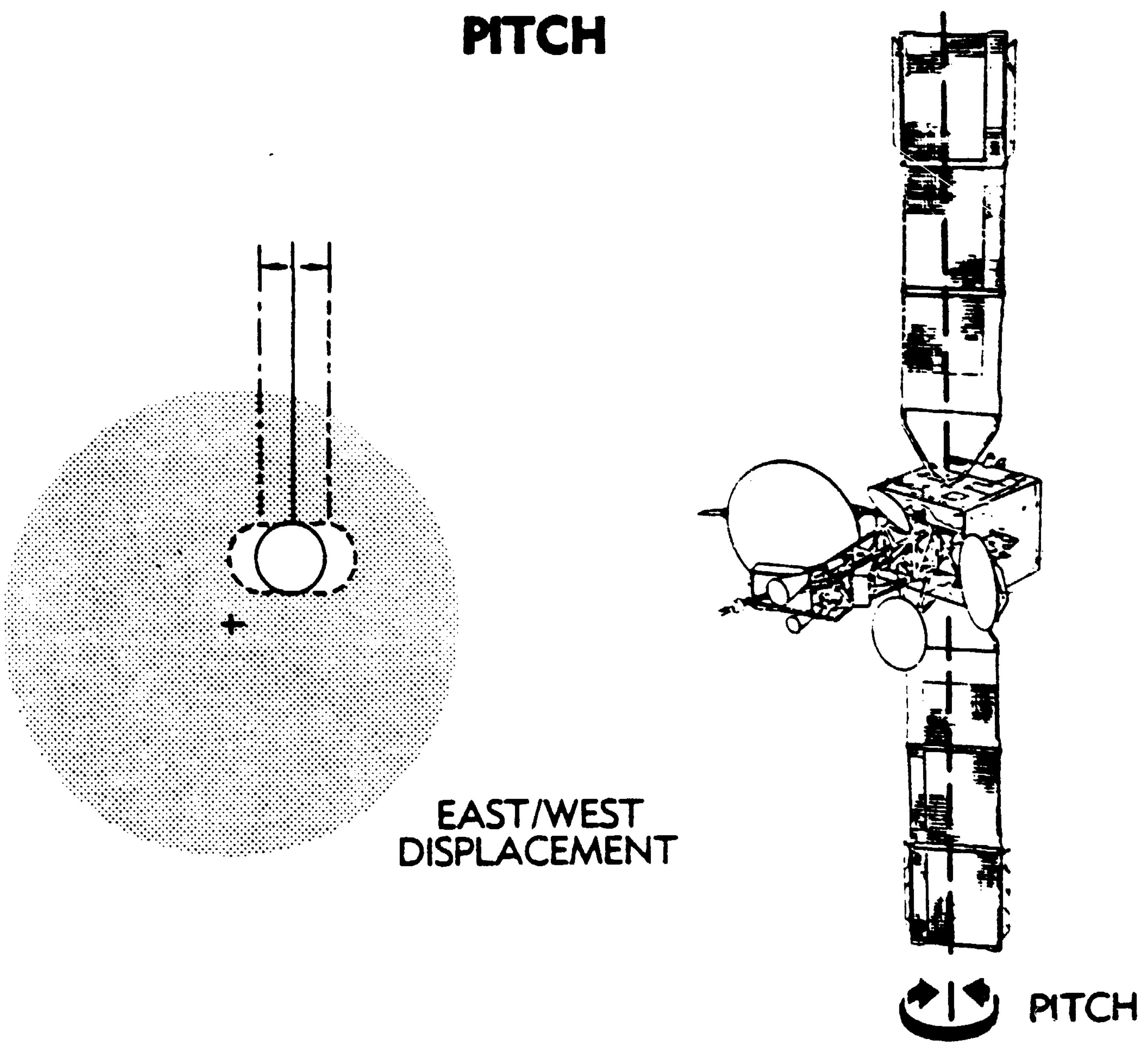


FIGURE 5-69

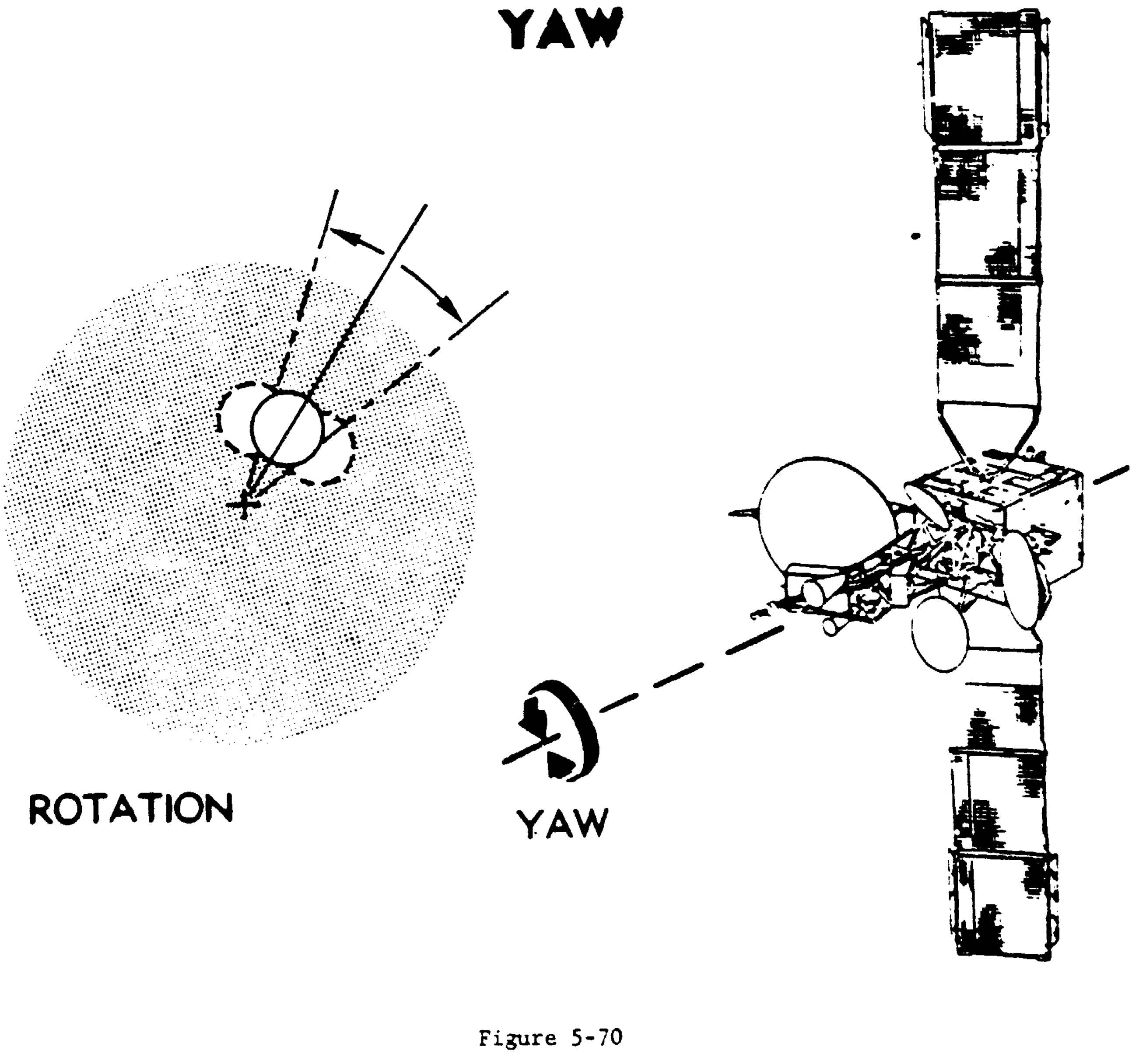


Figure 5-70

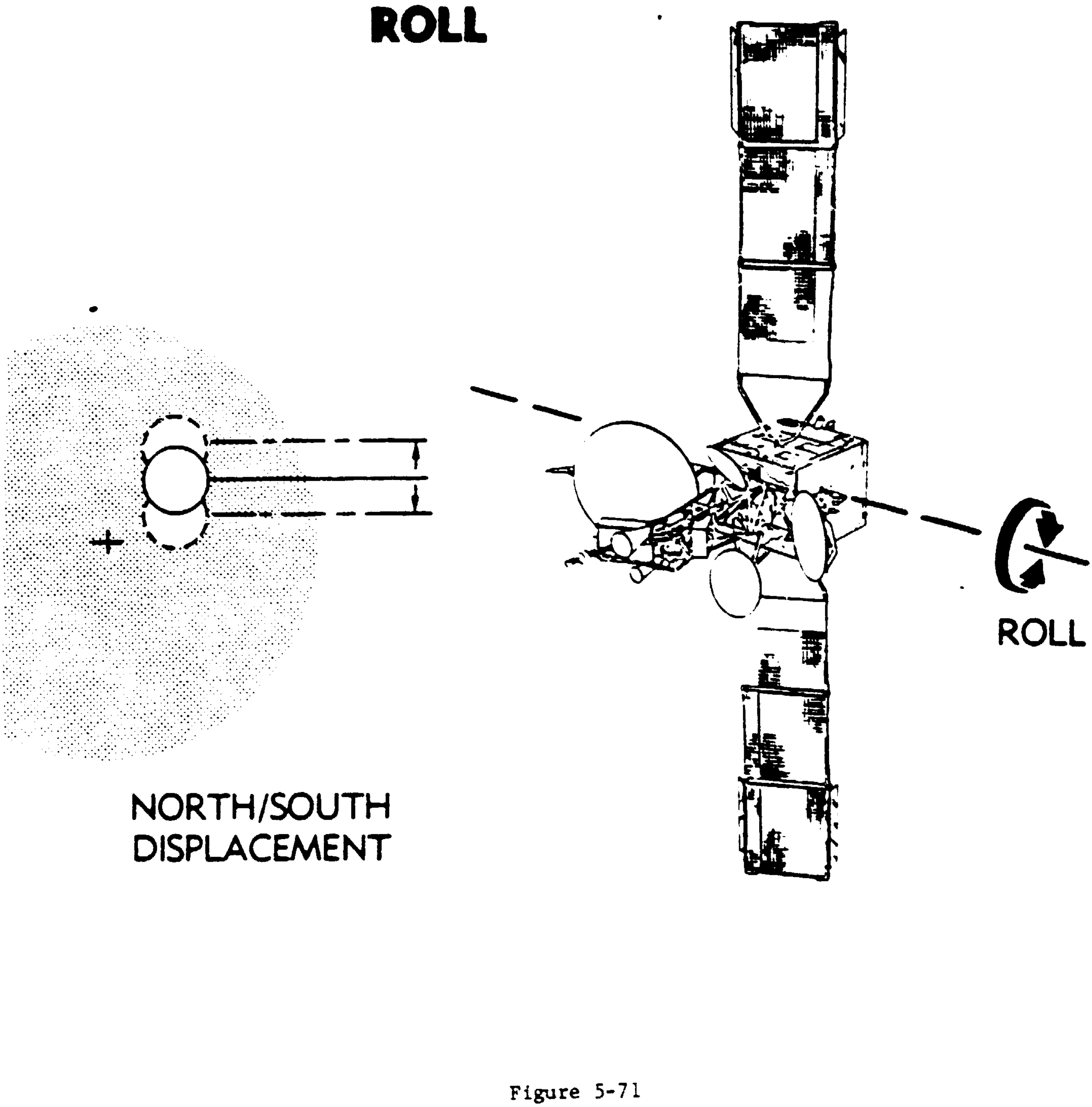


Figure 5-71

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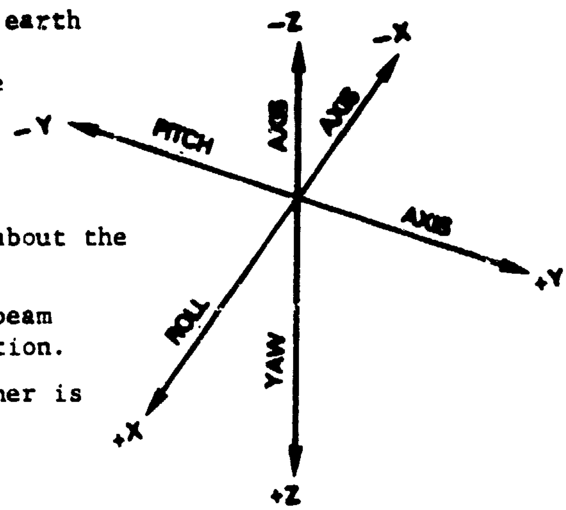
TABLE 5-55

Attitude Control Axes (Definition)

The three axis used in a satellite. The pitch, roll and yaw axes - when the satellite is in use, the earth is in the +Z direction, orbit motion is in the X direction, lines X-Z lie in the orbit plane while Y is the orbit normal vector (North-South Axis).



PITCH

- The pitch axis is defined here as a rotation about the North-South (orbit normal) axis.
- This results in a translation of the nominal beam position (solid circle) in an East-West direction.

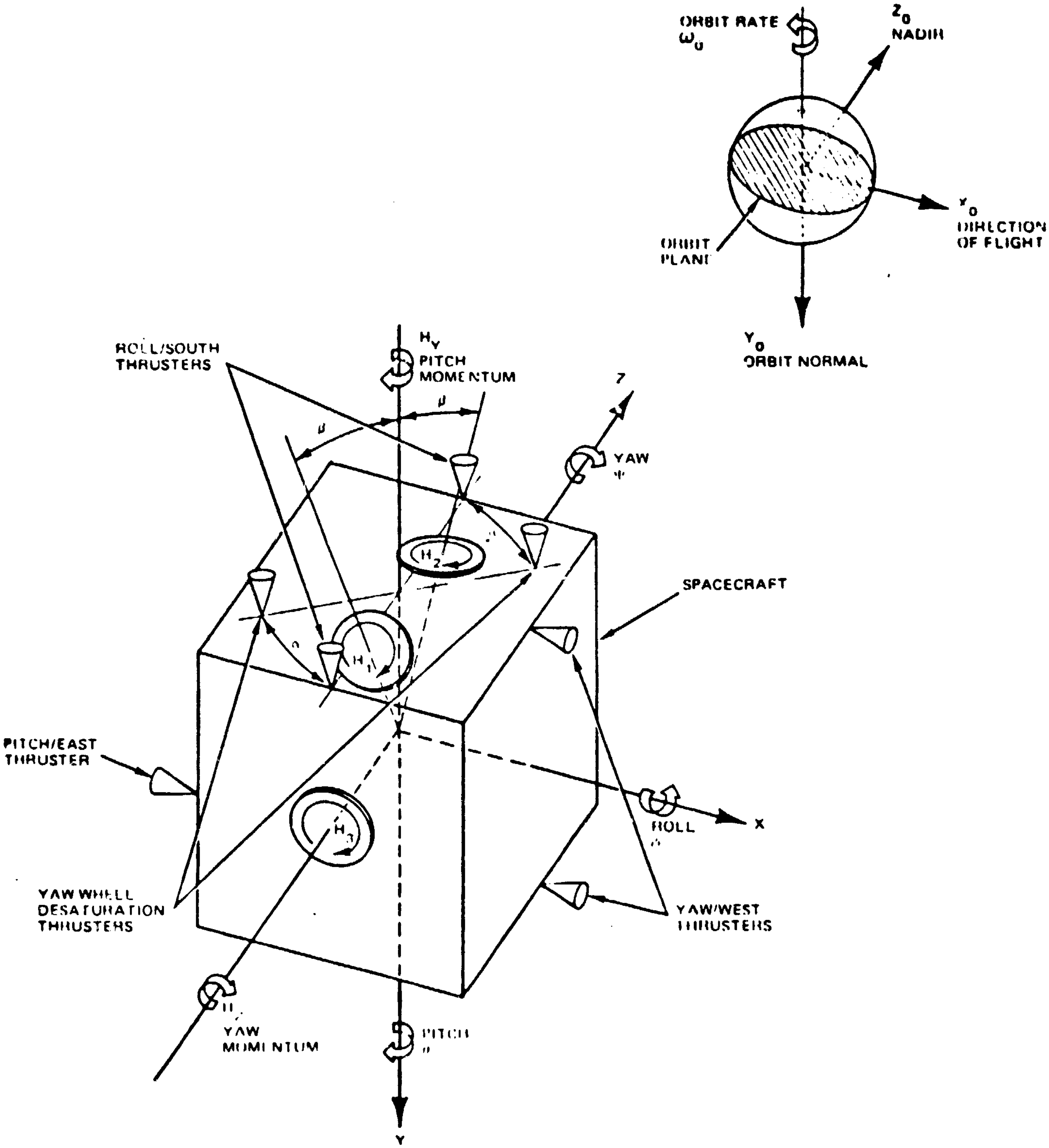
(Note: This is one of two axis systems -- the other is derived from the motion of an aircraft).

ROLL

- The roll axis lies in the flight direction.
- The antenna beams are translated in a North-South direction.
- As the satellite goes through its 24-hour orbit any pitch error becomes translated into an equal magnitude roll error six hours later. In six more hours it reverts to the pitch error.
- The pitch and roll errors are (360/18) times as important as a yaw error due to the limited field (18 degrees) occupied by the earth.

YAW

- The yaw error is caused by a rotation about the local vertical (the line joining the satellite to the center of the earth through the sub-satellite point on the earth's surface).
- If only one beam is used and it is centered on the sub-satellite point the influence of a yaw error would be zero if circular polarization was used. For off-sub-satellite beams (see Figure) the yaw error represents a rotation.
- Much greater yaw errors can be tolerated in even these cases than for the pitch/roll errors.



5-72

Figure 5-72. Spacecraft Coordinates and Orientation of Control System Components

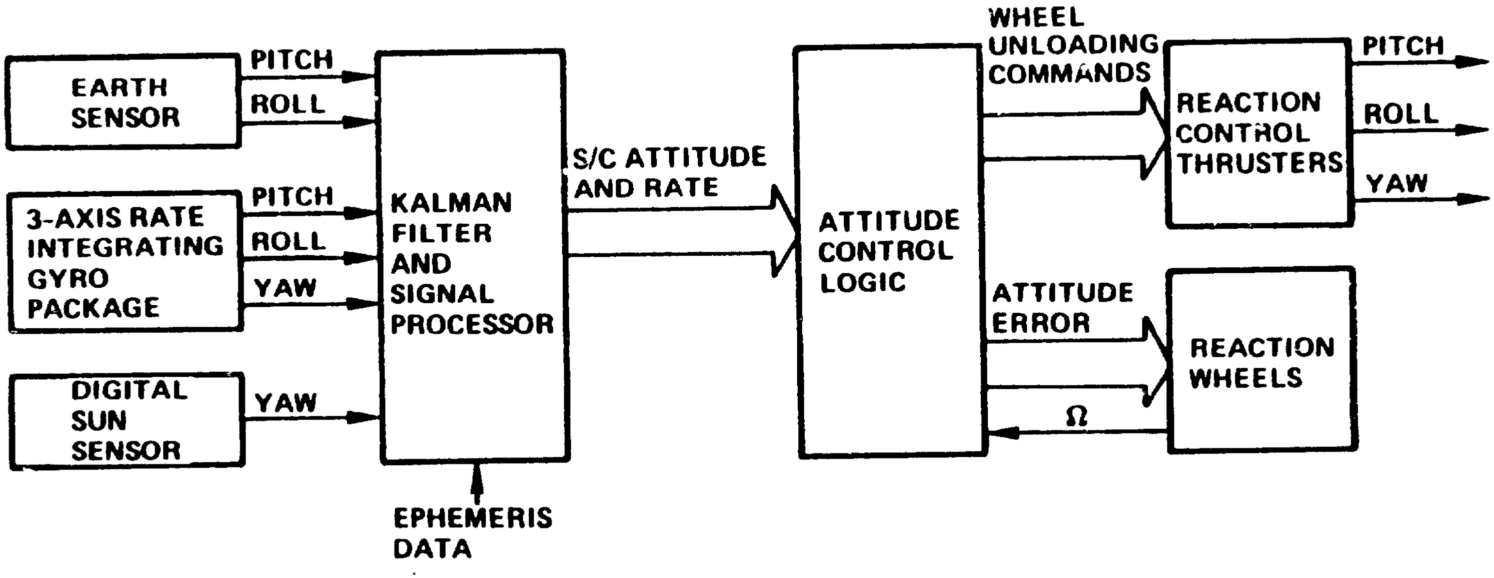
TABLE 5-56

ANTENNA POINTING CONTROL

	Roll	Pitch	Yaw
INTELSAT IV - Digital Modes	±0.33	±0.2	--
INTELSAT IVA, COMSTAR Analog - Analog Earth	±0.197	±0.185	--
INTELSAT V - 6 GHz Ant.	±0.15	±0.2	±0.46
INTELSAT V - 4 GHz	±0.14	±0.14	±0.41
Anik	±0.134	±0.169	--
RCA Satcom	±0.19	±0.21	--
NATO III	±0.247°	±0.246°	--
CS	±0.143°	±0.222°	--
ETS II	±0.40°	±0.346°	--

Figure 5-73

ACS SIMPLIFIED BLOCK DIAGRAM



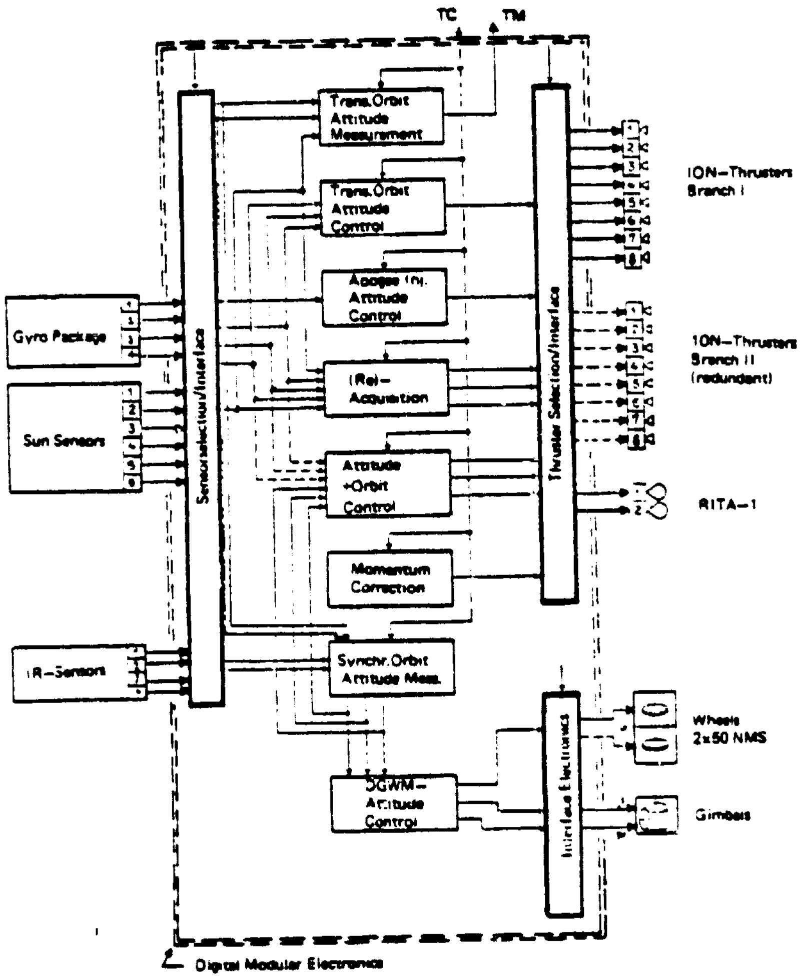


Figure 5-79. Attitude Control System of TV-SAT by MBB

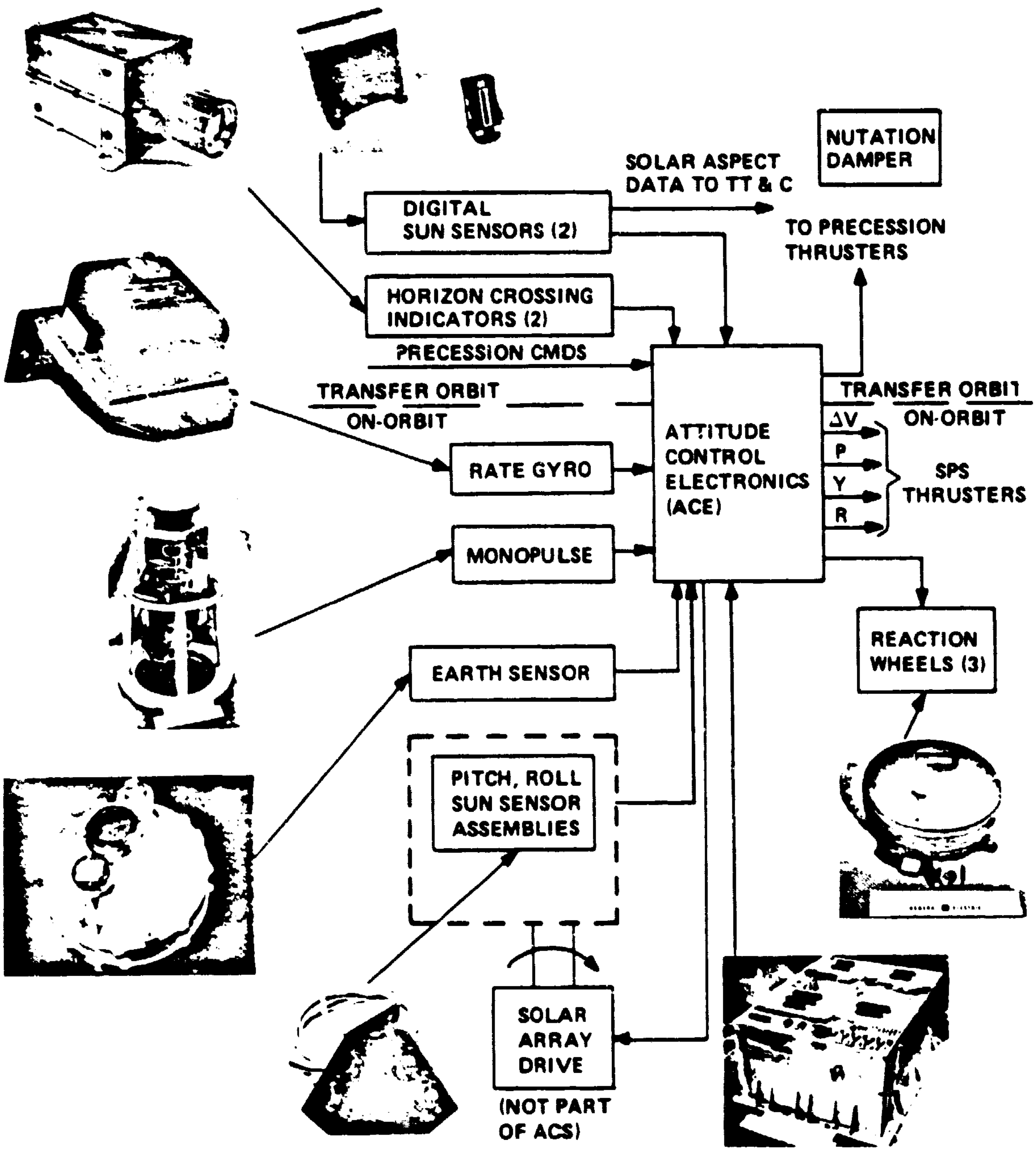


Figure 5-75. BSE Attitude Control System by G.E.

TABLE 5-57

Attitude Control Subsystem Component Complement & Functions

Transfer/Injection Mode	Function	On-Orbit Mode	Function
Digital Sun Sensor	Generate Solar Aspect Data & Sun Reference Pulse	Earth Sensor	Generate earth referenced Error Signals
Horizon Crossing Indicator	Detect Space/Earth Boundary	Monopulse	Generate RF Beam Referenced Error Signals
Nutation Damper	Damp nutations	Analog Sun Sensor Assy	Generate Sun Referenced Error Signals
		Reaction Wheels	Generate Control Torques, Store Cyclic Momentum
Control Electronics	Process Signals	Control Electronics	Process Signals
		Rate Gyro Package	Generate Rate Error Signals

After injection into synchronous orbit, the spacecraft is despun and the solar arrays and antenna reflectors are deployed. The spacecraft roll axis is aligned to the sun line by firing hydrazine thrusters (Figure 5-76). The spacecraft rotates about the roll axis until the earth is viewed by the geostationary earth sensors, at which time the spacecraft is locked onto the earth by switching the ADCE to stationkeeping mode when the pitch axis is parallel to the earth spin axis. Finally, one of the redundant pair of momentum wheels is spun up.

In the normal on-station mode, pitch control is maintained by momentum bias. The momentum wheels operate at 3500 r/min and provide nominally 35 newton-meter-seconds of stored momentum. Roll and yaw control is provided by firing small hydrazine thrusters. Three geostationary infrared sensors provide earth reference data: two redundant earth sensors scan the earth east-west (E-W); a third redundant earth sensor scans the earth north-south (N-S). To allow re-pointing of the spacecraft for antenna pattern measurement, a pair of E-W and N-S scanning earth sensors are used to provide a wide field of view.

For given mission duration, the fuel required to execute full N-S stationkeeping represents 15-20 percent of the useful satellite mass if a conventional hydrazine system is employed. According to Collette and Herdan, it is possible to reduce this fuel mass by one of the two following ways: 1) suppression of N-S stationkeeping requirements, where this is acceptable for the mission; 2) increase of the specific thruster impulse capability.

If stationkeeping can be suppressed, savings in mass result, but one more degree of freedom is needed on-board so that while the spin axis of the momentum wheel stays parallel to the earth axis, the main body of the satellite is sinusoidally nodded once per day around its roll axis to maintain correct antenna coverage. The simplest way to implement this facility is to gimbal the momentum wheel around one axis (parallel to the roll axis of the satellite) and provide

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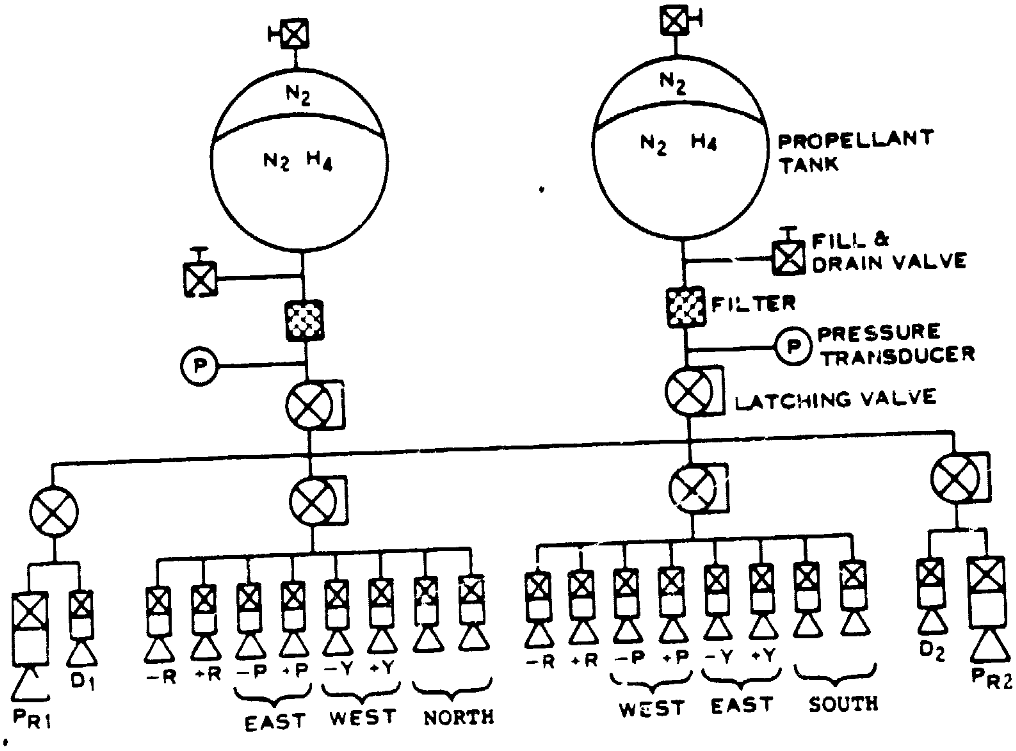

Figure 5-76

stepper motor actuation. Another possibility is to keep the spacecraft attitude constant and not the antenna or antennas on a daily basis, which may be acceptable for a satellite with a single antenna, but becomes impractical for more complex arrangements.

If N-S stationkeeping is essential, methods exist to improve on the specific impulse of conventional thrusters including the use of bi-propellant, power augmented electrothermal hydrazine decomposition, or electrical propulsion thrusters. The specific impulse of the latter is an order-of-magnitude higher than the other and in fact the dry mass of its components, including a high-voltage power supply, represents most of the mass of such a system.

5.6.7.4 Improving Pointing Accuracy

With the use of smaller diameter antenna beams comes the requirement for (1) tighter control on pointing accuracy (variability), and (2) ability to bias antenna position. The bias capability is needed for both pitch and roll to optimize antenna location for different orbit slots and to optimize coverage on station. The latter capability is simply provided by a 3-axis control system or mechanical antenna positioners.

Assuming a 12 GHz antenna pointing requirement on a spacecraft design with a shortest and/or most symmetric feed support structure, the most straight-forward improvement in pointing, by approximately 0.045° in pitch and 0.028° in roll is accomplished, achieved by speeding up the wheel (3500 to 4500 rpm) and introducing more sophisticated control logic in the ADCS. The electronics changes require the addition of a tachometer loop in the pitch wheel regulator and the use of "observer"-type regulators for roll, yaw and pitch station-keeping loops. "Observers" basically estimate the steady-state disturbance torques due to CM shifts and thruster misalignments, and compensate for the associated attitude offsets. (Yaw pointing, though not critical, will tend to improve in proportion to roll - particularly in the normal on-orbit mode).

Consider adding a third momentum wheel (Table 5-58) for improved accuracy, two possible 3-wheel options are available. The simpler and more straightforward would be to add a third identical momentum wheel, and operate the set with two-out-of-three redundancy, (i.e., two wheels would be running at a time). The associated weight penalty is about 10 kg, in return for a roll pointing improvement of approximately 0.03°.

The same improvement can be achieved for a weight penalty of approximately 5 kg by making the third wheel a smaller "reaction-wheel", installed along the yaw axis and driven about a low bias speed. The wheel is driven from a combination of roll sensor and tack signals, and basically allows roll pointing to be continuous (rather than the dead-band type as is done currently). Small angular changes in the mounting of the two baseline momentum wheels would also be required. The resulting trio of dissimilar wheels can still be run with two-out-of-three redundancy. This 3-wheel configuration would require additional roll control electronics.

By including a monopulse tracking or a similar RF sensing technique, pointing in pitch and roll can be improved by about 0.04°. The improvement in the sensor performance alone accounts only for a total (RSS) improvement of 0.01° in each axis. However, the self-referencing of the antenna (single-antenna configuration) eliminates an additional 0.03° in alignment and thermal deformation errors.

With very tight angular pointing requirements design control of structural and thermal deformation of the spacecraft is extremely important. Very slight deformation in the spacecraft, especially if in the neighborhood of an attitude sensor, may result in relatively large errors in the spacecraft's attitude-keeping capability.

TABLE 5-58

3-AXIS ATTITUDE CONTROL CONCEPTS

I PITCH MOMENTUM BIAS (1)

PITCH ROLL ATTITUDE (2) SENSORS	TORQUE ACTUATORS	ATTITUDE P/R	STABILITY (3) Y	REMARKS
EARTH SENSOR (ES)	2-PMW	0.1°	0.25°	• USED ON INTELSA • SIMPLE; LIGHT WEIGHT • POOR ATTITUDE STABILITY
	2-PMW AND 1-R/Y RW	0.05°	0.15°	• INADEQUATE ROLL YAW STABILITY
EARTH SENSOR AND 2-RIG	3-SKEWED PMW OR 2-SKEWED PMW AND 2-R/Y RW	0.002°	0.05°	• HEAVY • MARGINAL YAW STABILITY
MONOPULSE RECEIVER	(ANY OF ABOVE)	(SEE REMARKS)		• REQUIRES DEDICATED GROUND STATION & HIGH GAIN ON-BOARD RECEIVE ANTENNA • BETTER STABILITY THAN OPTION 1. BUT WITH GREATER COMPLEXITY.

PMW = PITCH MOMENTUM WHEEL
R/Y RW = ROLL/YAW REACTION WHEEL
RIG-RATE INTEGRATING GYRO

(1) YAW ATTITUDE SENSORS NOT REQUIRED YAW CONTROL BY ROLL COUPLING (GYRO COMPASSING)
(2) REDUNDANCY NOT INCLUDED
(3) 30 MINUTE PERIOD.

When considering attitude control errors on the order of 0.001°, the overall ability os a satellite to point to a particular location on the surface of the Earth is no longer primarily a function of the attitude control system. Rather, an equivalent contribution of pointing error can be caused by uncertainties in ephemeris data. For example, a pointing uncertainty of 0.001° will produce a pointing error of about ±9 m from a 500 km orbit (Doc. 2/44-E)

Figure 5-77 (due to S. Marx of FACC and Associates) illustrates the above paragraphs in terms of how pointing accuracy improvements for a 6 GHz antenna or a large 1000 Kg 3-axis satellite (Atlas Centaur class) can be achieved, showing the various techniques needed to achieve around 0.05° pitch and roll in both East-West and North-South.

5.6.8 Space Power Systems

A communication satellite requires D.C. power to operate all its electronic equipment, including the transponder, and the attitude control system. The power sources can include solar cells, batteries or nuclear isotope systems as listed in Table 5-59.

D.C. or primary power requirements will vary with the size and weight of the communication satellite. Some of the primary powers associated with present satellites as derived from solar cells can be listed as follows:(see Figure 7-78).

Satellite	Weight in Orbit (Kg)	Primary Power (watts)	Type Spacecraft
Intelsat I	38	40	Spinner
Intelsat II	152	120	Spinner
Intelsat IV	700	400	Spinner
Intelsat V	967	1200	3-Axis Stabilized
Anik	240	320	Spinner
Palapa	246	307	Spinner
Symphonie	230	780	3-Axis
BSE (Japan)	317	1010	3-Axis
CS (Japan)	287	529	Spinner
CTS	347	918	3-Axis

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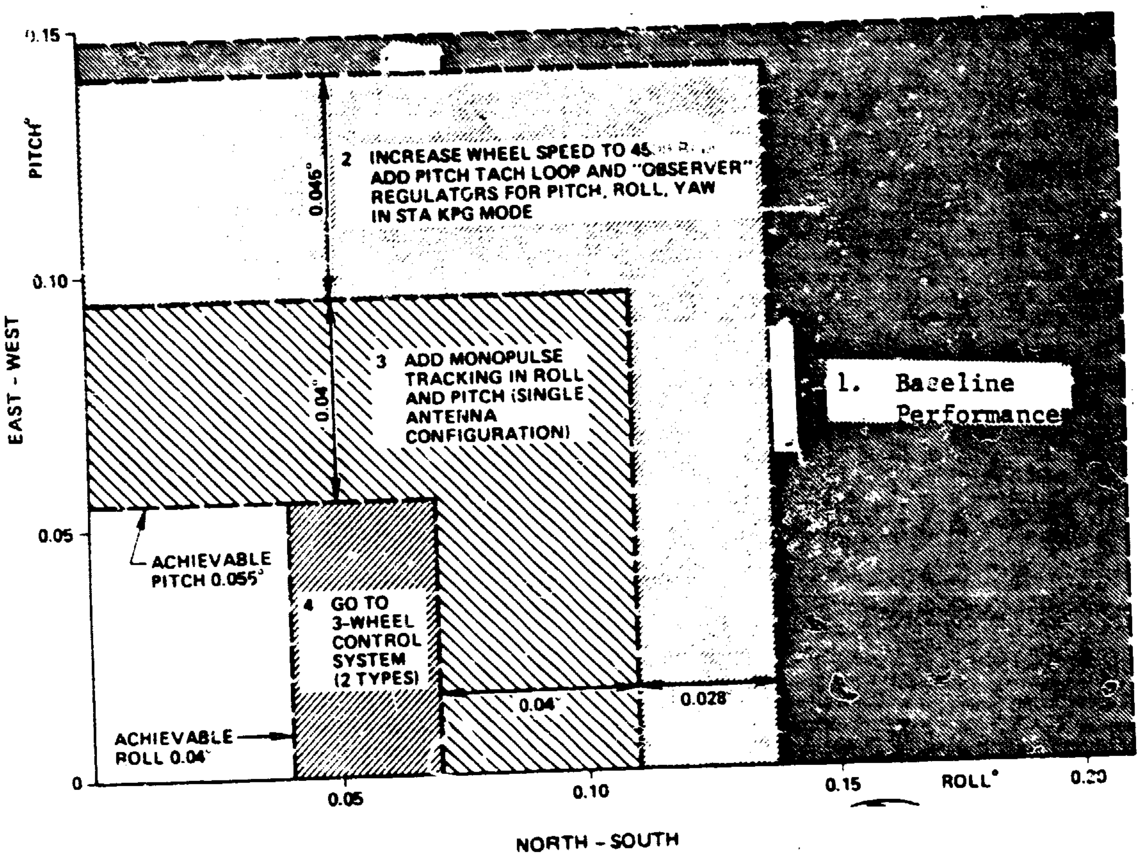

Figure 5-77

Possible Performance Improvements for Pointing Accuracy of a Hypothetical Satellite.

TABLE 5-59

SATELLITE POWER SYSTEMS

Type	Species	Characteristics	Typical Use	Mfg.	Country
Batteries	Nickel-Cadmium Cells (Ni-Cd)	13-18 watt hours/kg 5-7 years life	Intelsat V Meteosat	GE Sharp SAFT HSD	USA Japan France U.K.
	Nickel-Hydrogen Cells (Ni-Hz)	55-75 watts hours/kg 10 years life in orbit	Intelsat V	---	---
RTG Radio Isotope Thermoelectric Generator	RTG uses Pu238 in PuO2 form to heat silicon germanium thermocouples	300 watts SOL 260 watts EOL	LES 8-9	GE	USA
Kilowatt Isotope Generator	KIG uses isotope heat source to drive an organic Rankine cycle system	500-2000 watts	Developed by ERDA for Shuttle use	Sundstrand Energy Systems	USA
Solar Cells (See Table					

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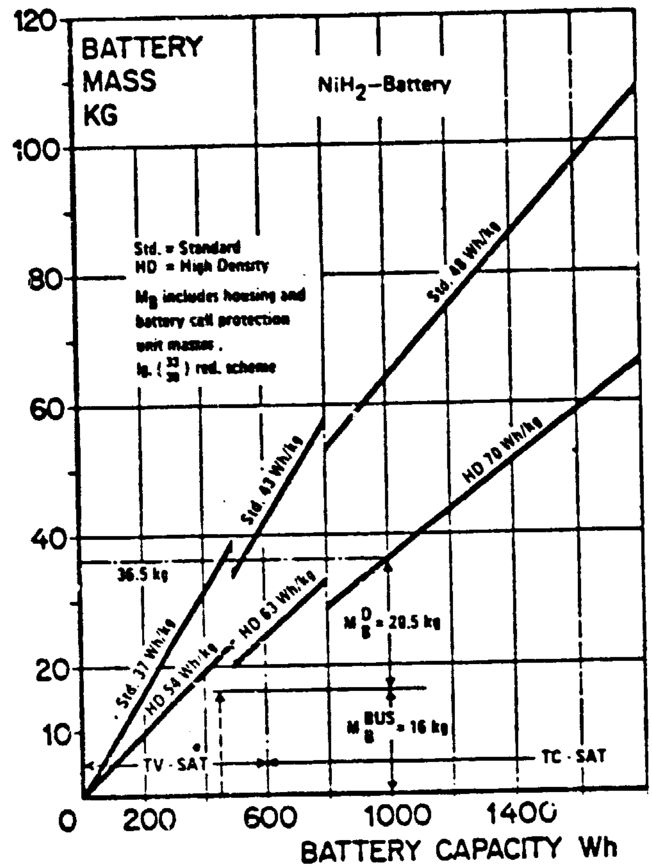

* no TV - operation during eclipse

: Battery System Mass vs. Capacity (Payload Eclipse Battery)

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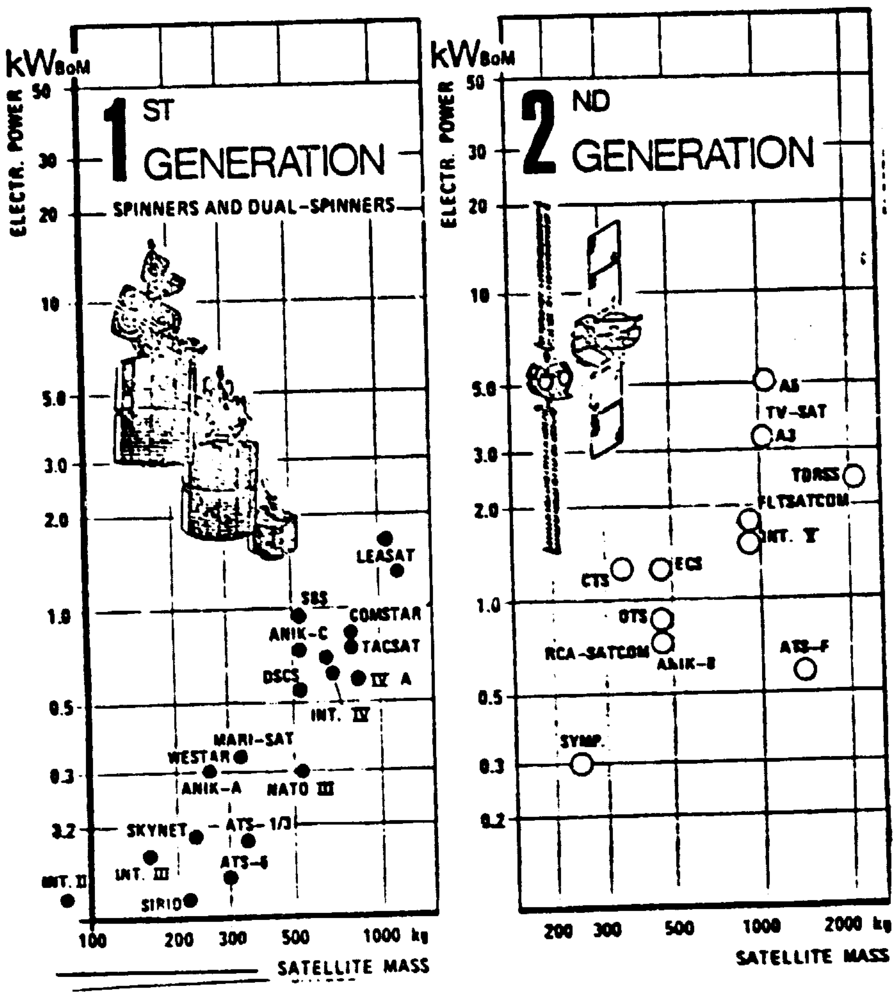

Figure 5-78

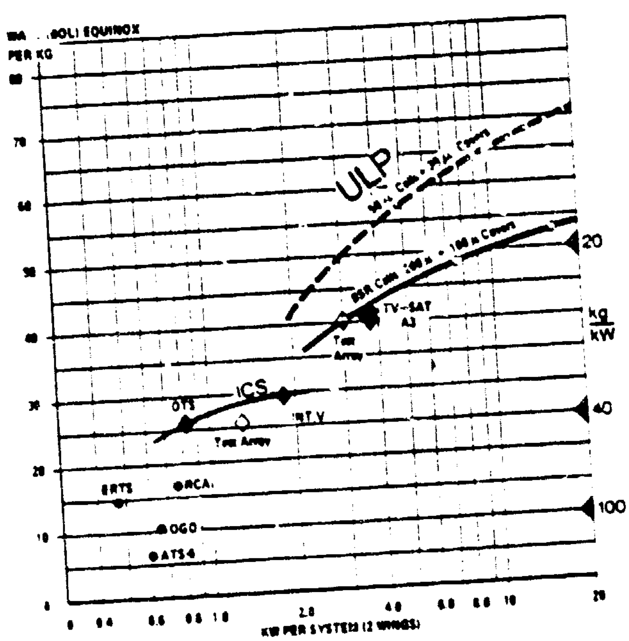

Figure 5-79

ULP Performance Diagram

Note that in the above satellites, primary power levels from 300 to 2000 watts are achieved with the 3-axis stabilized satellites having a much greater ratio of primary power to weight due to the more efficient cell illumination. It is of interest that comparable Soviet satellites of the Statsionar-T series develop up to 2 kw of power from solar cells while the U.S. Skylab developed 5 kw from its solar array. As will be shown, MBB has designed the ULP to achieve 3 kw in TV-SAT (Figure 5-79).

Solar cells are the widest used form of solar power or communication satellites, while batteries are carried on the satellite to power the satellite electronics while the satellite is in the earth's shadow. Nuclear power sources for communication satellites are just starting to be used where their extreme cost does not make such sources economically unfeasible. LES-8 and LES-9, for example, carried RTG radioactive isotope thermoelectric generators generating up to 300 watts, while developments of kilowatt isotope generators being developed for ERDA give promise of power levels in the kilowatt range.

Table 5-60 lists the various types of solar cells manufactured by a U.S. manufacturer, Spectrolab (a division of Hughes). Of these types, the Heleos cell provides the highest power per cell, while the Hybrid B cell is the most cost effective. For increased power, the sculptured hybrid cell should be used, provided increased cost and temperature can be tolerated. Ford Aerospace (FACC) experience in solar cells is shown in Figure 7-80.

Solar cells are made not only in the U.S. by Spectrolab, but also in Germany by AEG Telefunken, in France by SAT, and in Japan* by Sharp. By now, AEG Telefunken, as supplier of solar cells to not only OTS, ECS, and Meteosat and other European satellites, but also the Intelsat-V, bids to become the world's largest solar cell manufacturer. Table 5-61 lists these four worldwide solar cell manufacturers and some of the satellites to which they have furnished cells.

---

* NEC now makes GaAs solar cells.

TABLE 5-60

NOMENCLATURE AND PERFORMANCE FOR TYPES OF SOLAR CELLS

Spectrolab Name	Hughes Name	Other Names	Power 2 x 2 CM or Milliwatts	Flight Experience
Conventional	---		56	SMS, Nato-III
Hybrid A	K4	Violet	60	ETS II, GOES, BC
Hybrid B	---	Blue, Violet, Hybrid	64	ECS
Helios	K6	High Efficiency, p + Back Field	69	Pioneer, Venus, UK6, CTS
Sculptured Hybrid	---	Black Hybrid, Textured, Nonreflective	70	-----
Sculptured Helios	K7	Black Helios, Textured, Nonreflective	75	IEEE (NASA International Sun Explorer)

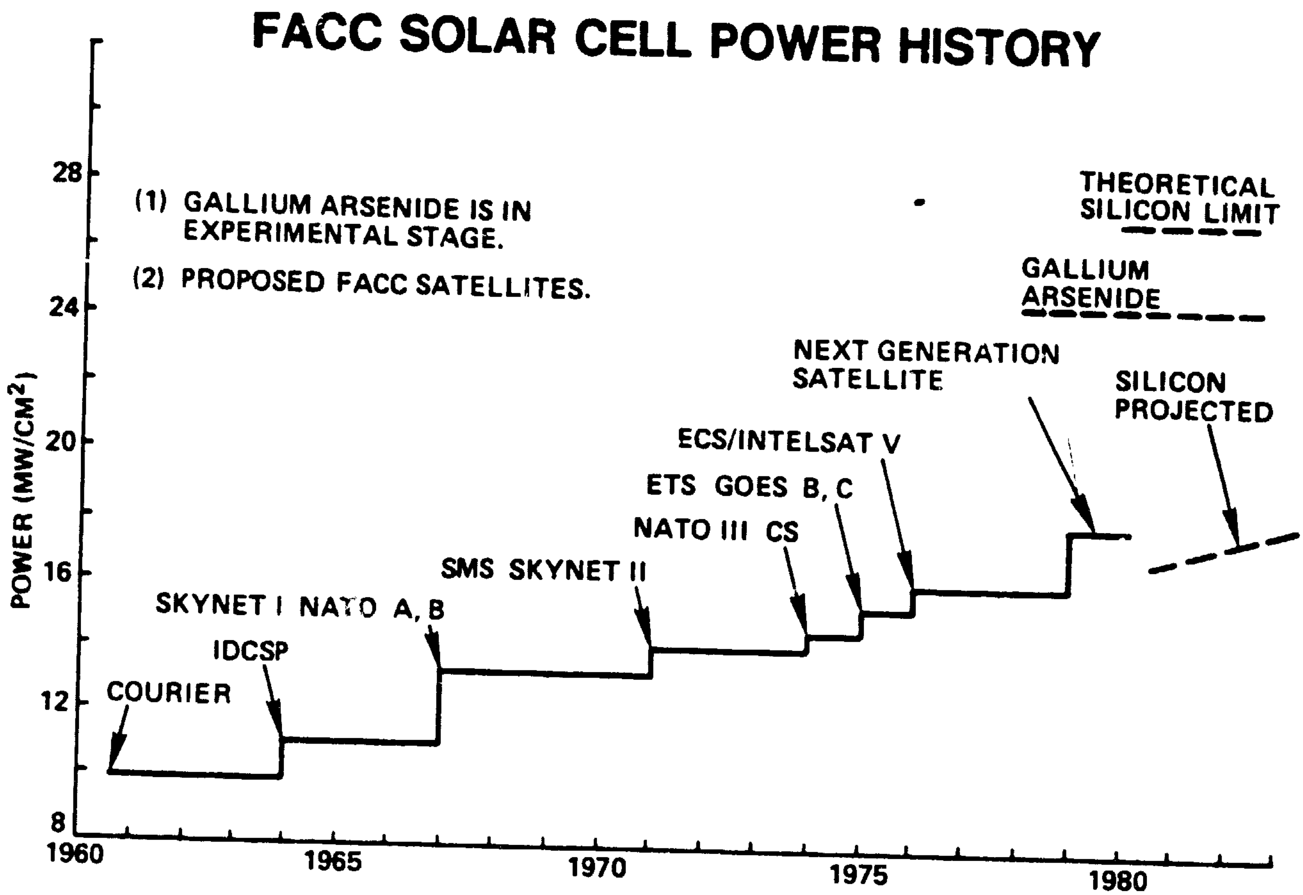
FACC SOLAR CELL POWER HISTORY
(1) GALLIUM ARSENIDE IS IN EXPERIMENTAL STAGE.
(2) PROPOSED FACC SATELLITES.
THEORETICAL SILICON LIMIT
GALLIUM ARSENIDE
NEXT GENERATION SATELLITE
SILICON PROJECTED
ECS/INTELSAT V
ETS GOES B, C
NATO III CS
SMS SKYNET II
SKYNET I NATO A, B
IDCSP
COURIER
POWER (MW/CM²)
28
24
20
16
12
8
1960
1965
1970
1975
1980

FIGURE 5-80

TABLE 5-61

PRINCIPAL WORLDWIDE MANUFACTURERS OF SOLAR CELLS

Country	Company	Application
USA	Spectro Lab (Hughes)	INTELSAT IV, IV-A
Germany	Telefunken AEG	OTS, INTELSAT V
France	SAT (Societe Anonyme de Telecommunications)	Symphonie, INTELSAT III
Japan	Sharp	Ionosphere Sounding Satellite

TABLE 5-62

PRINCIPAL WORLDWIDE MANUFACTURERS OF BATTERY CELLS

Country	Company	Typical Application
USA	G.E.	INTELSAT V, RCA Satcom
	Eagle Picher	SMS
Germany	Telefunken AEG	OTS, Symphonie
France	SAFT (Societe des Accumulateurs Fixes et de Traction)	OTS, METEOSAT
Japan	Sharp Co.	ISS

Battery cells for space, too, are a worldwide technology, as listed in Table 5-62, however, most U.S. manufacturers of communication satellites believe G.E. to be by far the most experienced and competent.

The technology of nuclear power for communication satellites, despite the LES-8 and LES-9 success, is still far in the future. Present estimates are that a nuclear power plant suitable for space applications now costs around $25,000/watt of electrical power (LES-8). This is expected to drop to less than $7,000/watt by the mid-1980's.

A major program by the U.S. Energy Administration is presently underway to use nuclear power to energize spacecraft on DoD military missions or deep space NASA missions.

The U.S. program encompasses three different technologies that collectively offer power levels ranging from a few hundred watts to several kilowatts in the near term, with the prospect of many tens of kilowatts in the longer term. The latter would be useful for spaceborne radar surveillance. The three major efforts include:

- Radioisotope/Static: In sizes up to several hundred watts, offering significantly higher efficiencies, lower weight and cost, which will be available in the early 1980's. Electricity is generated by thermoelectric materials which are heated from a Plutonium-238 source. This is the same basic concept that has been used since the SNAP-3A was used to power the Navy's Transit Navigation Satellite launched on June 29, 1961.
- Radioisotope/Dynamic: Uses a Plutonium-238 heat source to produce high-temperature gases that drive a turbine-alternator, is expected to be cost-effective in the 0.5-5 kw range. Two competing systems, one employing a Brayton cycle and the other called organic Rankine, each

designed to produce 1.3 kw, underwent test and evaluation in early 1978. One of the two will be selected for next-phase funding, which is to produce a system qualified for space flight by early 1982 in the USAF's next space test program (STP) satellite.

- Reactor/Dynamic: Suitable for power levels of 10-100 kw or more, currently is under study at the Los Alamos Scientific Laboratory. The technique shows promise of producing electricity at a cost below $100 per watt in large sizes, possibly by the late 1980's.

Radioisotope/static power sources have repeatedly demonstrated their long-term reliability in numerous satellite and space probe missions. But they have been relatively heavy and expensive. Current designs contributed the two General Electric-built 150-W generators used in each of the USAF/Lincoln Laboratory LES-8/9.

In 1980, the design of a broadcast satellite is now requiring up to 2.5-3 Kw and only solar cells arrays are of practical consideration. Solar array technology and battery technology have been the object of a study by Los Alamos Scientific Laboratory, and their results are shown in Tables 5-63 and 5-64.

5.6.8.1 Solar Arrays (From CCIR Doc. 2/94-E)

During the past several years there has been a considerable effort underway by a number of organizations to develop lightweight, deployed solar arrays. Two distinct types of solar arrays have been studied; namely, deployed, rigid arrays and deployed, flexible arrays.

The deployed, rigid arrays have been exclusively the foldout type either folded around the satellite body during transfer orbit or contained in a flat pack, accordion fold arrangement during transfer orbit. Deployment occurs in several steps usually commencing with the pyrotechnic release of latches or the cutting of cables.

TABLE 5-63

Los Alamos Scientific Laboratory

SOLAR ARRAY vs REACTORS IN 1985

	10 kWe		50 kWe		100 kWe	
	Solar	Nuclear	Solar	Nuclear	Solar	Nuclear
W/kg	24	14	24	40	22	55
Cost, delivered to geosynchronous orbit (Million $)	8	7	32	10	63	14
Shuttle Compatible (~ 1910 kg)	Yes	Yes	Difficult	Yes	No	Yes
Space Flight	Demonstrated	Possible	Possible	Possible	Doubtful	Possible

Feature	Solar	Nuclear
Orientation	Sunward	None - No power transfer slip rings, array deployment, tracking disturbances, or battery cycle problem
Location	Shadowed by large antennas	Minimize shielding
Maneuverability	Difficult fold-up arrays	No problem
Radiation		
Natural	Degrades	No effects
Induced	None	Shielding necessary
Safety and Handling	Minimum	Flight tested on SNAP 10A
Disposal	Minimum	Long-term earth or sun orbit

los alamos scientific laboratory of the University of California

TABLE 5-64

SOLAR TECHNOLOGY

	1976	1985	1995	2005
CELLS	14% Si	18% Si/GaAs	20% VJ	22% GaAs
ARRAY	KAPTON/Si GLASS	KAPTON	MEMBRANE	THIN FILM
STRUCTURE	ALUMINUM	GRAPHITE	COMPOSITE	ULTRA LIGHT-WEIGHT
ORIENTATION MECH.	RETRACTABLE, SEPARATE AXIS CONTROLS	NON-RETRACTABLE, COMMON CONTROL	NON-RETRACTABLE, IC CONTROL	NON-RETRACTABLE, CENTRAL CONTROL
BATTERY	Ni-Cd	$Ni-H_2$	$Ni-H_2$/LiS	LiS
CONTROLS	INDIVIDUAL BY-PASS	INTEGRATED PARTIAL IC	ALL IC TECHNOLOGY	CENTRAL CONTROL

There are two basic types of deployed, flexible substrate arrays, foldout and rollout. The foldout solar arrays use a flat pack concept to contain the solar cell blanket during launch. The deployment sequence begins with the pyrotechnic opening of a box or release of latches or cables holding the array against the spacecraft body.

Deployment of the foldout array takes place by extension of a pantograph, a boom, or telescopic mast system attached to the array.

During transfer orbit, the rollout array is wrapped around a drum attached to the spacecraft. During deployment, the solar cell blanket is rolled out by the extension of a boom which is attached to the blanket. For both foldout and rollout systems a yoke is used to separate the array from the spacecraft.

A major advantage of flexible, foldout systems over flexible, rollout systems, is their inherent higher packing density since no drum is required.

Table 5-65 shows the weight-to-power and power-to-weight ratios for several deployed, rigid solar arrays. This table is based on a one kilowatt wing of a two kilowatt solar array system. It first lists the weight to power at beginning of life, equinox conditions, including the array with its blanket, deployment, yoke, and stowage systems.

It should be noted in Table 5-65 and, later, in Table 5-66, that in going from a designed or tested solar array system to a flight-qualified array, extra weight is estimated to provide for redundancy, temperature control, etc. It is even more evident when the Fleetsatcom or CTS and FRUSA numbers are compared to the typical early design numbers. Several examples of rigid solar arrays are shown. The first one listed which is being developed for an operational spacecraft is Fleetsatcom. The Fleetsatcom array is a rigid deployed array, initially folded around the periphery of the spacecraft. It uses conventional aluminum honeycomb substrates and solar cells.

TABLE 5-65

Deployed rigid solar array comparison

	FLEETSATCOM TRW - Conventional, rigid foldout	MBB-ICS Foldout (carbon fiber)		MBB-ULP (very light materials)		Matra Foldout (glass fiber technology)		Flight Type Arrays Next 3-5 yrs (ESTIMATE)	Flight Type Arrays Post 1980 (ESTIMATE)
		A	B*	A	B*	A	B*		
Array, including deployment and stowage, at Beginning of Life (B.O.L.) Equinox kg/kW	54.0	31.0	31.0	18	18	28.6	28.6		
Orientation Mechanism kg/kW	7.7	[4.3]	[3.4]	[4.3]	[3.4]	[4.3]	[3.4]		
Miscellaneous** kg/kW	included in above	[1.5]		[1.5]		[1.5]			
Total at B.O.L. Equinox kg/kW	61.7	36.8	34.4	23.8	21.4	34.4	32.0	35-50	25
Total at B.O.L., Equinox W/kg	16.2	27.2	29.1	42.0	46.7	29.1	31.3	20-29	40
Total at End of Life (E.O.L) 5 yr Summer Solstice W/kg	11.4	20.9	22.4	27.7	30.8	20.4	21.9	14-20	26
Total at E.O.L. (5 yrs) Summer Solstice if advanced cells are used W/kg	13.1	24.1	25.8	31.9	35.4	23.5	25.2		Included in above

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TABLE 5-66

. Deployed, flexible solar array comparison

	SNIAS Flexible Foldout	RAE Flexible Foldout	CTS Flexible Foldout	Hughes FRUSA Flexible Rollout	Flight-type Arrays Next 3-5 yrs (ESTIMATE)	Flight-type Arrays Post-1980 (ESTIMATE)
Array, including deployment and stowage at Beginning of Life - Equinox kg/kW	23.0	16.6	37.7	35.8	----	----
Orientation Mechanism kg/kW	4.3	3.4	included in above	included in above	-----	----
Miscellaneous* kg/kW	1.5		included in above	included in above	----	----
Total at B.O.L., Equinox kg/kW	28.8	20.0	37.7	35.8	25-35	18
Total at B.O.L., Equinox W/kg	34.7	50.0	26.5	27.9	29-40	56
Total at End of Life (5 yrs) Summer solstice W/kg	22.9	36.2	17.5	18.4	19-26	37
Total at E.O.L. (5 yrs) Summer Solstice if advanced cells are used W/kg	26.3	41.6	20.1	21.2		included in above

The MBB improved composite structure (ICS) array uses aluminum honeycomb substrates and carbon fiber reinforced epoxy (CRFP) facesheets in a flat pack design with the deployment energy supplied by spiral springs on the panel hinges. This concept was used on the ESRO OTS and Marots satellites.

The ultra lightweight panel (ULP) by MBB is an advancement on the ICS system using the same deployment approach but including a carbon fiber framework and very lightweight solar panels.

Table 5-66 is similar to Table 5-65 except that it concerns flexible substrate solar arrays. It includes data on several solar arrays. The array developed by Societe Nationale des Industries Aerospatiales (SNIAS) uses a pantograph, foldout system with launch stowage in an aluminum honeycomb-walled box. The pantograph is spring-loaded and self-deploys when released. The rate is controlled by a winch and motor. The solar cells are mounted on a Kapton substrate designed in modular form to be usable for different power levels.

The last columns in Table 5-66 are the estimates on weight-to-power for flight-type flexible solar arrays for use in the next three to five years and, similarly, for advanced flight-type systems for use in the post-1980 time period.

5.6.8.2 <u>DC Power Bus System in a Broadcast Satellite</u>

Figure 5-81 shows the circuit diagram for the Japan Broadcast Satellite (BSE) as published by G.E. Note the use of solar arrays and batteries; the batteries and battery charge regulators are controlled by the TT&C link; while a power controller is used to provide stable bus voltage to each of the user loads (transponder, TT&C system, ACS, etc.), the heaters which are used to maintain spacecraft temperature, and the various latch valves.

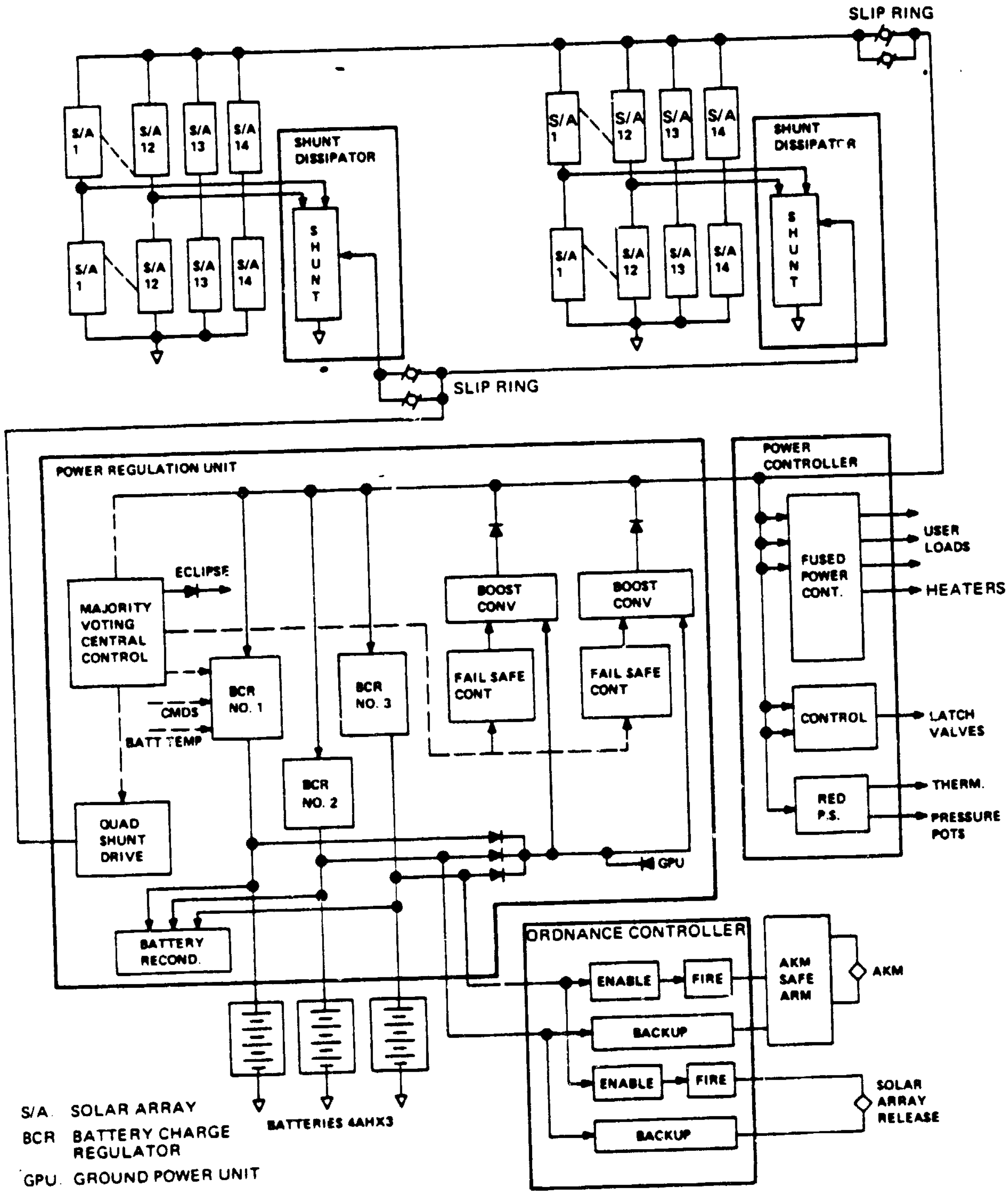


Figure 5-81. BSE DC Power Bus

5.7 Some Aspects of Broadcast Satellite Design

The broadcast satellite which will use conventional expendable launch vehicles such as Atlas-Centaur, Delta 3910/3920, and Ariane I to Ariane III is fairly constrained by these vehicles in mass (1800-2300 Kg launch payload mass) and size. Figure 5-82 shows conventional broadcast satellites which have been discussed earlier; Figure 5-83 shows Intelsat-VA growth potential to 2300 Kg as provided by Ariane III which is also the launcher of TV-SAT A-3. Figure 5-84, for the sake of completeness, shows the giant LEASAT spinner which is designed for shuttle launch. These are all large satellites capable of carrying high power payloads of the type typical of broadcast satellites.

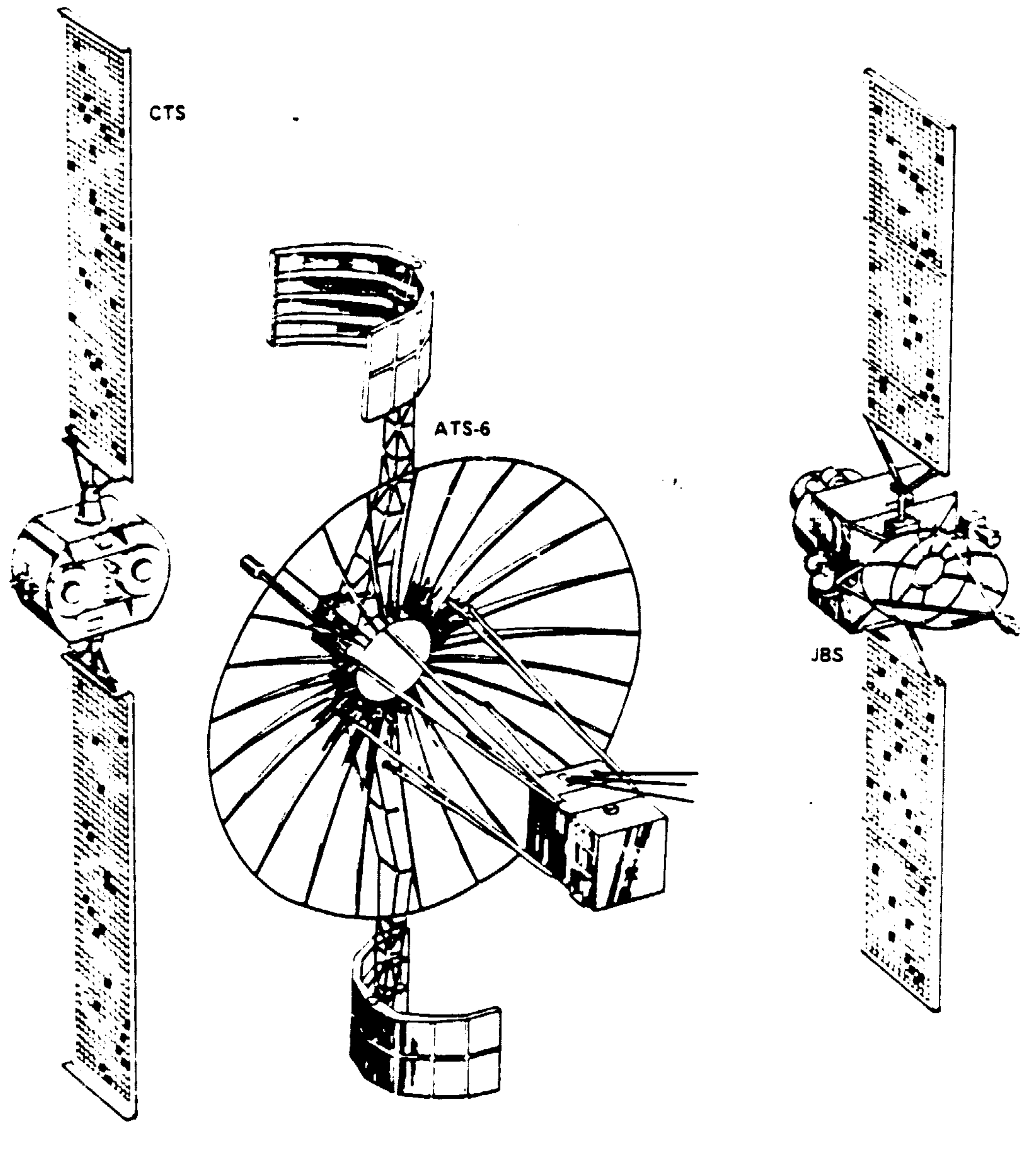
As has been mentioned earlier, the TV broadcast satellite must be designed from a different vantage point than the communication satellite. It must provide high EIRP of 60 dbw plus, (as compared to the 30-35 dBw of a SATCOM, for example), and must serve the function of providing broadcast into a specific service area rather than providing point-to-point communications between widely separated points as is representative of SATCOM or WESTAR.

In the design of a broadcast satellite, it is therefore necessary to define the following:

(1) The service areas to be covered. This will determine the antenna system required.

(2) The per-channel EIRP. If WARC recommendations of 60-65 dbw are followed, then as will be shown, the problem of spacecraft power will be of paramount importance. If the Canadian approach of 50 dbw is adopted, this problem may be eased, but actually replaced by a number-of-channels problem.

(3) The power level of power amplifiers and the available efficiencies will be a key factor with antenna design in producing EIRP.



Broadcast Satellite

FIGURE 5-82

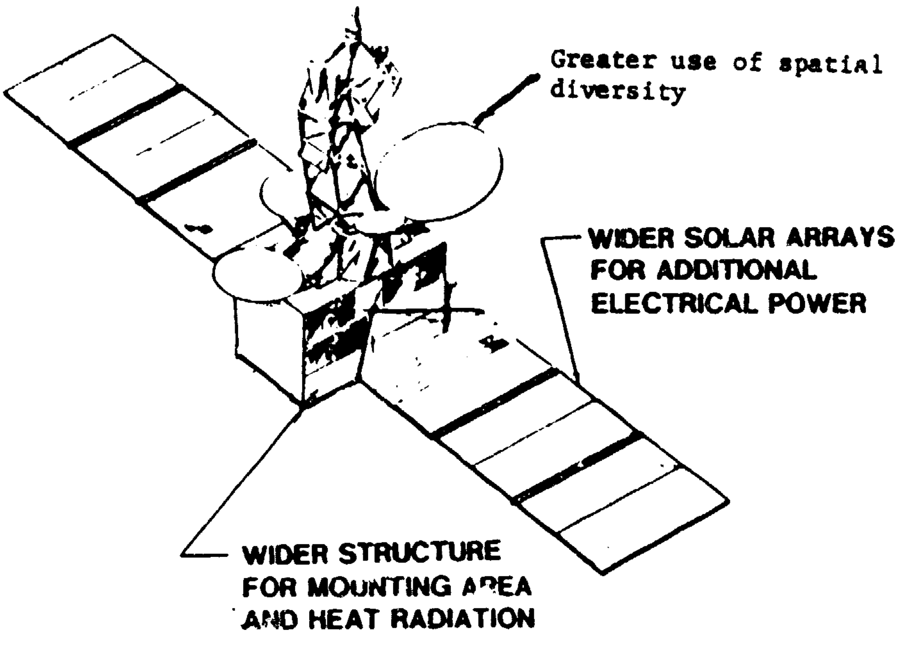

Greater use of spatial diversity
WIDER SOLAR ARRAYS FOR ADDITIONAL ELECTRICAL POWER
WIDER STRUCTURE FOR MOUNTING AREA AND HEAT RADIATION

Figure 5-83

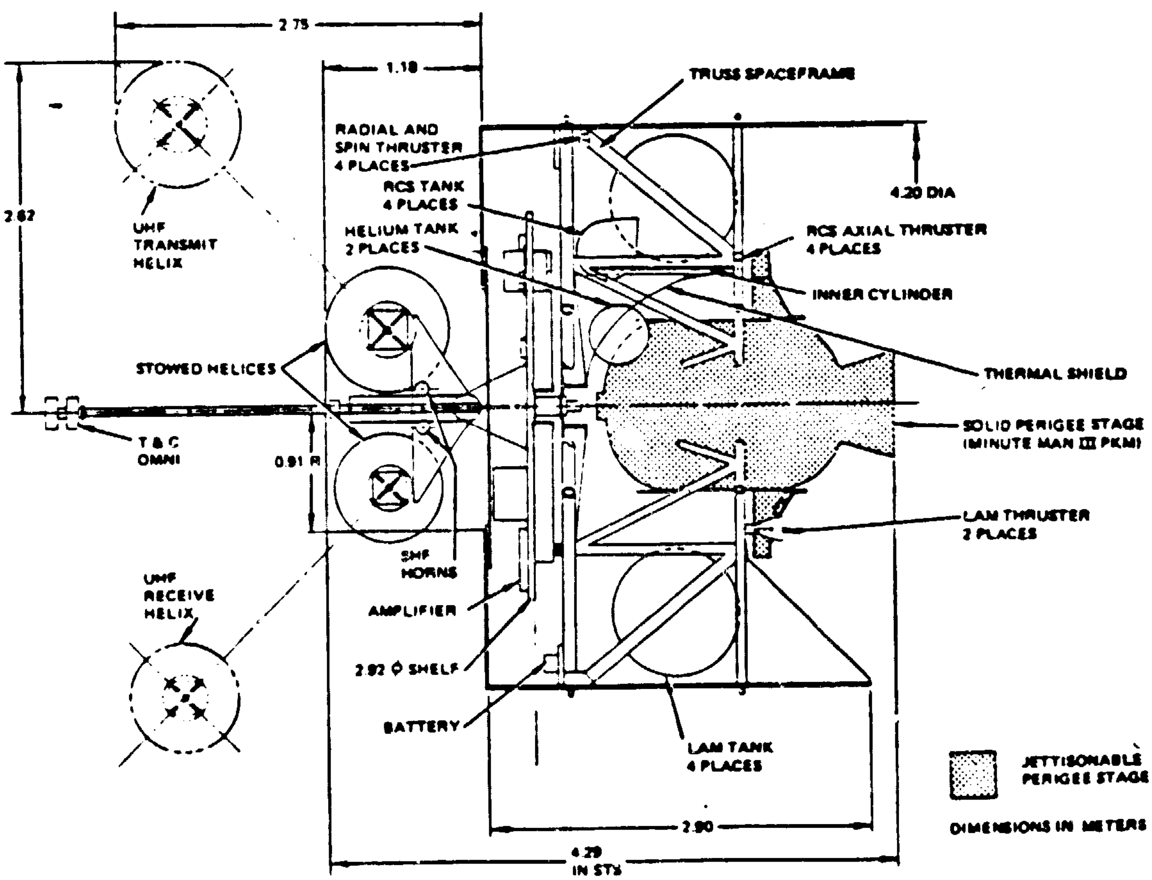
Fig. 3 LEASAT overall configuration.

LEASAT weight summary

Subsystem	Weight, kg
Communications	204
T&C	75
Attitude control	25
Reaction control (dry)	16
Liquid apogee motor (dry)	127
Power and distribution	309
Thermal control	65
Structure	368
Dry hardware	1189
Minimum margin	45
Expendables (perigee, apogee, on-orbit)	5350
PKM/adapter	314
Weight at Shuttle separation	6898

Table 4 LEASAT power summary, watts

Communications	732
T&C	61
Attitude control	34
Thermal control	56
Power and distribution	69
Battery charge/heaters	142
Required	1093
Minimum source sizing	1180 (5 years)
Minimum margin	87 (5 years)



LEASAT general arrangement.

Figure 5-84

(4) The broadcast satellite will require a high level of d.c. power to provide the power amplification required to produce the EIRP.

(5) The number of channels or the number of separate areas serviced will determine how much total EIRP must be reproduced. This will then determine the satellite d.c. power requirements; this will be a principal factor in satellite weight.

5.7.1 Broadcast Coverage Area

Figures 5-85 through 5-88 show the problem of U.S. coverage as compared with the Japanese coverage by CS (shown in Figure 5-85 which can be accomplished with a single rather simple antenna system.

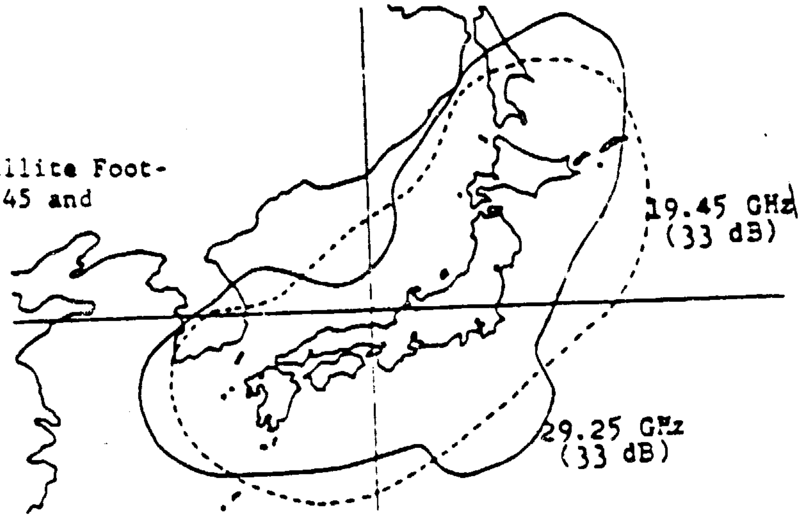
The coverage of the U.S. Conus can be accomplished by one beam, or three beams, or 25 beams, or 77 beams, or 130 beams, depending on the beam width of each component beam in an antenna such as the multiple-feed offset fed reflector system discussed earlier in this section.

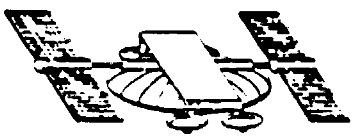
Providing an interconnected large number of beams will, of course, allow specific and separate coverage areas such as four time zone areas of the areas which can be easily separated by using the detail or the granularity of the, say, 77 beam system.

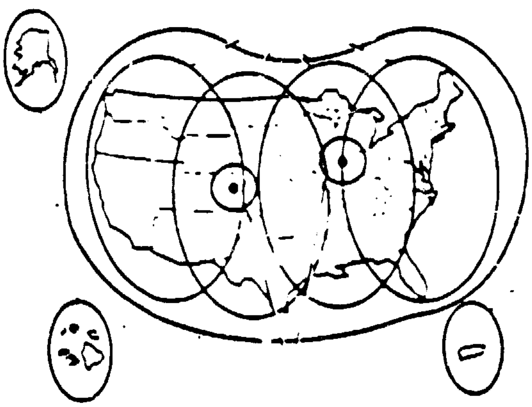
5.7.2 Antenna Beam Granularity and EIRP

Table 5-67 lists the antenna gain, diameter, and 3-db beamwidth for each component beam provided by a multiple-beam antenna system. Note that as each beam's beamwidth decreases, the antenna diameter increases and the gain also increases. At 12 GHz, about 12-14 ft is the maximum antenna size that can be unfurled or positioned from an Atlas Centaur class satellite, and thus the beamwidths are limited to around 0.4 degrees and 50 db of gain (which is in the Morgan-Podracsky sense-structure gain as contrasted to strictly RF gain which must be powered by a solar power system .

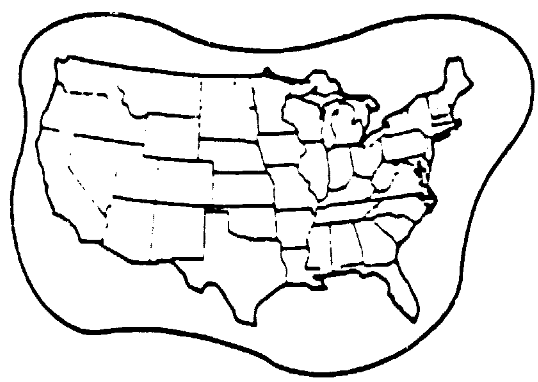
Japan CS Satellite Foot-
print on Japan at 19.45 and
29.25 GHz







Spot Beam Coverage of U.S.,
Alaska, Hawaii and Puerto Rico by
Proposed NASA PSC Satellite

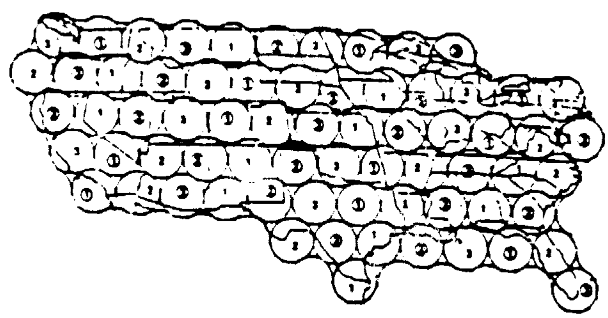


Coverage of U.S.
Continental Area by Zone Beam
of Proposed NASA PSC Satellite

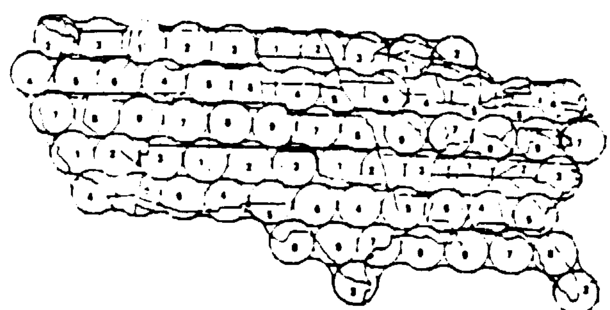
FIGURE 5-85

Figure 5-86.   25 Beam Coverage of USA Using 1 degree Beams.

FIGURE 5-86



triangular layout of doublets, dual polarization, polarization reuse spots.
$\alpha = .5°$, $n = 68$, $N_B = 45$, $N = 15$.



rhomboidal layout of singlets, single polarization.
$\alpha = .50°$, $n = 68$, $N_B = 68$, $N = 7.55$.

FIGURE 5-87*. Beam coverage of USA using 0.5 degree beams to achieve isolation.

* Afta P. Foldes, AIAA, Orlando, Florida, 1980.

0.35° BEAM FOOTPRINT AND FREQUENCY BAND DISTRIBUTION

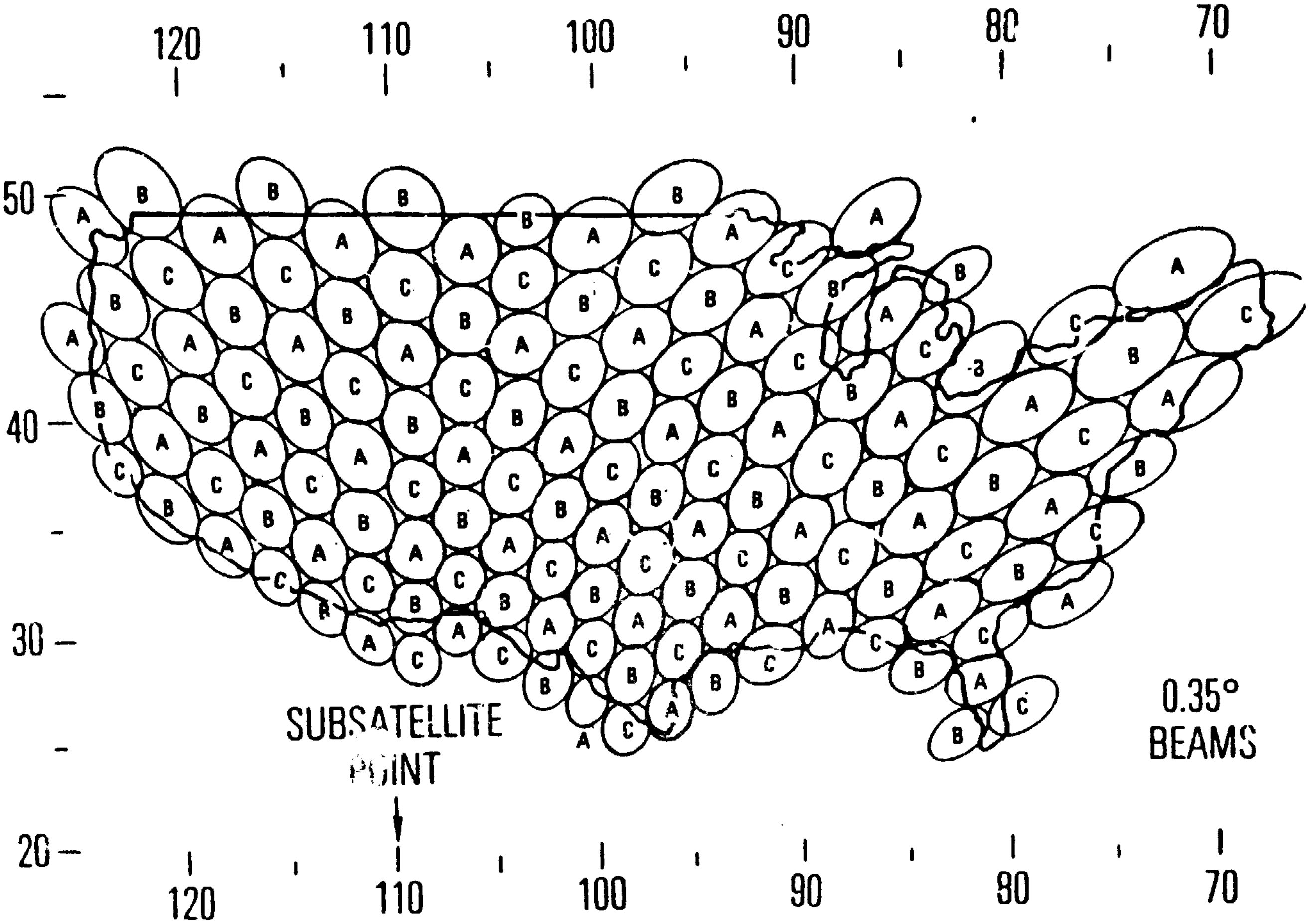


FIGURE 5-88 - Coverage of USA by 130 0.35° beams.

R. Bowman
J. Board

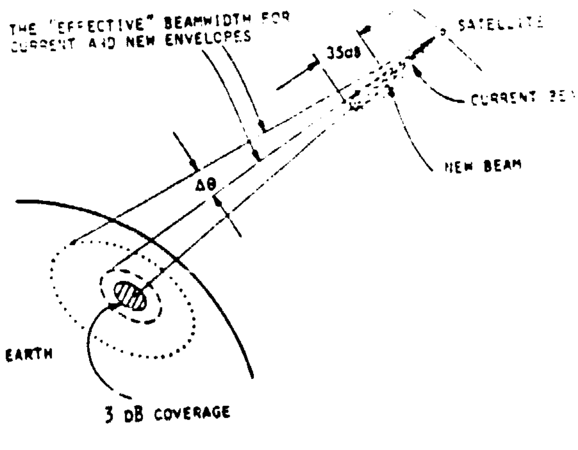


Figure 5-89 — *The meaning of "effective" beamwidth and Δθ of spacecraft antenna in terms of orbit utilization efficiency.*

TABLE 5-67

SPACECRAFT ANTENNA			POWER REQUIRED PER BEAM (dbw)		APPROXIMATE NUMBER OF BEAMS REQUIRED FOR U.S. COVERAGE	AMOUNT OF TWTA POWER REQUIRED FOR FULL U.S. COVERAGE	
Diameter (ft)	Gain/dB	3dB Beam Width°	60 dbw	65 dbw		EIRP 60 dbw	EIRP 65 dbw
5.9	44	1°	16	21	25	995	3147
6.3	44.8	0.9°	15.2	20	30	993	3000
7.3	45.7	0.8°	14.3	19.3	35	987	2978
8.2	47	0.7°	13	18	42	840	2650
9.6	48.4	0.6°	11.6	16.6	53	766	2422
11.4	49.9	0.5°	10.1	15.1	77	788	2495
14.2	51.8	0.4°	8.2	13.2	100	660	2100
16.5	53	0.35°	7	12	120	600	1902

Table 5-67 also includes a key consideration in broadcast satellite; what total TWTA power (per footprint) is required to drive the antenna feed system through a beam forming network (which will have some loss) to achieve an EIRP of 60 dbw or 65 dbw. As shown in Table 5-67, as the antenna size increases, assuming the approximate number of beams required for conus coverage, the amount of TWTA decreases since less and less is required of each feed horn as the antenna gain increases. Assuming no significant beam forming network loss, (it will be around 1-2 db) it is evident that for 0.5° beamwidth beams, 750 watts of TWT saturated power availability for all 77 feed horns is required. Assuming TWTA with 50% efficiency, this would require 1500 watts from the d.c. bus for the power amplifier system or around 2000-2300 watts for the entire spacecraft.

Operating with 0.5 degree beams (or smaller) makes possible significant reduction in interference between adjacent areas (see Table 5-68) and indeed, this can be increased by the use of different polarizations or different frequencies (channels).

Note from Table 5-67 the enormous d.c. power increase implicit in requiring 65 dbw rather than 60 dbw For all cases listed involving beamwidths from 1 degree to 0.35 degrees, TWTA power of 2 kw and therefore a d.c. bus capability of at least 5 kw is required - definitely beyond the state-of-the-art at this time.

5.7.3 Number of Channels to be Serviced

Table 5-67 illustrates the problem in serving a country as large as the United States mainland, as compared, for example, to that of FRG which will be illuminated by TV-SAT. It is evident from Table 5-67, that the TWTA power of 750 watts can be divided up any of several ways. It can be used to provide a single TV channel to U.S. Conus, or to provide one channel to each of four time zones. But without providing n-carrier per transponder operation and thereby requiring a serious decrease in EIRP, it is clear that the only means to increase

TABLE 5-68

DISTANCE ON EARTH FROM BEAM CENTER TO 20 dB BEAM POWER REDUCTION POINTS FOR VARIOUS SATELLITE ANTENNA BEAMWIDTHS

Antenna Beam Width	Beam Angle from Center at Which Beam Power is Down 20 dB	Distance on Earth from Beam Center to Point of 20 dB Beam Power Reduction		
		Equator	Latitude 41° (NYC)	Latitude 50°
1/4°	0.345°	132 miles	165 miles	221 miles
3/16°	0.26°	100 miles	119 miles	165 miles
1/8°	0.173°	66 miles	72 miles	132 miles

the number of channels or useful bandwidth is to increase or maximize d.c. power in the broadcast satellite. This d.c. power requirement is actually the pivot-point about which TV broadcast satellite design and service is determined or boundered.

5.7.4 D.C. Power in a Broadcast Satellite

Present large communication satellites produce around 1-1.5 kw of solar array power. Intelsat-V, for example, uses solar arrays which provide 1.4 kw BOL power to guarantee a 1 kw EOL power.

The solar array power problem has been the subject of much investigation in all countries - and in particular in FRG where the ULP solar array*, under design at MBB for use in TV-SAT, has been designed to produce up to 3.5 kw (see Figure 5-78), and according to Figures 5-90 and 5-91, can provide this unusual solar array power on a spacecraft of the same general mass range as Intelsat-V.

With the 3 kw of solar array power on an Atlas Centaur upgraded to 2300 kg payload (same as Ariane III), it is clear from Table 5-67 that the U.S. conus areas can be provided with from 3 to 4 TV broadcast channels with 60 dbw each, and with the use of different time zone beams with minimum interference at zone boundaries well within the protection ratios (see Section 6) required and which can be served by both use of different channels and different polarizations.

The TWTA used to serve the multiple beam antennas for 60 dbw illumination are technologically well advanced. As listed earlier, and presented in Figure 6-92, due to R. Strauss, TWT up to the 750 watt level are available from European tube manufacturers.

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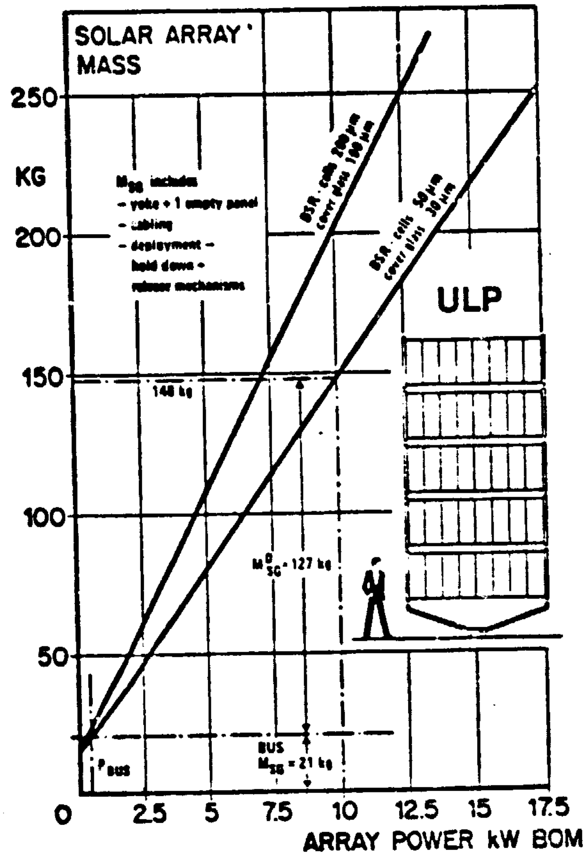
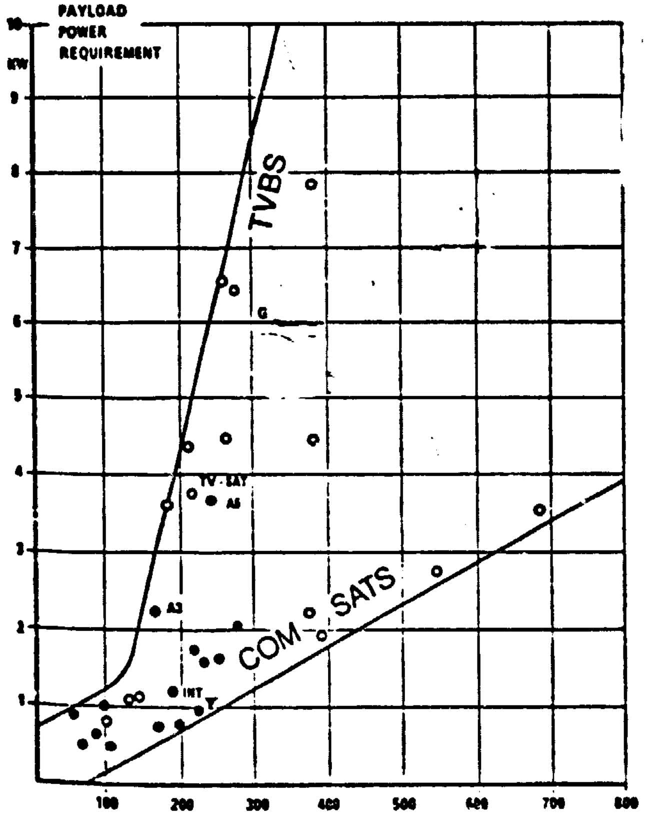
* D. Koelle and W. Kleinau, "A Third Generation Communication Satellite Concept" AIAA 8th Communication Satellite Systems Conference, April 1980, Orlando, Florida, Paper 80-0505.

Figure 5-91



ULP Solar Array Mass vs. Power (BoM)

Figure 5-90



Payload Power vs. Payload Mass COMM. PAYLOAD KG

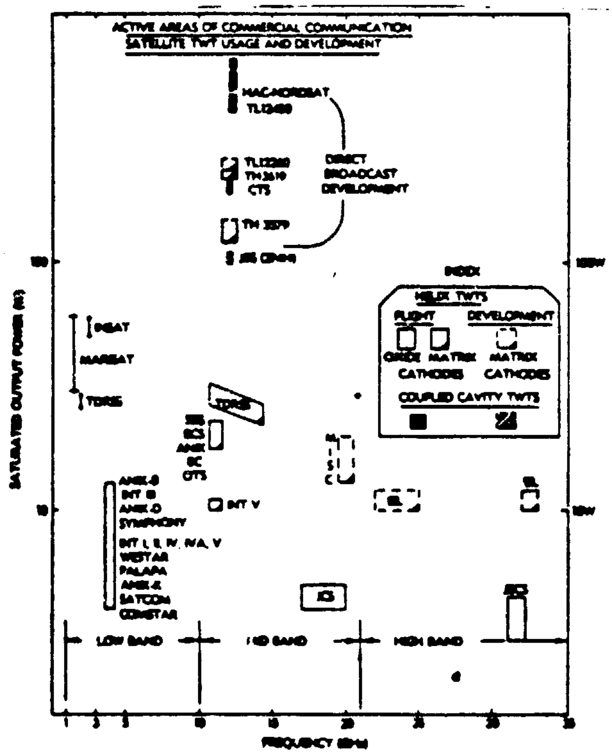


Figure 5-92.

-Due to R. Strauss of Comsat Labs.

Active Areas of Commercial Communications Satellite TWT Usage and Development

A consideration in optimizing solar array power is the design of the spacecraft, spinner or 3-axis. Figure 5-93 shows that due to form factor, the flat array significantly.uses mass more effectively then a cylindrical array; with a 320 pound advantage accruing to the flat array.

5.7.5 Basics of Satellite Design and Configuration

The preceding paragraphs have highlighted the need of a broadcast satellite serving the full Conus area of the U.S.A. with 60 dbw beams, to carry a large antenna up to 14 feet in diameter, and to carry a solar array capable of producing more than 2-3 kw of d.c. power.

Figure 5-94 shows a variety of 3-axis body stabilized satellite concepts in the Atlas Centaur/Ariane class, as provided by various individuals and companies. As shown in Figure 5-95 in a concept for a switching satellite due to D. Jarret as presented in 1976 at the 6th AIAA Sat. Conference in Montreal, is applicable to broadcast satellite design considerations since it is designed to both support a large transmit antenna illuminated by multiple feeds.

The satellite in Figure 5-96 due to FACC in a 20/30 GHz study for NASA-Lewis is equally applicable since it provides two giant antennas - one for receive - in an interactive system, using a basic bus derived from Intelsat-V.

Figure 5-97 is a German concept made at DFVLR in the mid 1970's which is interesting since it shows the giant antenna and the ULP solar array, and included 200 watt TWT which were not in existence at that time.

Figure 5-98 shows a TRW giant satellite concept derived from TDRS for the NASA 20/30 GHz study, while Figure 5-99 shows an advanced RCA Satcom - the pioneer in domestic television distribution - which uses a single large antenna with a feed system in cassegrain optics which could provide broadcast satellite

MASS OF SOLAR ARRAY (INCLUDING SUBSTRATE)

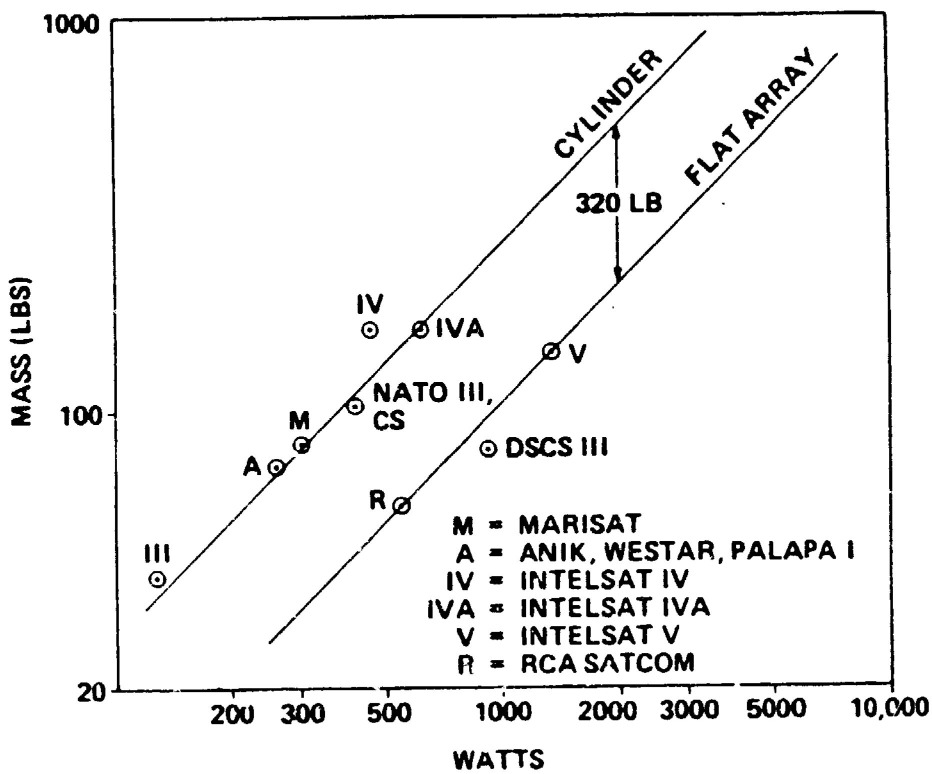


FIGURE 5-93

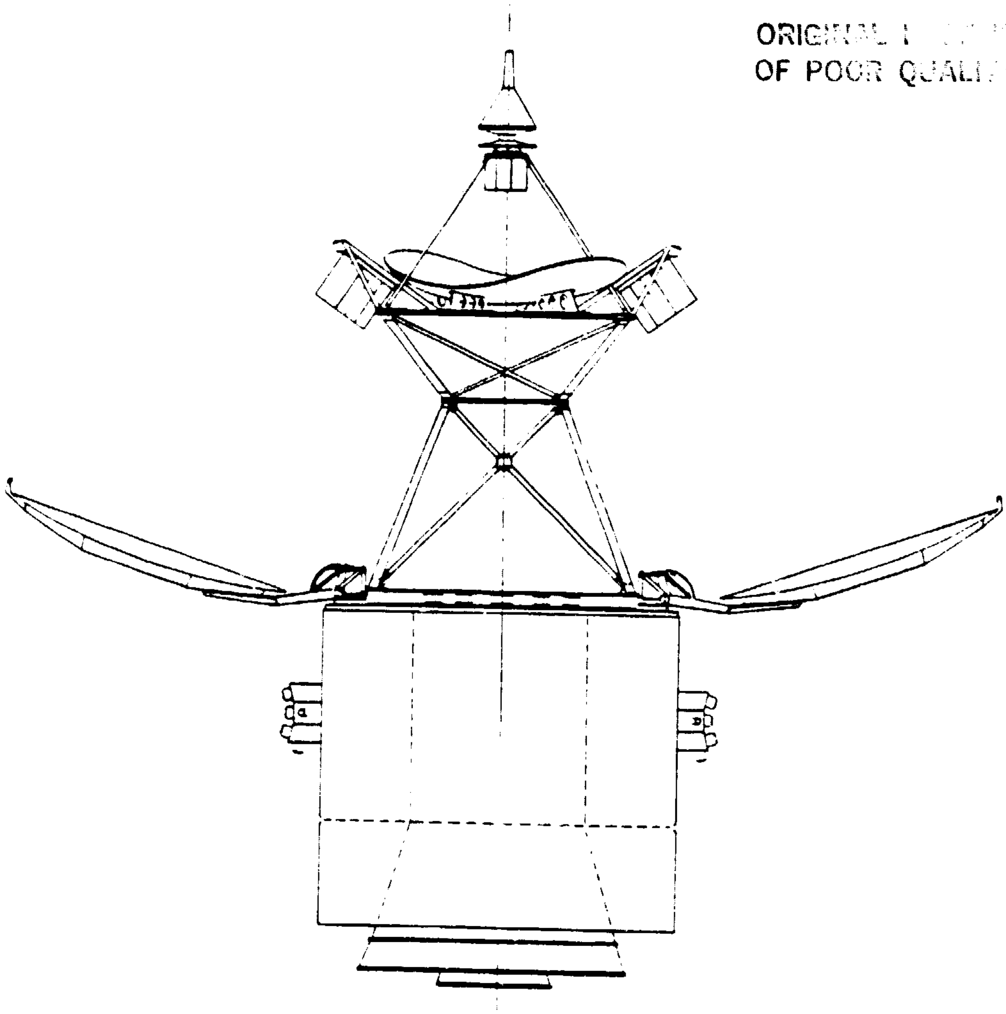


FIGURE 5-94

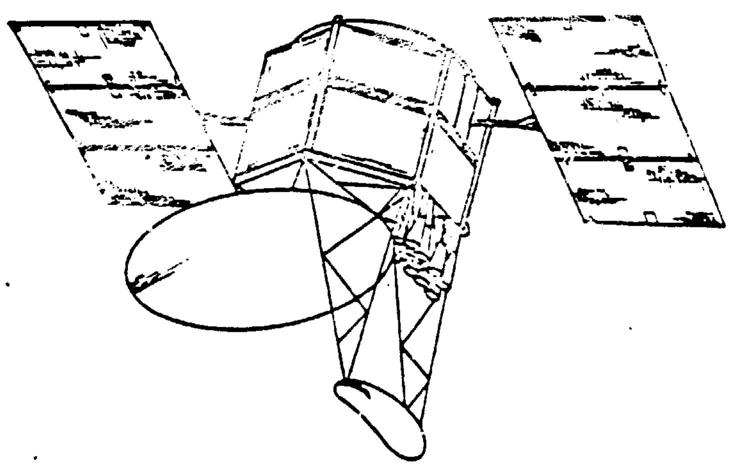


FIGURE 5-95

Concept of a [illegible] [illegible]bilized Multiple-Beam Communication Satellite Using [illegible] [illegible] Reflector as Presented by D. Jarret to the AIAA in [illegible]

SPACECRAFT CONFIGURATION -

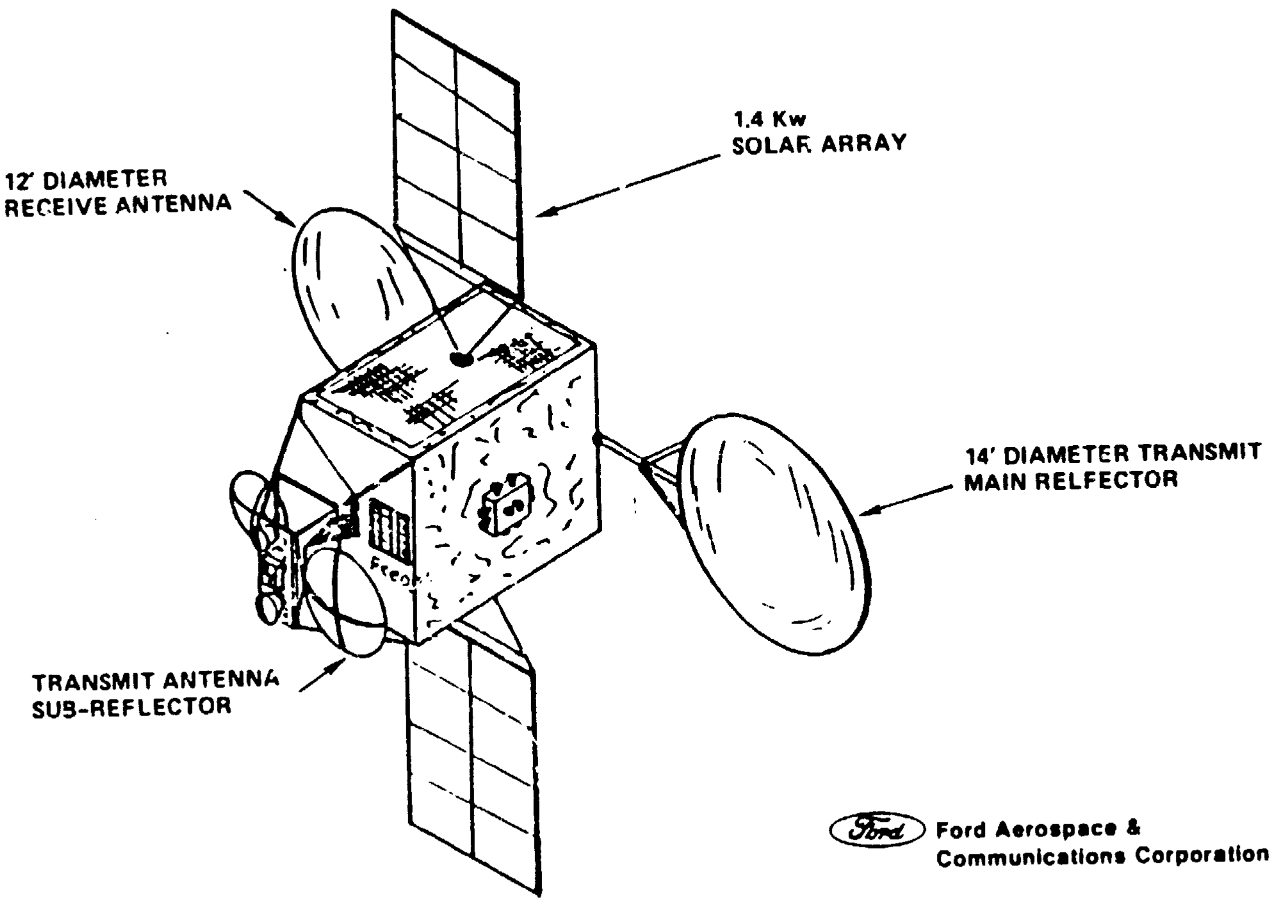
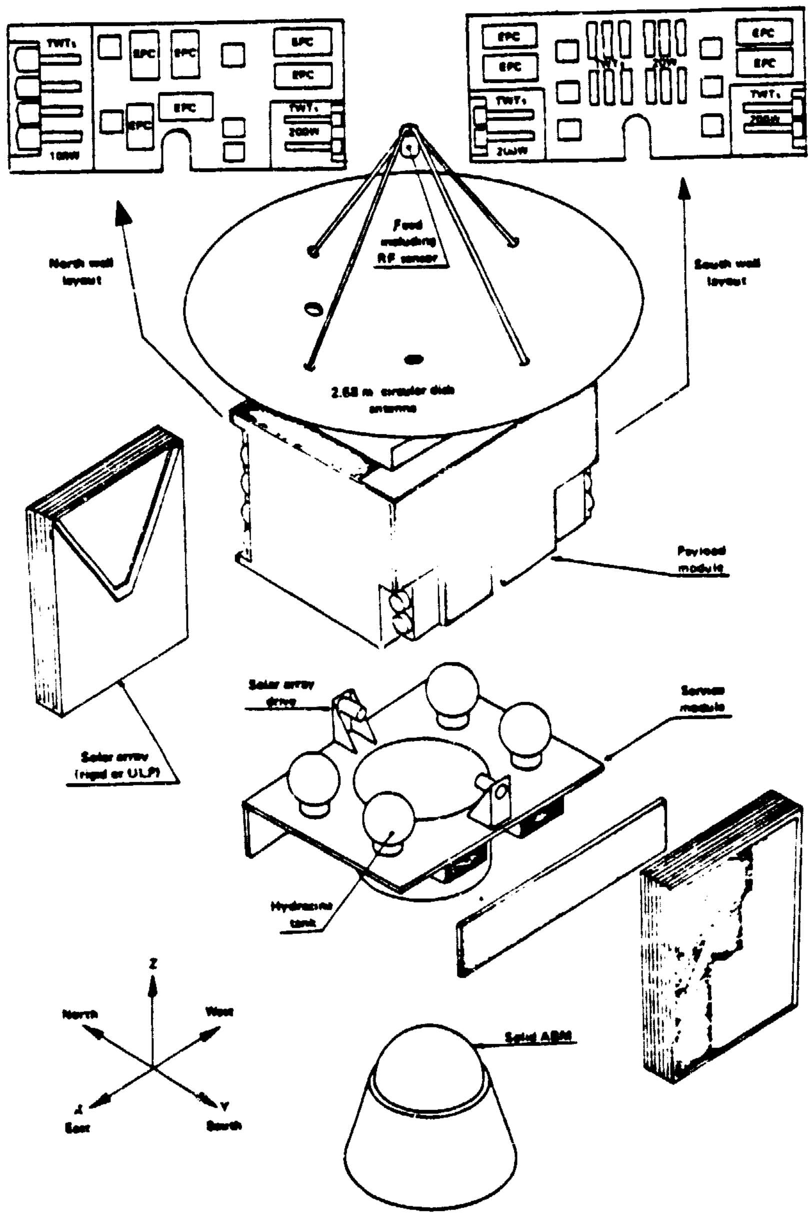


FIGURE 5-96

ARIANE CONCEPT FOR TV BROADCASTING (NORDSAT)



Satellite configuration.

FIGURE 5-97

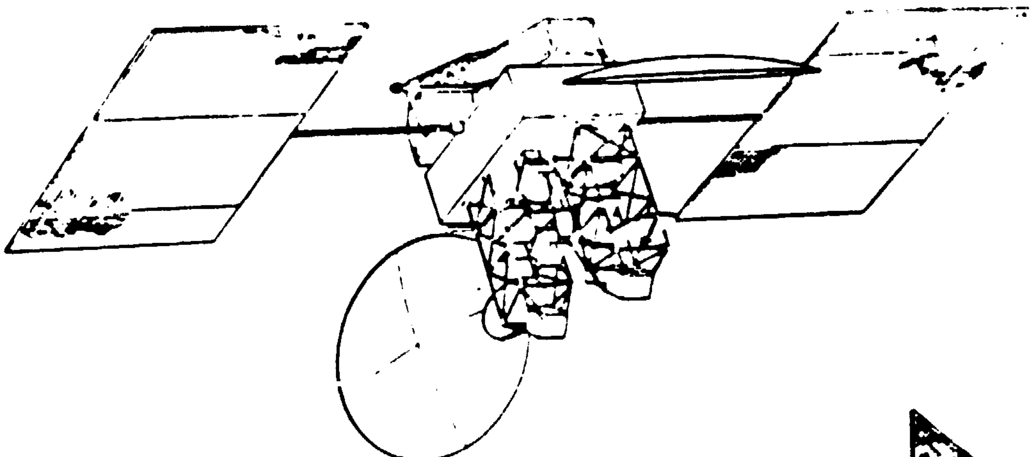


Figure 5-98 - TRW

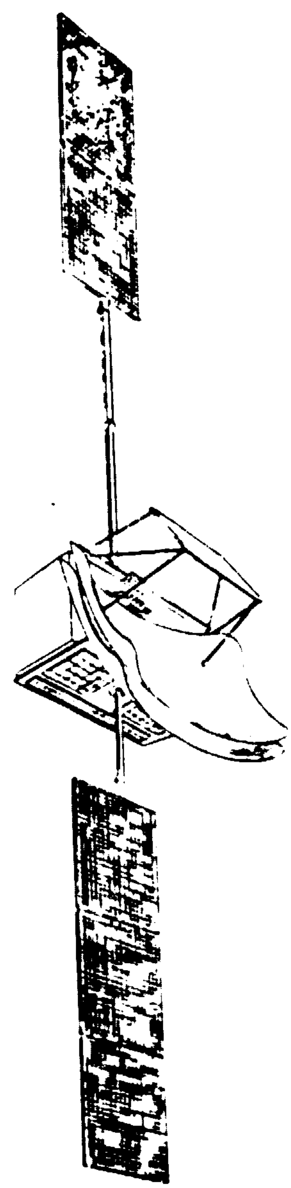


Figure 5-99 - RCA

RCA Satcom II Characteristics

Launch Vehicle	STS/PAM
Transfer Orbit Weight	3050 lbs.
Mission Life	10 yrs.
Transfer Orbit Stabilization	Spin
Synchronous Orbit Control	Stabilite®
End of Life Array Power	1000 W
Battery Capacity	80 A-hr.
Operating Transponder Channels	24
Spare Power Amplifiers	8
Receive Frequency Band	5.925 to 6.425 GHz
Transmit Frequency Band	3.7 to 4.2 GHz
EIRP Per Channel	34.5 dBW
G/T	-3.5 dB/K
Minimum Polarization Isolation	33 dB

service. While the d.c. power of the RCA Satcom is relatively low (1000 watts EOL) for broadcast satellite requirements, its general design follows the others presented and consistent with TV-SAT-A3 design described earlier which indicate that bus design and attitude and thermal control are technologically mature provided solar array power can be provided to power to TV channels required.

6.0 TV EARTH TERMINALS

6.1 The Small TV Earth Terminal

The word "small" describing miniature earth terminals for broadcast satellite systems also implies low $ cost - a welcome development in the 1980's after almost two decades of satellite systems requiring large million dollar earth terminal installations.

Commercial satellite communications arrived in the mid 1960's using large 30-meter antenna earth terminals to receive from largely global beams. These terminals cost, in 1960's dollars, from 5 to 8 million dollars. The advent of 10-meter antenna earth terminals in the early-mid 1970's, due to higher flux density produced by regional beams, reduced these costs to from 0.5 million to 2 million dollars for full receive-transmit telephony and TV terminals to around $65K for a 4 GHz 10-meter TVRO terminal using a then new GaAs FET amplifier.

The advent of the 4.5 meter TVRO terminal in the 1976 era further reduced these costs to around $35K, and competition due to deregulation of the need to acquire a license to receive commercial 4 GHz TV broadcasts from domestic communications satellites, brought these costs as low as to around $10-15K.

In the decade of the 1980's, the use of TV broadcast satellites with EIRP in excess of 60 dBw, the continued development of low noise amplifier technology using GaAs FET techniques and the use of new integrated circuits made possible by commercial color TV developments has made possible small 1-meter TVRO terminals at 12 GHz costing well under $1K, with similar terminals in the 0.8 GHz and 2.5 GHz frequency range costing in the same dollar range.

Much has been written about the development of low cost 3-meter antenna S-band and UHF systems for use with ATS-6 and of 1 and 2-meter 12 GHz TVRO antennas used with CTS, Anik-B and Japan's BSE and the emergence of a private-user 4 GHz TVRO business (to be discussed) is providing considerable development of low cost TVRO earth terminal systems and technology. This report will only present the highlights of these developments, but will address the specific technologies and costs which will be realized in a future marketplace where small TVRO and interactive terminals in the quantities of 100,000, 1 million, and 10 million will be required. When such quantities are addressed, many technologies and circuits which are not economic in small volume procurement then become candidates for the most cost effective systems.

6.1.1 Types of TV Ground Terminals for Broadcast Satellites

Figure 6-1 illustrates a typical TV antenna system which includes an external antenna with outdoor electronics (if TVRO, LNA only; if interactive, LNA and HPA). A cable connects this out-of-doors installation to an indoors system which can include the receiver and a TV receiver, and an exciter and telephone if the system is interactive.

The circuit diagram of this system is shown in Figure 6-2. Note that the basic TVRO video earth terminal includes only an antenna, a LNA (low noise amplifier), and a video receiver which is directly connected to a commercial TV set, or to a TV distribution system such as a cable system or a VHF broadcast transmitter. Figure 6-2 includes an interactive video earth station which includes a transmit capability for either or both video and voice . Figure 6-3 shows a typical TVRO earth terminal developed in Japan for use with the Japan BSE. This earth terminal receives an FM TV signal at 12 GHz, using a 90 mm dish, and delivers a vestigial sideband video carrier and an FM sound carrier at a prescribed channel frequency to a standard TV receiver. This type of receiver, to be discussed in this chapter, is intended to sell for less than $300 in quantities greater than 100,000.

The TVRO terminal of Figure 6-3 is described in terms of basic specifications in Table 6-1. Table 6-2 gives more detailed Antenna/LNA/LO specifications; note

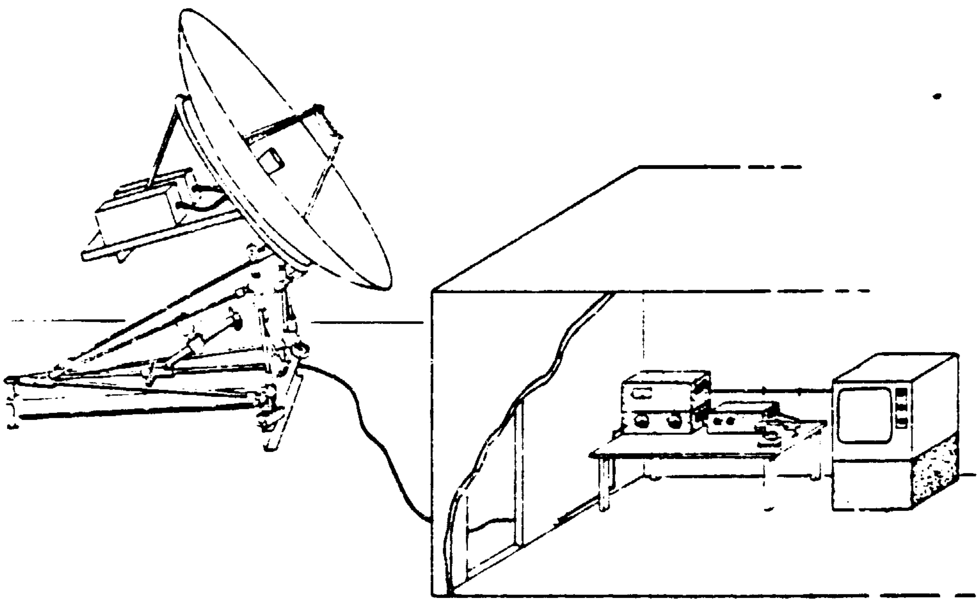
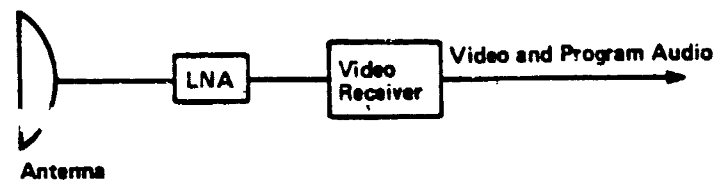
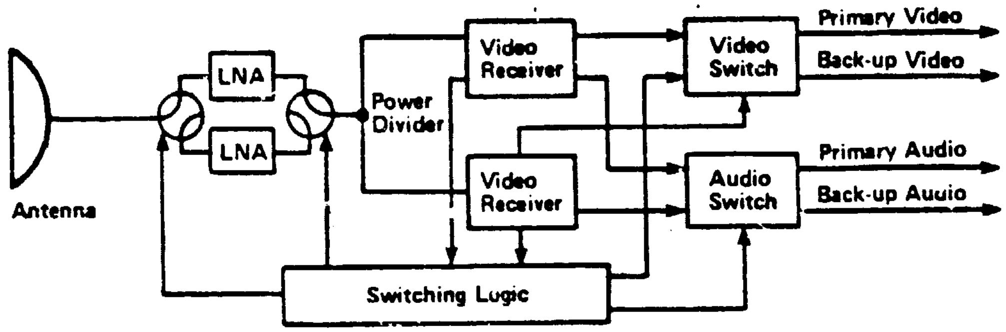


Figure 6-1

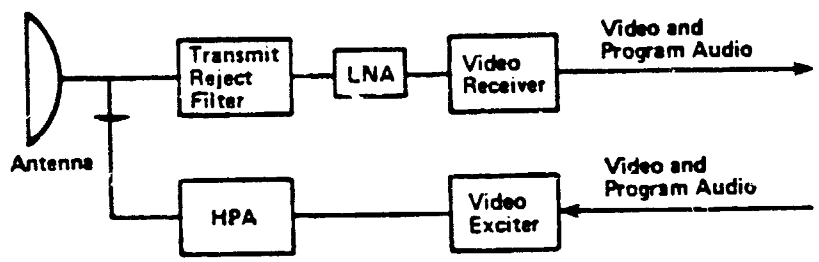
TV Ground Terminal



Basic Receive Only Video Earth Station Block Diagram

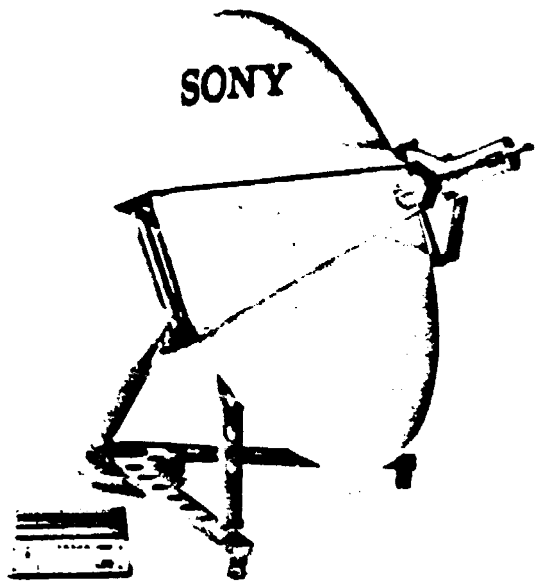


Redundant Receive Only Video Earth Station Block Diagram



Basic Transmit/Receive Video Earth Station Block Diagram

Figure [illegible]. TV Terminals



1. Sony hopes to grab *a share of the potentially lucrative direct-to-home broadcasting market using simple receive-only stations. This one uses a 90-cm dish, and 60-cm dishes have been successfully tested.*

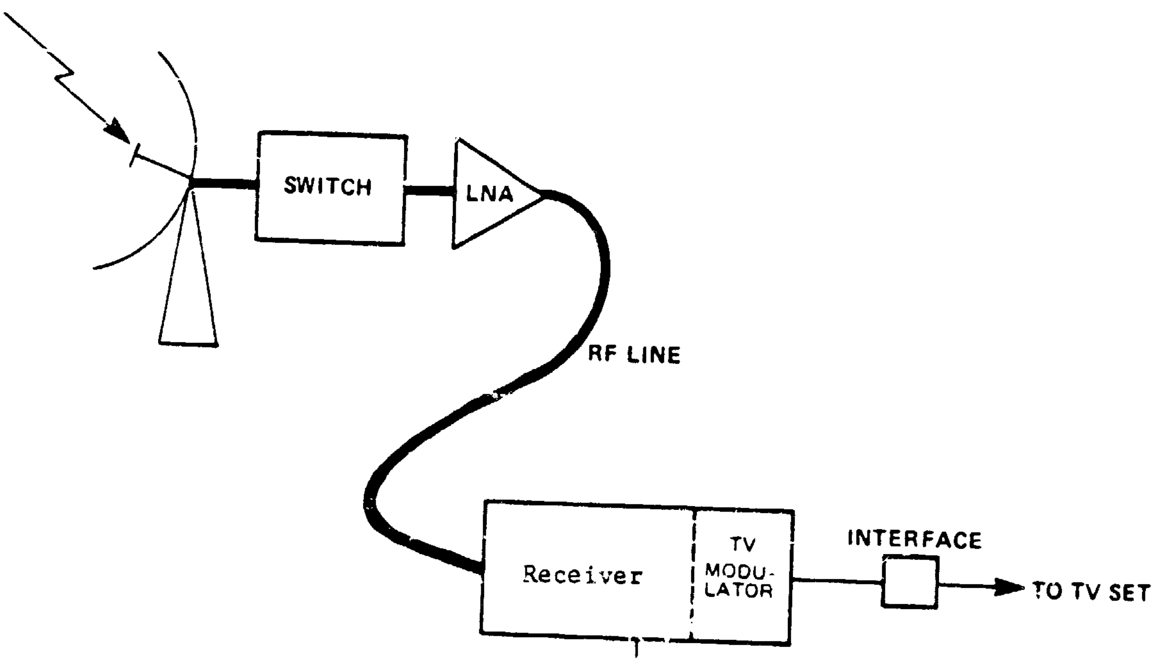


Figure 6-3. Japan's Small Earth Terminal Contender

TABLE 6-1

Typical 12-GHz TV Individual-User
TVRO Terminal

Receive Frequency	12.2-12.7 GHz
Antenna	1 m
Receive Noise Temp	50K for Antenna 550K for Receiver
Receive Signal Level	-110 dBW
TV-V Signal	FM, 12 MHz P-P Deviation
TV-Audio Signal	FM-FM, 2 MHz P-P Deviation 4.5 MHz Subcarrier
Video Bandwidth	4.2 MHz
Video S/N	46 dB, weighted
Audio Bandwidth	15 kHz
Audio S/N	50 dB

Table 6-2

Typical Antenna/LNA/L.O Specifications

Antenna Type	1 m cassegrain antenna with currugated horn and continuously variable linear polarization
Elevation angle range	5° to 30°
Azimuth angle range	350°
Wind velocities	
Operational	Up to 30 m/s
Surviving	Up to 50 m/s
Polarization discrimination	>35 dB within 1 dB main lobe width
Antenna gain	≥39.0 dBi at 12.2 GHz
Antenna temperature	≤75° K at 10° elevation
Frequency range	12.2 to 12.7 GHz
Temperature range	
Outdoor unit	-45° C to + 40°C
Indoor unit	0° C to + 40°C
Noise Figure	≤5.0 dB
LO stability	1×10^{-6}/month
LO phase noise, C/No	>90 dBHz at 1000 Hz >68 dBHz at 100 Hz >40 dBHz at 10 Hz
Gain stability	0.5 dB/day

that a G/T of 8 is used requiring an LNA noise temperature of around 5 dB. The receiver provides a video signal-to-noise ratio (S/N) of 46 dB and an audio signal ratio (S/N) of 50 dB when the terminal is directed toward the BSE broadcast satellite with an EIRP of 56 dBW (See Table 6-1).

6.1.2 System Requirements for Received Picture Quality

The ultimate question in TV transmission is the customer acceptance of the displayed TV image. This has been related by the TASO study (see below) to the rms RF signal-to-noise ratio (S/N in a 6 MHz band for NTSC television system.

Almost all of the recent American literature, including the Jansky and Bailey report referenced in the RFP, refers back to this experimental study reported by the Television Allocations Study Organization (TASO) in 1959. The TASO study was conducted at the RCA Laboratories in Princeton, New Jersey, in May and June 1958. Almost 200 observers participated in the experiment, resulting in approximately 28,000 separate observations in 63 electrical test conditions. The subjective effects of noise on pictures and of co-channel and adjacent-channel interference were determined.

The raw data obtained by the TASO Panel was analyzed further by the FCC and reported by Harry Fine of the FCC in 1961. His principal results are shown in Figure 6-4. The picture grades are defined in Table 6-3. Note that for S/N above 45 dB, TASO Grade 1 is achieved in which the noise is not perceptible and the picture is of extremely high quality.

The signal-to-noise ratio (S/N) is obtained from standard link budgets. Table 6-4 describes link budgets for 12 GHz individual and community reception where the satellite EIRP is 63 dBW for the direct-to-home receiver and 55 dBW to the community receiver; a G/T of 8 is assumed for the direct-to-home receiver, and S/N's in the 45 to 47 dB range are obtained for a TV signal using an FM in a 20 MHz bandwidth.

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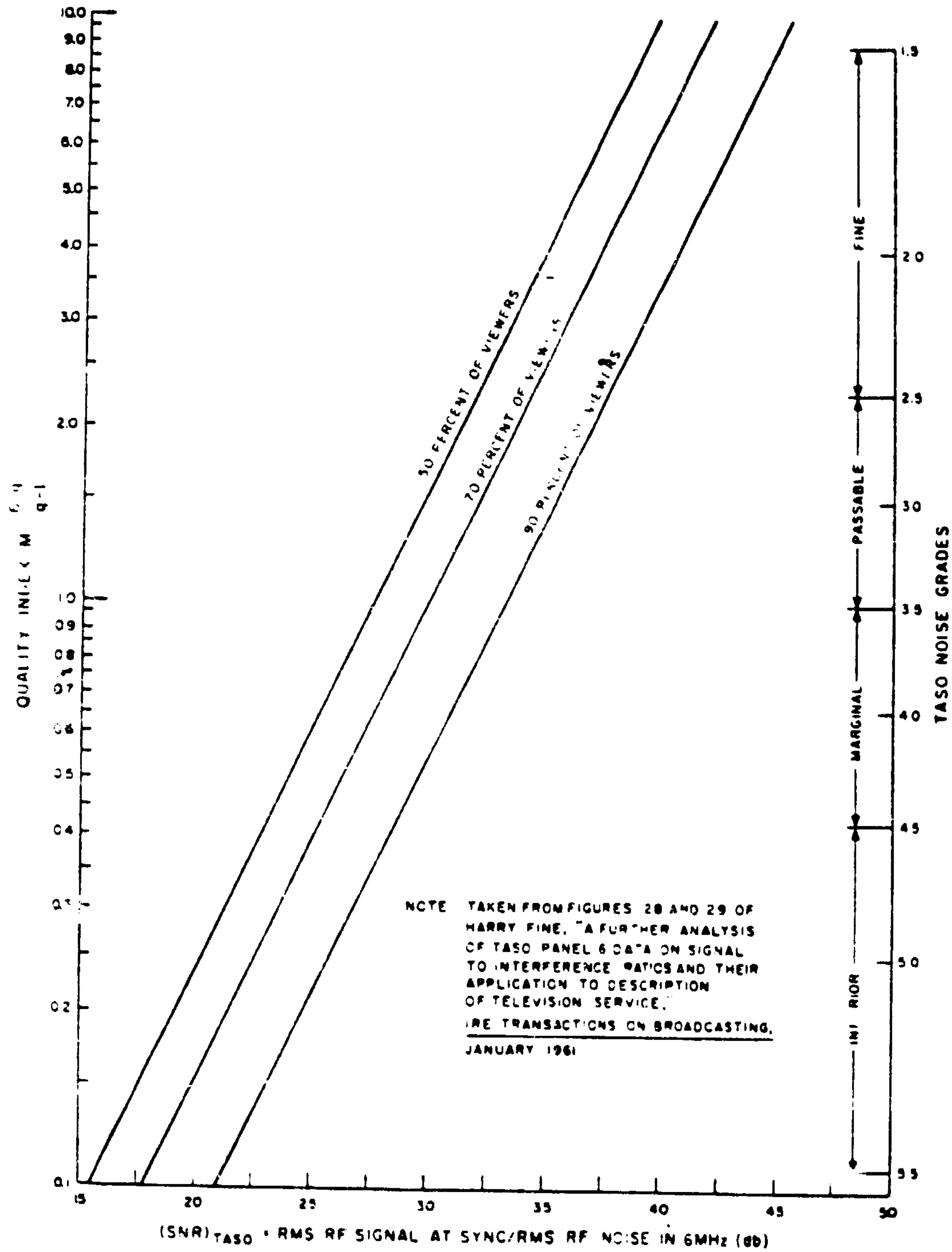

Figure 6-4

TASO Noise Grades as Functional of Signal-to-Noise Ratio

TABLE 6-3

TASO Grade Definitions

Grade	Grade Number	Grade Name	Definition of Grade*
1	$1.00 \leq q \leq 1.50$	Excellent	"The picture is of extremely high quality, as good as you could desire." Noise is not perceptible.
2	$1.50 \leq q \leq 2.50$	Fine	"The picture is of high quality, providing enjoyable viewing. Interference is perceptible."
3	$2.50 \leq q \leq 3.50$	Passable	"The picture is of acceptable quality. Interference is not objectionable."
4	$3.50 \leq q \leq 4.50$	Marginal	"The picture is poor in quality and you wish you could improve it. Interference is somewhat objectionable."
5	$4.50 \leq q \leq 5.50$	Inferior	"The picture is very poor, but you could watch it. Definitely objectionable interference is present."
6	$5.50 \leq q \leq 6.00$	Unusable	"The picture is so bad that you could not watch it."

*As defined in "Engineering Aspects of Television Allocations, Report of TASO to the FCC," March 16, 1959, Pages 453, 454.

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TABLE 6-4

Link Budgets for FM/TV Downlinks at 12 GHz

Parameter	Individual Reception	Community Reception
EIRP	63.0 dB	55.0 dB
Free Space Loss	-205.0 dB	-205.0 dB
Service area edge factor	-3.0 dB	-3.0 dB
Rain attenuation margin	-2.0 dB	-2.0 dB
Other Losses	-0.6 dB	-0.6 dB
G/T	8.0 dB	14.0 dB
-k	228.6 dBW	228.6 dBW
C/No	89.0 dB	87.0 dB
B (20 MHz)	73.0 dB	73.0 dB
C/N	16.0 dB	14.0 dB
S/N*	47.0 dB	45.0 dB

* peak-to-peak luminance to weighted rms noise

Figure 6-4A shows how antenna diameter/gain and S/N can be related as a function of LNA noise figure at 12 GHz showing that a 1-meter antenna system with a noise figure of 4 dB will yield a S/N of at least 45 dB which will give TASO grade 1 quality to the user. Table 6-5 describes additional link budgets at 12 GHz as derived for Doc. 10-11/1114-E based on present and achievable techniques, for Regions 1, 3 and Region 1. This table is in C/N, and includes the received power flux density PFD.

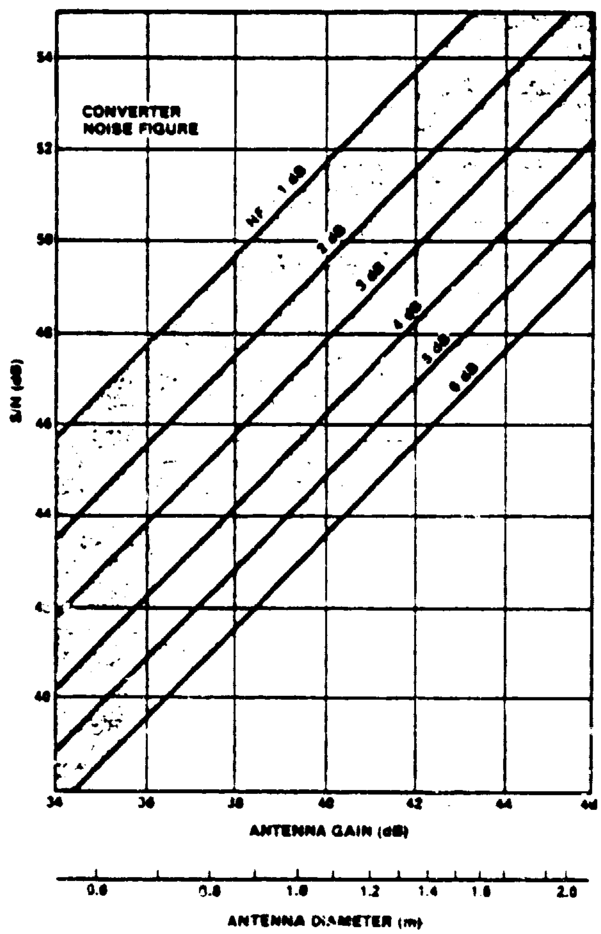
6.1.3 <u>General G/T Versus Antenna Diameter Considerations in TV Earth Terminals</u>

In USSG-10/11B Doc BC-852, Dr. Firouz Naderi has developed several very useful curves which relate LNA or receiver noise figure and antenna gain for various ranges of G/T at 0.7 GHz, 2.6 GHz, and 12.2 GHz.

Note from Figure 6-7, that a noise figure of 6 dB and an antenna diameter of 1 meter gives a G/T ≅8 dB. The value includes a coupling loss of 0.5 dB and an antenna temperature of 171K. Note that retaining the 1-meter antenna diameter and reducing the noise figure to 3 dB increase the G/T to 12 dB while retaining the 6 dB noise figure receiver and increasing antenna diameter to 1.5 meters also increases the G/T to 12 dB.

Thus it is possible to make cost trade-offs between the cost of increasing antenna diameter and the cost of reducing noise figure in order to achieve a particular G/T.

Tables 6-6A and 6-6B, for video only, also due to Dr. Naderi, relate two values of S/N and four different bandwidths in MHz to the <u>sum</u> of satellite EIRP, earth terminal G/T. Note that from Table 6-6, a satellite with an EIRP of 68.6 and an FM bandwidth of 27 MHz will provide a S/N of 43 dB with an antenna terminal of G/T = 8 dB at 12 GHz. While the EIRPs are believed to be extremely conservative (slightly high), the trends in G/T for various bandwidths for a given S/N can also be established, with a spread of almost 6 dB existing between the 18 MHz and the 36 MHz system.



GAIN AND NF: The relationship between received picture weighted S/N and antenna gain varies with the converter's noise figure. To produce a S/N ratio of 45 dB, using a converter with a 4.5-dB noise figure, an antenna with a gain of 39 dB is needed.

Figure 6-4A

TABLE 6-5

Characteristics of Representative Receiving Systems and Resulting Power Flux-densities Derived from Doc 10-11/1114-E

Type of Reception	Individual A	Individual B	Individual C	Individual D	Community A	Community B	Community C	Community D
HP beamwidth (degrees)	2.4	1.5	2.0	1.8	1.0	0.75	1.0	1.0
Antenna diam. (m)	0.75	1.2	0.9	1.0	1.8	2.4	1.8	1.8
Noise factor (dB)	6.2	3.7	5.0	4.6	4.2	2.2	4.2	4.2
G/T (dB)	4	12	6	8	14	20	14	14
Overall C/N required (dB)	14	14	14	14	14	14	14	14
Frequency band (GHz)	12	12	12	12	12	12	12	12
Bandwidth (MHz)	18	27	27	18/23	18	27	27	18/23
PFD (dBW/m^2)	-103	-109	-103	-104/ -103	-112	-117	-111	-112/ -111

A: readily achievable
B: achievable at additional cost
C: adopted by WARC-BS for Regions 1 and 3
D: adopted by WARC-BS for Region 2 (US)

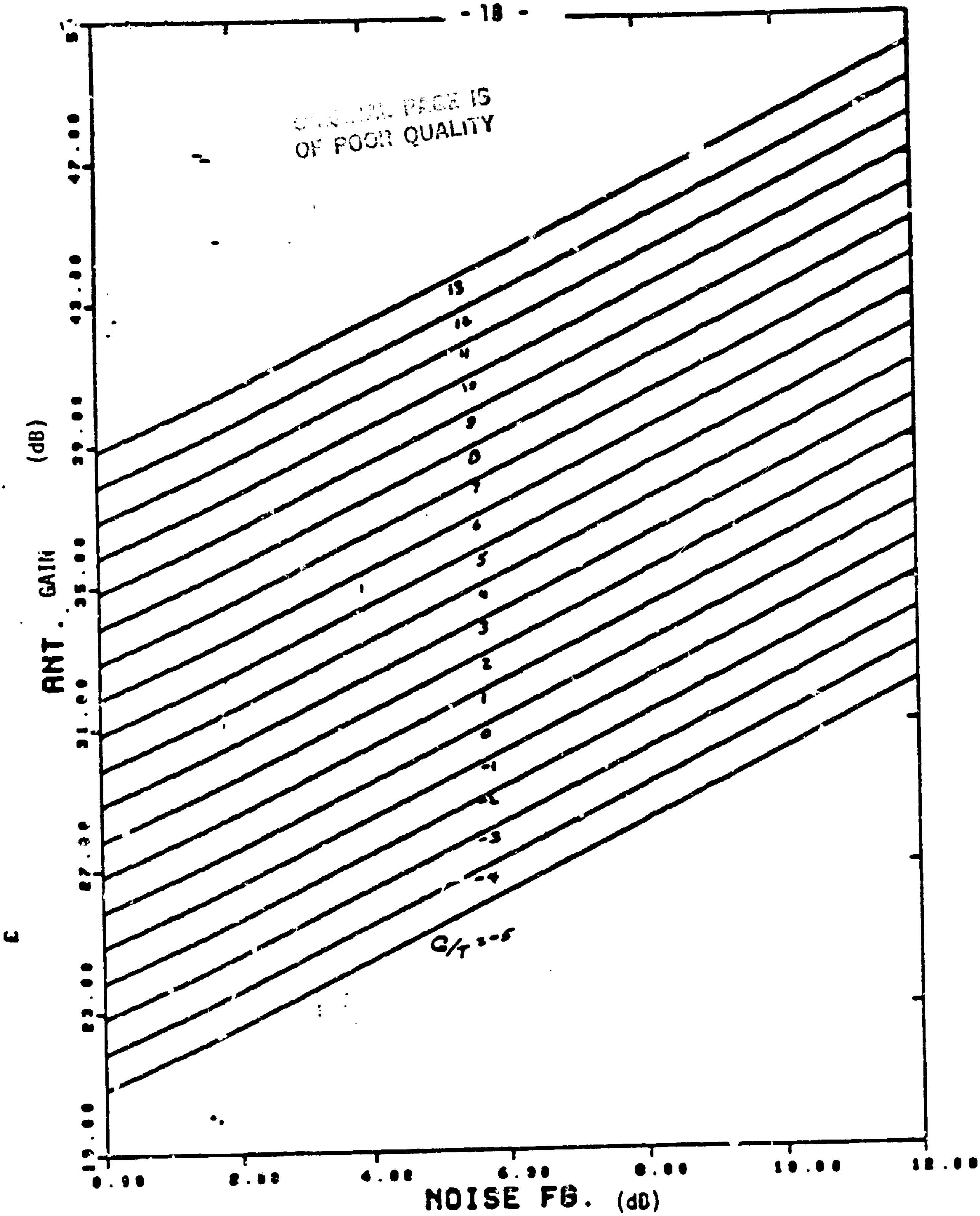


Figure 6-5

G/T as a function of antenna gain and the receiver noise figure frequency = .7 GHz, coupling loss = .5 dB, antenna temperature = 350 K.

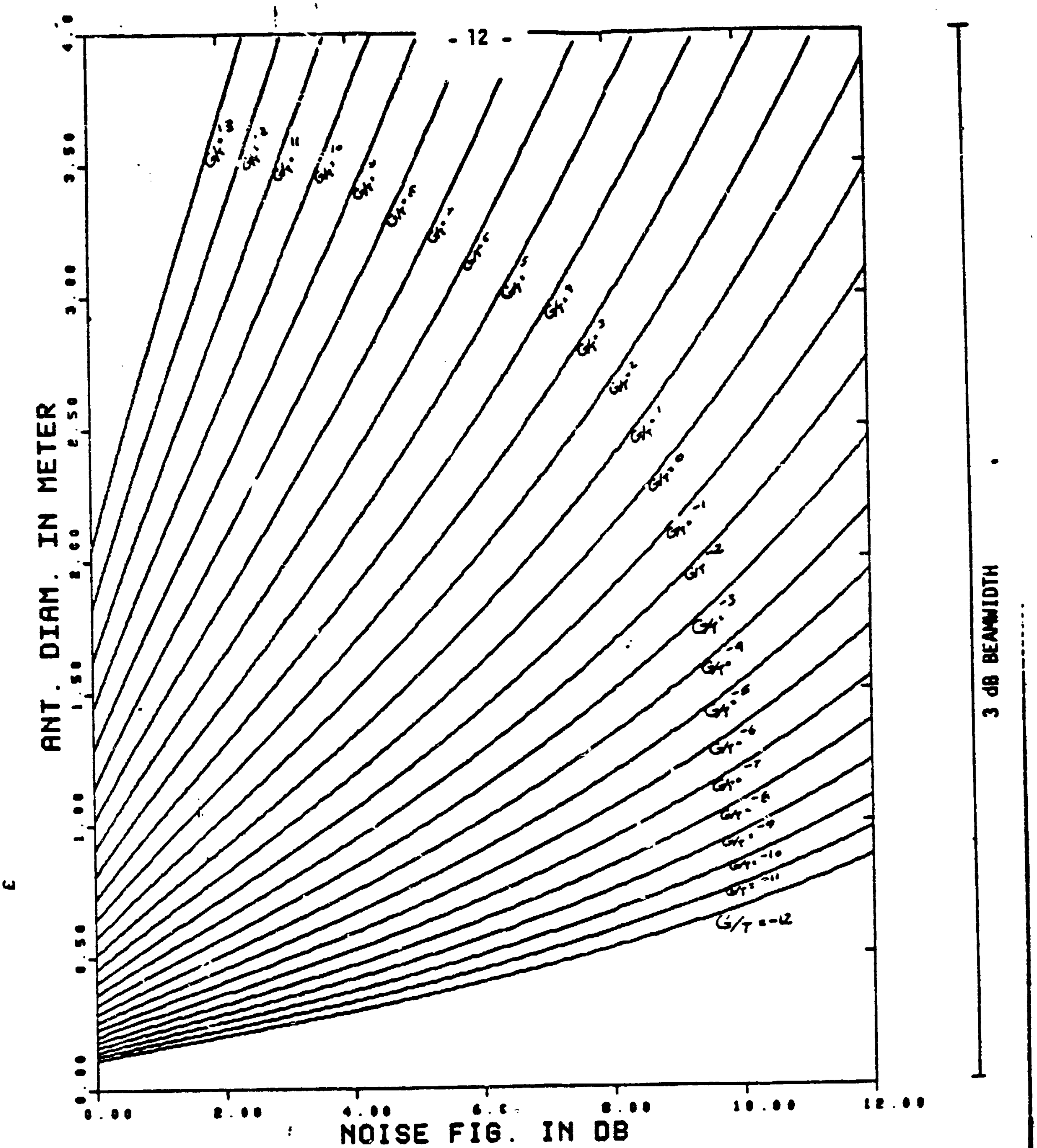


Figure 6-6

G/T as a function of antenna sizes and receiver noise figure frequency = 2.6 GHz, coupling loss = .5 dB, antenna temperature = 50 K

C-5

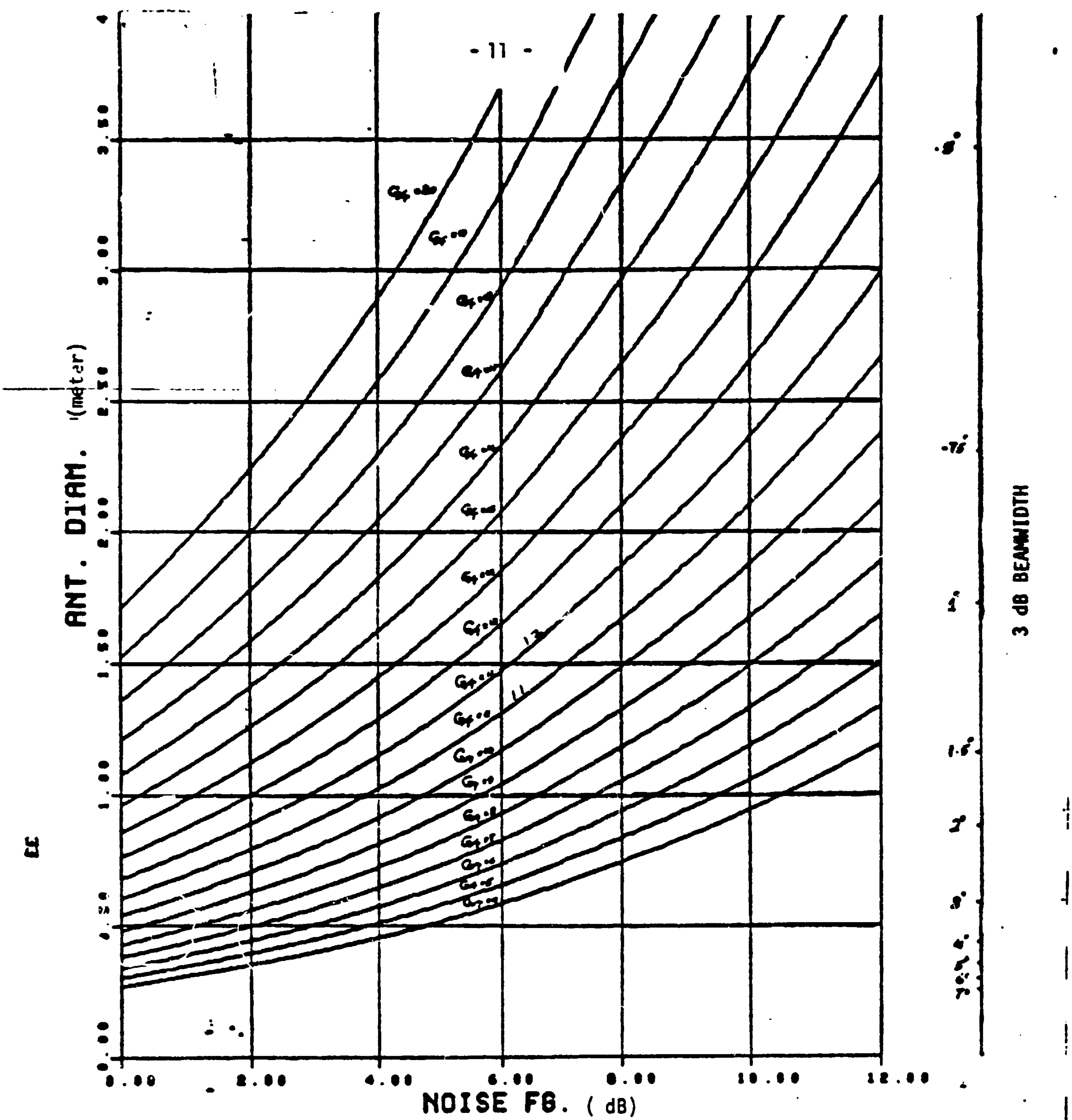


Figure 6-7

G/T as a function of antenna size and receiver noise figure. Frequency = 12.2 GHz coupling loss = .5 dB, antenna temperature = T_{ar} + T_{as} where T_{ar} = antenna temperature due to rain = 171 K(corresponding to 4.1 dB rain attenuation for 25° elevation angle and 99.9% reliability in an average year) and T_{as} = antenna temperature due to sources other than rain.

TABLE 6-6A

The required algebraic sum of the satellite EIRP and the ground terminal G/T for individual reception.

Bandwidth in MHz	The required satellite EIRP + ground terminal G/T in dB for S/N = 43 dB		
	UHF	S	Ku
18	42.9	54.4	72.3
23	39.3	50.8	68.7
27	37.2	48.7	66.6
36	37.0	48.5	66.4

TABLE 6-6B

The required algebraic sum of the satellite EIRP and the ground Terminal G/T for community reception.

BC-852

Bandwidth in MHz	The required satellite EIRP + ground terminal G/T in dB for S/N = 49 dB		
	UHF	S	Ku
18	48.9	60.4	78.3
23	45.3	56.8	74.7
27	43.2	54.7	72.6
36	39.7	51.2	69.1

6.1.3.1 S/N, FM Bandwidth and Protection Ratios

The degree of interference perceptibility of interference for FM television signals depends on the amount of thermal noise present and permits a higher level of interference when the picture is degraded by the presence of thermal noise. The CCIR has expressed a protection ratio PR which in turn is related to a protection constant PC as follows:

$$\begin{aligned} PR &= PC - (49 - S/N) \qquad && S/N < 49 \text{ dB} \\ &= PC && S/N > 49 \text{ dB} \end{aligned}$$

where all quantities are expressed in decibels and S/N is the peak-peak luminance signal to RMS thermal noise ratio. Figure 6-7A due to Collin and Gabel, shows the required protection ratio as a function of S/N for various FM bandwidths. These protection ratios will result in just perceptible interference during less than 5% of the time. Since it can generally be expected that S/N will equal 49 dB or more the required protection ratio will equal the protection constant.

For example, a 8 MHz bandwidth FM television signal will require the level of interference to be 35 dB below the desired signal. It is apparent that the sidelobe level of the ground station antenna receiving this signal should be at least 36 dB below the main lobe in order to provide adequate discrimination against unwanted signals for FM television broadcasting with bandwidth as low as 8 MHz.

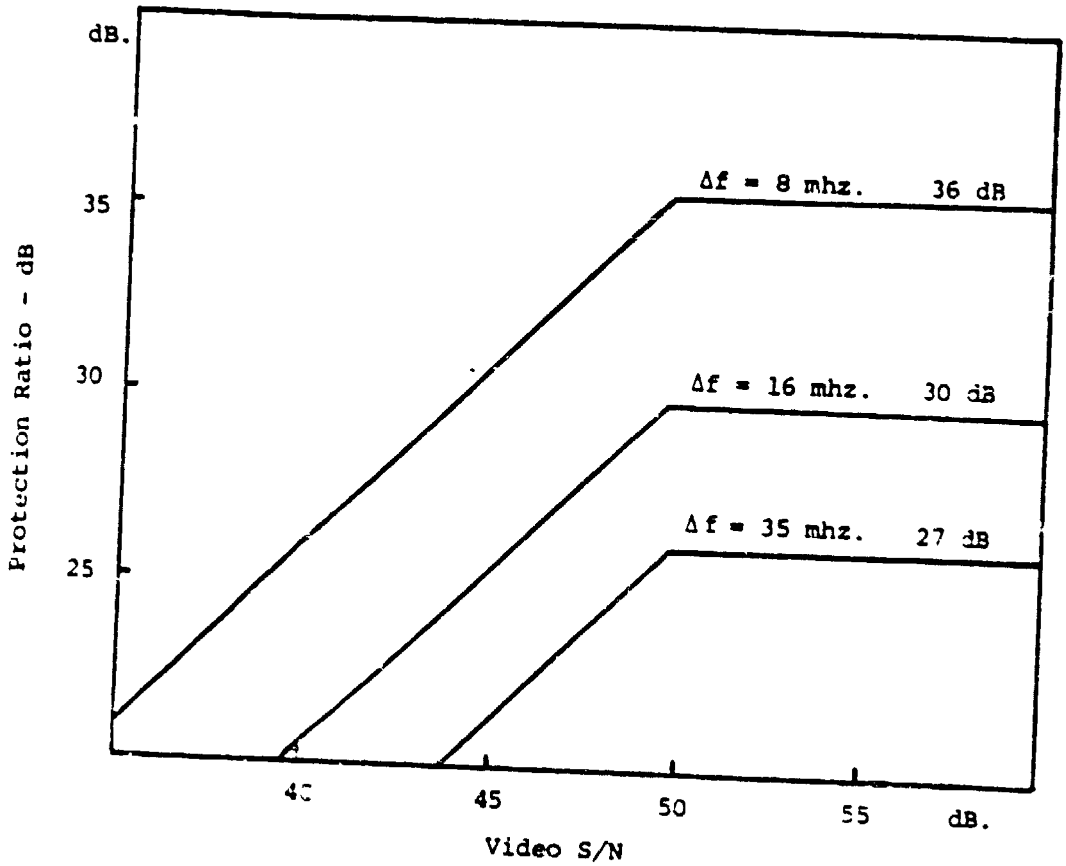


Figure 6-7A. Protection ratio as a function of video signal to noise ratio.

6.2 Present TVRO Earth Terminals

As has been described earlier in this report, numerous broadcast TV systems have already been built and tested or are in operation at the three frequency ranges in question.

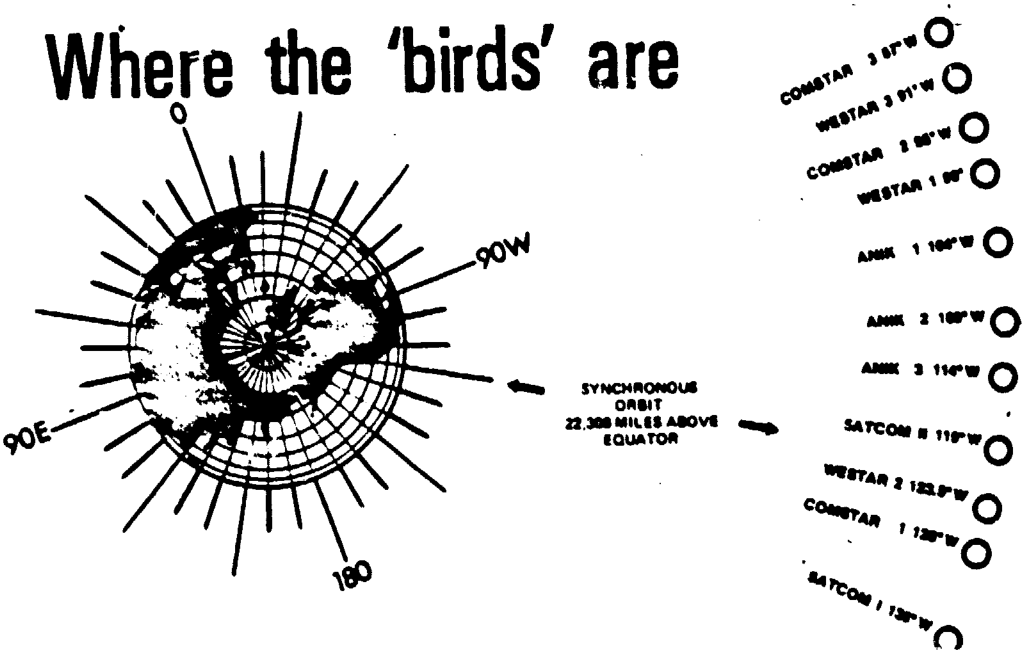
The preceding sections have discussed the use of high power satellites at UHF/S-band/Ku-band for broadcasting into small low cost terminals. These include systems for which significant hardware and test commitments have been made. These systems are listed below and will be discussed in the next paragraphs.

UHF	- USSR Statsionar-T into Siberia at 715 MHz (community).
	- ATS-6 Experiment into India at 900 MHz (community).
S-band (2.6 GHz)	- ATS-6 educational TV experiments into Rocky Mountains and Appalachia.
	- INSAT into India (community).
Ku-band	- CTS into Canada and U.S., testing 0.7 meter to 4.5 meter systems for direct-to-user and community reception.
	- ANIK-B and ANIK-C into Canada, testing lower EIRP transmission into small (1.2-1.6 m) antennas.
	- Japan BSE into Japan testing direct-to-user systems.

These systems essentially set the stage for WARC-77 and for the intense interest on a worldwide scale that has been manifested at WARC-79 and which has created the intensive broadcast satellite developments described in Section 2.

6.2.1 TVRO Earth Terminals for Domestic 4/6 GHz Satellites

Any developments, worldwide, in TVRO earth terminals at any frequency, will benefit from the intense developments now underway in the United States as a result of the use of the RCA SATCOM 1 and 2 and WESTAR 1 and 2 domestic satellites. As shown in Figure 6-8 each RCA SATCOM uses frequency use via vertical and



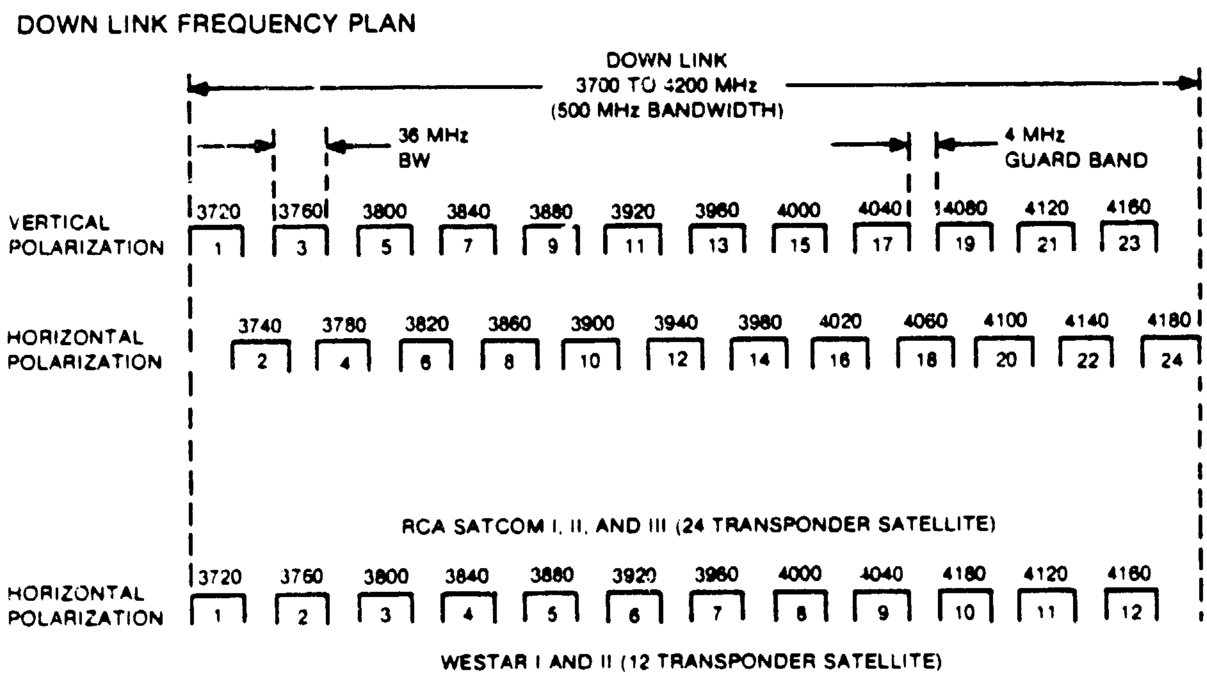


Figure 6-8

Transponder Frequency Plans of RCA SATCOM and WESTAR horizontal polarization to provide 24 channels in the 3.7-4.2 GHz downlink. Each WESTAR provides only 12 channels. Each satellite has an EIRP of around 32-34 dB which then places significant requirements of antenna size and LNA noise temperature, making very small (1 meter) antenna diameters impossible, but achieving exceptional reception with 4.6 meter antennas and good reception with 3-meter antennas. Figure 6-9 shows the recommended minimum antenna size and LNA noise temperature for use with SATCOM 1 over the continental United States.

The uses of the SATCOM and WESTAR satellites for television distribution are myriad. They range from television network video and sound distribution, to cable TV distribution, special programming for music, sports, news, conferences, etc., to selected user communities, and even for broadcasting sessions of the U.S. Congress in Washington, D.C.

Table 6-8 lists the Cable TV earth terminals as of April 2, 1979 (already out of date a year later) showing the number of earth terminals (10 meter and 4.5 meter variety) which serve the use above. Figure 6-10 shows the circuit diagram of a cable TV TVRO earth terminal manufactured by Microwave Associates (MaiCom). Figure 6-11 shows the salient features of Scientific Atlanta's Model 8502 TVRO earth terminal - probably the most widely used earth terminal in the world in 1979-1980. Table 6-12 lists selected TVRO receiver specifications. This receiver must follow an LNA with a noise temperature at the 100-120°K level.

With the advent of high quality TVRO earth terminals such as the Scientific Atlanta terminal above, a family of very low cost private user or personal earth terminal systems has been developed to sell from $1000 to $12000. Figures 6-12 and 6-13 show respectively a very low cost high quality 12-ft dish manufactured by LINDSAY, and the very, very low cost SWAN spherical antenna which is reported to be capable of costing less than $300 on a build-your-own basis.

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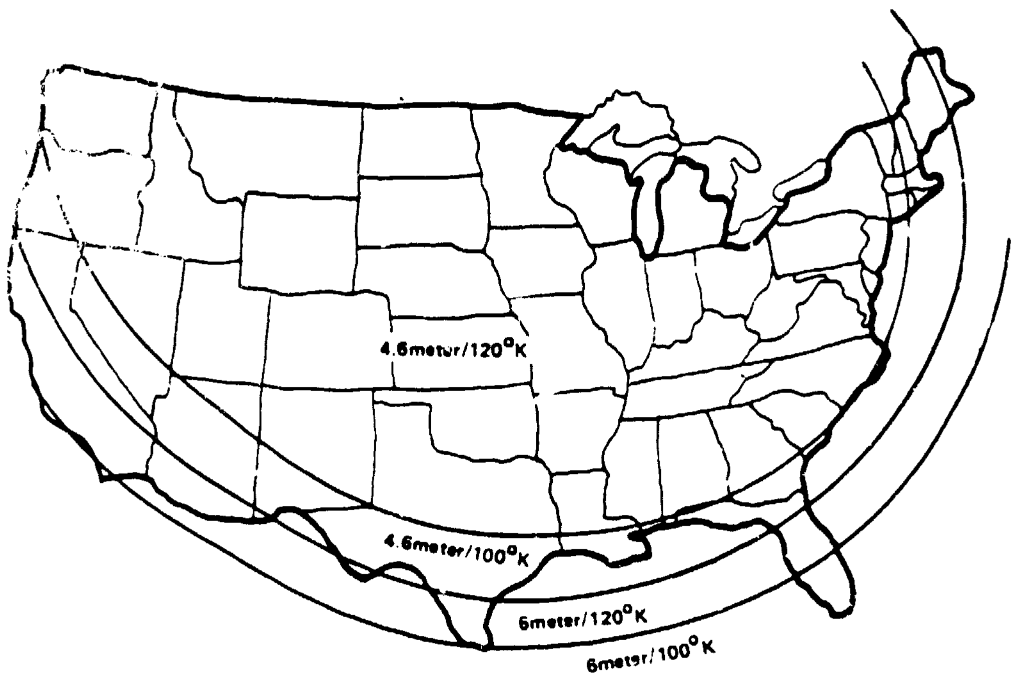

Figure 6-9
Recommended minimum antenna size and Low Noise Amplifier
for use with SATCOM-1

TABLE 6-8

CATV Earth Stations State Listing

	Total Subscribers In Thousands +	Under Construction Or No Data	Total Earth Stations
Alabama	213	10	65
Alaska	5	4	5
Arizona	52	3	23
Arkansas	107	5	37
California	863	11	78
Colorado	68	6	22
Connecticut	123	4	12
Delaware	58	0	3
District of Columbia	0	0	0
Florida	477	16	68
Georgia	240	11	50
Hawaii	24	2	4
Idaho	48	1	12
Illinois	318	12	57
Indiana	172	6	35
Iowa	64	8	21
Kansas	148	11	63
Kentucky	88	2	27
Louisiana	167	8	39
Maine	32	1	6
Maryland	85	3	12
Massachusetts	71	2	10
Michigan	191	5	36
Minnesota	115	9	42
Mississippi	165	6	45
Missouri	76	7	27
Montana	73	5	23
Nebraska	62	1	15
Nevada	29	0	5
New Hampshire	27	0	6
New Jersey	70	4	15
New Mexico	176	3	27
New York	349	7	29
North Carolina	187	10	43
North Dakota	33	5	14
Ohio	410	2	44
Oklahoma	157	11	56
Oregon	136	0	26
Pennsylvania	360	8	32
Rhode Island	N/A	1	1
South Carolina	94	10	28
South Dakota	24	4	8
Tennessee	119	8	42
Texas	611	34	147
Utah	16	5	10
Vermont	11	1	5
Virginia	128	4	29
Washington	146	2	22
West Virginia	181	9	32
Wisconsin	131	4	24
Wyoming	63	1	15
Totals	**7,500**	**283**	**1,498***

*Includes 115 microwave interconnects

+ John Lubetkin, marketing director for the Appalachian Regional Commission, estimates that the total of cable TVRO subscribers is underestimated by approximately 10-15 percent, and that the earth station total is underestimated by approximately 3-5 percent. Total as of April 2, 1979

Satellite Communications

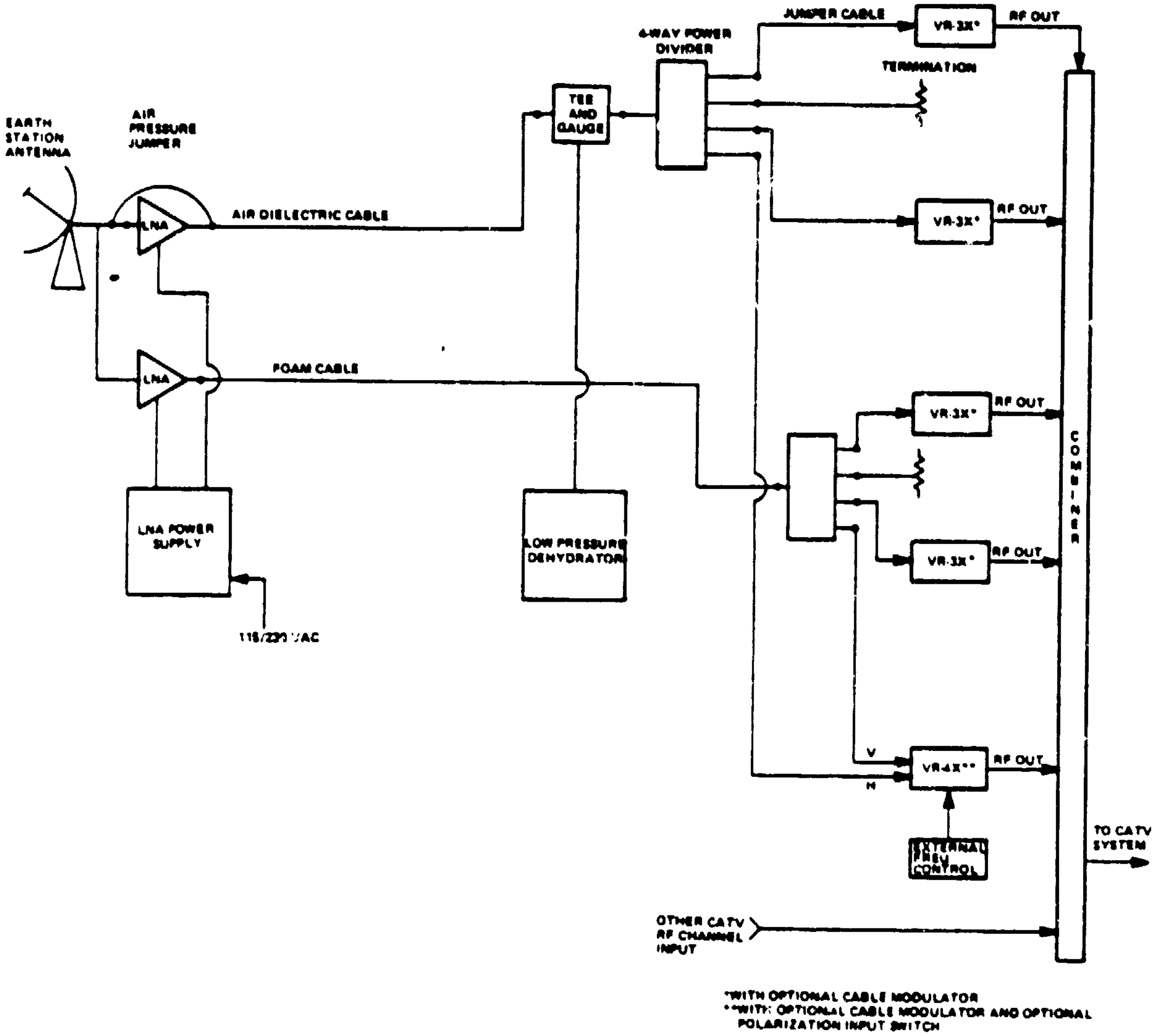

Figure 6-10. Cable TV TVRO Circuit

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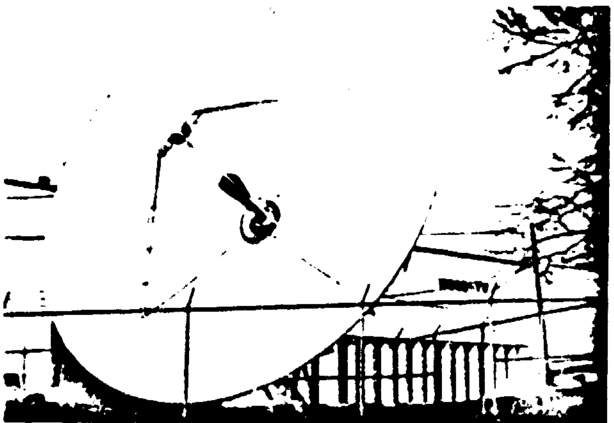
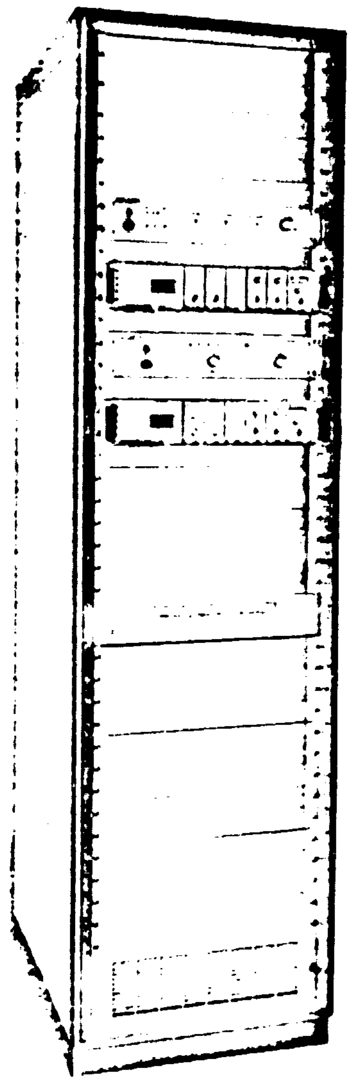
Packaged Systems
Television Earth Stations

Figure 6-11.
Scientific Atlanta's Model 8502



WCCB-TV Charlotte, North Carolina



Model 8502 Redundant Receive-Only Earth Station

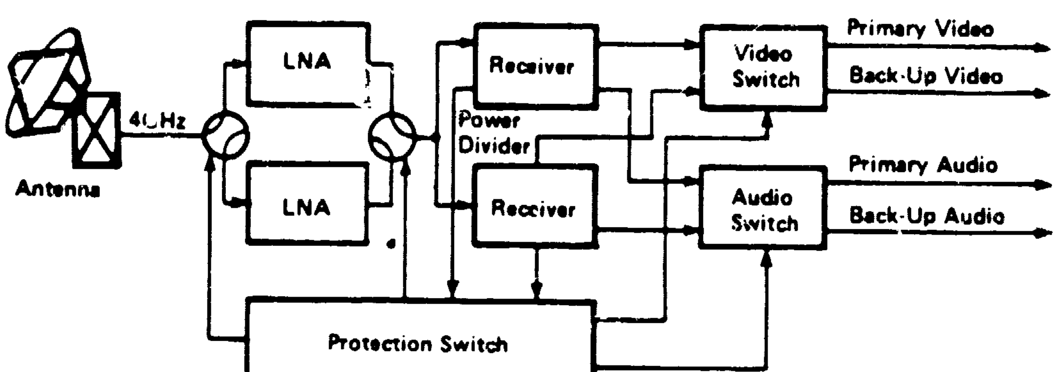
The Model 8502 receive-only earth station also contains the basic antenna, LNA, and receiver components. A second LNA and receiver, plus a protection switch, are included for increased reliability.

The protection switch continuously monitors the primary LNA and receiver for proper operation and automatically switches to the standby units should problems develop.

The Model 8502 redundant system provides considerable operational flexibility. It may be operated in several modes selected by a front panel switch:

a. Fully protected with automatic LNA and receiver switching for maximum protection against outage.
b. Simultaneous operation of one primary and one secondary channel. The secondary channel is automatically pre-empted and switched into primary service if needed for protection of the primary channel.
c. Simultaneous operation of two unprotected channels.

Receive-only earth stations typically require less than 610 mm (24 in.) of standard rack space to house the video receivers and switching equipment. Since this equipment can be located several hundred feet from the antenna, existing equipment-room space is frequently used.



Model 8502 Redundant Receive-Only Earth Station Block Diagram

TABLE 6-12

TVRO Receiver Specifications

General:

Frequency Band	3.7 - 4.2 GHZ
Input Impedance	50 OHMS
Input Return Loss	18 DB
Input Level	-70 To -40 DBM
Channel Bandwidth	30 MHZ
Noise Figure	13 DB
Tuning	24 Channel (Local or Remote)
Threshold	8 DB

Video Performance:

S/N, Weighted C/N of 14 DB	51 DB Typical
Clamping	>36 DB
Differential Phase	±1°, 10-90% APL
Differential Gain	4%, 10-90% APL
Line Time Distortion	1 IRE Units Max
Field Time Distortion	2 IRE Units Max
Short Time Distortion	4 IRE Units Max
Relative Chroma Delay	40 NS Max
Relative Chroma Gain	± 0.5 DB Max
Frequency Response 10 KHZ - 4.2 MHZ Filtered	± 0.5 DB Max
Level Out	1 V P-P (Adjustable)
Impedance	75 OHMS
De-Emphasis	525 Line NTSC 625 Line PAL/SECAM

Audio Performance

Standard Subcarrier Frequencies	6.2, 6.8, or 7.5 MHZ Others Available on Request
Subcarrier Deviation	75 - 200 KHZ Peak
De Emphasis	75 msec
S/N, C/N of 14 DB	60 DB
Frequency Response	± 1.0 DB, 50 HZ to 15 KHZ
Distortion	1% Max
Level Out	+15 DBM Test Tone (+18 DBM Peak)
Impedance	150/600 OHMS Balanced

Operating Environment

Temperature	0 to 50°C
Humidity	95% at 40°C
Elevation	0 - 15000 Feet

Power Requirements

Source	115/230 V - 50/60 HZ AC -22 to -29 VDC (Positive Ground)
Consumption	45 Watts

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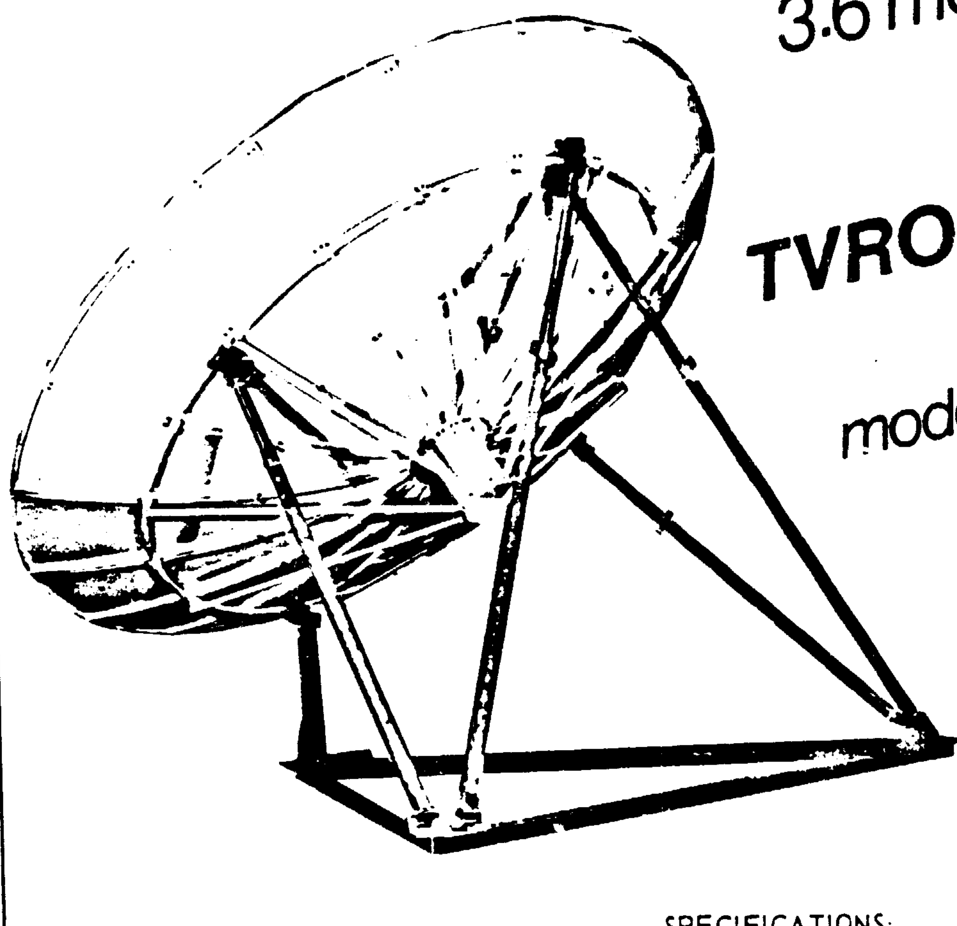
Lindsay — Introduces

3.6 meter (12 ft) Satellite TVRO antenna

model DB1200



The Lindsay 3.6 Meter earth station antenna features excellent gain and sharp directivity at a moderate cost.

The antenna utilizes pre-assembled, high tensile aluminum petal construction, mounted to self-aligning rings. The design allows for easy assembly in the field and keeps transportation cost down to a minimum.

The antenna uses a triangle mount to reflector attachment to provide maximum rigidity. The antenna also features 90 degree elevation adjustment with full polar tracking capabilities.

SPECIFICATIONS:

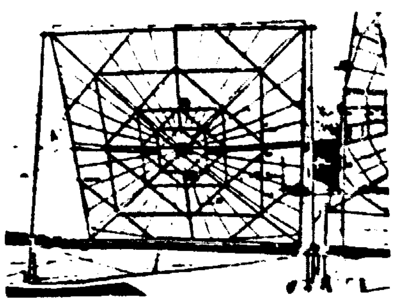
Diameter	12ft (3.6 meters)
Gain	41 dBi
f d	.4
Half Power Beamwidth	1.5 degrees
VSWR	1.3:1
Input Flange	CPR229G
Feed Polarization	Linear
Feed Adjustment	360 degrees
Temperature Range	-40° to +60°C
Ice Loading	1 inch Radial
Windrating (Survival)	100 MPH
Antenna Weight	250 Lbs
Antenna Mount Weight	150 Lbs

Finish: High refraction, electrostatic spray.

FIGURE 6-12. An Inexpensive 12-ft TVRO Antenna.

Now you can build your own Sateilite TV Earth Station in your own backyard for less than $999. This month we'll take a look at antenna design and how a spherical antenna can be built and erected.

ROBERT B. COOPER, JR.



TEN FOOT SWAN SPHERICAL is almost opaque although aluminum screen mesh reflector surface is in place. Note Swan's use of squares and spokes to create sandwich layers that rigidly support antenna and reflective surface. Antenna tilt is handled by telescopic rear support rods with lower-ground-lip on hinges.

Materials - Everything called for can be procured locally. Steel or aluminum pipe tubing (round or square stock) plus aluminum window screening, and common hardware such as machine bolts, are all that is required for the reflector system. The feed-antenna is constructed from galvanized sheet metal.

Cost - $300 Give or take very little Although if you are a good shopper in metal yards you might shave as much as $100 from the total cost.

Complexity - Far less complex to create the spherical surface design than to create a comparable parabolic surface The principle is easy to grasp and uncomplicated to duplicate

A ten-foot spherical antenna will have the gain of a 12-foot 55%-efficient parabolic antenna. A 14-foot spherical will have the gain of a 16-foot parabolic. A 16-foot spherical will operate like an 18-foot parabolic. (The height of the spherical surface is the same as the width. Therefore, when we speak of a 12-foot spherical surface the surface is actually 12 feet high by 12 feet wide.)

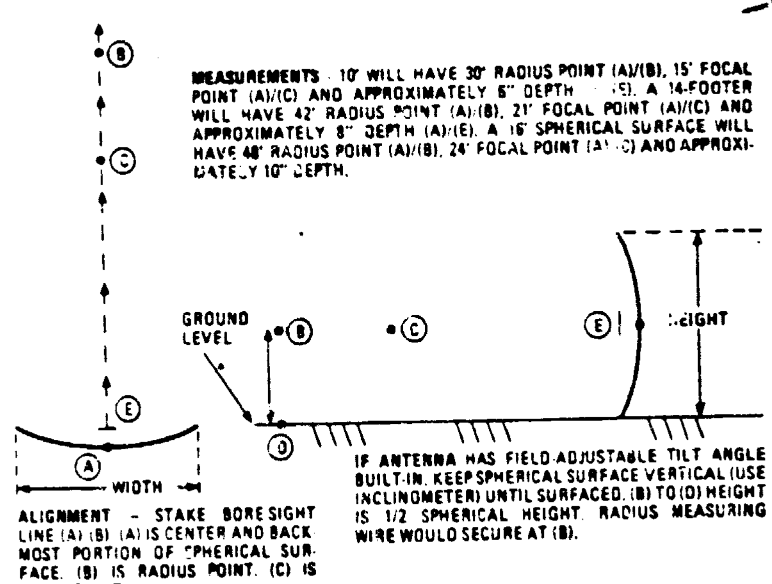
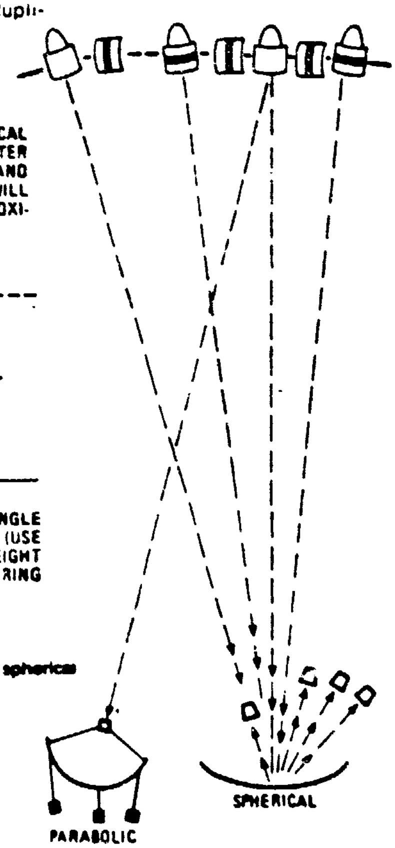


FIG. 6 - DETERMINING RADIUS point and focal point of the spherical reflector surface. The spherical reflector surface is as high as it is wide.



PARABOLIC VERSUS SPHERICAL an-

FIGURE 6-13. Very, Very Inexpensive ($300) TVRO Antenna at 4 GHz - Backyard Type.

Table 6-13 lists three "personal" earth terminal systems manufactured by Microwave General of Mountain View, California, to serve the growing demand high quality personal earth terminals to be installed in a user's backyard to provide reception of the almost 46 channels of television now available for SATCOM, WESTAR, and COMSTAR satellites.

Microwave General's TVRO systems are sold in two varieties shown in Figure 6-14. One provides direct input with a remodulated vestigial sideband carrier and FM sound carrier to a standard TV set at channel 3 or 4. The other involves providing the demodulated video and audio directly to a monitor or projection TV set.

TABLE 6-13.

Typical High Quality Direct-to-User TVRO System

MICROWAVE GENERAL

Personal Satellite Earth Station Terminal Characteristics

TERMINAL MODEL NUMBER	PES-3	PES-4	PES-5
Frequeny Range (GHz)	3.7-4.2	3.7-4.2	3.7-4.2
Gain (dBI) At (4 GHz)	39.9	39.9	39.9
Antenna System Fig. of Merit (G/T)	18	20	22
Antenna (3dB) Beam Width (°) At (4 GHz)	1.7	1.3	1.0
Low Noise Amplifier (Noise Temp.) °K (4 GHz)	100	120	120
Receiver Noise Figure (dB)	12	12	12
Receiver I.F. Band Width (Mhz)	25	25	25
Antenna Range of Adjustment (Azimuth) (°)	90	90	90
Antenna Range of Adjustment (Elevation) (°)	20-60	20-60	20-60
PRICE (Exclusive of Packing, Freight, Programming Fees & Any State or Local Taxes FOB Mountain View, CA.)	$9,950.00	$14,990.00	$19,990.00

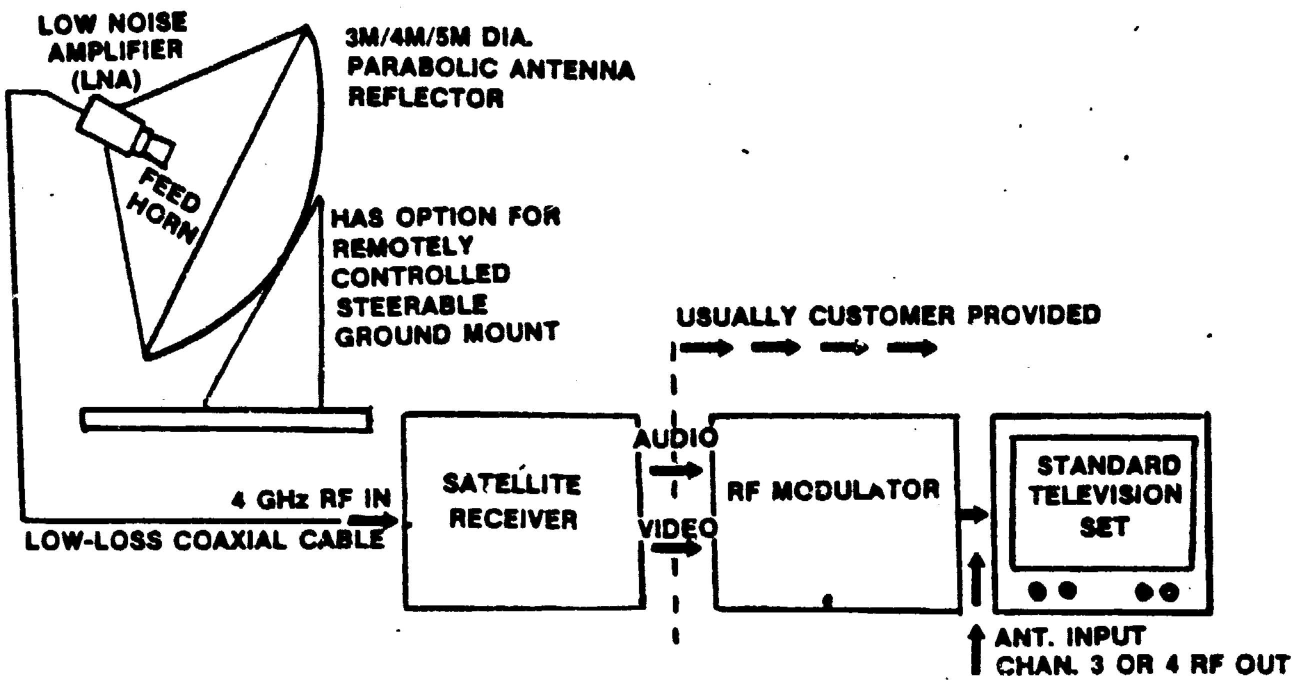
NOTES

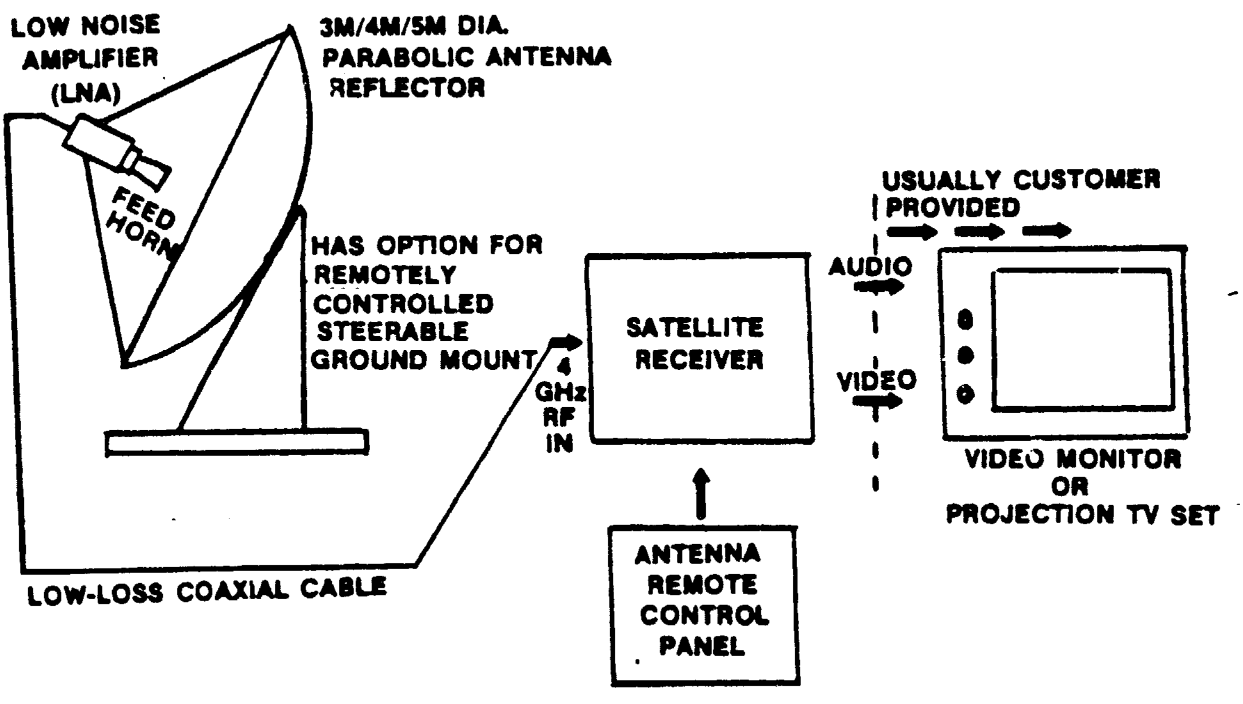
1. Basic PES-3 comes with a one piece fiberglass antenna, polar type mount focal pt. feed, feed support & feed rotator, & remote control 75' of cables, locally controlled receiver with video and audio outputs, low noise amplifier — a complete system exclusive of the T.V. monitor.
2. PES-3 can be used where worst case EIRP is 34dBw, such as Denver
3. PES-4 can be used where worst case EIRP is 32dBW, such as Seattle.
4. PES-5 can be used where worst case EIRP is 30 dBW, such as Los Angeles.

OPTIONS

1. Motorized antenna mount with remote control
2. Agile receiver, remotely tunable
3. Added gain via wings on 5m ant. only
4. Side lobe shroud for 5m ant. only
5. Motorized feed adjustments remote control 4m & 5m
6. Dual polarization feeds
7. Lower noise LNA's
8. Trailer for transport
9. Longer cable runs
10. Pressurization of feed & cables
11. Tan or green antenna & mount
12. Different types of antenna feeds
13. Multi segment antennas
14. Burglar Alarm
15. T.V. Monitors
16. R.F. Modulator for driving a T.V. Set.

*Delivery is typically 30 days





Two of Microwave General's systems are shown in the above block diagrams. They are basic personal earth stations with a 3-, 4- or 5- meter antenna.

Figure 6-14

6.2.2 TVRO Earth Terminal at UHF - EKRAN USSR (Table 6-14)

In the UHF EKRAN/STATSIONAR-T system in the USSR, the first class receiving system antenna is of the Yagi type made of thirty-two 3.5 m curtains. An active element, i.e., an exciter for each curtain is a short section of cylindrical helix fed by a coaxial cable. The reflector contains four linear elements which are fastened at the ends of a crossed structure in such a way that each of these elements forms the letter T with the mount. Thirty crossing directors are made of triangular pairs jointed together on a carrying tube jib. To facilitate the transportation the curtain jib may be disengaged approximately in the middle of its length.

All active and passive current carrying curtain elements are made of an aluminum alloy. Antenna structure permits step and smooth antenna changes along the angle of elevation between 0° and 70° as well as a non-operative azimuthal orientation within $\pm 180^{\circ}$ and semi-operative orientation within $\pm 7^{\circ}$ relative to any direction chosen. The support of the antenna is a meshed mast a 800 x 800mm square and is assembled of 3m individual sections. Depending on the section number the mean height of the antenna structure can be 6m, 9m, 12m and 15m. Figure 6-15 shows the general view of the antenna.

The first class receiving installation contains two identical FM receivers, one of which is operating and the other is back-up, the power to each being supplied from a separate 12.6V rectifier. A low-noise transistorized amplifier with the noise temperature of 450K and the gain of 18 dB is put at the input of each receiver.

Tunnel diodes and a local crystal oscillator are used in the frequency converter. The signal is basically amplified in a 70 MHz IF amplifier. Following the frequency detector a video signal is amplified to the 1V standard in a video amplifier while the 6.5 MHz subcarrier signal is demodulated in a separate unit which produces a sound signal at its output

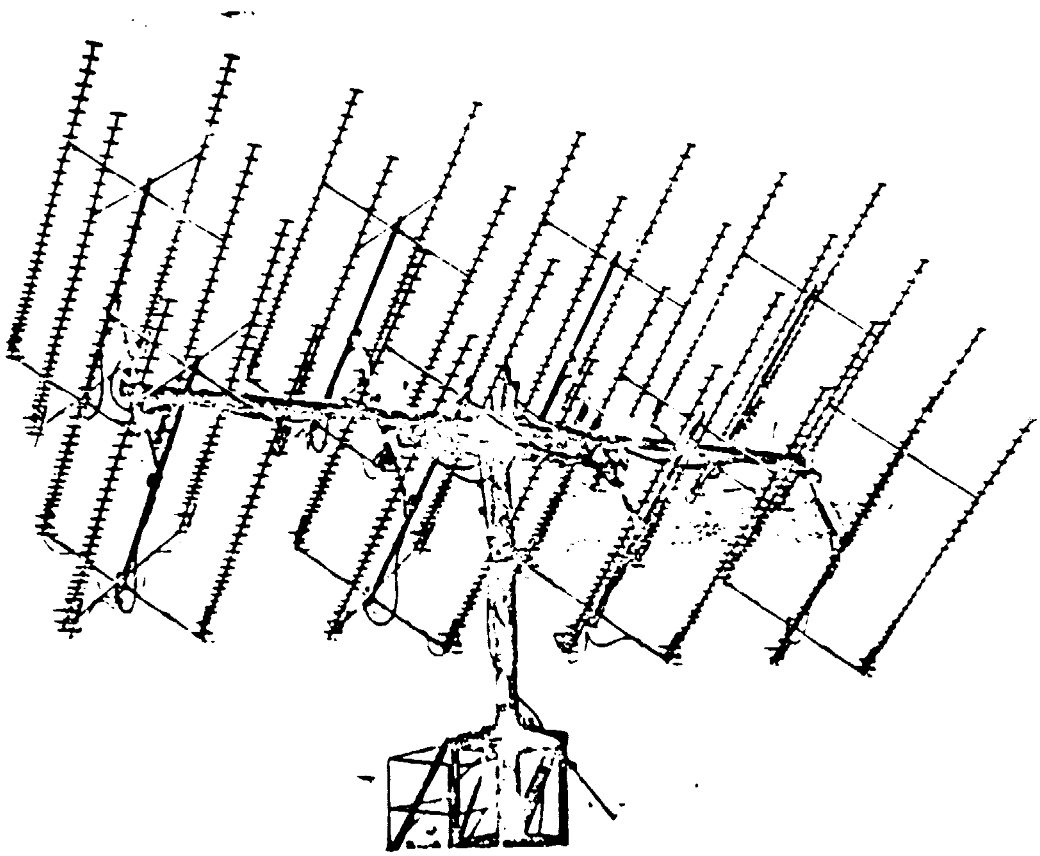
TABLE 6-14

EKRAN - STATSIONAR-T

Receive Terminals

	Large Community* Receivers	Small Community* Receivers or Cable TV
o Frequency*	702-726 MHz	702-726 MHz
o FM deviation	±9 MHz	±9 MHz
o Type antenna	8 - 30 element YAGI	4 - 30 element YAGI
o Antenna Gain	30 dB	23 dB
o Feeder loss	1 dB	1 dB
o Noise temperature of Transistor Amplifier	800°K	800°K
o S/N Video	55 dB	48 dB
o S/N Audio	56 dB	49 dB

* For local rebroadcast at 50 MHz vestigial sideband for video using SECAM (audio AM).



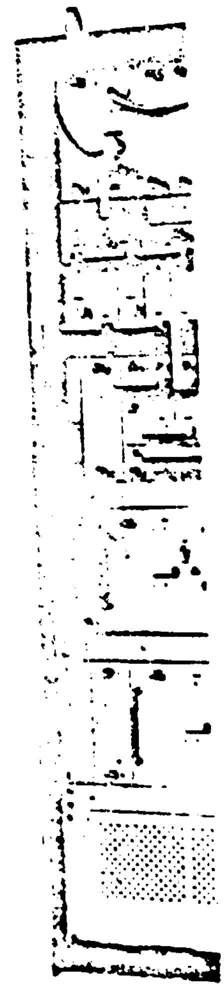


Figure 6-15. EKRAN UHF TVRO Receiver

The first class installation is designed to be connected with a local TV center or a high power repeater which has video and sound modulators and accordingly the receiver has two outputs - for a video and a sound signal. The receiver is put in a rack with the dimensions 340 x 700 x 1390 mm, its mass is about 60 Kg.

The second class receiver antenna is a cophased array made of the same four Yagi elements as for the first class receiver. The curtains are in two stories, by two curtains in each, in such a manner that the curtain axes in the cross-section perpendicular to the main antenna, axis form the apexes of a square. The distance of 125 cm between curtains axes is taken in order to achieve the maximum gain and low sidelobe levels.

The antenna is mounted on a mast which can be put at the top of a building or singly (Figure 6-15).

The second class receiving installation is a simplified FM receiver without back-up which is designed to convert a FM signal to a standard AM-VSB video signal and a sound signal the carrier of which is shifted to 6.5 MHz relative to the video one. (Figure 6-16).

A low-noise transistor amplifier similar to that of the first class receiver is used at the input. After the frequency converter the signal is amplified in a 70 MHz IF amplifier and demodulated in a frequency detector and at its output a video signal and a FM 6.5 MHz subcarrier is obtained. A standard TV signal is formed in an AM modulator where a video signal modulates an amplitude of a given carrier frequency. The FM sound signal is obtained from a filter with the 6.5 MHz central frequency and it is fed to the balanced mixer together with the video signal from the local oscillator. At the mixer output the FM sound signal is extracted by the filter and it is then added to the AM video signal. This relatively complex FM-AM conversion is justified here by the fact

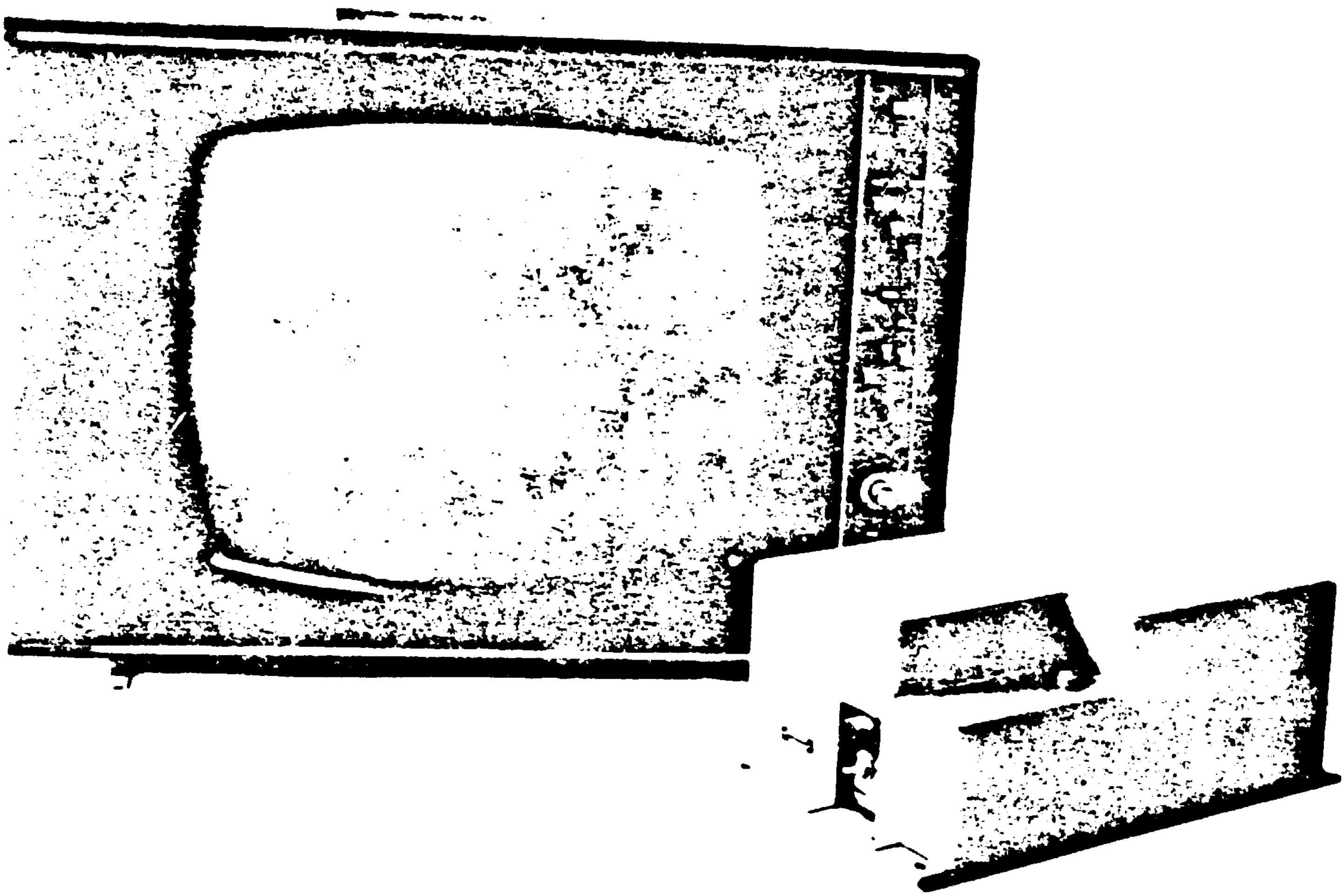


Figure 6-16. EKRAN TV Receiver

that with the direct conversion it is impossible to have the standard modulation depth for the terrestrial broadcasting (87.5%) keeping the normal video-to-sound signal ratios (10:1). The dimensions of the second class receiver are 165 x 240 x 440 mm, its mass is about 5 Kg. From the receiver output the standard television signal is sent to a low power repeater or to the distribution network.

6.2.3 TVRO Earth Terminals at S-Band

The most significant TVRO earth terminal built at 2.6 GHz was the terminal built for HET to receive educational TV from ATS-6 in the Rocky Mountain States. More than 150 of these terminals were built - with Prodelin supplying a 10-ft diameter plastic reflector and Hewlett Packard supplying the receiver.

This system, using the specifications listed in Table 6-15 provided a video S/N of 50 dB and up to 4 audio subcarriers using wideband frequency modulation (20 MHz p-p).

The Hewlett-Packard receiver was unique in that it was the first user of MIC techniques for TVRO applications, and as shown in Figure 6-17 provided discriminator action at the receive frequency.

A block diagram of the receiver RF circuitry is shown in Figure 6-17. It consists of two basic units:

Antenna Unit - A feed-mounted microelectronic package that combines the two orthogonal signals obtained from vertical and horizontal dipoles in the antenna. It has 55 dB of gain, a 300-MHz bandwidth, and a noise figure of better than 3.8 dB.

Indoor Unit - Contains microelectronic circuits that provide RF amplification, AGC and limiting, and an RF discriminator. In addition, it houses the channel-select filter, video amplifiers, audio subcarrier demodulators, and power supply.

TABLE 6-15

TV Broadcast Receiver Specifications for ATS HET Experience

Frequency Range	2.5-2.7 GHz
Frequency Modulation	20 MHz p-p
ATS-6 Effective EIRP	50 dBW
Antenna Diameter	10 feet
Antenna Unit	
BW	300 MHz
Gain	55 dB
Noise Figure	3.8 dB
Indoor Unit	
Limiter AGC	0-40 MHz, 30 dB
Static FM Threshold	-87 dBm
Differential Gain	4%
Differential Phase	2^{o}
Baseband Frequency Response	10 Hz to 4.2 MHz, $\pm$0.5 dB
Video S/N	50 dB
Number of FM audio subcarriers	4
Band for audio subcarriers	4.64-5.36 MHz

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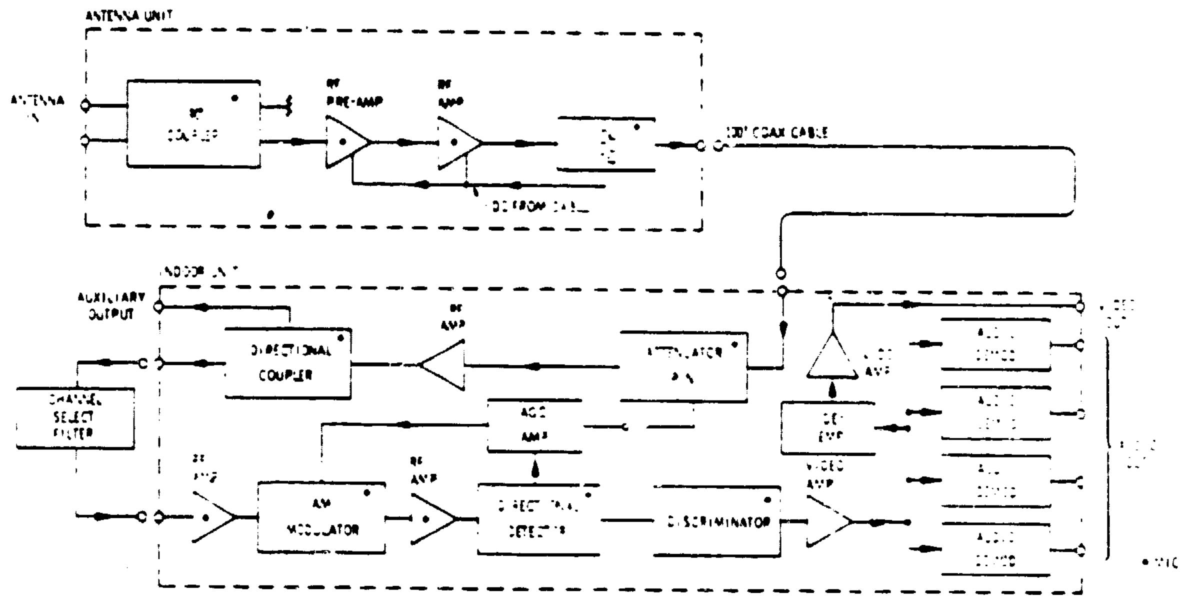

FIG.1 · RECEIVER BLOCK DIAGRAM

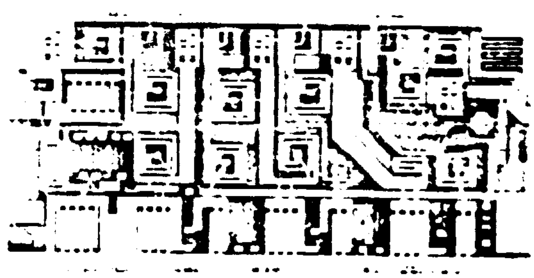

FIG. 2 · RF AMPLIFIER

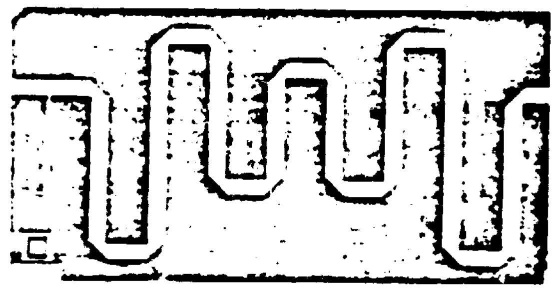

FIG. 3 · BANDPASS FILTER

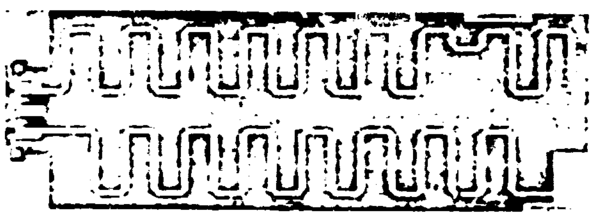

FIG. 4 · DISCRIMINATOR

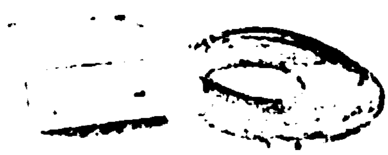

FIG 5 · COMPLETE RECEIVER SYSTEM

Figure 6-17. 2.6 GHz Receiver used for ATS-6/HET Experiment (Built by Hewlett Packard)

The characteristics of the TV Antenna to be used for INSAT are included in Table 6-16. This antenna will be large (6.1 meters in diameter) and will have a G/T of 13.4 dB^{o}K. This antenna will also be used for UHF reception of the DCP system which involved collection of degital data from many collection centers in India.

Limiting is provided in this receiver by a very wideband (0-40 MHz) AGC loop. This limiting method not only provides greater than 30 dB of limiting, but it provides AGC and signal-level monitoring functions as well. In addition, since there is no signal clipping as in conventional limiters, no carrier harmonics are generated so there is no need for filtering between the limiter and discriminator. This wideband feedback AM suppression system puts severe requirements on loop time delay. Only by using the compact, wideband RF components realizable with MIC technology is such a design practical.

6.2.4 TVRO Earth Terminals at Ku-Band

This part will review briefly the various efforts which have been directed toward the construction and test of TVRO terminals in Canada, Japan, Europe, and the United States.

Certainly the first impetus for the development of earth terminals to operate with TV broadcast satellites at Ku-band came about as a result of the highly successful operation of the Joint U.S.-Canadian CTS satellite. Tables 6-17, 6-18, list some of the principal earth terminals built by both the U.S. and Canada to test TV transmission from CTS. These terminals have diameters from 2 feet to 30 feet and provided facilities for both TVRO and Receive/Transmit functions. Table 6-19 describes in more detail two of the Canadian receive/ transmit terminals built by RCA Victor (now SPAR).

TABLE 6-16

S-Band Downlink of INSAT:

The characteristics of S-band Downlink RF signals are defined below:

Center Frequency	2575 MHz, 2615 MHz
Polarization	LHCP, Axial Ratio < 3.0 dB
EIRP	42 dBW min.
Required Ground Equpt.	
Bandwidth (RF)	80 MHz (nominal)
Data Bandwidth	36 MHz (nominal)
G/T (SCES)	13.4 dB/^{o}K
Modulation type	FM
Modulation	FM Dev. 17 MHz pk. to pk.
Frequency Stability	$\pm$ 60 KHz (Long term)

DCP & S-Band TV Antenna for INSAT:

Antenna	6.1M dia. parabolic chicken mesh reflector
Antenna Mount	X - Y
Frequency	2555 to 2635 MHz & 400 MHz
Gain	41.8 dB at 2.6 GHz & 22 dB at 402.75 MHz
Polarization	LHCP, axl. ratio <3 dB
Receive G/T	13.4 dB/^{o}K at 2.6 GHz

TABLE 6-17

U.S. CTS Earth Terminals

Terminal	Antenna: Diameter m	Antenna: Peak Gain (12 GHz) dB	Receiver: Preamplifier	Receiver: Total System Noise Temperature K	G/T dB/°K	Transmitter Power W
Cleveland (NASA)	5	52	TDA[a]	800	24	1250
Rosman (NASA)	5	53	(b)	450	26	1250
TV receive only; two-way voice	3	48	TDA[a]	900	18	500
Two-way voice	1.2	40	TDA[a]	900	10	20
Two-way voice	.6	34	TDA[a]	900	4	20

[a] Tunnel diode amplifier.

[b] Uncooled paramplifier.

TABLE 6-18

CANADIAN CTS GROUND TERMINALS

Function	Antenna Diameter (ft.)	Antenna Peak Gain (dB)	Antenna Beamwidth (°)	Receiver Type and Noise Temperature (°K)	G/T (dB/°K)	Maximum Transmitter Power (W)
Control Terminal						
Transmit and Receive TV and Multiplexed Voice Signals	30	59	0.18	Uncooled Paramp 425	32.0	1000
Remote Terminals						
TV Transmission	10	50	0.54	TDA, 1150	19.5	1000
TV Reception and Two-Way Voice	8	48	0.67	TDA, 1150	16.5	1
Two-Way Voice	4	42	1.3	Mixer, 2660	7.8	1
Receive FM Sound Broadcast	2 Equivalent	35	2 x 4	Mixer, 2660	0.8	--

TABLE 6- 19

The CTS Satellite TV Broadcast Earth Terminal
Built in Canada by RCA Victor/SPAR

Frequency Bands (GH^2) Receive/Transmit	11.7-12.4; 14.0-14.5	
Typical Use	Roof top, transportable experimental	
Antenna diameter Feet Meters	 2.66 0.812	 7 2.13
RF equipment mounting	Box on stand	Antenna back structure
Tracking	Manual	Remote motor drive
Gain at Rx (dB) Tx	38.3 39.5	47.0 48.4
Antenna noise temperature at $5^{o}K$ $10^{o}K$	80 55	70 50
G/T at 5^{o} ele. angle rec. noise temp (dB) $55^{o}K$ $250^{o}K$	 17.0 13.1	 26.0 22.0
3 dB beamwidth (deg): Rx Tx	2.44 1.82	0.66 0.57
Weight (lb)	130	720
Erection Time	None	6 hours

During one phase of the CTS experiment, the Canadian Communications Research Council (CRC) conducted tests and experiments on several small TVRO earth terminals manufactured in Japan, England, and the Netherlands, and several LNA's. These results, conducted by CRC's D. Halayko and R. Huck are listed in Table 6-20.

With the advent of ANIK-B, Canada is now into a phase of testing TVRO terminals capable of operating with a satellite having less EIRP than CTS. Table 6-21 describes a TVRO system built by SPAR (Figure 6-18) which provides a S/N of 48 dB. Figure 6-19 shows the terminal used to bring television to the King Family in Northern Ontario, Canada.

In the United States, Westinghouse was very active in developing small terminals for use with CTS(for Teleconferencing) and has recently established a partnership with Dornier (FRG) for worldwide marketing of their developments. Table 6-22 lists the salient details of the Westinghouse terminal including a transmit option which can be used to serve teleconferencing or interactive TV systems.

The Japanese experience in developing small earth terminals for use with BSE has been described in detail earlier, and will be discussed with respect to LNA developments later in this section. Figure 6-20 shows a 90 cm TVRO antenna system capable of providing a video S/N of greater than 45 dB by SONY. Figure 6-21 shows the SONY MIC 12 GHz LNA/Converter which is the heart of the SONY development. Table 6-23 lists the various antennas designed in Japan to operate with the Japanese BSE, whose overall system is pictured in Figure 6-22.

Some of the antenna systems listed in Table 6-23 at the 0.6 to 1.6 meter level are manufactured by SUMITOMO Electric Ltd (Figure 6-23).

TABLE 6-20

SPAR (CANADA) MICRO EARTH STATION - PERFORMANCE SUMMARY

	Target Specification	Present System
Input Signal Frequency	12 GHz, FM	12 GHz, FM
Antenna Input Signal Level	-120 dBm	-120 dBm
Receiver Noise Figure	4.5 dB	5.8 dB
Video S/N at Demodulator Output (for a peak-to-peak frequency deviation of 12 MHz)	46 dB	48 dB - Signal-to-Weighted RMS Noise
Sensitivity at Mixer Input	-79.2 dBm	-80 dBm
Group Delay Variation	---	5 ns over ± 9 MHz Deviation 20 ns over ± 15 MHz Deviation
Linearity	---	±1 dB over ± 15 MHz Deviation
Receiver Bandwidth (IF)	30 MHz	30 MHz (limited by BPF)
Antenna Diameter	1.0 M	1.22 M
Antenna RMS Surface Accuracy	0.5 mm	0.15 cm
G/T	10 dB	12 dB
Output Signal Level to TV Set	200 μV/300 (-48.75 dBm)	1 vp-p/75Ω Baseband

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TABLE 6-21

Small TVRO Terminals Tested at Canadian CRC
(Communications Research Center)

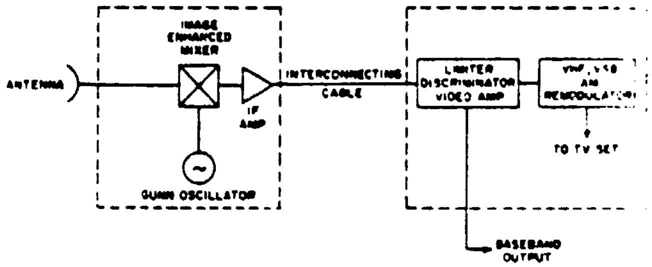


Figure 3
Block Diagram of a Typical TVRO Terminal

Country	Organization	Antenna Diameter
Canada	CRC	120 cm
Japan	Hitachi	N/A*
Japan	Mitsubishi	N/A*
Japan	OKI	160 cm
Japan	Sumitomo	N/A*
Japan	Sony	N/A*
England	Mullard	160 cm
Netherlands	Philips	160 cm

*The tests on these terminals were conducted as bench tests only as the antennas were not available.

	Ground Terminal (dB)			
	CRC	OKI	Mullard	Philips
Antenna Diameter Metres	1.2	1.6	1.6	1.6
Noise Figure dB	6.55	4.32	7.50	8.30
C/N (calc.) dB . . . A	18.6	22.1	19.6	19.1
C/N (meas.) dB . . . B	18.7	22.9	20.7	17.2
SNR, (calc. from A) dB	49.2	52.6	50.1	49.6
SNR, (calc. from B) dB	49.3	53.4	50.9	47.7
SNR_v (meas.) dB	47.7	51.9	50.7	47.3
SNR_4 (calc from A) dB	53.0	56.9	54.3	53.8
SNR_4 (calc. from B) dB	53.1	57.7	55.1	52.0
SNR_4 (meas., dB	45.3	56.3	51.8	31.8

Table 2
Measured and Calculated Link Analyses

Terminal	Measured N.F.	Image Frequency Centre Band	Corrected N.F.
Mitsubishi	5.90 dB	-13 dB	6.11 dB
Sony	4.28 dB	- 8 dB	4.92 dB
OKI	4.29 dB	-22 dB	4.32 dB
Hitachi	6.93 dB	-18 dB	7.00 dB
Sumitomo	5.79 dB	—	—
CRC	6.38 dB	-14 dB	6.55 dB

Note: The noise figures for the Philips and Mullard terminals could not be measured due to the construction of the outdoor unit. For comparison, noise figures for these terminals, taken from the specifications supplied with the ground terminals, are 8.3 and 7.5 dB respectively.

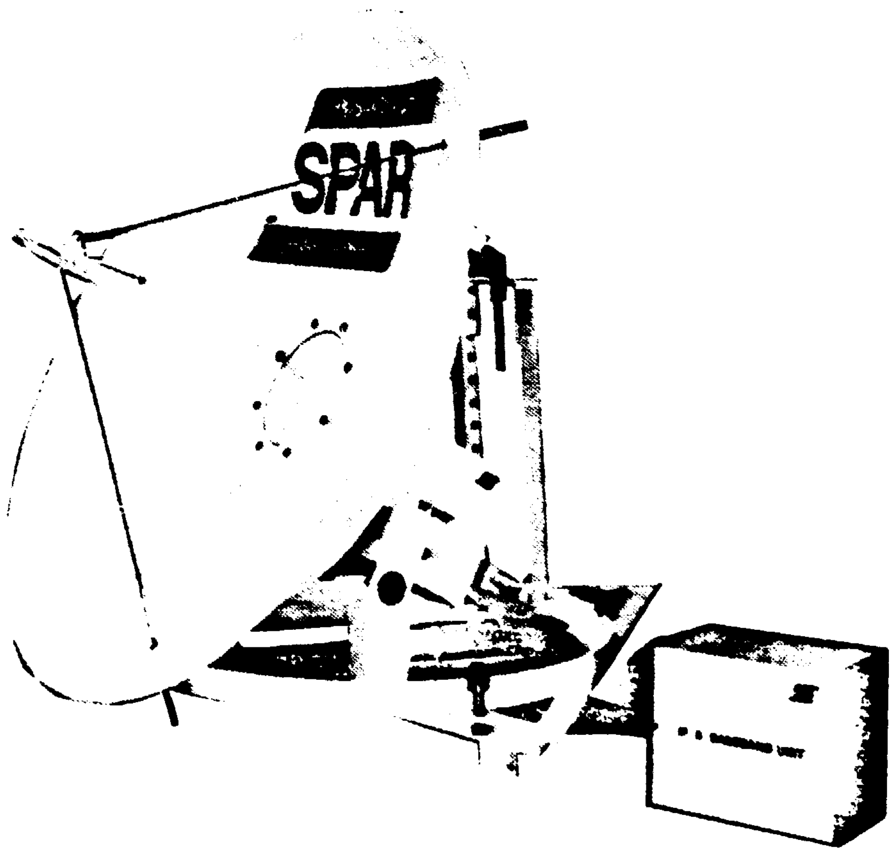
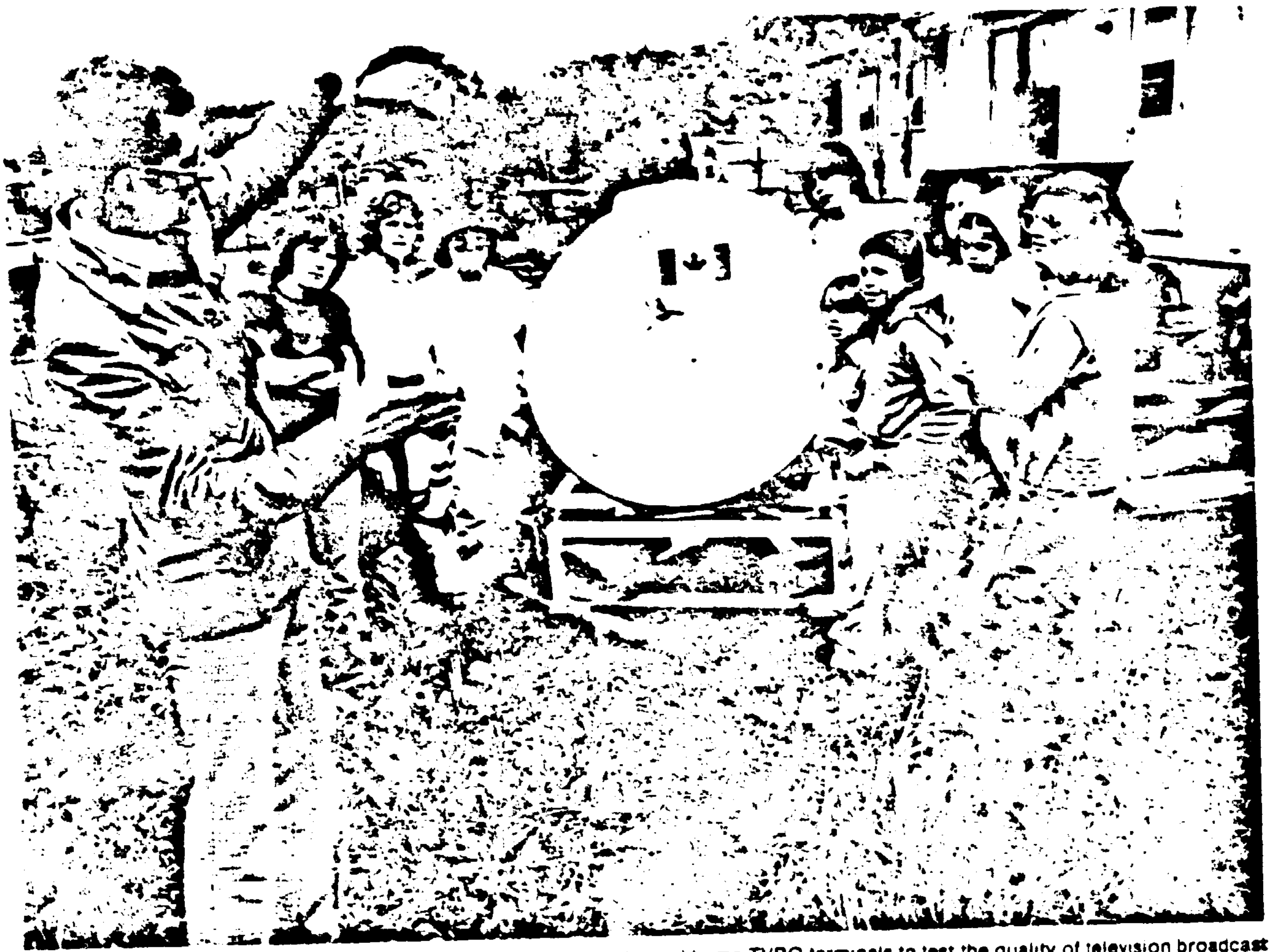


Figure 6-18

MICRO EARTH STATION FOR T.V. RECEPTION OF DIRECT BROADCASTING VIA SATELLITE.



WORLD'S FIRST: One hundred families in rural Canada are being loaned home TVRO terminals to test the quality of television broadcast with signal strength less than 50 dBw EIRP, using Anik-B. The King family home in MacDiarmid, Northern Ontario, is the first in the world to officially receive TV programing on a regular basis.

Figure 6-19

TABLE 6-22

Westinghouse TV Broadcast Terminal (US)

TVRO Option	
Receiver Band	11.2-12.2 GHz
Antenna Diameter	2 meters
Antenna Gain	45.3 dB
Polarization	Circular
LNA Noise Figure	3.9 dB
First Intermediate Frequency	1.2-2.2 GHz
Multi-channel Option	5 channels at first IF
Second Intermediate Frequency	70 MHz
Video Options	625 Line/50 Hz SECAM 625 Line/50 Hz PAL 525 Line/60 Hz/NTSC
Video Output Level	1 V pp (±3 dB adjustable) in 75 ohms
Differential Gain	±5%
Differential Phase	±5%
Signal/Noise Ratio, Luminance Weighted	45 dB at 14 dB C.N. (with 13.3 MHz p.p. deviation at frequency of zero emphasis
Sound Sub-Carrier Frequencies	5.5 MHz and 6.0 MHz
Remodulation Option	Any VHF or UHF carrier freq. Output to 75 ohm line
Transmit Option:	
Transmit Band	14-14.5 GHz
Output Power	Max. 0.8 Watt
Linear Operation	I.M. ≤ -18 dBc for 2 equal outputs each of 400 MW
Flat Frequency Response	±0.25 dB/36 MHz

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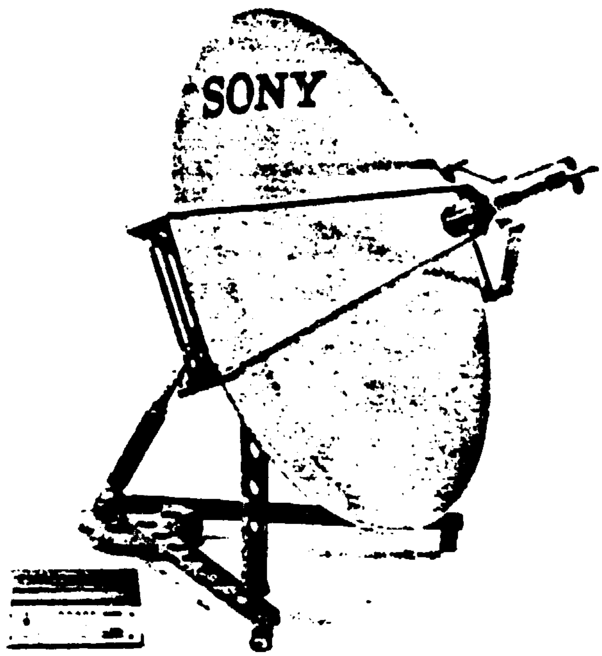
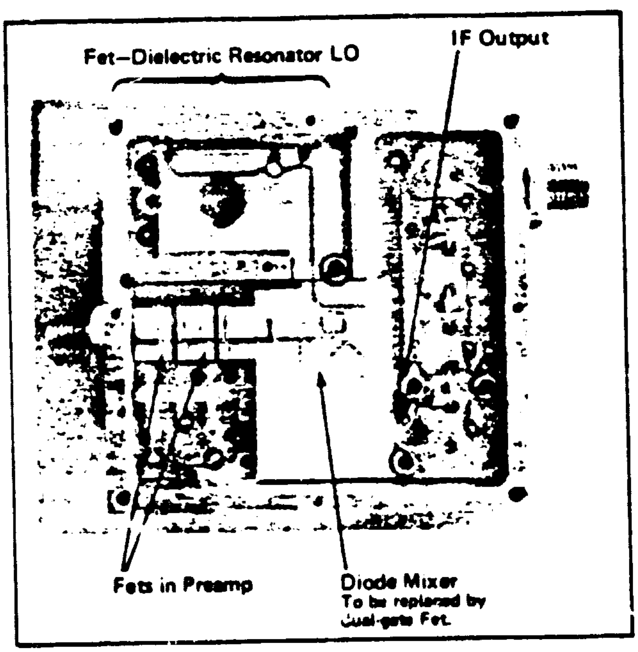


TYPHOON-PROOF: Rigid antenna stands are needed in Japan to withstand 60-mi/h winds. Fet front-end is located at the focal point of this 90-cm antenna for the Sony SCX 380 satellite TV receiver.

Figure 6-20



Sony's hybrid MIC for converting 12-GHz TV from satellites to a 290–470-MHz IF uses a GaAs Fet preamplifier and LO with GaAs Fet and dielectric resonator. It may also soon use a dual-gate GaAs Fet in place of its present diode mixer. Noise figure is 3.5 dB.

Figure 6-21

TABLE 6-23

Earth Terminals used with the Japanese BSE

Ground Station	Antenna Diameter	G/T	TV Channel Capacity TX	TV Channel Capacity RX	Transmission Power
Main Transmission & Reception Station	13m	32 dB	2 ch	2 ch	Maximum 2 KW
Transportable Transmission & Reception Station	4.5m	23 dB	1 ch	2 ch	Maximum 2 KW
	2.5m	18 dB	1 ch	2 ch	Maximum 2 KW
TVRO Stations	4.5m	24 dB	-	2 ch	-
	2.5m	19 dB	-	2 ch	-
Small Receiving TVRO	1.6m	15 dB	-	2 ch	-
Miniature TVRO	90cm	8 dB	-	1 ch	-

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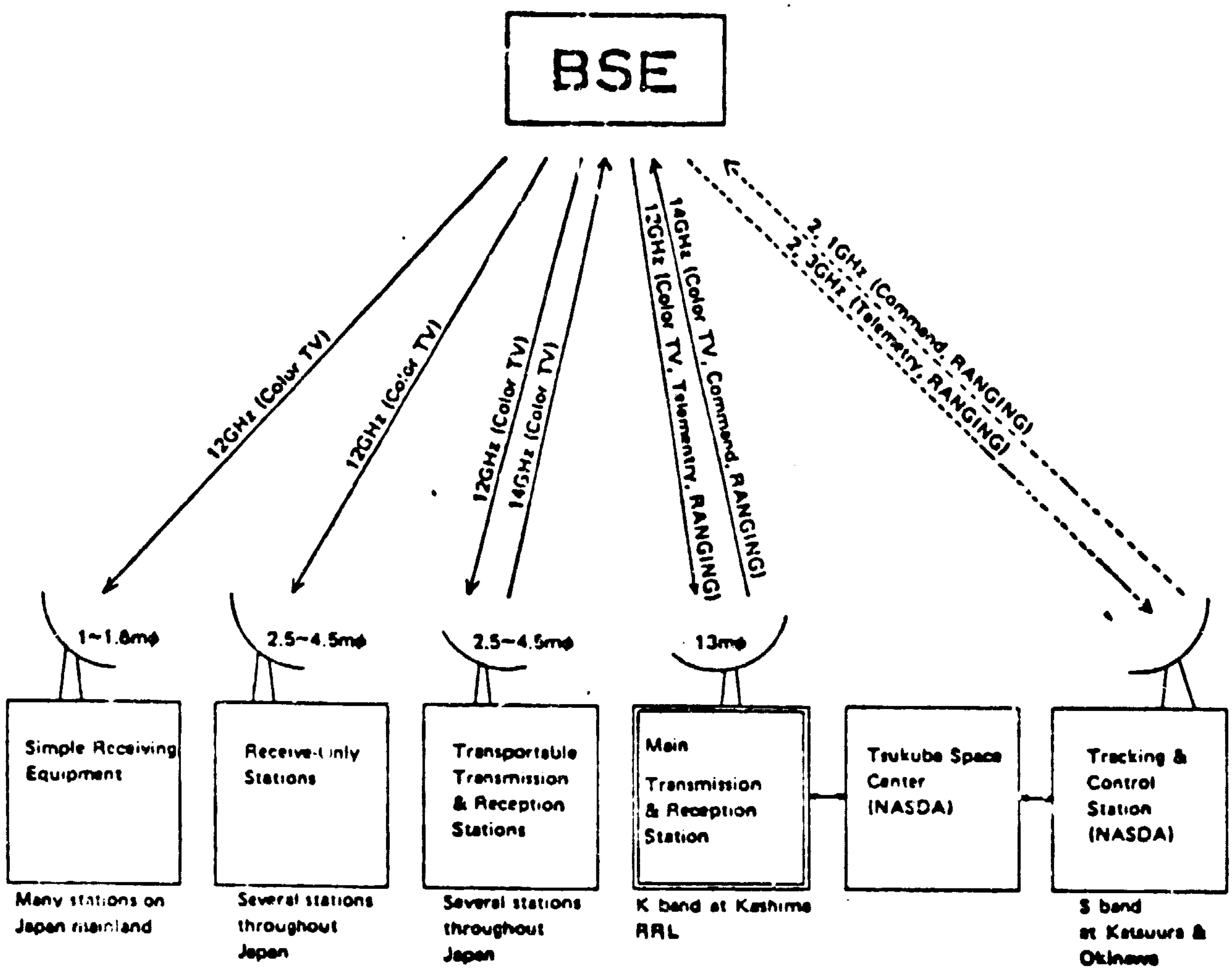
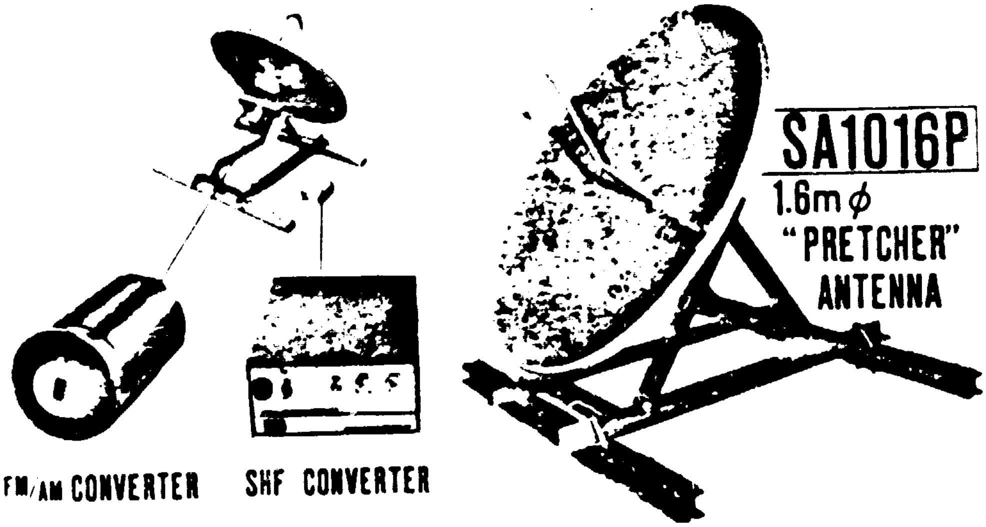


Figure 6-22
Japan BSE System

SUMITOMO ELECTRIC IND

FOR DIRECT RECEIVING
OF SHF WAVES FROM BROADCASTING SATELLITE



Outline of SHF RECEIVER

Frequency Band		11.7 – 12.2GHz
Modulation of Receiving Signals	Video Audio	AM FM FM FM
Nos of channel	Model SR 1101 Model SR 1102	1ch 2ch(25MHz Separation)
Input Level		−60 − −85 dBm
Modulation of Output signals	Video Audio	AM FM
Output Frequency		VHF TV channel
Output Level		90 dBμV ch at 75Ω
Weight	HF converter FM AM converter	2 5kg 3 5kg
Power Source		50 60Hz 100^{+15}_{-10}V

Features of PRETCHER ANTENNA

Model	Diameter (m)	Weight (kg)	Frequency Band (GHz)	Gain (dB)	Half Power Beam Width	F B (dB)	Polarization
SA1006P	0 6	4 5	11 7 – 12 2	34 9	2 77	40	Linear
SA1010P	1 0	7 0	11 7 – 12 2	39 6	1 60	50	Linear
SA1016P	1 6	20 0	11 7 – 12 2	43 9	0 96	60	Linear

Figure 6-23. The Sumitomo TVRO

6.2.5 Receive/Transmit Terminals at Ku-Band

As described in the preceding paragraphs, Receive/Transmit terminals for use with CTS have been built and tested in both Canada and the U.S. The Westinghouse terminal with its transmit option is of particular interest since it requires only 1 watt of transmitter power at 14 GHz - which is now easily obtained w[illegible] solid state FET's at the frequency. The Canadian CTS Transmit/ Receive use 14 GHz, 20 watt TWT power amplifiers purchased from Hughes Electric Dynamics Division with significant success.

Many receive/transmit terminals were built for use with the various CTS User Experiments (see CTS Reference Book, CTS File No. 3100-28 10/15/1975). Of interest to this study was the NASA-Lewis 1-meter ground terminal to provide a single telephone channel, and using a G/T of 5.2 and an EIRP of 48 dBW. Another user experiment was conducted by Niel Helm of COMSAT Labs using the 1.3 meter terminal (receive/transmit) for testing the establishment of emergency communications in disaster areas using duplex voice.

The list of interactive experience is actually very broad with one-way video with audio interactive used by Lister Hill National Center (HEW) and WAMI.

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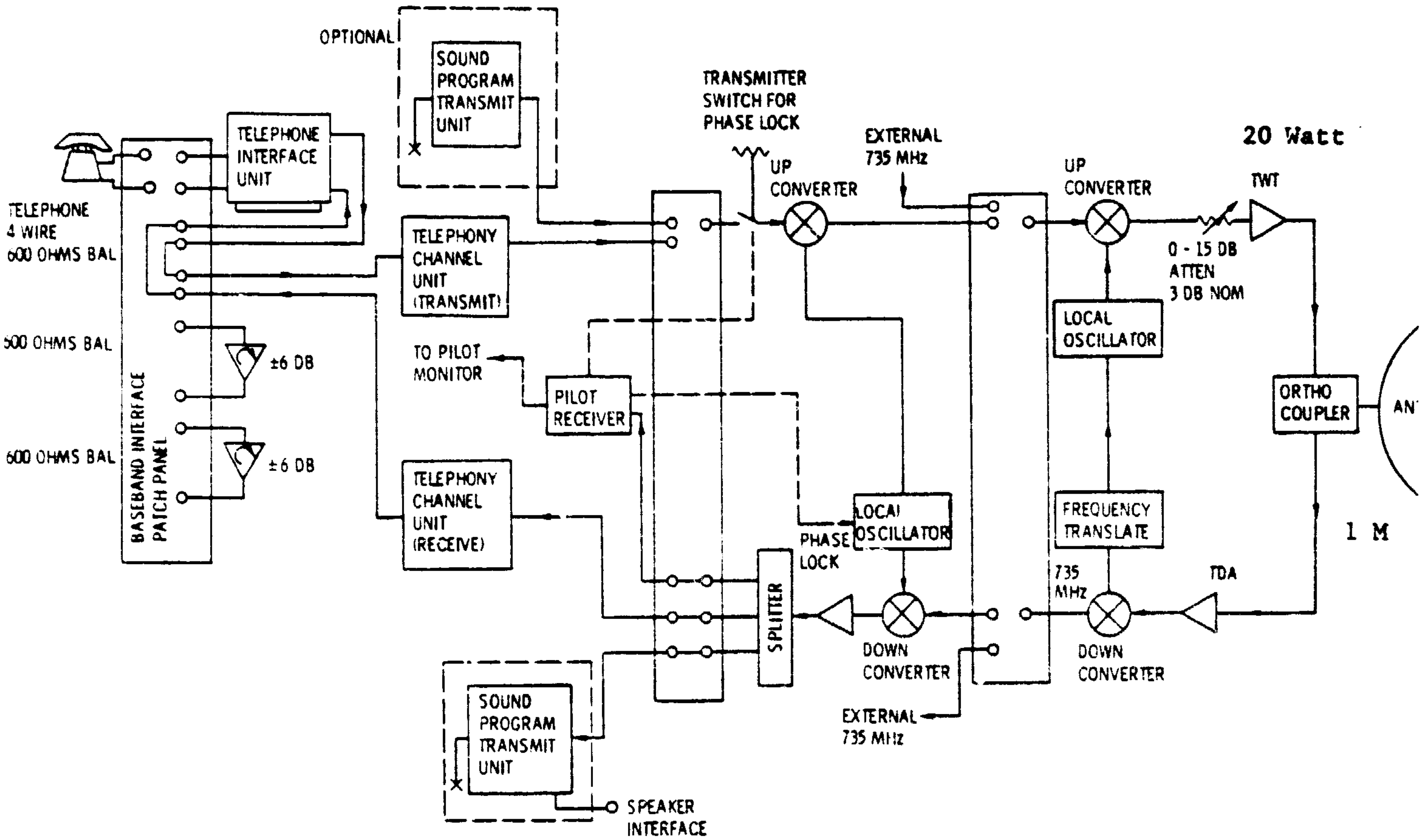
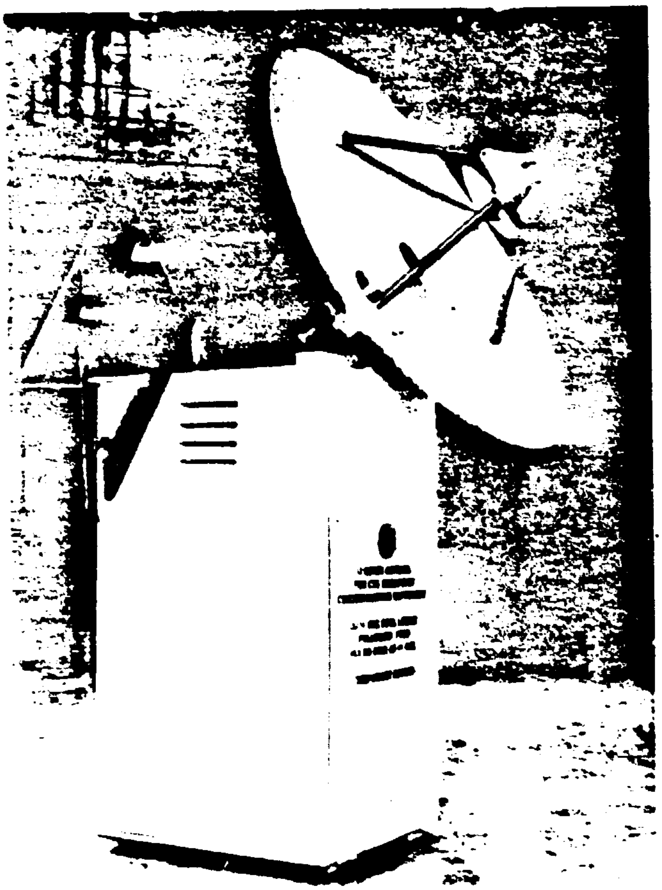


- 1-Meter-terminal block diagram.

Figure 6-24. NASA-Lewis Receive/Transmit 1-Meter Terminal for two-way Voice.



CTS Emergency Communications Experiment Equipment with 1.2-meter antenna for 12/14 GHz.

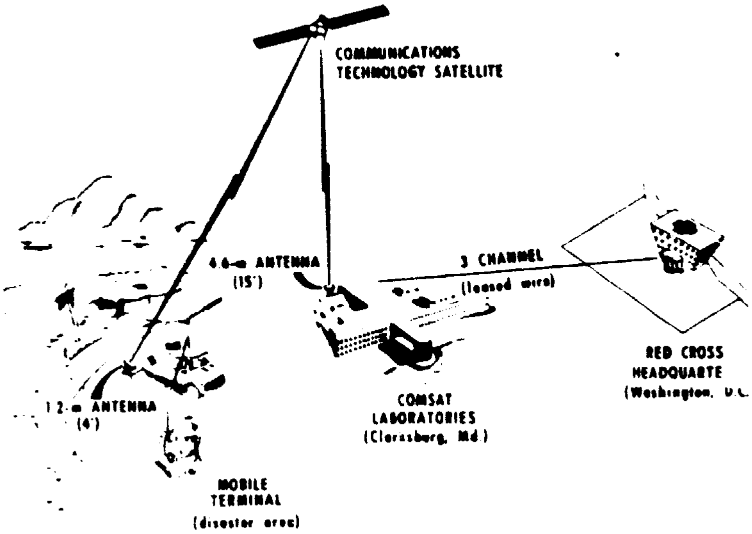


Figure 6-25

COMMUNICATIONS TECHNOLOGY SATELLITE (CTS) TRANSPORTABLE EMERGENCY EARTH TERMINAL EXPERIMENT

6.3 Technology of Small TVRO Earth Terminals

This section will discuss the most critical aspect of TVRO earth terminals which make such terminals possible on both a technical and an economic basis.

The overall technology of the TVRO earth terminal at UHF, S-band, and Ku-band is based on several subsystem technologies which include:

- o The antenna which provides the primary source of "aperture gain".
- o The low noise amplifier - where noise temperature with antenna determines the terminal G/T.
- o The TVRO receiver which includes:
    - the down-converter
    - the tuner
    - the AGC/AFC system
    - the IF amplifier
    - the video demodulation
    - the audio demodulation
    - the video signal processor
    - the remodulation for access to a channel of a standard TV set

Figures 6-26 through 6-31 provide block diagrams which include these subsystems. The antenna and LNA provide the TVRO terminal sensitivity - leading to the desired S/N. The down-converter and tuner translate a particular frequency band of the received signal to the demodulator where the video and audio signals included in the modulated carrier in that particular band can be processed.

The receiver can be of the phase-locked loop or discriminator variety and will be a determining factor in system sensitivity in addition to the role of G/T.

The threshold of a receiver is considered to be the point at which a change begins in the relationship between input carrier-to-noise and output signal-to-

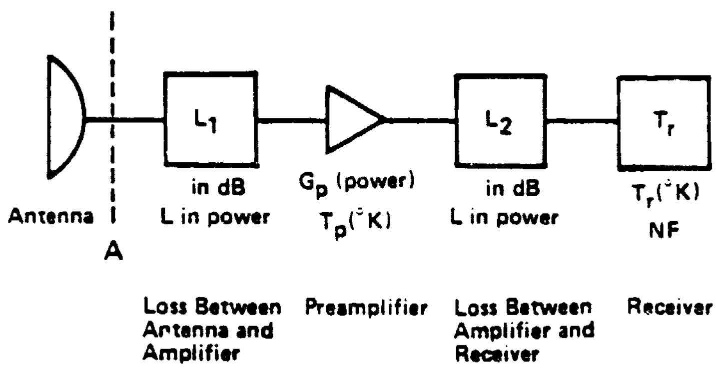


Figure 6-26 Receiver Earth Station Block Diagram

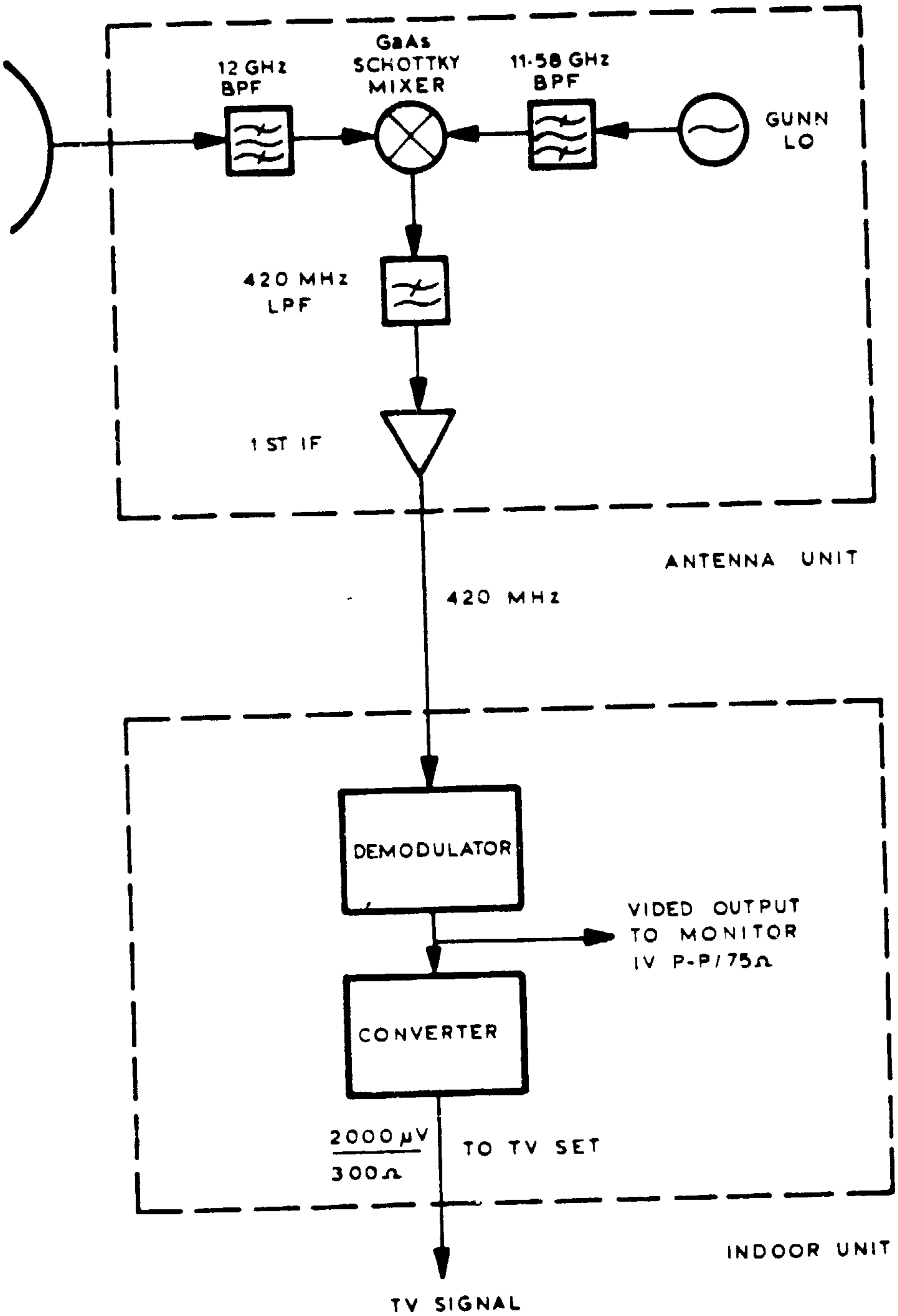


Figure 6-27

SYSTEM BLOCK DIAGRAM OF
ANTENNA UNIT AND INDOOR UNIT.

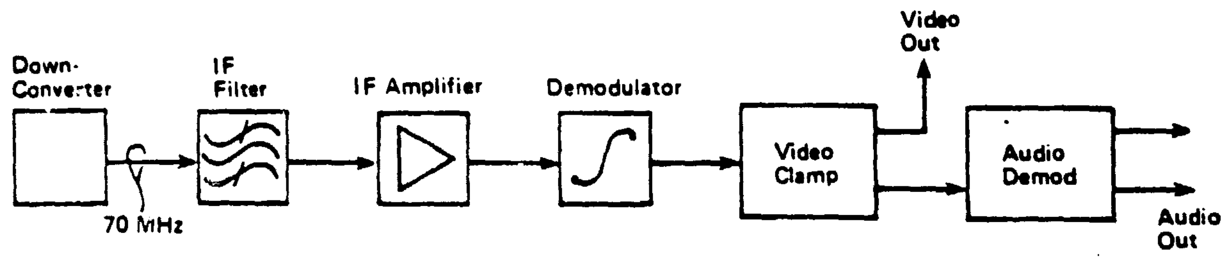


Figure 6-28 Receiver Block Diagram.

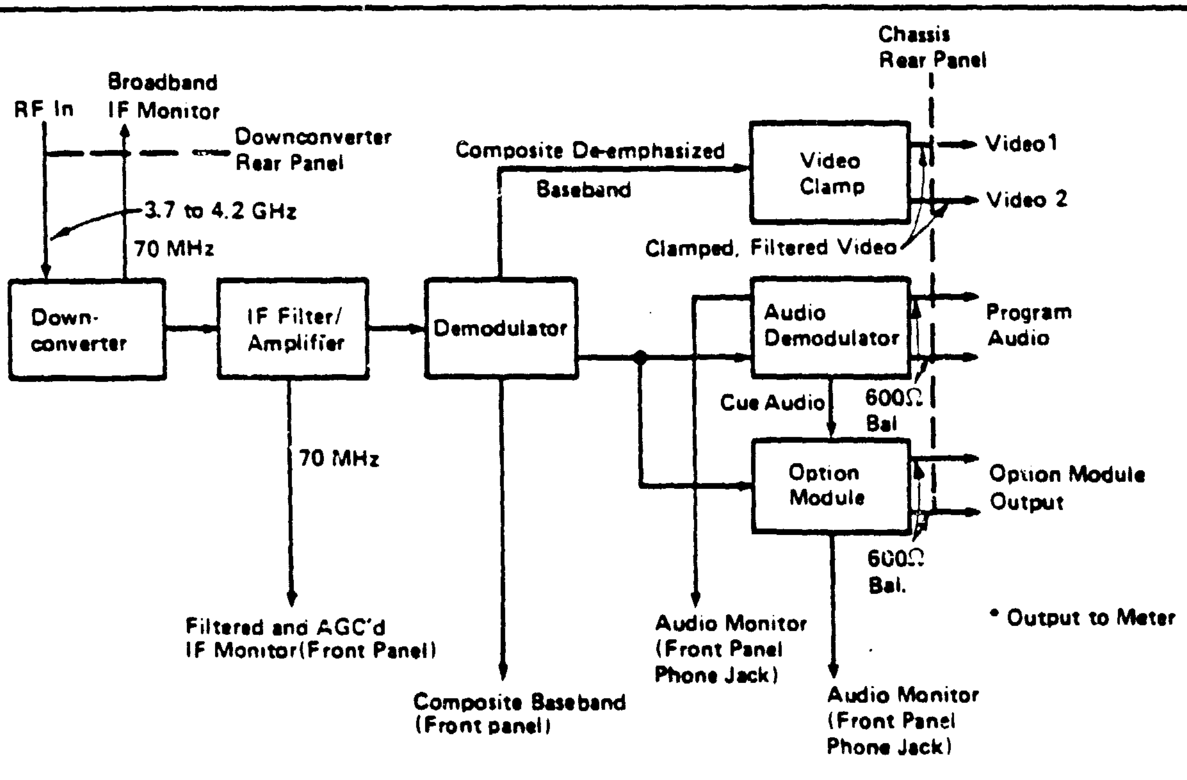


Figure 6-29 Model 414 Video Receiver Block Diagram.

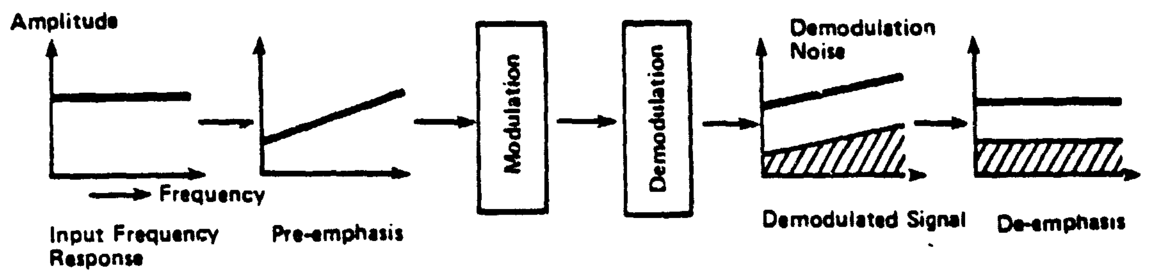
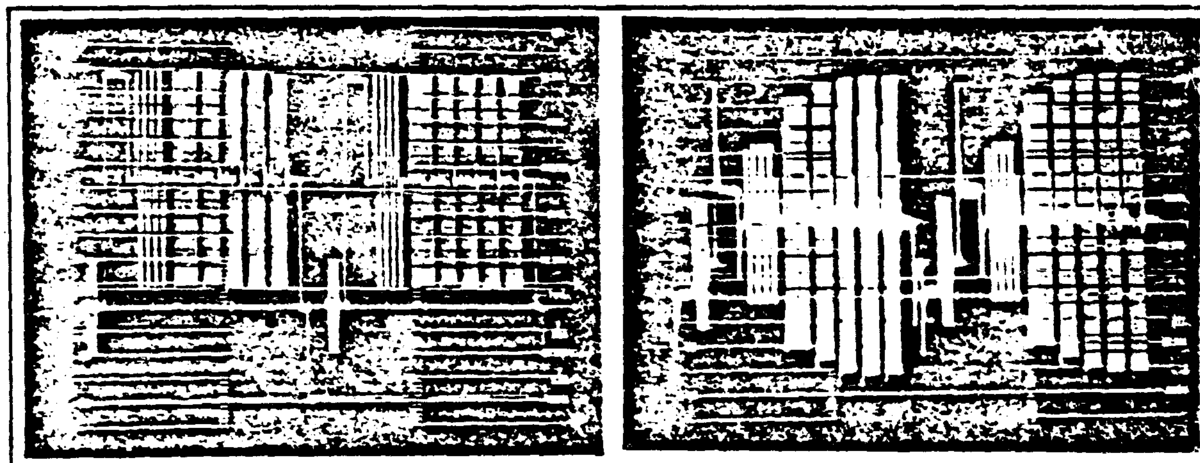


Figure 6-30 Pre and De-emphasis Effect On Triangular Demodulation Noise



a. Normal Multiburst

b. Pre-emphasized Multiburst

Figure 6-31 A pre-emphasized multiburst signal noise. It is the point beyond which a very small decrease in carrier power at the receiver input results in a large increase in noise at the output. The object in satellite reception is to achieve the lowest possible receiver threshold. This is done by selecting active components for the input amplification of the receiver which produces the least amount of noise, while maintaining the least amount of bandwidth necessary to reproduce the incoming signal with minimum mutilation. 98 percent of the incoming power should pass through to the output of the receiver in order to avoid mutilation of the signal portion which includes the audio sub-carriers. Therefore, there is a limitation imposed upon minimum allowable bandwidth. 33 MHz is a minimum acceptable bandwidth for accurately reproducing the incoming signal. Bandwidths of less than 33 MHz will likely cause mutilation of the signal and therefore can be viewed as a trade-off between performance in the reproduction of the signal and the placement of receiver threshold. In most satellite receivers, threshold occurs at a carrier-to-noise ratio of 11 dB.

In the threshold extension technique, manufacturers have moved the receiver threshold point from 11 dB carrier-to-noise down to 8 dB or less. If receiver threshold was successfully improved by 3 dB, one would achieve approximately the same result as if the antenna size was increased by 50 percent.

There are three things that can be done to lower the receiver threshold: 1) use lower noise components in the active devices at the input to the receiver; 2) decrease the bandwidth of the receiver at the possible expense of mutilating the signal: 3) use a phaselock loop or frequency compression feedback scheme which has the effect of reducing deviation and acts like an IF band-limiting filter, except that mutilation of the signal does not occur if it is done right. The bandwidth limiting scheme has been used by some manufacturers as a method of threshold extension. This method works to some extent, until the satellite carrier starts "loading up" his transponder, that is, adds additional subcarriers to better utilize the space he has rented. If the bandwidth on a satellite transponder is fully occupied, "threshold extension" by bandwidth limiting yields exactly the opposite of its intended effect.

The TVRO receiver must also account for the triangulation of the noise spectrum which occurs during the FM demodulation process. This causes the noise spectrum to increase in level with an increase in modulating frequency. This resutls in a decreasing signal-to-noise ratio at increasing baseband frequency. To overcome this effect, a de-emphasizing network is utilized in the receiver and a matching pre-emphasizing network in the transmitter. Pre-emphasis shapes the frequency response of the video signal and causes the highest frequency component of the video signal to be 13.2 dB (voltage ratio of 4.6) higher than lowest frequency component. Figure 6-31 shows a pre-emphasized multiburst. The weighted S/N improvement of a pre-emphasized video signal over a flat video signal is approximately 2.5 dB for 525 line transmission. Another factor of pre-emphasis used in video transmission is the improvement in color information by the reduction in distortion of the chrominance signal by the luminance signal. By reducing the relative level of the luminance signal to the chrominance signal the amount of chrominance-to-luminance distortion caused by non-linearities in the system is reduced.

6.3.1 Antenna Technology

The antenna technology for TVRO terminals has started to mature toward using low cost techniques as a result of the growing demand for antennas of all types to provide TVRO reception at 4 GHz in the U.S. which will boast of a number of terminals at the end of 1980 which will greatly exceed 3000. Actually, quantity lots of TVRO antennas are not new. The Russian EKRAN system now uses in excess of 3000 UHF TVRO terminals in Siberia for community reception, and India built

2400 S-band earth terminals to operate with ATS-6 in 1976 and will no doubt use these antennas with INSAT once that satellite is operational.

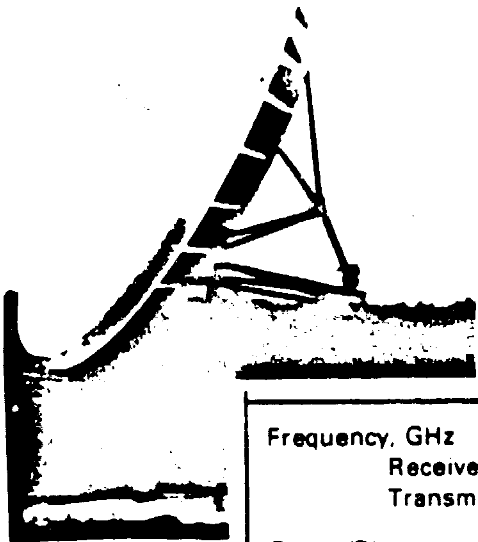
The TVRO earth terminal antenna business can be served by YAGI antennas at UHF now using very mature manufacturing technologies to make actually hundreds of millions of antennas for use in all parts of the world (and still expensive at the $60-200 range). At S-band and Ku-band, the TVRO antenna business can be served by the growing maturity of small (1-10 foot) antenna reflectors deriving manufacturing techniques from quantity procurements made for terrestrial radio systems and from the growing TVRO requirements brought about by Cable TV and industrial/military satellite users.

Today, two of the most respected antenna manufacturers, Prodlin and Andrew, offer parabolic antennas in the 2 to 10 foot range at very low prices. These sizes and prices (which will be discussed in the next section) are listed as follows:

Andrew			Prodelin (Fig. 6-32)		
Size (ft)	Model	Cost ($)	Size (ft)	Model	(Cost($)
2	241-740	375	-	--	-
4	202-740	485	4	P4-122C	480
6	203-750	590	6	P6-122C	590
8	204-740	850	8	P8-122C	980
10	205-740	1400	10	P10-122C	1580
6(spec)	45-140	285	-		
Tilt Mount		120/140	Mount		260/140

Figure 6-33 provides a curve of antenna (with mount) cost versus size for antenna diameters from 5 to 32 feet and for quantities from 10 to 150. The companies accessed were RSI, Prodelin and Andrew. The curves show that as antennas increase in size beyond 10-12 feet in diameter, the cost of structure becomes an increasingly large and critical part of overall cost.

Prodelin



	6 FT. DIAMETER (1.83 METERS) TRANSMIT/RECEIVE	10 FT. DIAMETER (3 METERS) TRANSMIT/RECEIVE	15 FT. DIAMETER (4.57 METERS) TRANSMIT/RECEIVE
Frequency, GHz	Dual	Dual	Dual
Receive	11.6 - 12.2	11.6 - 12.2	11.6 - 12.2
Transmit	14.0 - 14.3	14.0 - 14.3	14.0 - 14.3
Gain, dBi, Midband			
Receive	44.6	48.8	52.0
Transmit	46.0	50.0	53.6
VSWR, Max			
Receive	1.1:1	1.1:1	1.1:1
Transmit	1.2:1	1.1:1	1.1:1
HPBW, Degrees Midband, E plane			
Receive	0.85	0.51	0.34
Transmit	1.0	0.6	0.4
Power Rating, Average Transmit	1.25 Kw	1.25 Kw	1.25 Kw
Polarization	Linear, Orthogonal	Linear, Orthogonal	Linear, Orthogonal

Figure 6-32. Prodelin Antennas

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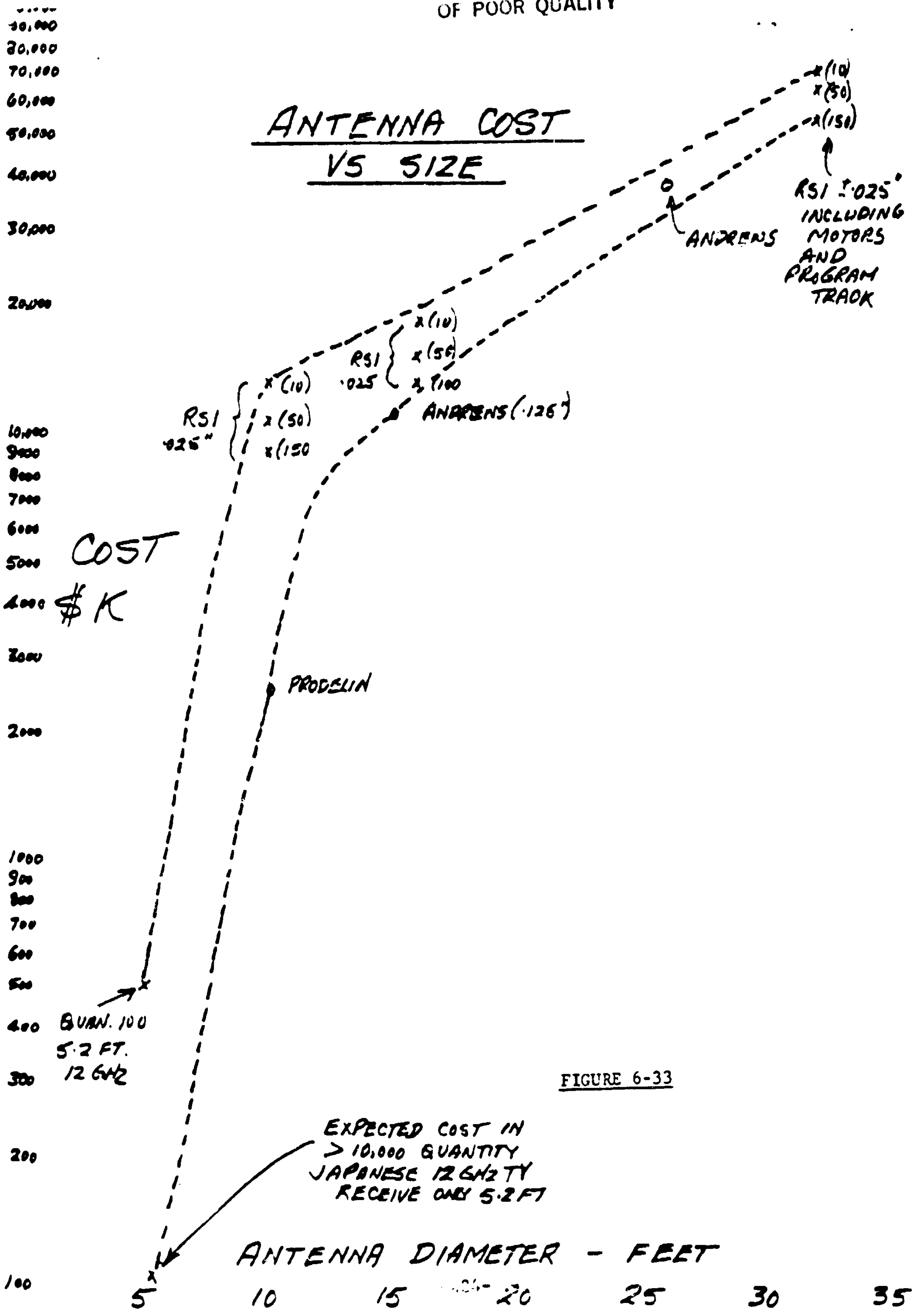


FIGURE 6-33

Thus parabolic antennas in the 2-10 ft range which will serve the S-band and Ku-band requirements of this study will use maturing manufacturing technology and it can be expected that these costs will significantly reduce with quantities in the 100,000 to 10 million units, as will be discussed in the next section.

Two other aspects of antennas will be discussed in this part; the use of array techniques for S-band and Ku-band, and the techniques of sidelobe reduction at Ku-band with both reflector and array systems.

6.3.1.1 Antenna Technology at 4 GHz

The technology of 4 GHz antennas, which has led to a family of low cost 2-10 ft parabolic antennas as described in the preceding paragraph, sets the stage for 1-meter antennas required for Ku-band and for 5-10 ft antennas required for community TVRO receivers at S-band.

One fall-out of the 5-10 ft antenna dish development in the United States is the development of assembly and material techniques which make such antennas easily transportable and erectable

Figure 6-34 shows how a Microwave General 5-meter dish is shipped in three sections for assembly at final destination. Other techniques include an unfurlable 10-ft antenna which was demonstrated at STP-80 held in July 1980 at the Hyatt House in San Jose, California, and other techniques including metalized fabric on thin metal panels stretched over a simple parabolic dish frame.

For the large antenna systems, the reflector cost is becoming less important than mount and support structures - particularly if such an antenna is to survive in a cold/rainy/windy/icy environment. However, these factors become less important - in fact virtually disappear, in the 1-meter TVRO antenna art.

6.3.1.2 Antenna Technology at UHF

At the ultra-high frequencies, and in particular at 0.7 GHz, antenna aperture gain is still easily achieved with a parabolic antenna for a G/T = 0

Microwave General's 5-meter dish arrives in three sections (above) and then assembly is hoisted in one piece onto its mounting.

Figure 6-34

where around 25-27 dB of gain is required. A 12-ft parabolic dish with 50% efficiency will provide 26 dB of gain which will easily serve this particular value of G/T. Thus the present low cost 2-10 foot antenna dish availability is readily applicable to the UHF TVRO earth terminal art.

Table 6-24 lists the various candidate UHF antennas which can provide the nearly 24-25 dB of gain necessary to develop a G/T of 0 dB with a low noise receiver with a noise figure of around 2-3 dB which is easily achieved at UHF. Parabolic antennas are very large and therefore relatively expensive and not really a first class candidate for the services. On the other hand, the YAGI and helical antennas have a long history of application in this frequency range.

The YAGI-UDA antenna is the world's most widely used TV antenna, and helical antennas are used on many satellites and many NASA and military UHF earth terminals. The YAGI is now used in the USSR for the 716 MHz earth terminal to STATSIONAR-T and although one YAGI antenna has been built which achieved 26 dB gain* at 400 MHz, it was so long (80 wavelengths) as to be structurally and economically non-viable. Actually, if the UHF broadcast satellite could be increased by 10 dB, then the same YAGI-UDA single antenna with 15 dB gain (Figure 6-35) and narrow-banded for reception from the satellite could be used effectively and very economically. Although,even in 1980, a YAGI antenna for commercial TV reception can cost up to $200. Thus, the cost and size of aperture at UHF will be relatively high relative to S-band and Ku-band despite cheaper receiver costs derived directly from commercial UHF TV receivers.

* P.C. Goldmark and J. Hollywood, "Antennas for improved hf point-to-point reception", CBS Laboratories Project 210, 1963.

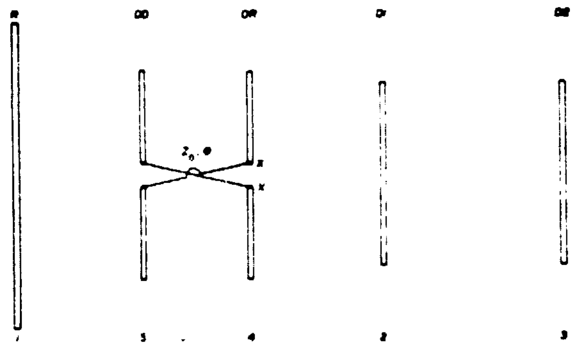
TABLE 6-24

UHF TVRO Antenna Techniques

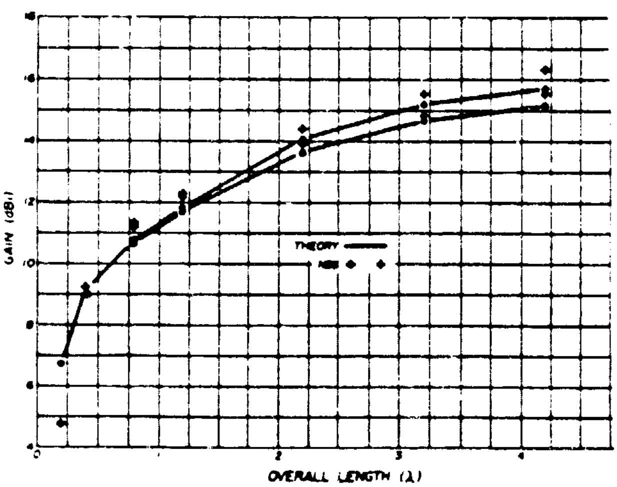
Candidate Technology	Description/Heritage	Usage
Prime focus parabolic or Torus antennas	Frame parabolic dish with mesh surface and prime focus dipole feed	Military Communications and radar
Array of Yagi Antennas with LNA at each Yagi	Yagis in an array	Yagi arrays used in USSR EDRAN system at 716 MHz to provide 25 dB gain
Array of antennafiers (low noise transistor integrated with dipole element)	Simple antennafiers now in use. Requires devel. use transistor gain as partial substitute for aperture in large array	Used for color TV sets as simple antenna/low noise transistor combination
Helical Antennas		Used with MARISAT, OSCAR, FLEETSAT.

Figure 6-35

Yagi antenna design



Layout of a Yagi with a broadband feed system of the type manufactured by KLM. The main driver (DR) and dependent driver (DD) are connected through a transposed transmission line with characteristic impedance Z_0 and phase angle θ. Performance of this type of Yagi can also be analyzed by computer, as discussed in the text.



Graphical comparison of the data from tables 2 and 3 showing theoretical (computed) gain and measured gain figures published by NBS. Computed curves support *NBS Report 688* which shows slight gain increase is possible with different-length directors.

Gain of six different NBS-designed Yagi antennas, in dBi, as determined by four different methods.

NBS Yagi type	NBS measurements	calculated from half-power beamwidth	pattern integration	computer derived
2 element (0.2λ)	4.77	7.50	6.71	6.70
3 element (0.4λ)	9.25	10.02	9.62	9.16
5 element (0.8λ)	11.35	11.86	11.41	10.73
6 element (1.2λ)	12.35	13.90	12.64	11.80
12 element (2.2λ)	14.40	15.28	14.28	14.04
17 element (3.2λ)	15.55	16.63	15.47	15.20
15 element (4.2λ)	16.35	17.38	16.22	15.71

Measured and calculated gain in dBi of Yagi antennas with average director lengths.

NBS Yagi type	director length	NBS measured gain	computed gain
5 element (0.8λ)	0.4260λ	11.27	10.68
6 element (1.2λ)	0.4240λ	12.24	11.71
12 element (2.2λ)	0.4017λ	13.92	13.62
17 element (3.2λ)	0.3946λ	14.83	14.68
15 element (4.2λ)	0.4008λ	15.55	15.15

The helical antenna is a candidate for a UHF array, although its cost and size will be large; it is of interest that helical antennas have been used to communicate with the amateur satellite OSCAR.

Attention is called to the very wide variety of UHF antennas which have been derived from ameteur radio and commercial radio communications; an excellent listing is provided by the magazine RF DESIGN in February 1980, which includes a description of:

- Traveling Wave Antennas
  - Yagi - Uda antennas
  - back fire
  - quad or closed loop array
  - quad - YAGI
  - helical
  - birdcage
- Long wire antennas
- Vee antennas
- Rhombics

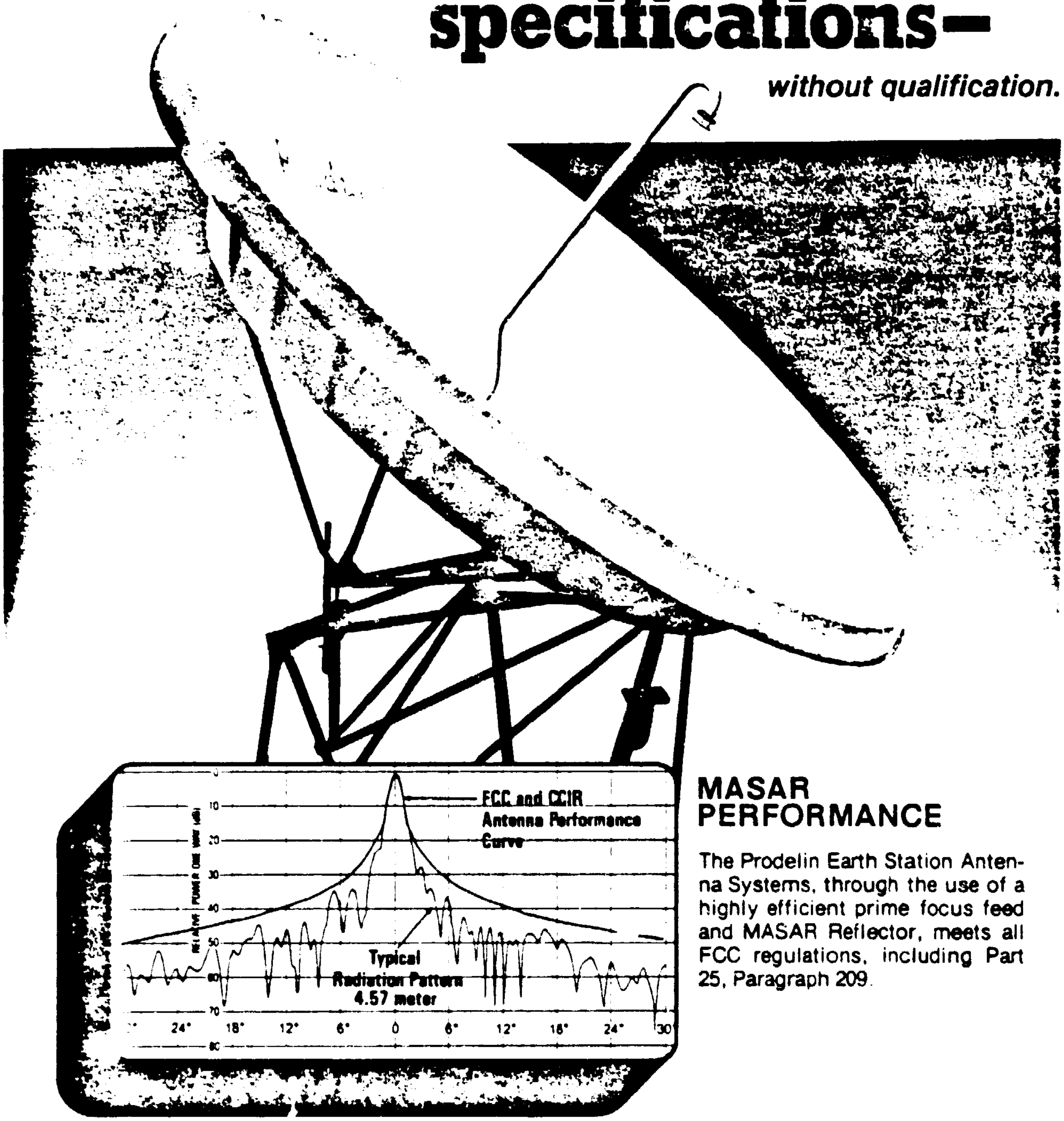
6.3.1.3 Antenna Technology at S-Band

Antenna technology at S-band is fairly mature. The wide-spread use of 10 meter antennas for the CTS and ATS-6 experiments involving production quantities have lead to the availability and prices described earlier with respect to 4 GHz TVRO systems and antennas; and antenna design has been further advanced toward meeting the 32-25 Log θ sidelobe requirements of the CCIR and FCC; see, for example, the Prodelin antenna described in Figure 6-36.

A. Bridges, "Really ZAP OSCAR with this Helical", 73 Magazine, P.5a, July 1975.

MASAR 4.57 meter earth station antenna system meets FCC and CCIR specifications–

without qualification.



MASAR PERFORMANCE

The Prodelin Earth Station Antenna Systems, through the use of a highly efficient prime focus feed and MASAR Reflector, meets all FCC regulations, including Part 25, Paragraph 209.

FIGURE 6-36

Table 6-25 lists the applicable antenna techniques for satisfying S-band TVRO requirements where 25-32 dB of antenna gain is required for G/T = 0 and G/T = 10 applications. Note that both parabolic antenna and phased arrays use lower gain elements.

Antenna gain in the 25-32 dB range at 2.6 dB is provided by parabolic antennas with sizes from 1 meter (25 dB gain) to 2 meters (32 dB gain) and are readily available from many manufacturers who are already manufacturing and selling at the rate of [illegible]0 antennas per month into the rapidly growing 4 GHz TVRO business in the United States.

Other types of S-band antennas using arrays of printed circuit elements or helical antennas, are being developed as a result of world-wide interest in the MARISAT (and IMMARSAT) system for maritime communications at 1.6 GHz. This system requires lower gain antennas (15-17 dB) and many types of antennas are used (parabolic or phased arrays) or have been considered.

Figure 6-37 shows a CHALMANT phased array antenna developed in Sweden* for MARISAT. This antenna uses an 8 x 8 element array (64 elements) where each element consists of a circular slot backed by a cylindrical cavity and a hybrid circuit. Each element has a directivity of 7 dB at 1.6 GHz. This antenna had a gain of approximately 20 dB at 1.6 GHz, a 3 dB beamwidth of 15° and a first sidelobe suppression of around 20 dB.

An extensive study of single-beam antenna types was made a decade ago by B. Mendoza of AMI for the U.S. Coast Guard in anticipation of MARISAT, and Tables 6-26 and 6-27 list some of the antenna alternatives considered. Note that according to Table 6-26, the parabolic antenna was considered simplest and most inexpensive.

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*F. Bolinder, "Phased Array Antennas for Marisat Communications", Microwave Journal, Dec. 1978.

TABLE 6-25

2.54 GHz TVRO Antenna Techniques

Candidate Technology	Description	Usage
Prime focus solid surface parabolic antenna	3 meter dish, plastic made by Prodelin	ATS-6 HET Experiment
Frame parabolic antenna using mesh wire surface	Use of mesh surface effective at S-band	Used in military and NASA systems
Phased array of printed circuit elements	Using flat helical elements	Developed in Scandinavia for use in 1.6 GHz MARISAT system
Phased array of helical antennas	Using traveling wave techniques using long helical	Now used in MDS transmissions

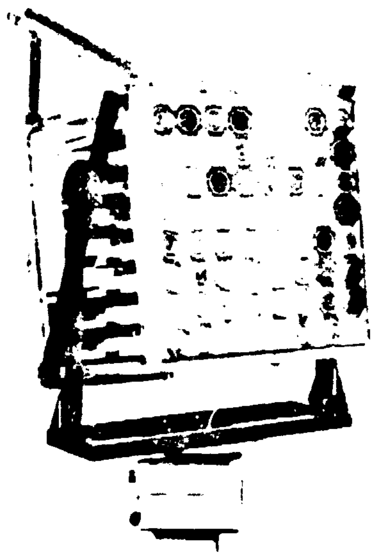

Fig. 1 CHALMANT, front view.

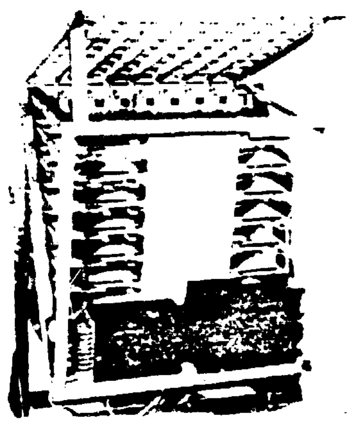

Fig. 2 CHALMANT, rear view.

Figure 6-37. Phased Array Antenna for MARISAT Communications

TABLE 6-26

Preferred S-Band Antenna Types for Marisat

Gain Range	Antenna Type	Remarks
3-6 dB	Turnstile on Ground Plane	Small and simple, curved for improved axial ratios
7-10 dB	Helix *or* Horn	Both inexpensive, horn better for tracking
11-15 dB	Short Backfire	Very efficient, simple, fair tracking
16-18 dB	Parabola	Simple and inexpensive at the higher gains

COMPARISON OF SINGLE-BEAM ANTENNA TYPES

PARAMETER / ANTENNA TYPE	GAIN (NOMINAL)	SIZE (AT NOMINAL GAIN)	BEAM SHAPE	BEAMWIDTH	GENERAL VOLUME	POLARIZATION	CAPABLE OF TRACKING?	SIDE AND BACKLOBES	COMPLEXITY, ETC. (RELATIVE COST*)
Parabola	15 dB (minimum)	30" (750 mm) min. Dia.	Pencil Beam	Typically 18° for 20 dB Gain	Moderately Large	Depends on Feed. C.P. readily achieved	Yes, with multi-element feed.	Low	Impractical at low gains (M)
Parabolic Cylinder	12 dB minimum	30" x 5" (750x185 mm)	Fan Beam	Function of Aperture (17° x120° for 12 dB example)	Moderately Large	Depends on Feed. Linear readily achieved	Yes, in elevation, with multi element feed	Moderate	Simple Fan Beam (M)
Planar Array	Gain varies with aperture size (8 - 18 dB)		Any Shape	Function of Aperture	Moderately Large	Depends on element. C.P. readily achieved.	Yes	Low	Versatile but Complex and Expensive (VH)
Linear Array	Gain varies with array length (9 dB ~ 780 mm)		Fan Beam	Function of Array Length (120°x18° for 9 dB array)	Moderate but long	Depends on element. Can be made circular	Not Readily	Moderate	Less Complex than Planar Array (H)
Crossed Yagi-Uda	Gain varies with length (10-15 dB) ~ (400-1000 mm)		Wide Symmetrical Beam	30°-50° for 11-15 dB	Moderate but long	Circular	Yes, but only with linear polarization	Moderate	Light but fairly complex (M)
Helix	Gain varies with length 9 dB ~ 8" (20 cm) 15 dB ~ 21" (54 cm)		Wide Symmetrical Beam	35° for 14 dB gain	Small	Circular	No	High	Small, Light, Simple to make (L)
Log-Periodic	9 dBi	38 cm x 51 cm (15"x20")	Wide Symmetrical Beam	50° at 9 dB	Moderately Large	Circular	Yes, but only with linear polarization	High	Limited to 9 dB gain (M)
Horn	14-19 dB	33-51 cm (12"to20")	Broad "Flat-topped" Fan Beam	Varies with gain (18° at 19 dB)	Moderately Large	Circular difficult with Sectoral Horns	Yes, with multimode horns	Moderate to high, depends on geometry	Fairly simple, but bulky (L)
Short Back-fire	14.5	40 cm (16")	Wide Symmetrical Beam	35°	Moderate	Circular	Yes, with multiple crossed dipole feeds	Low	Very efficient, Simple, (L)
Turnstile on Ground Plane	3-6 dB	10 cm (3.94")	Very Wide Symmetrical Beam	80°-120°	Small	Circular	Yes, with multiple crossed dipole feeds	Moderate to Low	Very Small: Low Gain (L)
Conical Log-Spiral	2-8 dB	23 cm (9")	Very Wide Symmetrical Beam	60°-180°	Small	Circular	Yes, if multiple arms are used	Low	Small: Low Gain (M)
Cavity-Backed Spiral	6 dB	15 cm (5.9")	Wide Symmetrical Beam	70°	Small	Circular	Yes, if multiple arms are used	Low	Small: Low Gain (M)
Cavity-Backed Crossed Slots	4.5 dB	11.5 cm (4.5")	Very Wide Symmetrical Beam	140°	Small	Circular	Not Practical	Moderate	Small, Wide Angle (M)
Cavity Backed Crossed Dipoles	3-6 dB	13 cm (5.1")	Very Wide Symmetrical Beam	80°-120°	Small	Circular	Yes, with multiple crossed dipole feeds	Moderate	Small, Low Gain (L)

TABLE 6-27. S-Band Antenna Alternatives for MARISAT.

* RELATIVE COST: VH = Very High; H = High; M = Medium; L = Low.

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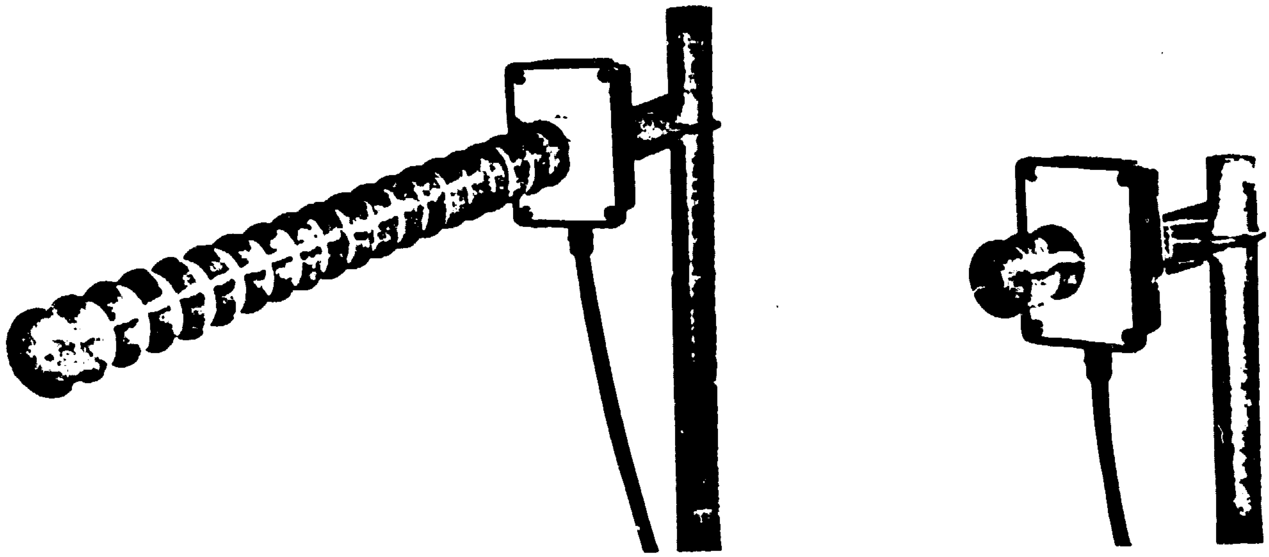
Lindsay

MDS antenna

LAZER series
model L-2115/L-2111



The Lindsay 2100 Series antennas are designed to provide good gain and directivity patterns.

The antenna features a complete weather sealed feed point and is designed in such a manner that a director system can be plugged in to increase the gain if so desired.

The antenna mounting clamp will take up to 1½ O.D. mast and allows for a vertical or horizontal mount with up to a 15 degree elevation adjustment.

SPECIFICATIONS	model L-2111	model L-2115
Frequency	2150-2162 MHz	
Gain	11.5 dBi	15 dBi
VSWR	1.4	1.4
Beamwidth	44 degrees	22 degrees
F/B Ratio	20 dB	20 dB
Polarization	Horizontal or Vertical	
Input Connector	N-Female	
Antenna Weight	18 oz.	2 lb.
Antenna Size	3"x4½"x6"	3"x4½"x30"

Adjustable antenna mount will take up to 1½" O.D. mast.

Figure 6-38. End Fire Antenna

Figure 6-38 describes the Lindsay End Fire Antenna used for S-band MDS Communications with a gain of 11-15 dBi

6.3.1.4 Antenna Technology at 12 GHz

This part will address the technology of antennas providing nominally one-meter aperture at 12 GHz.

The antenna technologies to be discussed in this part are the basis of what could become one of the most mass produced microwave products in the world. It is expected that there will be no definitive technique that will serve this application. This part will show that several candidate antenna techniques such as parabolic antennas and phased arrays are available to provide this one square meter aperture; while there is a significant cost differential between these various techniques at low volume manufacture, at quantities from 100,000 to 10 million, the relative costs differential will be insignificant (see next section) and final costs differential will more likely be determined by differences in handling, packing, and shipping costs, and in the costs and complexity of the mount system.

The candidate antenna and feed techniques for a 1-meter (nominal) 12 GHz TVRO antenna are listed in Table 6-28. The antenna techniques include both center-fed and offset-fed parabolic antennas, slotted waveguide arrays, and printed circuit arrays. The feeds include standard horn feeds (with various radiation pattern tapers), the innovated Kumar* feed and crossed dipole feeds. A main consideration will be not only cost and manufacturability, but also sidelobe level** since reduction in sidelobe level is a key factor to satellite spacing in geosynchronous orbit.

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* A Kumar, "Experimental Study of a Di-electric Rod Enclosed by a Waveguide for use as a Feed", Elec. Letters, Vol. 12, pp 666-668, Dec. 1976.

** R. E. Collin and L. Gabel, "Low Side Level Low Cost Earth Stations for 12 GHz Broadcasting Satellite Services", Contract NAS3-21365, Text 1979, NASA-Lewis.

TABLE 6-28

12 GHz TVRO Antenna Techniques

Component	Candidate Technology	Description/Heritage
Antenna providing 32-37 dB gain	Prime focus feed parabolic antenna	1-meter assembly; first sidelobes in 12-17 dB range
	Off-set Fed parabolic antenna	1-meter assembly; first sidelobes in 25-36 dB range
	Slotted waveguide array	36 x 36 inch flat plate; sidelobes 40-50 dB range
	Printed circuit array	36 x 36 inch flat plate with corporate feed; sidelobes in 40-50 dB range
Feeds	Standard horn	Standard techniques
	Kumar feed*	Used for reduced sidelobes
	Printed circuit crossed dipole feed	Directly coupled to LNA

* R. Collin and L. Gabel, Case Institute, Contract NAS-3-21365

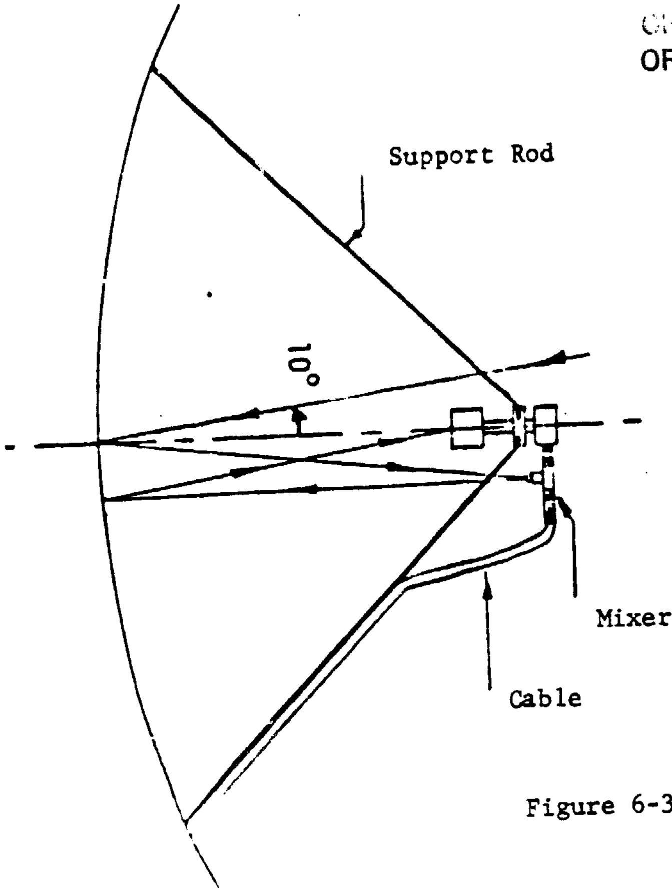

Figure 6-39. Interference from Support Elements in a 1-meter antenna

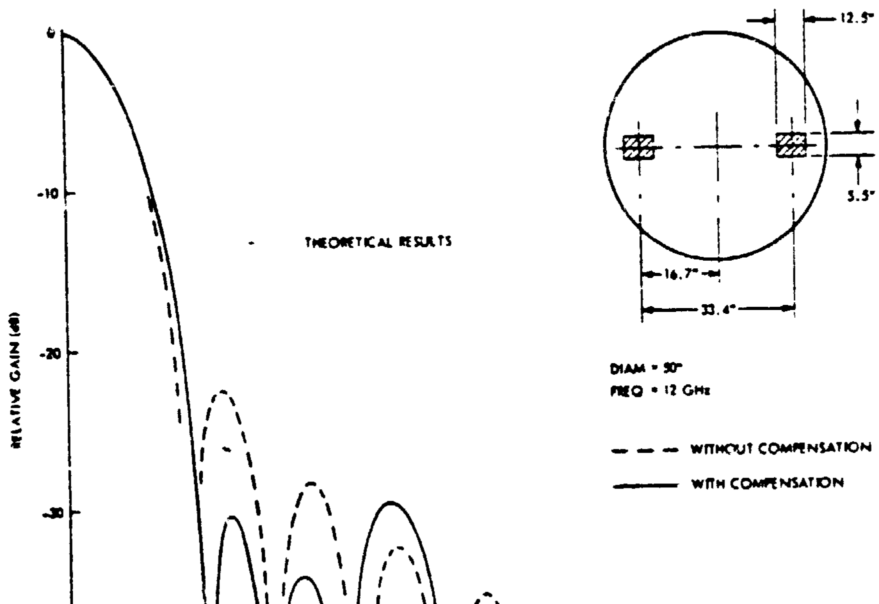

Figure 6-40
Radiation Pattern With and Without the Pair of Absorbers (8 dB Taper Illumination) [Han, 1972]

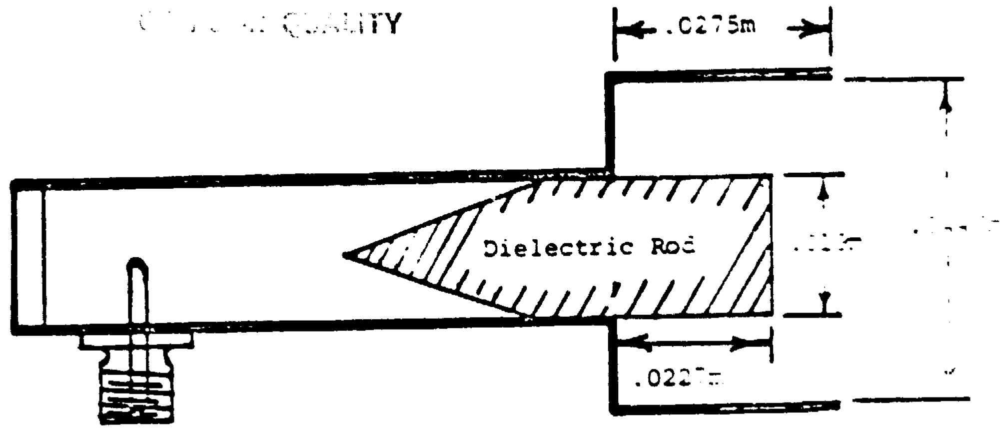

Figure 6-42
Simplified drawing of Kumar feed.

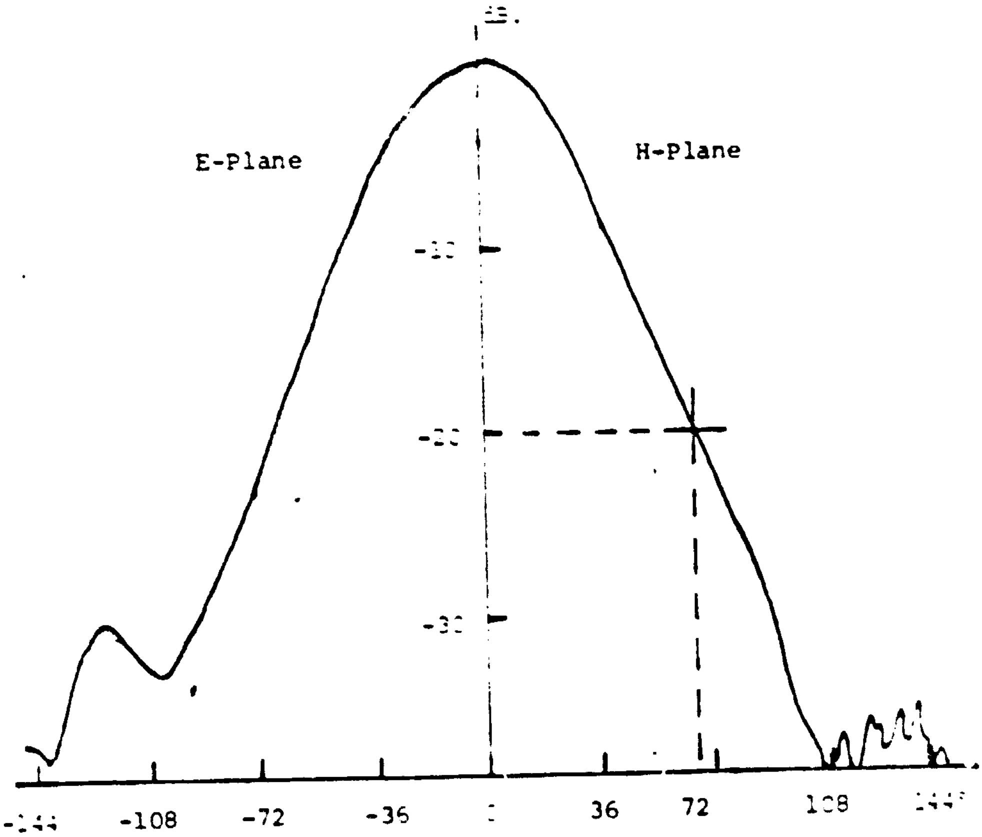

Figure 6-43
Radiation pattern of Kumar feed (10).

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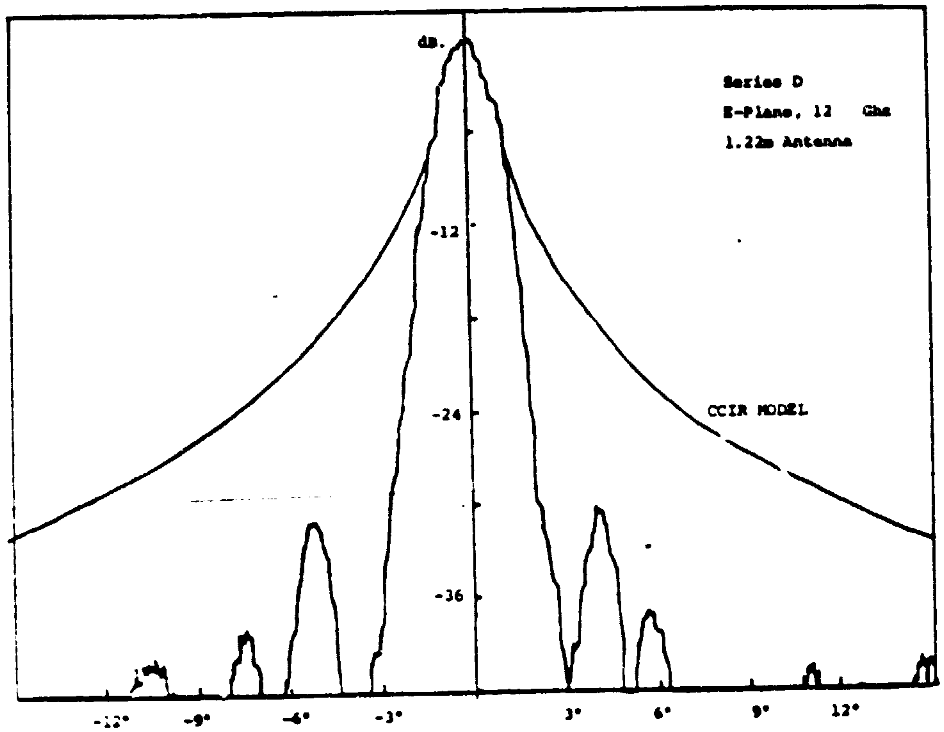

Figure 6-44
E-plane radiation pattern.

6.3.1.4.1 Small Prime Focus Parabolic Antenna

The small one meter 12 GHz antenna with prime focus feed, see Figure 6-3, would appear to be a very minor production item and present a manufacturing and fabrication problem no more difficult than a large frying pan or the stamped hood of a Ford Pinto. However, there are significant problems in surface tolerance and contour accuracy, feed design, and feed support design which must be reckoned with in order to assume achieving gain and overall performance, particularly in an out-of-doors environment.

R. Collin and L. Gabel of Case Institute of Technology of Cleveland, Ohio, have studied small antennas for 12 GHz broadcast satellite service (NAS Contract NAS-3-21365) and have provided several key observations relative to 4-6 ft antennas in the 12 GHz range:

- Standard available parabolic antenna in the 4-6 ft diameter range have near in-sidelobes in the range of -20 dB to -25 dB.
- According to Figure 6-7 a protection ratio of from 27 to 36 dB is required for a S/N greater than 48 dB; otherwise significant interference noise can be produced in the received television picture.

Interference can be produced by many sources; from adjacent satellites in the geosynchronous arc, to interference from reflections in the antenna support structure (see Figure 6-39), and from surface inaccuracies and deformities. Thus the 12 GHz 1-meter parabolic antenna system with feed and support structure, must be a structure with precision surface and carefully designed support elements to assure that maximum gain and minimum sidelobe level will be achieved.

There are relatively few techniques available for sidelobe reduction in a small prime focus parabolic antenna. One technique is to reduce the feed support element structure, modern design has recommended the so-called J-hook feed for minimum interference. Another technique is the use of absorbers (Figure 6-40) which were successfully used by C. C. Han and J. C. F. Albernaz (Stanford PhD Thesis 1972) to reduce sidelobes to below -30 dB for a 50 inch dish.

Another technique which can be exploited for sidelobe reduction is feed design. By shaping or tapering the feed radiation pattern; i.e., the Kumar feed of Figure 6-42 and Figure 6-43, an antenna radiation pattern with sidelobes below -30 dB (Figure 6-44) could be achieved.

Table 6-29 lists the recommendations made by Collin and Gabel for sidelobe reduction; they list surface accuracy and feed design as techniques for achieving -30 dB sidelobes but point out the difficulties of achieving -35 dB sidelobes.

6.3.1.4.2 Offset Fed Parabolic Reflectors

One approach to further reduction of sidelobe level in a small parabolic antenna is to offset the feed and eliminate the destructive direct interference of the support rods. This can result in somewhat lower antenna efficiency but small increases in diameter are relatively inexpensive, and the offset fed reflector-antenna - now becoming widely used in new 4.5 meter and 10 meter antennas at 4 GHz - is a very viable approach to small antenna design with sidelobe levels as low as -35 dB, and in addition, provides a more accessible point at which to mount the feed which will also include the LNA and down-converter.

An additional technique which has been tested in Japan and disclosed to CCIR USSG-4 is the use of a Gregorian fed antenna system in which the path from the feed to the sub-reflector is surrounded by absorbing material thereby reducing the sidelobe level to less than -35 dB.

6.3.1.4.3 Microstrip Antenna Arrays

When microstrip resonators are constructed with low-dielectric-constant substrates they act as radiators. The result is a conformal, or low-profile antenna, best suited for applications where small size and low weight are the

TABLE 6-29

Recommendation for Sidelobe Reduction in Small 12 GHz Earth Terminals
by
R. E. Collin & L. R. Gabel

1. Sidelobes that are at least 5 dB below those specified by the CCIR model pattern can be achieved by using a feed producing about 20 dB edge taper.

2. Good aperture efficiency with low sidelobes can be achieved by using a hybrid mode feed.

3. In order to obtain sidelobes as low as -35 dB the surface contour of the paraboloid will probably have to be accurate to within $\pm \lambda_o/25$ at least.

4. Small errors in the surface of a paraboloid produces large variations in the sidelobe pattern below -30 db and hence does not result in reproducible sidelobe patterns from one antenna to the next.

5. The use of small reflector plates is a simple way to reduce the sidelobe level.

6. Currently the accepted tolerance on surface deviations is $\lambda_o/16$ which is not sufficient to generally obtain sidelobes below -35 dB.

7. The structural rigidity of many of the commercially available low cost paraboloids is not good enough to ensure that surface distortions considerably greater than $\lambda_o/16$ does not occur.

8. Antennas designed for transmitting use and incorporating a vertex plate in order to maintain a low VSWR for the feed are not suitable for low sidelobe level about -30 dB even if a large amount of aperture field taper is used.

9. A -35 dB sidelobe objective for low cost small diameter 12 GHz antennas appears realistic and attainable in a single plane.

10. Techniques to mass produce low cost but accurate paraboloids need to be developed.

prime requirements. These microstrip antennas have the advantages of low production costs, high design flexibility, and ruggedness. Other attractive characteristics are:

- o The paper-thin antennas don't disturb aerodynamic flow or disrupt the the mechanical structure.
- o These antennas are compatible with modular designs. Solid-state components can be added directly to the microstrip antenna board.
- o Feed lines and matching networks are simultaneously etched with the antenna structure.
- o Linear and circular polarizations are possible.
- o Dual-frequency antennas can be constructed.
- o There are no cavity backings required.

Microstrip radiators can be grouped into three categories: the wide microstrip antenna, the patch microstrip antenna, and finally, the microstrip slot antenna.

Figures 6-45* through 6-47 show various types of microstrip antennas including a 12 GHz 512 element slot array and 9.4 GHz planar array. Figure 6-47** shows a variety of patch microstrip antennas which can be used.

These antenna arrays, using microstrip, are of particular interest since the array elements can be positioned to provide sidelobe reduction to less than -40 dB and such antennas are relatively easy to fabricate in quantity.

Figure 6-48 shows a commercial implementation of microstrip slotted-arrays for use by NHK in Tokyo to receive TV broadcast from the Tokyo tower at 12.1 GHz,

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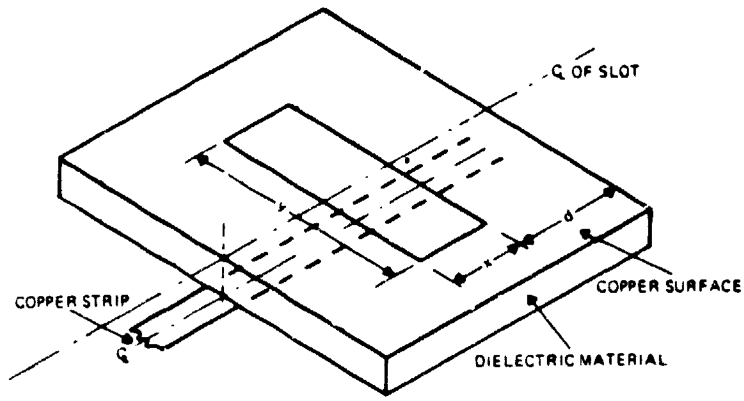
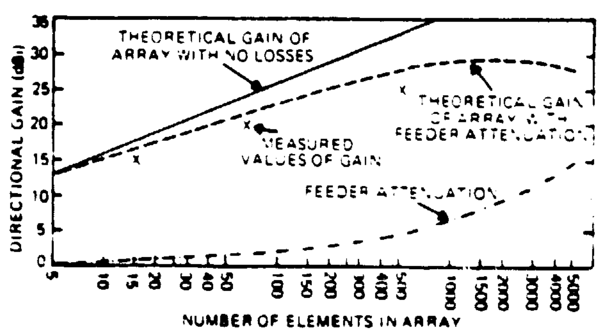
* M. Collier, "Microstrip Antenna Array for 12 GHz TV", Microwave Journal, Sept. 1977.

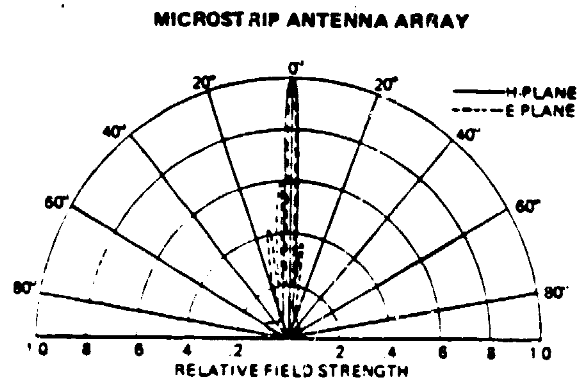
** I. J. Bahl, "Build Microstrip Antennas with Paper-Thin Dimensions", Microwave, Oct. 1979.



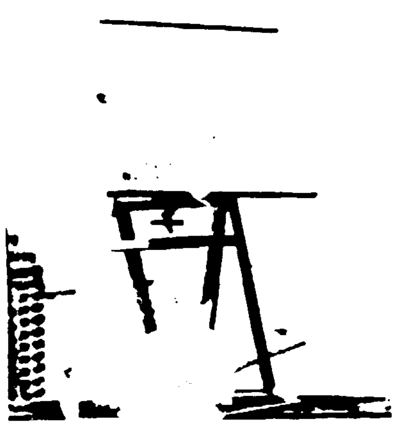
Sketch of a single slot fed by a microstrip line.



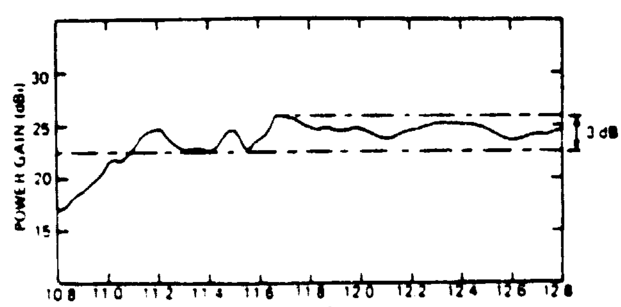
Power gain of slot array versus number of elements.



Polar diagram for 512 element slot array.



Co... ...e antenna array
on support frame.



Power gain versus frequency for 512 element slot array.

Figure 6-45. Microstrip Antenna Array

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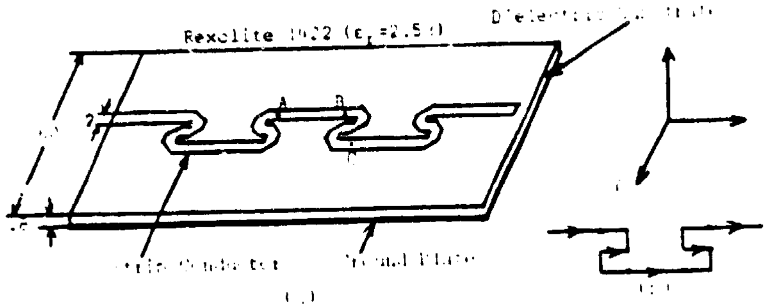
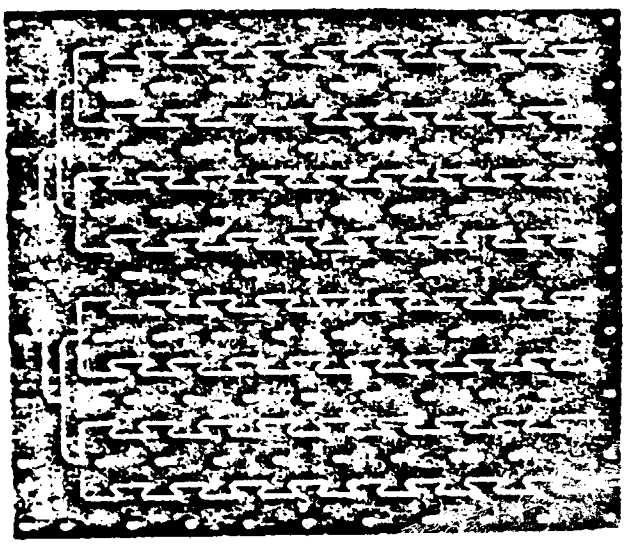


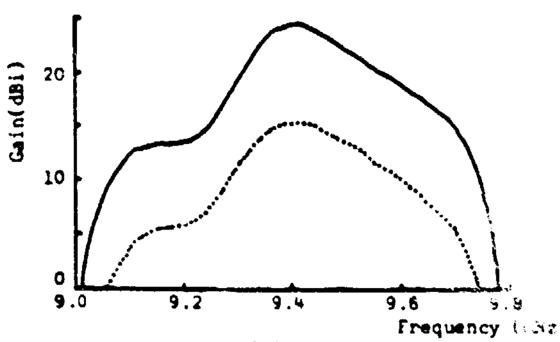
Antenna Configuration



Planar Array Antenna

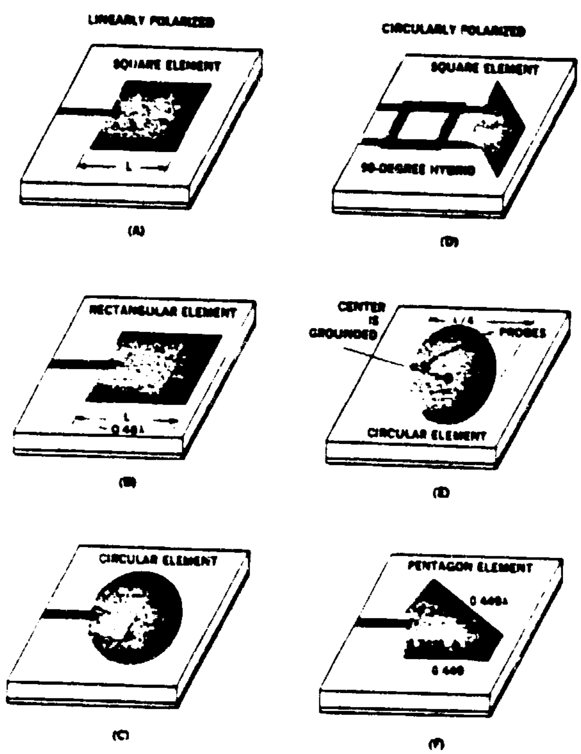
Table 1. Characteristics of Planar Array Antenna

Frequency	9.4 GHz
Mainbeam direction	θ=91°, ϕ=0°
Gain	24.7 dBi
Beamwidth	7.3° (E-plane)
	7.2° (H-plane)
Sidelobe level	-13.3 dB (E-plane)
	-12.6 dB (H-plane)
Cross polarized level	-33.3 dB (E-plane)
	-22.7 dB (H-plane)
Input VSWR	1.37 : 1
Gain-beamwidth product	15500



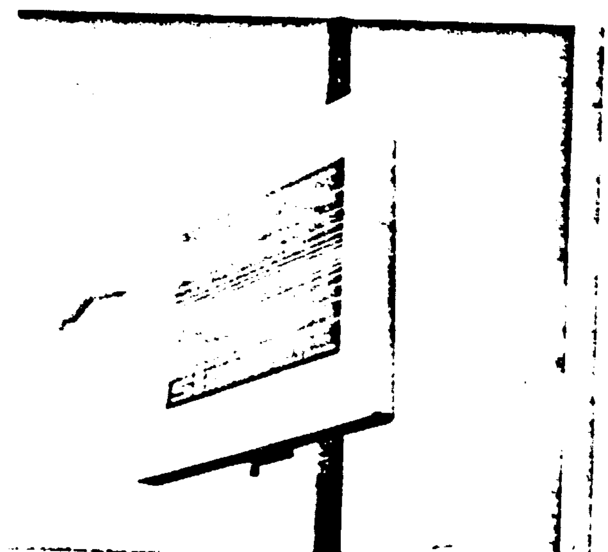
Gain versus Frequency

re 6-46. Planar Antenna Array



. *Various patch microstrip antennas*

Figure 6-47



This directional 340 × 330 × 24 mm **antenna** *operates at 12.1 GHz to receive line-of-sight TV broadcasting from Tokyo Tower. By reducing sidelobes, ghost images caused by reflected signals are eliminated.*

Figure 6-48

to avoid picking up "ghost images" reflected from the neighboring building. Typical Yagi TV antennas, with their wide-beam reception, pick up reflected signals. The propagation delay of these signals causes the ghost image. However, a slotted-array microwave antenna that eliminates ghosts now is commercially available from Toshiba Corp., Kawasaki. With 30.1 dB gain, the 12.1 GHz antenna is highly directional, and the low sidelobes effectively eliminate reception of signals reflected from buildings.

"This antenna was designed for ease of fabrication and installation", explains antenna specialist Katsumi Hirai of Toshiba. A slot-array of 306 elements is mounted on one side of the antenna structure, and feed lines lead to a down-converter installed in the middle of the opposite side. The downconverter uses silicon mixers with a temperature-stable Gunn oscillator. A bandpass filter is included in the front end, with the IF amplifier built into the MIC module. The patterns and performance of this antenna array is given in Figure 6-49.

6.3.1.4.4 Slotted Waveguide Antenna Arrays

Probably the most interesting and promising of the new candidate TVRO antenna technologies is an antenna technique which is old in the radar art. This technique is the slotted waveguide array shown in Figure 6-50 which has the following advantages:

- o Very high efficiency - around 85%
- o Manufacturable by using milled plates brazed together; very expensive in small quantities but very inexpensive when manufactured by special tooling and machinery
- o The arrangement of slates can lead to sidelobe reduction in the 40-50 dB range. Theoretically capable of zero sidelobes by using a Gaussian distribution of slots

Ant. Configuration

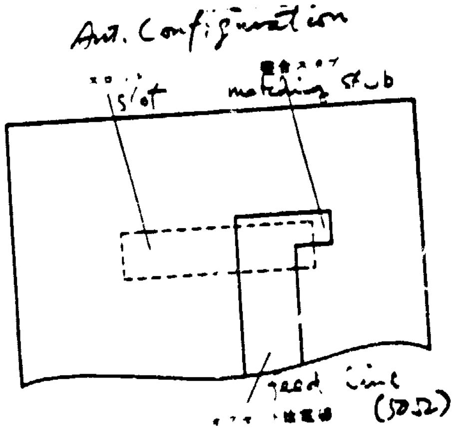


図4 スロットアンテナ給電構造

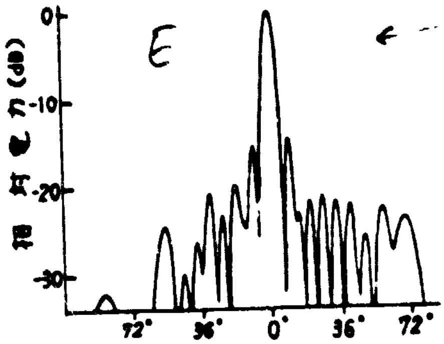


図10 E面指向性

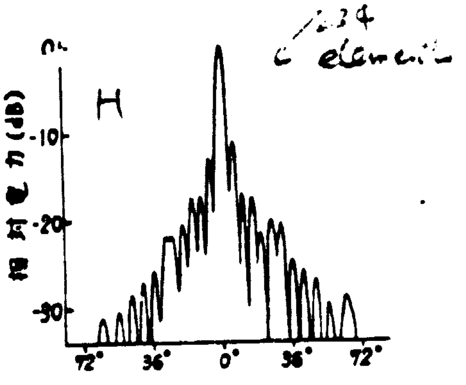


図11 H面指向性

Radiation patterns

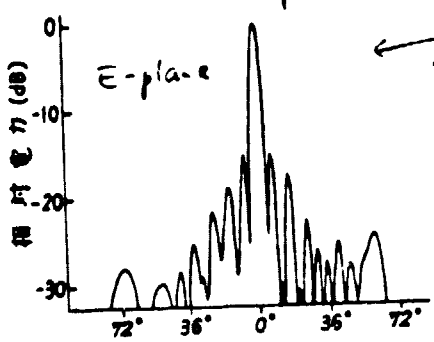


図12 E面指向性

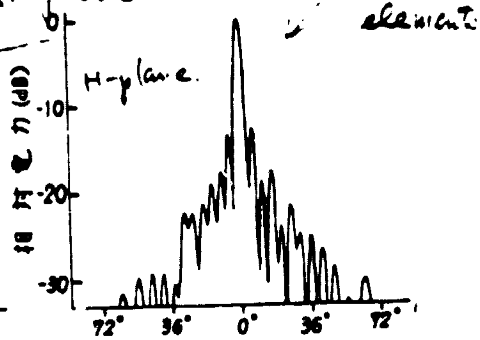


図13 H面指向性

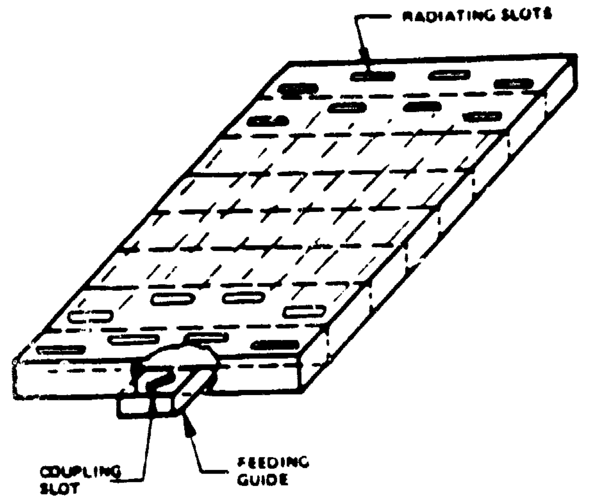
表1 試作アレイアンテナの主要特性

Prototype Ant.

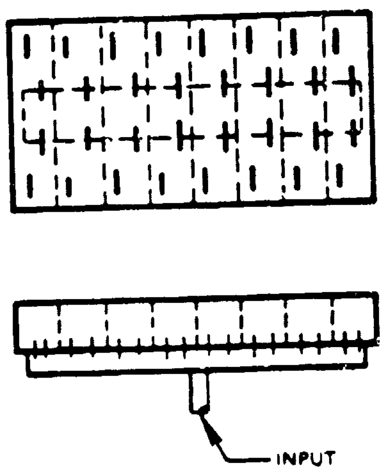
			234素子スロットアレイアンテナ 234 elements	306素子スロットアレイアンテナ 306 elements
receiving freq. band	受信周波数帯域		12.092 ~ 12.2 GHz	12.092 ~ 12.2 GHz
dimensions	外形寸法		270㎜ × 330㎜ × 24㎜	340㎜ × 330㎜ × 24㎜
gain	利得		29.1 ~ 29.3 dB	29.9 ~ 30.8 dB
half power beamwidth	電力半値幅	E面 plane	5.7 度 degree	4.3 度 degree
		H面 plane	4.0 度 degree	4.0 度 degree
side lobe level	サイドローブレベル	E面 plane	−14.2 ~ −14.5 dB	−14.3 ~ −15.0 dB
		H面 plane	−10.8 dB	−9.6 ~ −12.6 dB
	VSWR		less than 1.5 ~~以下~~	less than 1.5 ~~以下~~
weight (including a converter and supporting structures)	重量 (コンバータ・取付機構含)		1.85 Kg	2.22 Kg

Figure 6-49.

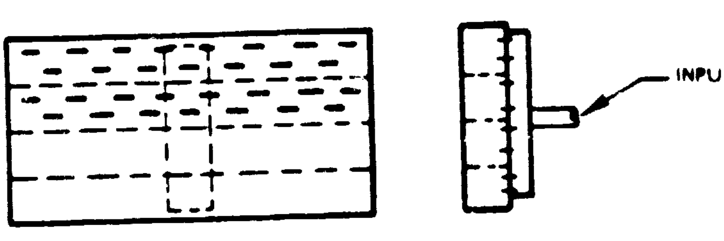
東芝総合研究所 電子機器研究所
〒210 川崎市幸区小向東芝町1
TEL 044-511-2111



·5 *Slotted Waveguide Array Antenna*



HORIZONTAL POLARIZED SUBARRAY



VERTICAL POLARIZED SUBARRAY

Figure 6-50

- o Capable of using a single waveguide feed - very low loss, and placing the LNA in a very convenient location
- o Elimination of feed supports, etc., typical of parabolic reflector systems

The slotted waveguide array antenna involves a set of contiguous waveguides with slots in the radiating face as shown in Figure 6-50; Figure 6-51 shows the slot dimensions and impedances of a small four slot array* illustrating the size of a typical structure. The bandwidth can be extended from the narrow band shown in Figure 6-51 to more than 500 MHz at Ku-band.

Figure 6-52 and Table 6-30 show a slotted waveguide 11 GHz phased array designed by Dr. A. Smoll of FACC for a spacecraft application. Note the small size of the 11 GHz array (11.7 x 18 inches) which was designed to provide a contoured footprint with 28 dB gain onto the islands of Indonesia (Figure 6-53). While this slotted waveguide array is linearly polarized, it can be converted to circular polarization by a plastic overlay which includes a special zig-zag pattern of printed lines.

6.3.2 Low Noise Amplifiers

The low noise amplifier (LNA) is the key device with the antenna gain for establishing the G/T of the TVRO broadcast satellite receiver at any frequency.

Historically, until 1974, the parametric amplifier (uncooled, thermo-electrically cooled, and cryogenically cooled) was the workhorse for virtually all LNA applications which required noise figures less than 2 dB or 200°K. Above that noise figure, bipolar transistor and tunnel diode amplifiers and the mixer provided noise figures in the 3-6 dB range.

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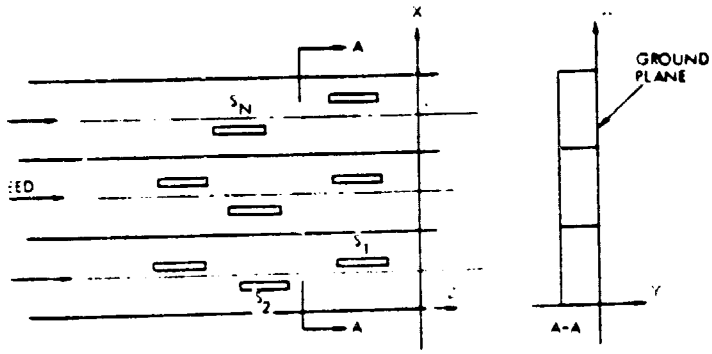
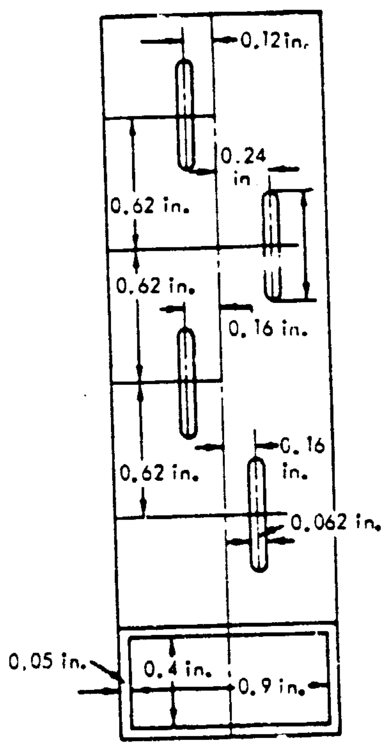
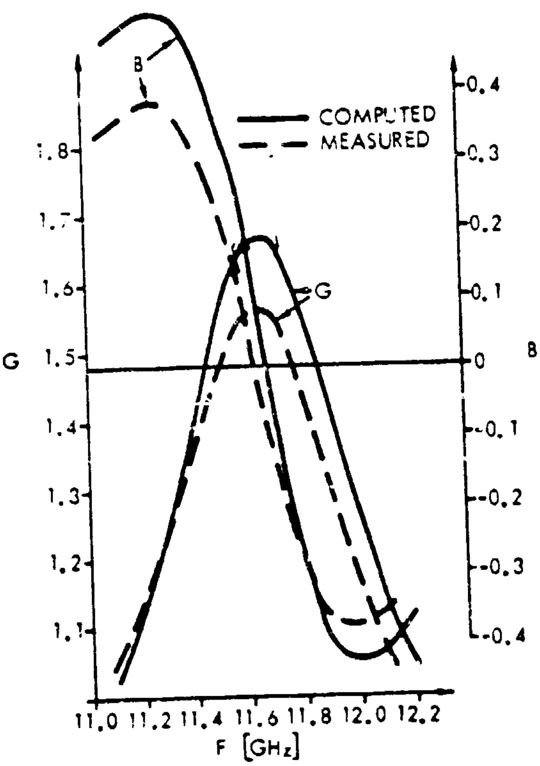
* Reported by Raytheon investigators at the UPSI Conference, Seattle, Washington, June, 1979.



Two Dimensional Slot Array





- Input Admittance Y/Yo = G+jB of a Four Slot Linear Array

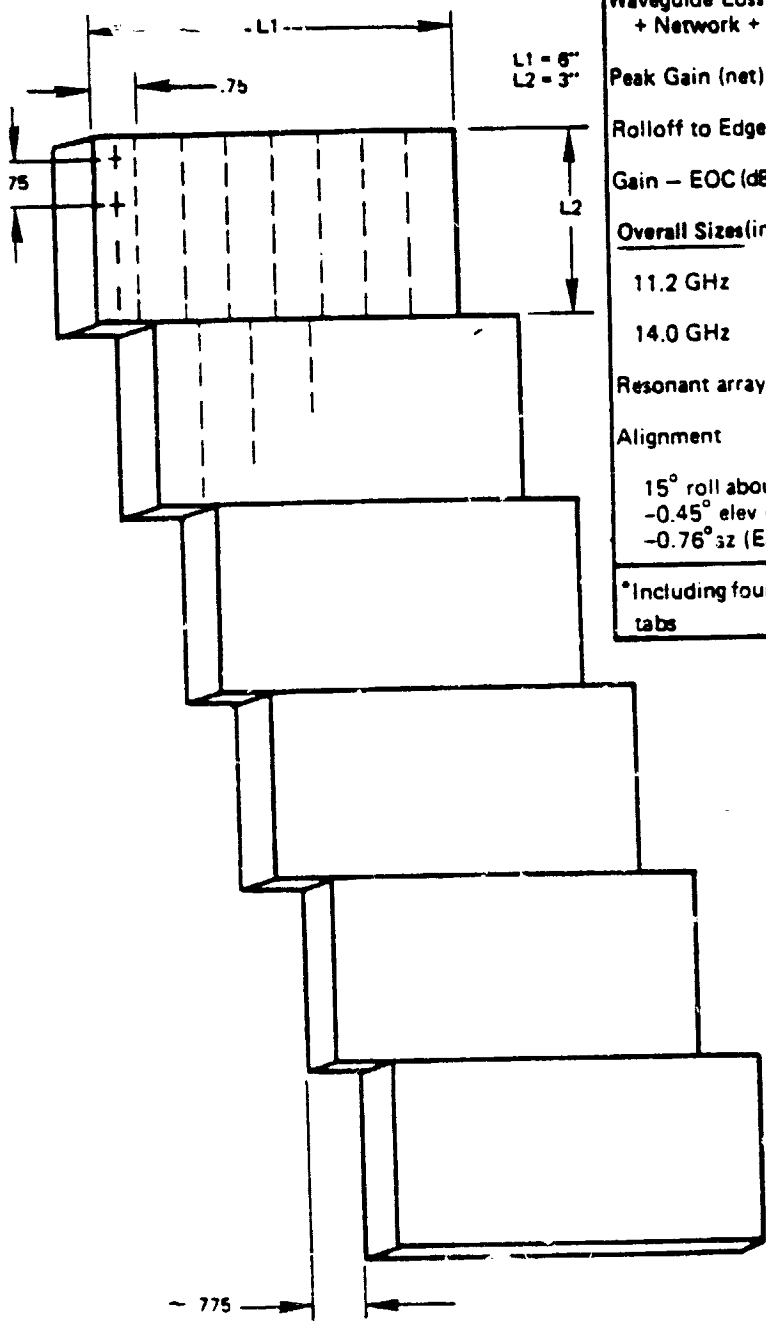
Figure 6-51

Table 6-30

Details of Phased Array

Peak Directivity (dBi)				29.2
Waveguide Loss (182.88 cm at 9 dB/2540 cm) + Network + Cover Loss (dB)				0.7
Peak Gain (net) (dBi)				28.5
Rolloff to Edge (dB)				-4
Gain – EOC (dBi)				24.5
Overall Sizes(in)	**Horz**	**Vert**	**Depth**	**Mass***
11.2 GHz	11.7	18	0.75	1.0 kg
14.0 GHz	9.3	14.4	0.6	0.8 kg
Resonant arrays – broadwall shunt slots				
Alignment 15° roll about Yaw axis -0.45° elev (North) -0.76° az (East)				

*Including four 91.44 cm waveguide runs and mounting tabs



K-Band Antenna Using Six Arrays Stair-Stepped for Area Coverage

Figure 6-52

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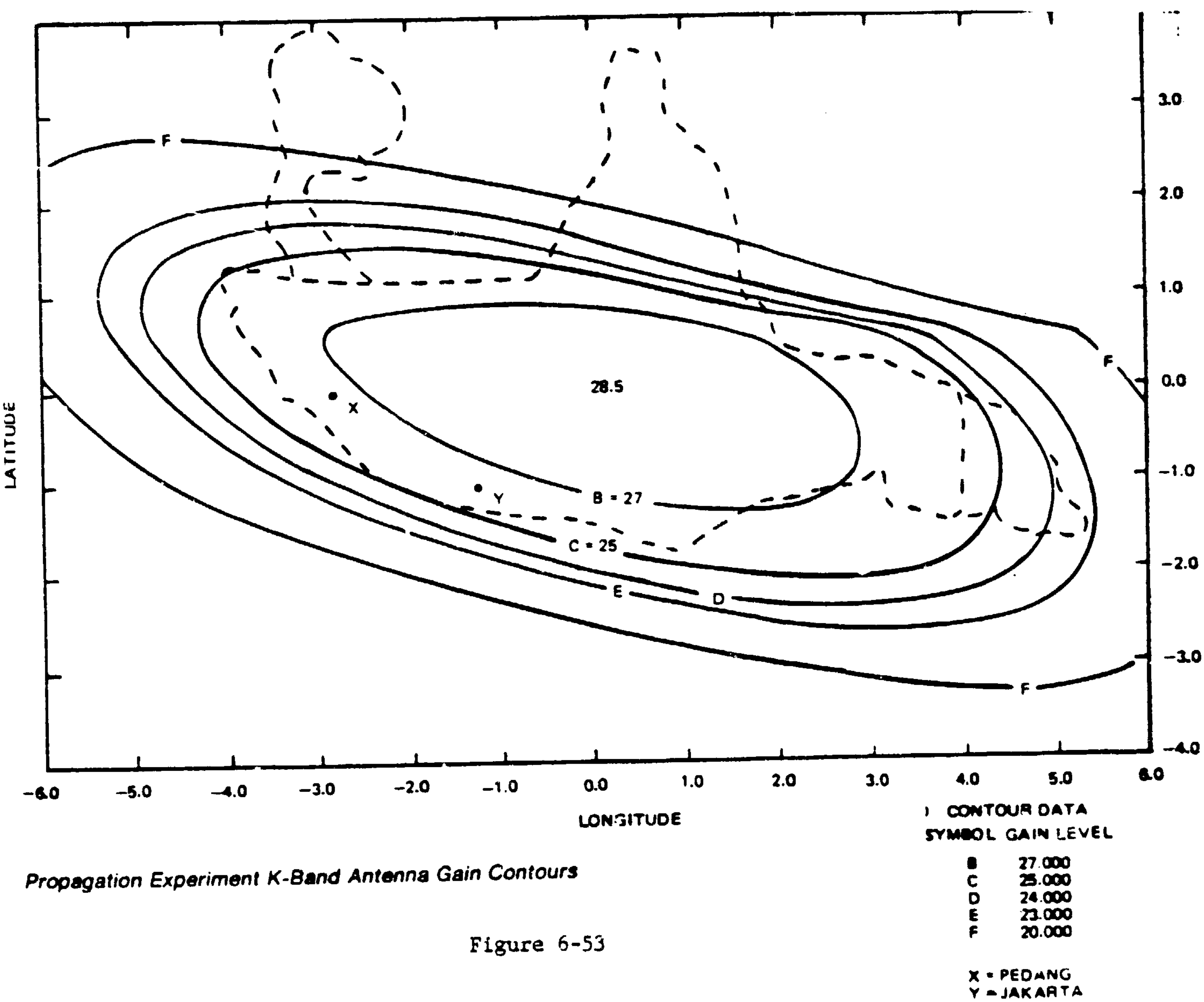

Propagation Experiment K-Band Antenna Gain Contours

Figure 6-53

The advent of the FET in the early 1970's, its introduction into 4 GHz TVRO systems with its 2 dB noise figure during the late 1970's, and further improvement in Schottky mixer diodes and mixer circuits, has caused a virtual revolution of LNA techniques with the FET (J-FET) amplifier competing with the bipolar transistor at UHF, replacing the bipolar transistor with 1-3 dB noise figures at frequencies for 2 GHz to 13 GHz (the bipolar transistor is not a viable LNA above 4 GHz), and competing with the low noise mixer at frequencies above 10 GHz.

Table 6-31 lists typical noise figures showing noise figures in the 1-2 dB range now common over most communication frequencies by 1980; with mixer conversion losses also plunging below 3 dB.

Table 6-32 lists many of the low noise amplifier manufacturers now active while Table 6-33 and 6-34, and Figures 6-54 through 6-60 list and describe many of the LNA devices of interest to a TVRO designer for 0.8, 2.6 and 12 GHz.

Perhaps surprisingly, television manufacturers are planning to use GaAs FETs in UHF tuners, despite higher noise than bipolars, because of the disappointing intermodulation distortion caused by drastic impedance changes of bipolar forward AGC. Matsushita Electronic Industries Ltd. has already tested a plastic packaged FET observers think might be manufactured for as little as one dollar. But performance is poor, 1.3 dB NF at 1 GHz, and the company has not yet made a meaningful commitment to development. NEC, however, already has a commercially available FET, the NE218, which reaches 0.9 dB NF at 2 GHz and will work as low as 70 MHz. Some instability may occur at 2 GHz, but ease of matching should preclude this.

According to J. Fawcett (MSN, Feb 1980), competition in low-noise GaAs Mesfets at 12 GHz can be seen in two of the best - and most expensive - devices: the NE137 from NEC, and the MGF-1403. The NE137 will soon be commercially

TABLE 6-31

Typical Satellite Communication Amplifiers

Type Amplifier		FET or Transistor	Bipolar Transistor Amp or GaAs FET	GaAs FET	GaAs FET	Mixer
Frequency Range GHz		0.8	2.5 GHz	3.7-4.2	11.7-12.2	11.7-12.2
Gain		10-50	10-50	10-50	10-50	
Intercept Point		+20	+20	+25	+20	
Noise Figure	1975	1.5	3.5	2.5	-	3 dB*
	1976	1.5	3.0	2.0	5.0	
	1977	1.5	1.5 (FET)	1.5	3.5	
	1978	1.5	1.5	1.25	3.0	
	1979	1.2	1.5	1.0	2.7	
	1980	1.0	0.7	0.7	2.5	3 dB

* Conversion loss.

TABLE 6-32

LOW NOISE AMPLIFIERS (LNA'S)

Manufacturer	Type	Noise Temperature (^{o}K)	Frequency (GHz)
AIL	Cryogenic Up-Converter	7	0.5-2.2
AIL, SCI	Cryogenic Paramp	10-20	
AIL, Comtech Micromega	Uncooled Paramp	30-[illegible]	
Amplica, Avantek, Dexcel	FET Amp	100-200	
AIL, GTE-Telecomunicazioni	Cryogenic Paramp	20	3.7-4.2
AIL, LNR	Thermoelectrically Cooled Paramp	30-40	
AIL, NEC, LNR	Thermoelectrically Cooled Paramp	35-50	
AIL	Uncooled Paramp	45-65	
AIL	Cryogenically Cooled Paramp	50-60	
Comtech, Fujitsu, GTE-Telecomunicazioni, LCT, NEC	Uncooled Paramp	55-75	
AIL, Ferranti, LCT, SCI	Uncooled Paramp	75-90	
NEC	Thermoelectrically Cooled FET Amp	70^{o}	
AEG-Telefunken, Amplica, Avantek, Dexcel, NEC, Plessey, SCI	FET Amp	80-150	

TABLE 6-32

LOW NOISE AMPLIFIERS (LNA's) - Continued

Manufacturer	Type	Noise Temperature (K)	Frequency (GHz)
AIL	Cooled Paramp	10-50	11.7-12.2
AIL, Amplica, Comtech, GTE-Telecomunicazioni, LCT, LNR, NEC, SCI	Thermoelectrically Cooled Paramp	80-200	
AIL	Uncooled Paramp	100-160	
AIL	Cryogenically Cooled FET Amp	120-140	
LNR	Uncooled Para-Conv.	205-240	
AIL, NEC	Thermoelectrically Cooled FET Amp	300-400	
AIL, Amplica, NEC, Plessey, SCI	FET Amp	400-600	
LNR, NEC	Schottky-Barrier Mixer	600-800	
Comtech, Mitsubishi, NEC	Cryogenic Paramp	50-60	17.7-20.2
AIL, LNR, Mitsubishi, NEC	Uncooled Paramp	200-400	
AIL, LNR, Mitsubishi, NEC	Cooled FET Amp	500	
LNR	Schottky-Barrier Mixer	600-1000	
Avantek	FET Amp	600-1000	
AIL, Fujitsu, LNR	Uncooled Paramp	400-600	34-37

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AERCOM

TABLE 6-33

Various Lower Frequency Bipolar and FET Commercial Amplifiers

Low Noise Amplifiers

Frequency (GHz)	Model No.	Gain (dB)	NF (dB)	P_0 @ 1 dB Comp. (dBM)
2.2-2.3	AT3210	35	1.3	+13
3.7-4.2	AT5324	35	1.5	+11
4.4-5.0	ATA5315	36	2.5	+15

BIPOLAR AMPLIFIERS

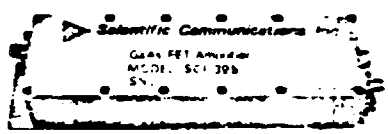
An extensive line of bipolar amplifiers for radar, telemetry and other communications applications. The table shows some of the amplifiers that have been produced for specific customer requirements. Custom designed units can be provided to fulfill a variety of applications

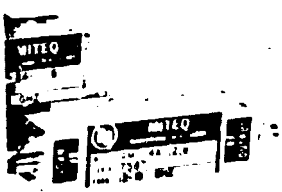
FREQ RANGE MHz	GAIN dB Min	GAIN ±dB Max	NOISE dB Max	VSWR Max IN	VSWR Max OUT	Power Out Max
50-200	30	0.5	2.0	2.0	1.5	+7
10-300	30	0.5	4.0	2.0	2.0	+3
30-300	23	0.5	4.0	2.0	2.0	-3
30-300	20	0.5	3.5	2.0	2.0	-3
30-300	50	0.5	4.0	2.0	2.0	-3
20-500	20	1.0	3.5	2.0	2.0	-3
20-500	40	1.0	2.7	2.0	2.0	-3
20-1000	18	1.0	4.0	2.0	2.0	+3
50-88	14	0.5	3.5	2.0	2.0	-2
250-500	20	0.5	4.0	2.0	2.0	-3
300-600	20	0.5	4.0	2.0	2.0	-3
420-450	30	0.5	1.6	2.0	2.0	0
600-1200	20	1.0	2.5	2.0	2.0	-3
950-1250	20	0.5	2.25	2.0	2.0	-5
1200-1400	20	0.5	2.2	2.0	2.0	-5
1435-1540	20	0.5	2.5	2.0	2.0	+5
1000-1500	20	0.5	3.5	1.5	1.5	-5
1400-1600	20	0.5	3.0	1.5	1.5	-5
1400-1700	20	0.5	3.0	2.0	2.0	+5
1400-1700	20	0.5	4.5	2.0	2.0	+7
1700-2400	20	0.5	3.0	2.0	1.5	+7
1700-2300	18	0.5	3.5	2.5	2.0	+3
2200-2300	18	0.5	3.0	2.0	2.0	+3
2200-2300	20	0.5	2.5	2.5	1.5	+5
2200-2300	30	0.5	2.5	2.5	1.5	+7
2800-3100	17	0.5	4.3	2.0	2.0	+3

GaAs FET AMPLIFIERS

A broad range of GaAs FET amplifiers offer low noise and high performance for applications in radar telemetry and satellite communications. Custom designed units can be supplied quickly due to advanced computer aided design technology and complete manufacturing capability. Readily supplied options include waveguide input, A-C or D-C operation, connector types, fault monitor circuitry and packaging and mounting provisions. Also, redundant configurations of GaAs FET amplifiers are offered including integral switching, local and remote control, and status indication. The table shows some of the amplifiers produced.

Freq. Range MHz	Gain dB	Gain Flatness ±dB	Noise Figure dB	VSWR In/Out	Power Out +1.0 dB Compression
1.42-1.44	30	0.5	1.5	1.5:1	+6
1.42-1.44	35	0.5	1.5	1.5:1	+6
1.67-1.70	30	0.5	1.8	1.5:1	+10
1.65-1.75	30	0.5	1.5	1.5:1	+5
1.65-1.75	40	0.5	1.5	1.5:1	+5
1.65-1.75	30	0.5	1.2	1.5:1	+5
1.65-1.75	40	0.5	1.2	1.5:1	+5
2.20-2.35	25	0.5	1.5	1.5:1	+10
2.20-2.35	30	0.5	1.5	1.5:1	+10
2.20-2.35	30	0.5	1.7	1.5:1	+10
2.20-2.35	40	0.5	1.2	1.5:1	+10
2.70-2.90	18	0.5	2.5	1.5:1	+10
2.70-2.90	20	0.5	2.5	1.5:1	+10
2.70-2.90	25	0.5	2.5	1.5:1	+7





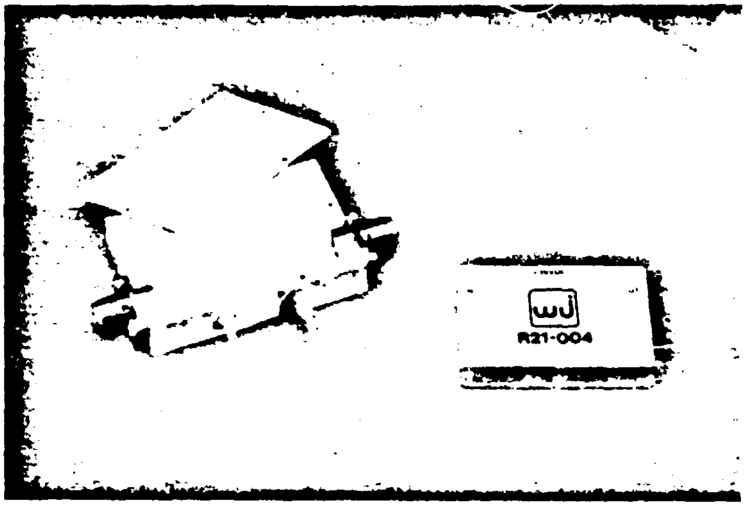
Model No.	Frequency (GHz)	Gain (dB) Min.	Gain Variation (±dB) Max.	Noise Figure (dB) Typ.	Noise Figure (dB) Max.	VSWR Max. Input	VSWR Max. Output	Dynamic Range 1 dB Gain Comp. Output (dBm) Min.	Dynamic Range 3rd Order Inter. Pt. (dBm) Typ.
AMF-2A-1617	1.6-1.7	25	0.5	1.4	1.6	1.25	1.5	5	15
AMF-3A-1617	1.6-1.7	35	0.5	1.4	1.6	1.25	1.5	10	20
AMF-2A-2223	2.2-2.3	22	0.5	1.5	1.7	1.25	1.5	5	15
AMF-3A-2223	2.2-2.3	35	0.5	1.5	1.7	1.25	1.5	10	20
AMF-2A-2124	2.1-2.4	20	1.0	1.6	1.5	1.25	1.5	5	15
AMF-3A-2124	2.1-2.4	33	0.75	1.6	1.8	1.25	1.5	10	20
AMF-2A-1720	1.7-2.0	20	0.75	1.7	2.0	1.35	1.5	5	15
AMF-3A-1720	1.7-2.0	30	0.75	1.7	2.0	1.35	1.5	10	20
AMF-2A-2729	2.7-2.9	20	0.5	1.7	1.9	1.25	1.5	5	[illegible]
AMF-3A-2729	2.7-2.9	30	0.5	1.7	1.9	1.25	1.5	[illegible]	20

WJ-R21-004

MINPAC AMPLIFIER

2.2 TO 2.3 GHz

- LOW NOISE: 1.8 dB (TYP)
- MEDIUM GAIN: 24 dB (TYP)
- LOW VSWR: <1.4:1 (TYP)
- MEDIUM LEVEL OUTPUT: +11 dBm (TYP)
- SMALL SIZE



Guaranteed Specifications

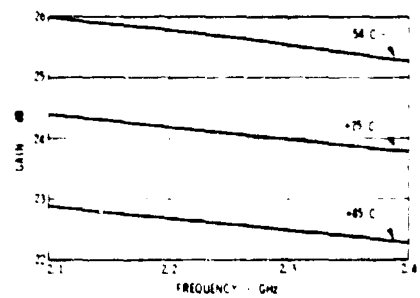
Characteristic	Typical	+25°C	−54°C-+85°C
Frequency (Min.)	2.0-2.5 GHz	2.2-2.3 GHz	2.2-2.3 GHz
Small Signal Gain (Min.)	24.0 dB	23.0 dB	21.0 dB
Gain Flatness (Max.)	<±0.4 dB	<±0.6 dB	<±2.0 dB
Noise Figure (Max.)	1.8 dB	2.3 dB	2.7 dB
Power Output at 1 dB Compression (Min.)	+11.0 dBm	+10.0 dBm	+8.0 dBm
Reverse Isolation (Min.)	>50.0 dB	50.0 dB	50.0 dB
VSWR (Max.) Input/Output	<1.4:1	2.0:1	2.0:1
Third Order Two Tone Intercept Point (Min.)	+25.0 dBm	+23.0 dBm	+20.0 dBm

DC Volts (Nominal) 15, **DC Current at 15 Volts** 60 mA (100 mA max.)

Note: Internal regulator allows operation from any V_{cc} between +10 VDC and +20 VDC

Typical Performance at 25°C

Gain



Noise Figure

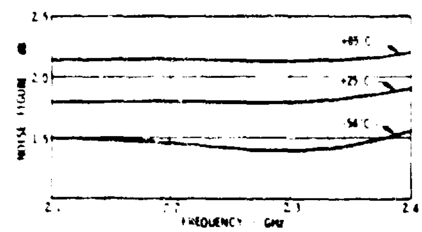
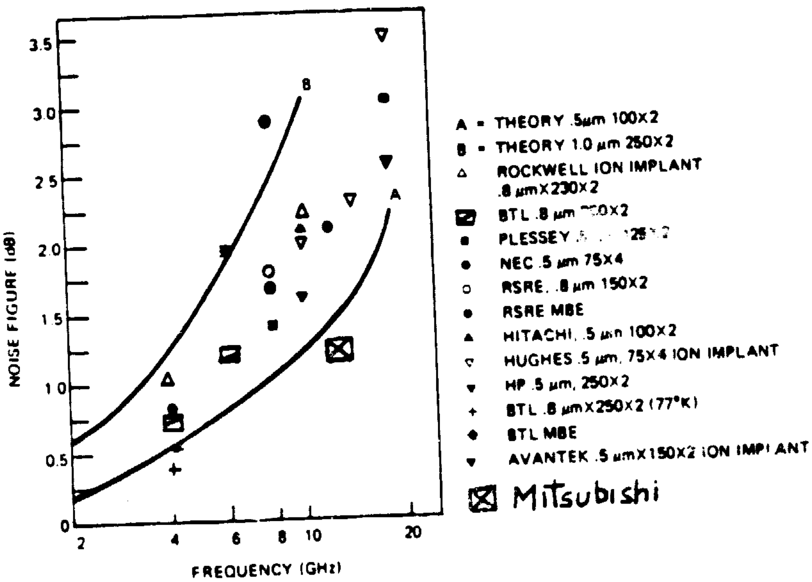


TABLE 6-34

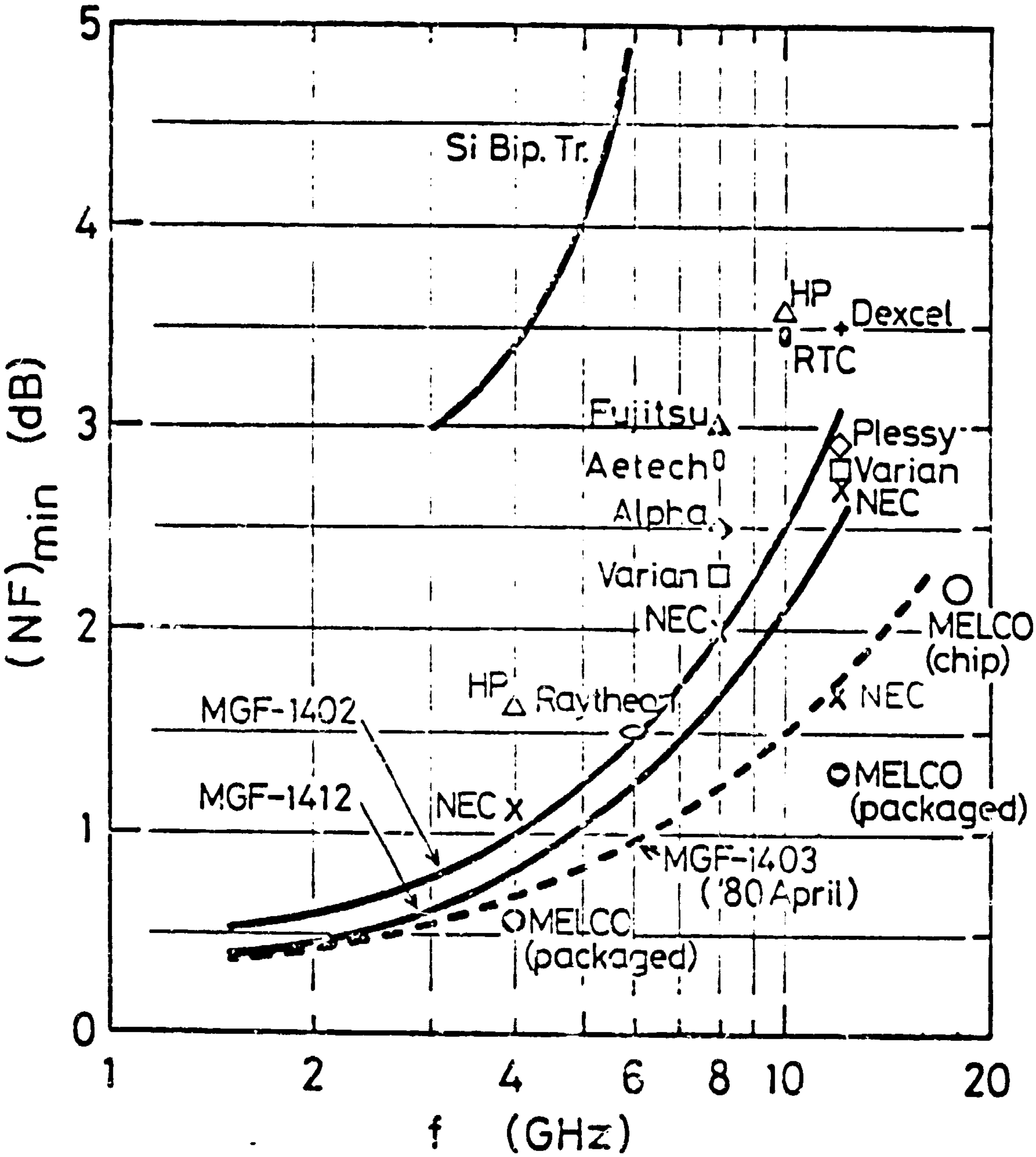
Watkins Johnson S-Band Low Noise Bipolar Amplifier



Theoretical NF as a function of frequency (Lines A & B) with selected experimental data.

Figure 6-54

Comparison of Performance (Low Noise GaAs FET)



Jan, 1980

NEW PRODUCT BULLETIN

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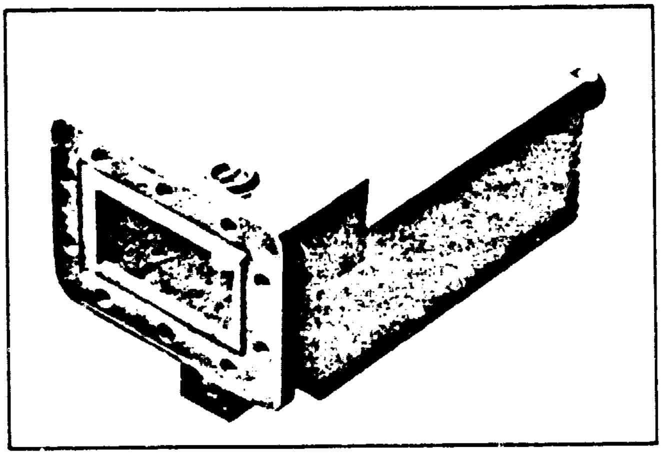
3.7 to 4.2 GHz Low Noise Amplifiers 95° K to 290° K Noise Temperature

AMPLICA presents a new family of SC Band Low Noise GaAs FET Amplifiers designed with performance, production and economy in mind. Model 729CWNL is currently in production offering 120° K noise temperatures over the full 3.7 - 4.2 GHz frequency range. Other units in this family provide noise temperatures ranging to 290° K which permit effectively selecting the best Noise Temperature for your system at the lowest possible cost. Model 729 thru 733CWNL all possess rugged weatherproofed construction with waveguide pressurization capability. Standard units come with regulated power supply allowing the DC Voltage to vary from +15 to +25 volts without degrading performance. Options for negative power supplies and AC supplies are available. Just recently joining the family of Low Noise Amplifiers for satellite earth station requirements is the Ultra Low Noise Model 728CWNL which offers a noise temperature of 95° K. This unit is thermoelectrically cooled and provides the high reliability of solid state construction and the Ultra Low Noise capability provided by an ingenious thermoelectric cooled design. Various gain options may be provided for each member of the SC Band LNA family. Amplica also offers Ultra Low Noise Amplifiers in the 11.7 to 12.2 GHz satellite communications band, see Bulletin No. 10671 for further details.



The following are the SC Band Low Noise GaAs FET Amplifier Common Specifications

Frequency Range:	3.7 to 4.2 GHz minimum
Gain:	50 dB minimum
Gain Flatness:	± 0.5 dB/500 MHz ± 0.25 dB/40 MHz
Output Power @ 1 dB Gain Compression:	+10 dBm minimum
Intercept Point:	+20 dBm minimum
Input VSWR:	1.3 maximum
Output VSWR:	1.5 maximum
Input Power/Current:	+15 to +25 Vdc @ 110 mA nominal
Input Connection:	CPR 229G
Output Connection:	Type "N" Female
Weatherproofing:	Provided
Mating AC or DC Connector:	Supplied
Size:	See attached outline drawing

Model No.	Noise @ +23 C
728CWNL*	95° K (1.23 dB)
729CWNL	120° K (1.5 dB)
730CWNL	150° K (1.8 dB)
731CWNL	180° K (2.1 dB)
732CWNL	225° K (2.5 dB)
733CWNL	289° K (3.0 dB)

NOTE: **For −18 to −30 Vdc add (−1) to model number.**
For −40 to −60 Vdc add (−2) to model number.
For 115 Vac add (−3) to model number.

**Model 728CWNL is thermoelectrically cooled and requires approximately 6 volts @ 5 amps, power supply (not included).*

Amplica, Inc.

Figure 6-55

Bulletin No. 10673

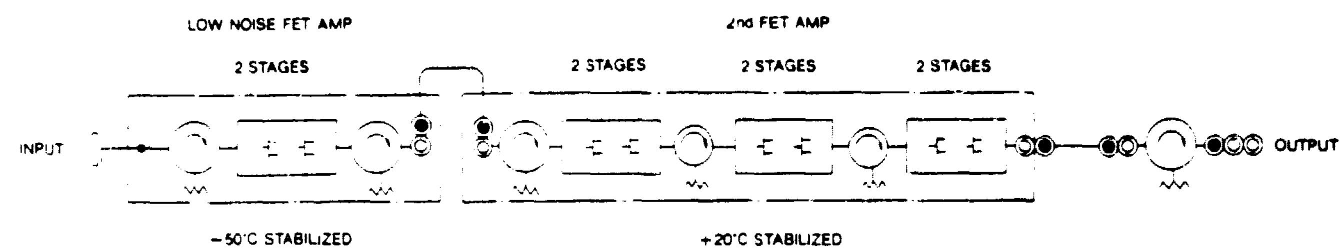
-485-

950 LAKEFIELD ROAD, WESTLAKE VILLAGE
CALIFORNIA 91361 • (213) 889-8700 • TWX 910-336-1291

C&C
COMPUTER AND COMMUNICATIONS

NEC

LA1218 12GHz Low Noise FET Amplifier



LNA UNIT Block Diagram

NEC has been developing various kinds of LNA's, such as the 4 GHz LNA, 11 12 GHz LNAs, etc.

The LA-1218 Low Noise FET Amplifier only uses FET Amplifiers to obtain the specified performance. Eight "Super Low Noise" GaAs FET's are used to achieve very low noise temperature and obtain the specified gain. FET amplifiers are temperature-stabilized to achieve excellent gain stability.

Features

- Super Low Noise FET
- Maintenance-Free Stable Operation
- High Reliability

Specifications

Frequency range	11.7 ~ 12.2 GHz		
Band width	500 MHz		
Noise temperature	Less than 193 K 175 K Typ.		
Gain	52 dB min.		
Gain ripple	1 dB p-p over specified band		
Gain stability	1 dB p-p/week		
Operating temperature	-30°C to +50°C		
Size/Weight		W x D x H (mm)	Weight (kg)
	RF UNIT	250 x 240 x 180	13
	CONT & MON UNIT	480 x 490 x 177	20

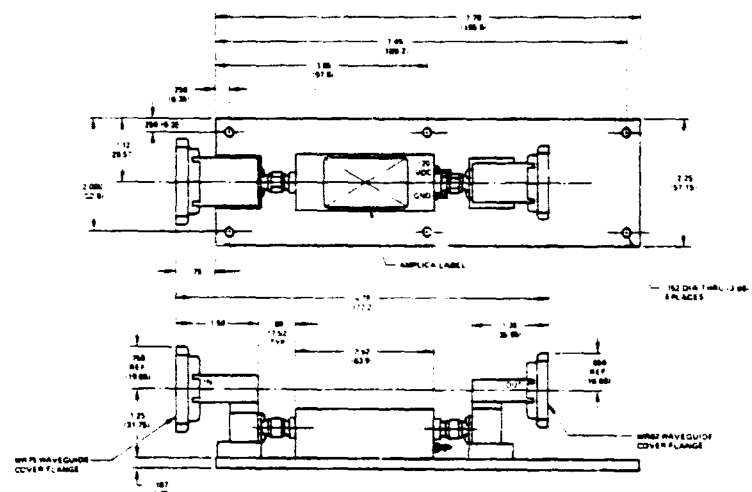
Figure 6-56

NEW PRODUCT

BULLETIN

11.7 to 12.2 GHz Low Noise Amplifiers
380°K Noise Temperature

The new model 735 XSL offers 3.6 dB Noise Figure (380° K) over the total 11.7 to 12.2 SATCOM receive band. This unit is hermetically sealed and utilizes rugged, reliable thin film MIC construction. The GaAs FET low noise input stage optimumly combines with a low loss isolator to insure good VSWR and lowest noise temperature. The output stages are balanced stages to insure wide dynamic range and minimum interaction problems due to cascading. This amplifier design approach has been utilized over 500 MHz bands extending from 8.5 GHz to 13 GHz with equally outstanding noise figure performance. Noise figures as low as 2.5 dB are available over narrow frequency bands with center frequencies as high as 10 GHz. Check the following specs and then throw your paramps away. Model 735XSL is capable of meeting all environments of MIL-STD-5400 or MIL-E-16400.



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SPECIFICATIONS

MODEL NO.	FREQUENCY RANGE (GHz)	GAIN MIN. (dB)	NOISE FIGURE MAX. (dB)	GAIN FLATNESS MAX. (± dB)	OUTPUT POWER @ 1 dB COMPRESSION (dBm)	INTERCEPT POINT TYPICAL (dBm)	VSWR IN & OUT MAXIMUM	DC CURRENT @ 13.5 ± 1.5 VDC NOMINAL (mA)
735XSL	11.7 - 12.2	30	3.6	0.5	+ 7 dBm	+17	1.5	150
†* 734XSL	11.7 - 12.2	30	4.5	0.5	+10	+20	1.5	150
†* 733	11.7 - 12.2	30	5.5	0.5	+12	+22	1.7	150

**Available with SMA input and output*
†Available with other gain options

C-6

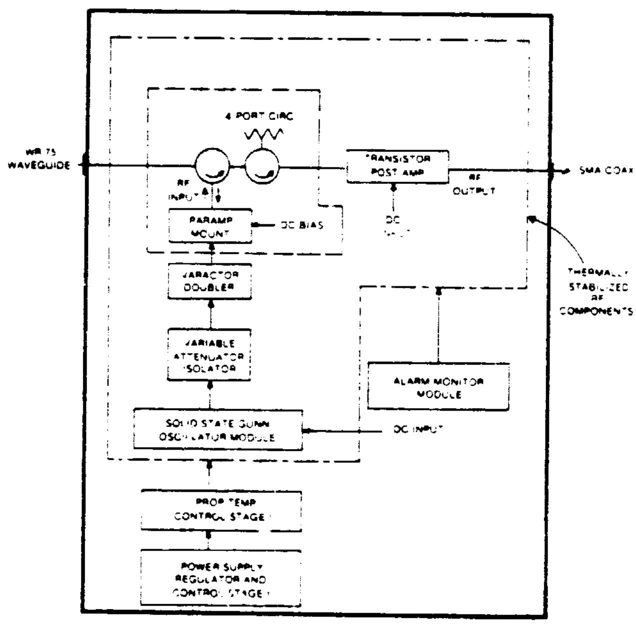
Figure 6-57

Amplica, Inc.

Bulletin No. 10671

...0 LAKEFIELD ROAD, WESTLAKE VILLAGE,
...FORNIA 91361 (213) 889-8700 TWX 910-336-...291

11.7-12.2 GHz: Ku-Band Satellite Communications



K-BAND LOW NOISE AMPLIFIER BLOCK DIAGRAM

MODEL	NOISE TEMPERATURE Typical	Maximum
Low Noise Amplifiers		
NC12-95	90K	100K
NC12-111	110K	120K
NC12-131	130K	140K
Paraconverter™ (Integrated Paramp/ Downconverter)		
NC12/D-131	130K	140K

Figure 6-58

Mitsubishi GaAs Fets and Related Devices

(Nov. 13, 1979)

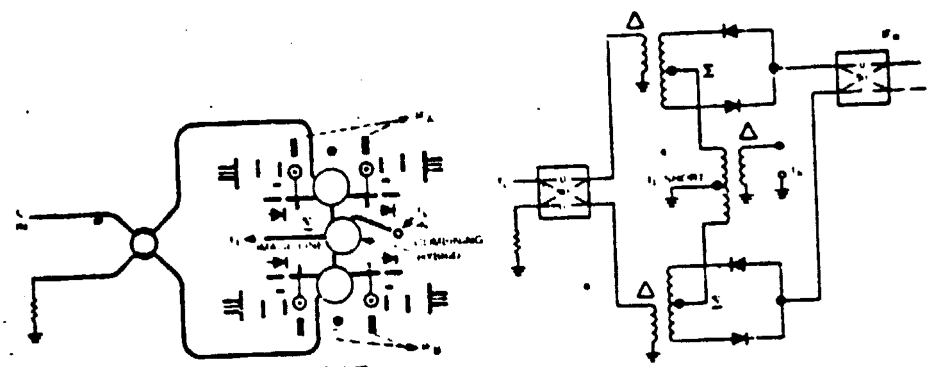
	Commercially Available		Commercially Available in the Very Near Future			Laboratory State-of-the-Art Results
	Type	Typical Characteristics	Type	Expected Typical Characteristics	Delivery	
Low noise GaAs Fet	MGF-1400 MGF-1401 MGF-1402 MGF-1412 (Note 1)	NF_{min} = 0.8 dB @ f = 4 GHz NF_{min} = 1.7 dB @ f = 8 GHz NF_{min} = 2.5 dB @ f = 12 GHz (Note 2)	MGF-1403 (Packaged) MGF-C-1403 (Chip)	NF_{min} = 1.7 dB @ f = 12 GHz (Packaged; Chip 0.3–0.4 better) NF_{min} = 2.5 dB @ f = 18 GHz (Chip)	Sample: Jan. 1980 Commercial device: April 1980	NF_{min} = 1.3 dB @ f = 12 GHz (Packaged) NF_{min} = 1.8 dB @ f = 16 GHz (Chip) NF_{min} = 2.1 dB @ f = 18 GHz (Chip)
Medium power GaAs Fet	MGF-1800 MGF-1801 (Note 1)	g_m = 100 mS $P_{1\,dB}$ = 21.5 dBm @ f = 12 GHz				
High power GaAs Fet	MGF-2124 MGF-2148 MGF-2150 MGF-2172	$P_{1\,dB}$ = 2 W G_{LP} = 5 dB @ f = 12 GHz (Packaged, without internal matching)	MGF-2124M MGF-2148M MGF-2150M MGF-2172M	$P_{1\,dB}$ = 2.5 W G_{LP} = 5 dB @ f = 12 GHz (with internal matching)	Sample: April 1980 Commercial device: July 1980	$P_{1\,dB}$ = 10 W G_{LP} = 4.5 dB @ f = 10 GHz (with internal matching)
GaAs Fet oscillator	F0-1001(S) F0-1002(S) F0-1201(S) F0-1202(S)	Δf = ±500 kHz (Δf = ±200 kHz) over −20 to +60°C for any frequency between 9 and 14 GHz				

(Note 1) Chip devices as well as packaged devices are available. Their type is represented by MGF-C-.
(Note 2) NF_{min} of 0.7 dB at f = 4 GHz can be guaranteed by selection of MGF-1412.

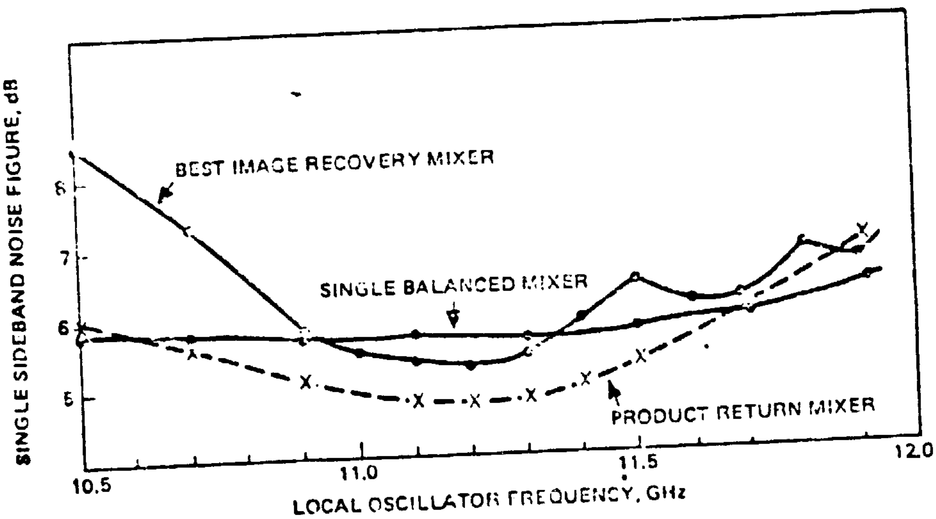
Figure 6-59

2 dB CONVERSION LOSS MIXER AT 11 GHz USING A PRM CIRCUIT

Ben R. Hallford*



Product Return Mixer Circuit



- Noise Figure Comparison

*Collins

Figure 6-60

available with a noise figure of about 2 dB at 12 GHz. Laboratory devices provided 1.68-dB NF. A "deeply recessed" half-micron gate drops source resistance and noise figure. Unconventional structure of Mitsubishi's low-noise FETs has produced 1.3 dB at 12 GHz in the laboratory. More significantly, commercial samples are now available that provide 1.7 dB at 12 GHz, but at a cost that matches their Rolls Royce performance, $283.50 apiece. The battle continues at 4 GHz, where a pair of less expensive devices, the NE218 and MGF-1412, both offer around 0.7 dB NF.

6.3.3 TVRO Receiver Technology (Analog)

Figure 6-61 shows the basic block diagram of a TVRO system which includes a frequency converter and a receiver. The frequency converter (single or double) includes the LNA and the tuning system, and the receiver accepts the received FM TV signal, provides IF amplification, and AGC, demodulation, video and audio signal processing, and remodulation of the video and audio to a carrier which can be applied directly to one of the channels of a commercial TV set.

Figures 6-62 and 6-63 illustrate modern color TV receiver design including the use of a varactor-tuned oscillator controlled by a channel tuning system - now microprocessor-controlled in almost all commercial receivers which provide touch-tuning and instant control of up to 100 channels at VHF and UHF and which use several varieties of electronic tuning systems to provide the varactor tuning voltage which determines each channel; i.e., potentiometer tuning, frequency synthesizer, and voltage synthesizer

Tables 6-35 through 6-36 list many of the receiver technologies and their heritage for UHF, S-band, and Ku-band, and include the LNA and down-converters since these later circuits may become actually an integral part of the receiver.

In the overall TVRO system, the designer makes use of two modern technologies which have been developed for Color TV receivers during the 1970's; i.e.,

- o The varactor controlled (VCO) frequency converter where a tuning voltage alone determines the channel frequency of interest. This is a "fortunate" technology since the varactor controlled VCO can exist at any frequency from UHF to Ku-band, and only an applied programmed voltage is required to select the desired channel.
- o The tremendous development of inexpensive integrated circuits which now provided units which serve all TV receiver functions from TV tuners, to IF amplifiers, to demodulators and signal processors.

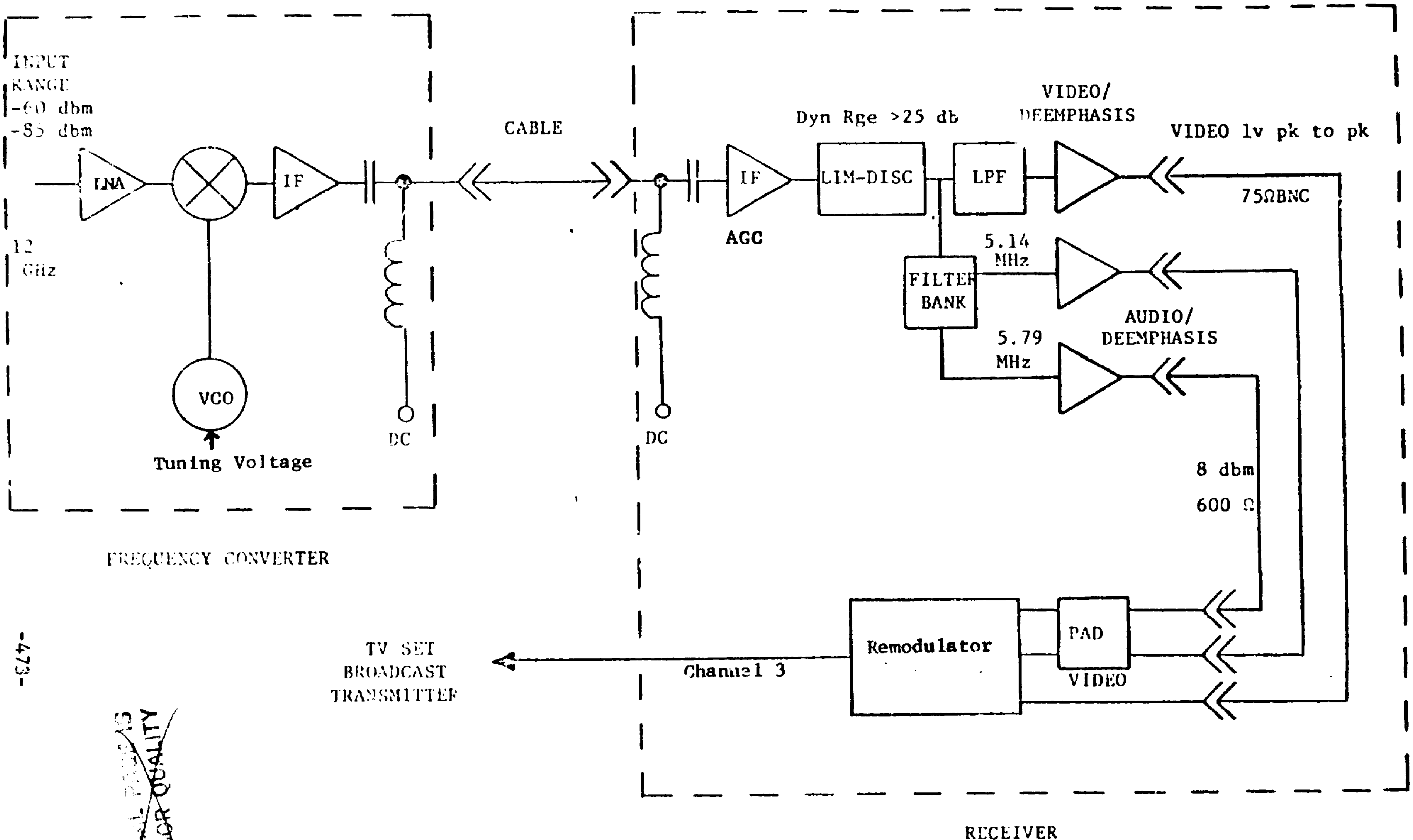


Figure 6-61. TVRO Receiver

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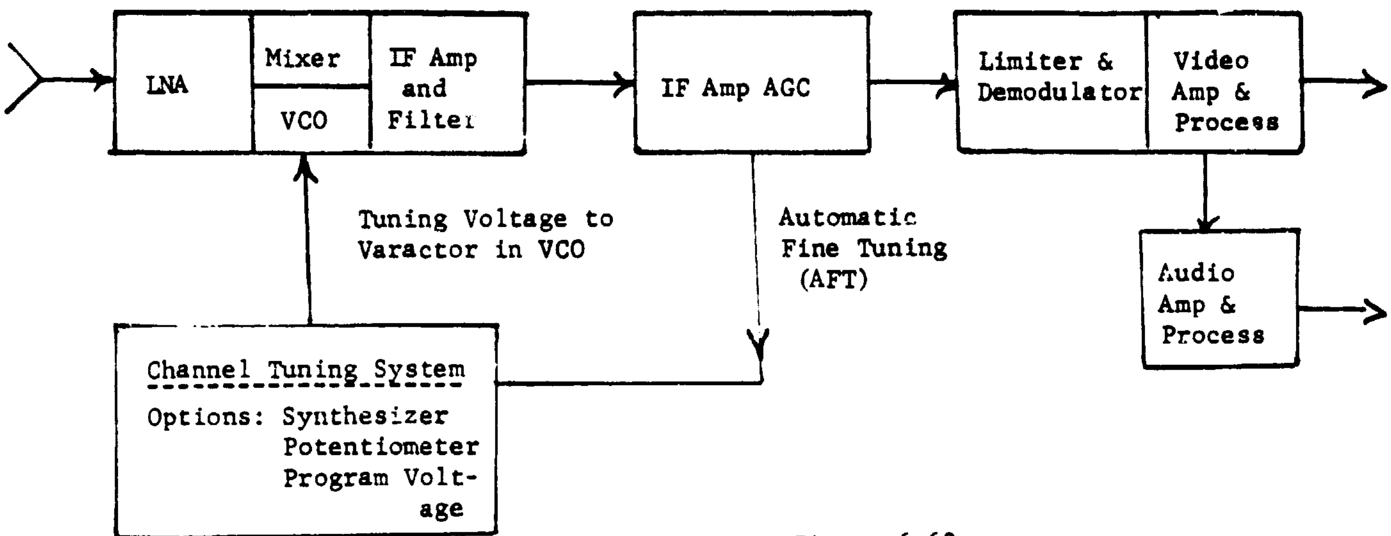


Figure 6-62

Color TV Receiver Design, Circa 1980

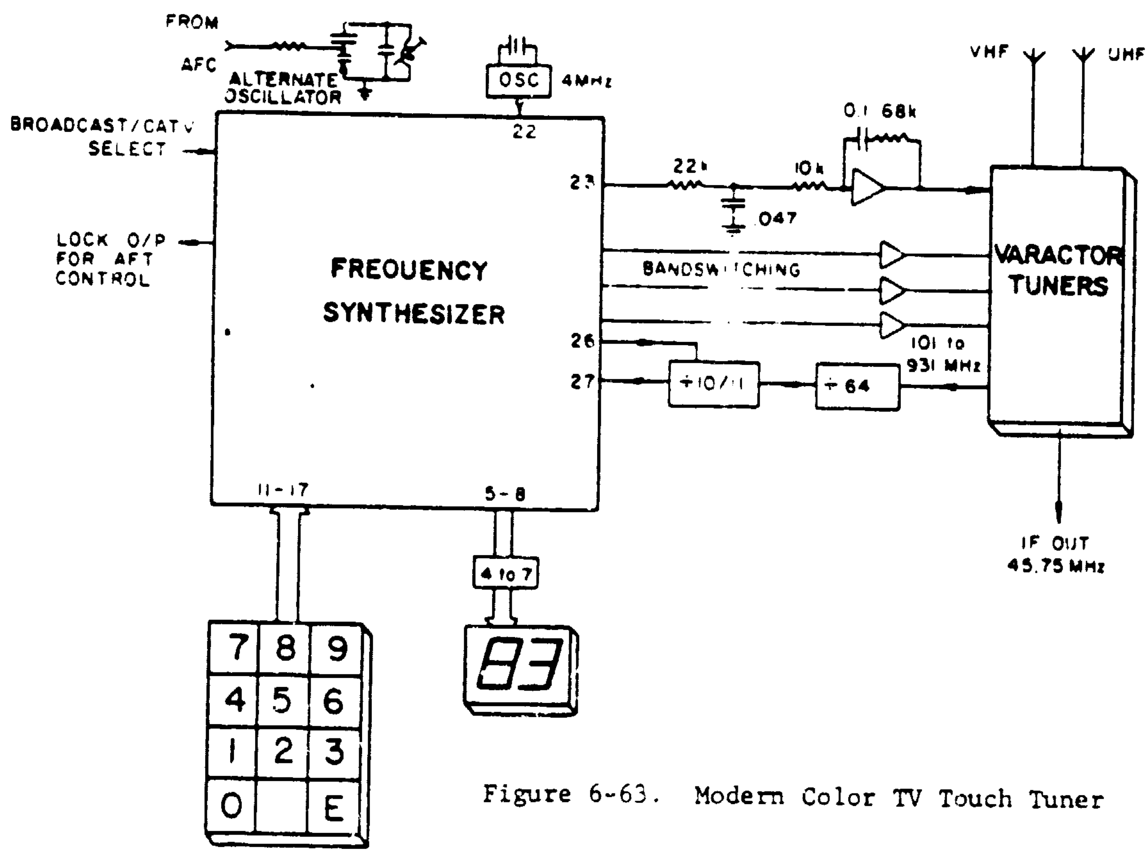


Figure 6-63. Modern Color TV Touch Tuner

Thus the world of the TVRO designer is the world of the Color TV receiver specialist since the color TV art, sparred by worldwide competition involving millions of receivers, is the development ground of many applicable ingenious circuits.

6.3.3.1 The TVRO Receiving System

Tables 6-35 through 6-38 list the various subsystem of a TVRO receiving system for UHF, S band, and Ku-band.

As indicated in these tables, an LNA or first stage provides the low noise amplification required with the antenna gain to provide the required G/T leading to the S/N. Note that at all three frequency ranges, a down-converter and a tuning oscillator are required. Once the channel is selected and its modulated carrier is down-converted to a desired IF frequency (around 70-120 MHz), then integrated circuits can be used for IF amplification, AGC, video detection, sound detection, video and sound processing, and remodulation to a desired TV receiver channel (channel 3,4,5) with a carrier which is vestigial sideband for video, and FM for sound.

The receivers have circuits of commonality. All LNA's use either a bipolar transistor amplifier or some form of FET; MOSFET at UHF and GaAs FET at S-band and Ku-band.

All receivers use a voltage controlled oscillator for tuning regardless of whether single or double conversion is used.

All receivers now use integrated circuits, IC's, to perform IF, detection, processing and remodulation; in fact, as will be discussed are derivable from the hundreds of IC's which have been developed for color TV receivers and TV game systems. This availability of IC's which has been a major development of the 1970's is a critical factor in TVRO receiver low cost and performance and manufacturability.

It is implicit in tables 6-35 through 6-38, as was described earlier in this section, that in all cases the LNA and down-converter and first IF stage are antenna mounted, and connected by cable to the indoor receiver whose input frequency range is at a frequency at which tuning is accomplished - around 500-1000 MHz, or at 70 MHz after tuning has already been accomplished by a tuning voltage supplied by the receiver.

6.3.3.1.1 The TV Tuner

At least a quarter of a billion VHF TV tuners have been built since the start of commercial TV. This technology started with using amplification provided progressively by Tubes, Nuvistors, bipolar transistors, and MOSFETS. Figure 6-64, from RCA, shows both bipolar and MOSFET tuners, including the detail of the IF amplifier and second detector, and the RCA CA3120E IC which processes the video and provides AGC. By the end of the 1980's integrated circuits approches to the tuner/mixer/LO voltage tuned oscillator, and IF were starting to be introduced into television sets including very sophisticated tuners, to be described below.

TABLE 6-35

UHF TVRO Receiver Subsystem

Component	Candidate Technology	Description/Heritage
LNA	Bipolar Transistor	1-3 dB NF/TV sets
	MOSFET (silicon, JFET)	1-3 dB NF/FM Tuners
Down-converter	Intégrated Circuit	Similar to use in color TV rec.
Oscillator	Varactor tuned OSC	Similar to use in color TV rec.
	Synthesizer IC	In IC's for color TV rec.
IF, AGC, AFT Detector and Video Processor	Integrated Circuits	In use in color TV rec.
Remodulator to UHF/VHF	Integrated Circuit	In use in color TV rec.
Circuit boards and hardware	5-6 layer board Cabinet/P.S./Knobs	Conventional receiver construction

TABLE 6-36

2.54 GHz TVRO Receiver Techniques

	Component	Candidate Technology	Description/Heritage
Antenna Mounted	LNA	FET Amplifier	1 dB (70K) noise fig.
		Bipolar transistor amplifier	1.5 dB (120K) noise fig.
		Low noise mixer	3 dB conversion loss
	Down-converter	Single conversions	Candidate for monolithic techniques including LNA and oscillator
Interior Installation	Oscillator	VCO	Varactor-tuned oscillator now used in color TV rec.
		UHF synthesizer IC's plus multiplier	Synthesizer now used in color TV rec., including remote tuning
	IF, AGC, AFT Detector and Video Processor	Integrated circuits	In use in color TV receivers. Modified for use with FM video carrier
	Remodulator to UHF/VHF	Integrated Circuit	In use in CATV systems and in TV games

TABLE 6-37

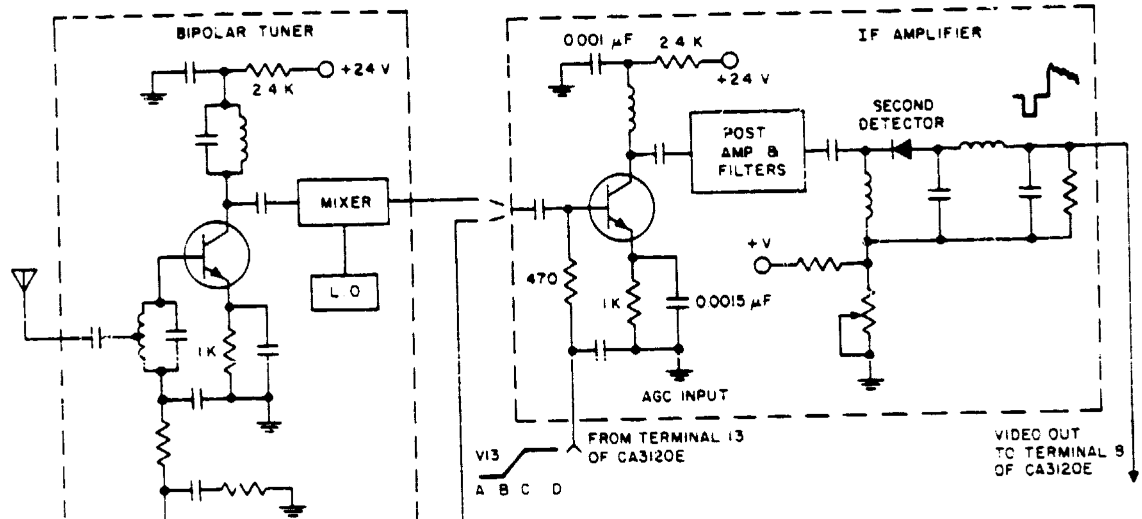
12 GHz TVRO LNA/First Down-Converter Techniques

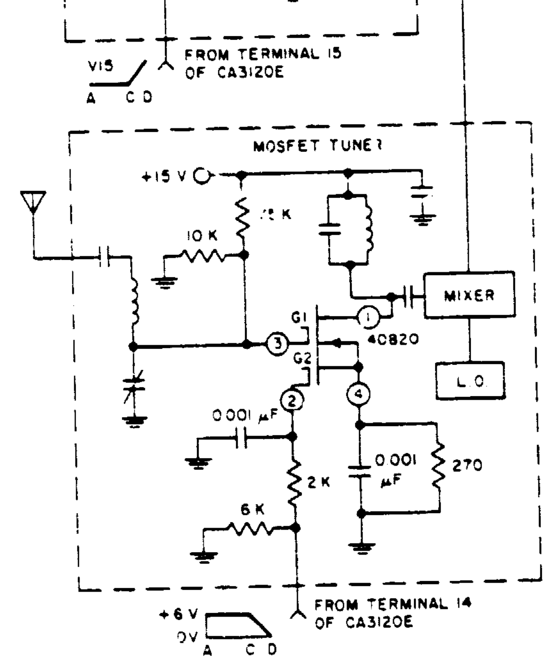
Component	Candidate Technology	Description/Heritage
Low noise amplifier (mounted with or integrated with feed)	FET amplifier	150-350° NT-presently high cost due to high FET cost
	Konishi Mixer (mixer mounted in waveguide)	400° NT - Very low cost claimed
First down-converter and oscillator	Single conversion	Conversion to intermediate freq. 950-1450 MHz or similar range

TABLE 6-38

12 GHz TVRO Receiver Techniques

Component	Candidate Technology	Description/Heritage
Second down-converter	Single conversion	Input 450-1450 MHz Output 70 MHz
Tuning Oscillator	VCO for tuning	Varactor tuned microwave FET oscillator-use mono-lithic techniques derived from TV sets
	Synthesizer for tuning using IC's	Synthesizer IC used in UHF/VHF TV sets
IF, AGC, detector and video/audio processor	2-3 integrated circuits	Derived from IC's used in modern color TV receivers
Remodulator to UHF/VHF	Integrated circuit	In use for modern CATV systems and TV games





Interface of i f amplifier with bipolar and MOS FET tuners.

The RCA-CA3120E is a 16-pin, dual-in-line, monolithic-silicon integrated circuit that processes a video signal and provides the following outputs:

- Non-inverted video output
- Noise-processed, inverted video output
- Dual-polarity, composite synchronization signals
- Automatic gain-control signals (agc):
  - Undelayed forward agc for i f amplifier
  - Delayed forward agc for tuners with bipolar transistors
  - Delayed reverse agc for tuners with FET's

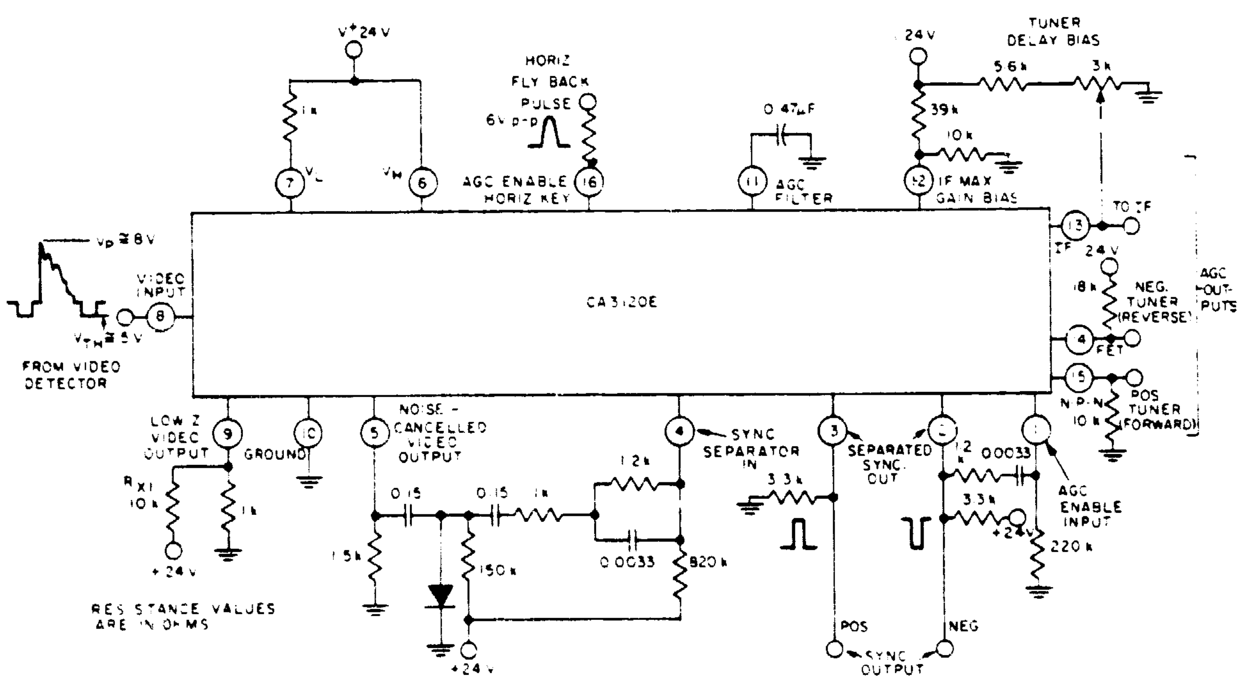


Figure 6-64

Typical application of the CA3120E.

6.3.3.1.2 VHF Tuner IC

The tuner block was not integrated for a long time, while the other circuits in TV receivers have been progressively integrated in this field. There are now two approaches to manufacture or to develop a new small sized TV tuner.

One approach to making a TV tuner is to use hybrid method using an alumina substrate, on which capacitors and resistors are printed and to which discrete semiconductors and inductors are soldered, instead of using a conventional PC board.

Another approach is the semi-hybrid method using a conventional glass epoxy laminated substrate, on which chip-capacitors and chip-resistors are mounted, and into which discrete semiconductors and inductors are inserted and soldered automatically. The latter approach is an excellent mass-production technique for mounting or solder a large number of chip components on a PC board. However, it is a difficult approach to utilize novel technique except the mass-produced chip mounting technique.

A third approach is to produce a frequency converter IC and electronic tuner, in which the IC and chip components, such as capacitors and resistors, are mounted to reduce its size and cost. By using an NSA (Nitride Self-Aligned) bipolar process with 4 GHz f_T transistors, a monolithic frequency converter IC shown in Figure 6-65, was developed*, consisting of a local oscillator, mixer, IF amplifier, UHF-IF amplifier, AGC amplifier and voltage regulator. This IC was developed by Toshiba.

An electronic tuner was fabricated with the IC, chip-resistors and chip-capacitors soldered automatically on a glass epoxy substrate.

---

* Torii et al. "Monolithic Integrated VHF TV Tuner", IEEE Transactions on Consumer Electronics, Vol. CE-26, May 1980.

This tuner, whose size, including a UHF tuner, is 68 x 80 x 20 mm, provides cost reduction and improves performance, especially, in respect to IF rejection, S/N ratio in UHF reception, local oscillator leakage level and stability, compared with a conventional discrete transistor tuner (see Figure 6-66).

Candidate circuits using integrated circuits, for VCO and mixers, using GaAs FET's are shown in Figure 6-67. According to Hewlett Packard's Dr. Van Tuyl at ISSCC-78, FET circuits for monolithic gallium arsenide, such circuits are adaptable to MIC circuitry, and indeed have been built in monolithic gallium arsenide substrates up to 15 GHz.

In 1981, Siemens of Munich FRG announced the development of a monolithic microwave integrated circuit using GaAs with special application to television receivers. This amplifier had a gain of 20 db, noise figure of 4 db, and frequency range of 40 to 1000 MHz. (MSN, May 1981). This amplifier (2 stages) was developed to address a very wide market and to utilize the attractiveness of GaAs to high volume production.

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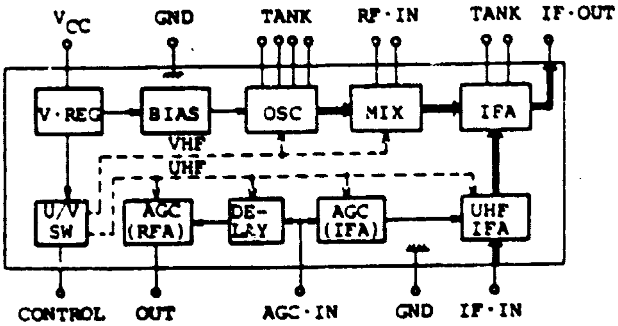

Frequency converter IC block diagram

Figure 6-65

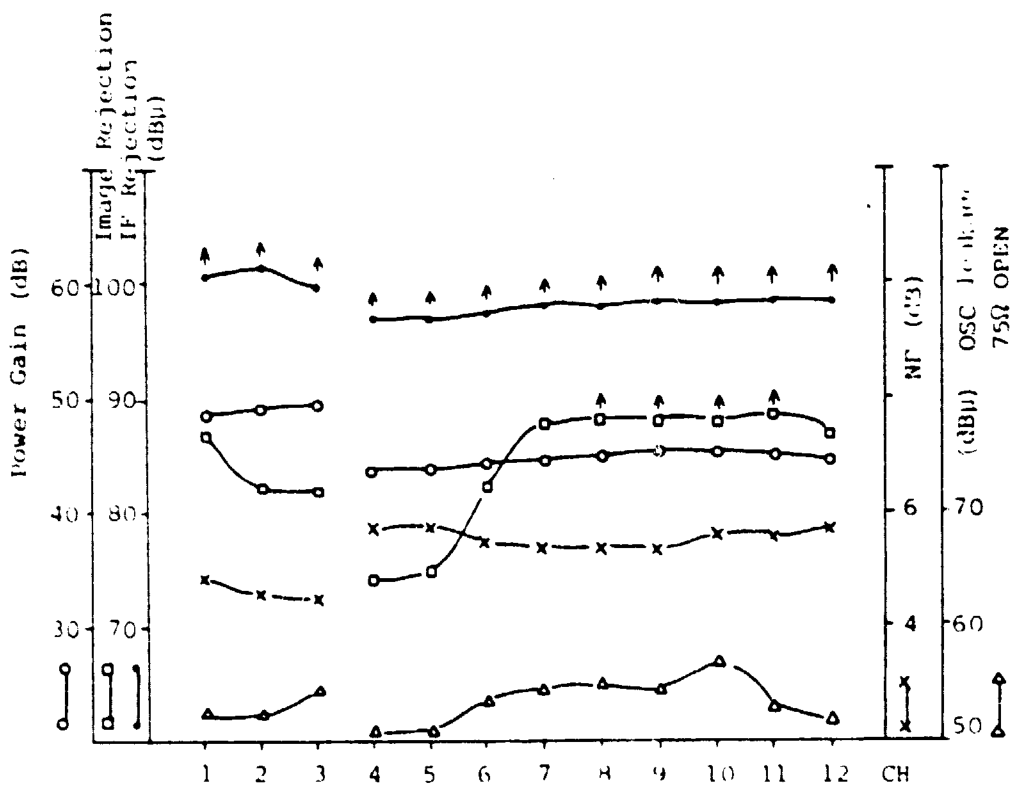

Figure 6-66
Tuner characteristics

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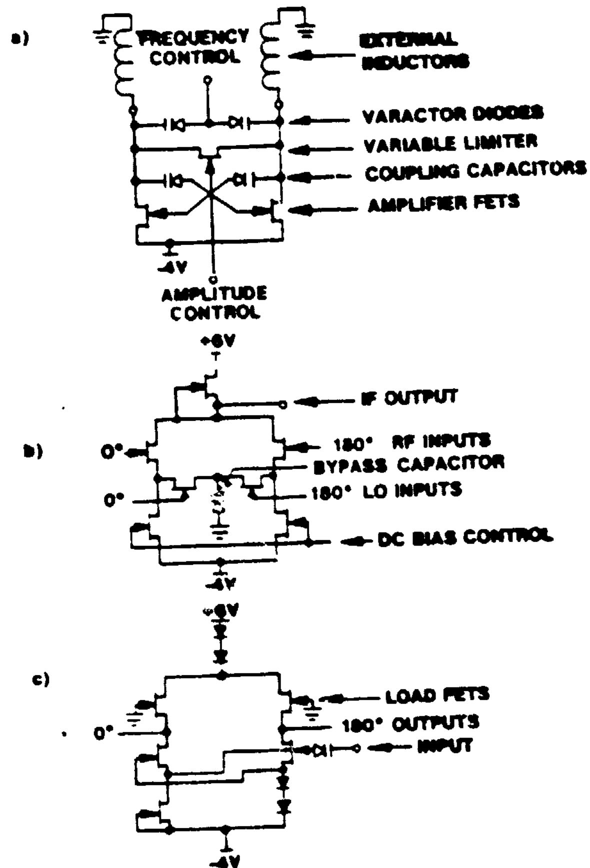


–Principal circuits of the chip: (*a*) push-pull local oscillator, (*b*) doubly-balanced mixer, (*c*) phase-splitting RF input buffer.

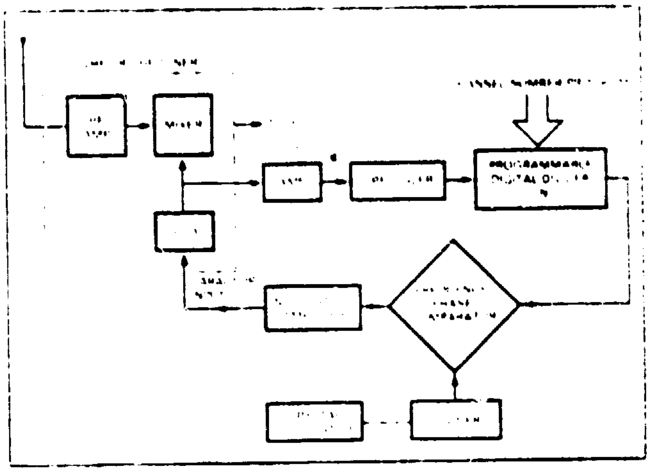
Figure 6-67 (R. Van Tuyl

6.3.3.1.3 Tuner Channel Control for TV Tuner VCO's

The introduction of the varactor tuned oscillator into the TV channel tuner changed the design of monochrome and color TV sets in the early 1970's. Voltage control of frequency rather than mechanical capacitance or inductance control of frequency became the standard tuning technique using potentiometer techniques. With the advent of the calculator and the microprocessor, a new technology of tuners in the 1980's now has been developed which uses keyboard, and which produces channel selective voltages from either a frequency synthesizer or a voltage synthesizer, and into which, now, functions of memory, time control, or additional functions such as antenna movement and computer controlled remote control have been added.

Figures 6-68 through 6-73 illustrate some of these new tuner techniques. Figure 6-68 shows a standard frequency synthesizer using a VCO, and an X-tal oscillator compared with the scaled down version (using a prescaler and digital divider) of the VCO output. This comparison is provided in a phase detector whose output is a voltage which controls the VCO. Figure 6-69 shows how Zenith Corporation has advanced the standard synthesizer art illustrated in Figures 6-70 and 6-71, by including keyboard and microprocessor control of both the synthesizer and an LED read-out.

Figures 6-72 and 6-73 show advanced circuit implementations of UHF/VHF tuner techniques including remote control and advanced set in time. Such techniques are uniquely adapted to TVRO receive systems including remote control of the VCO in the antenna mounted LNA/down-converter system.



Frequency Synthesizer Block Diagram

Figure 6-68

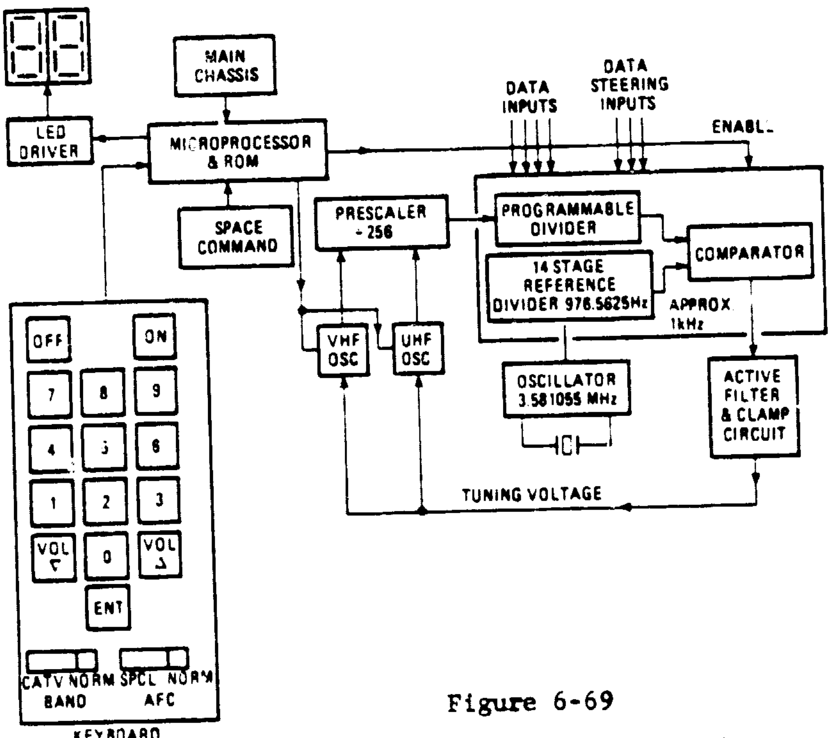
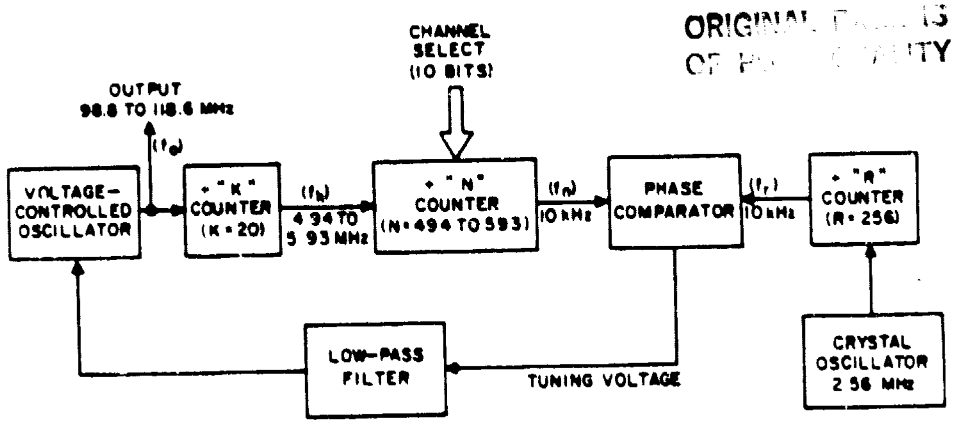


Figure 6-69

—ZENITH'S NEW TUNING SYSTEM is based on a phase-locked-loop controlled by a microprocessor. The system features keyboard entry of channel information and ability to tune 105 channels—82 UHF/VHF channels plus 23 CATV channels.



f_c (CHANNEL SPACING) = 200 kHz

$k = 20$

$f_k = \frac{f_o}{20}$; $f_k\,MAX = \frac{118.6\ MHz}{20} = 5.93\ MHz$, $f_k\,MIN = \frac{98.8\ MHz}{20} = 4.94\ MHz$

$f_r = \frac{200\ kHz}{20} = 10\ kHz$

$N\ MAX = \frac{118.6\ MHz}{200\ kHz} = 593$

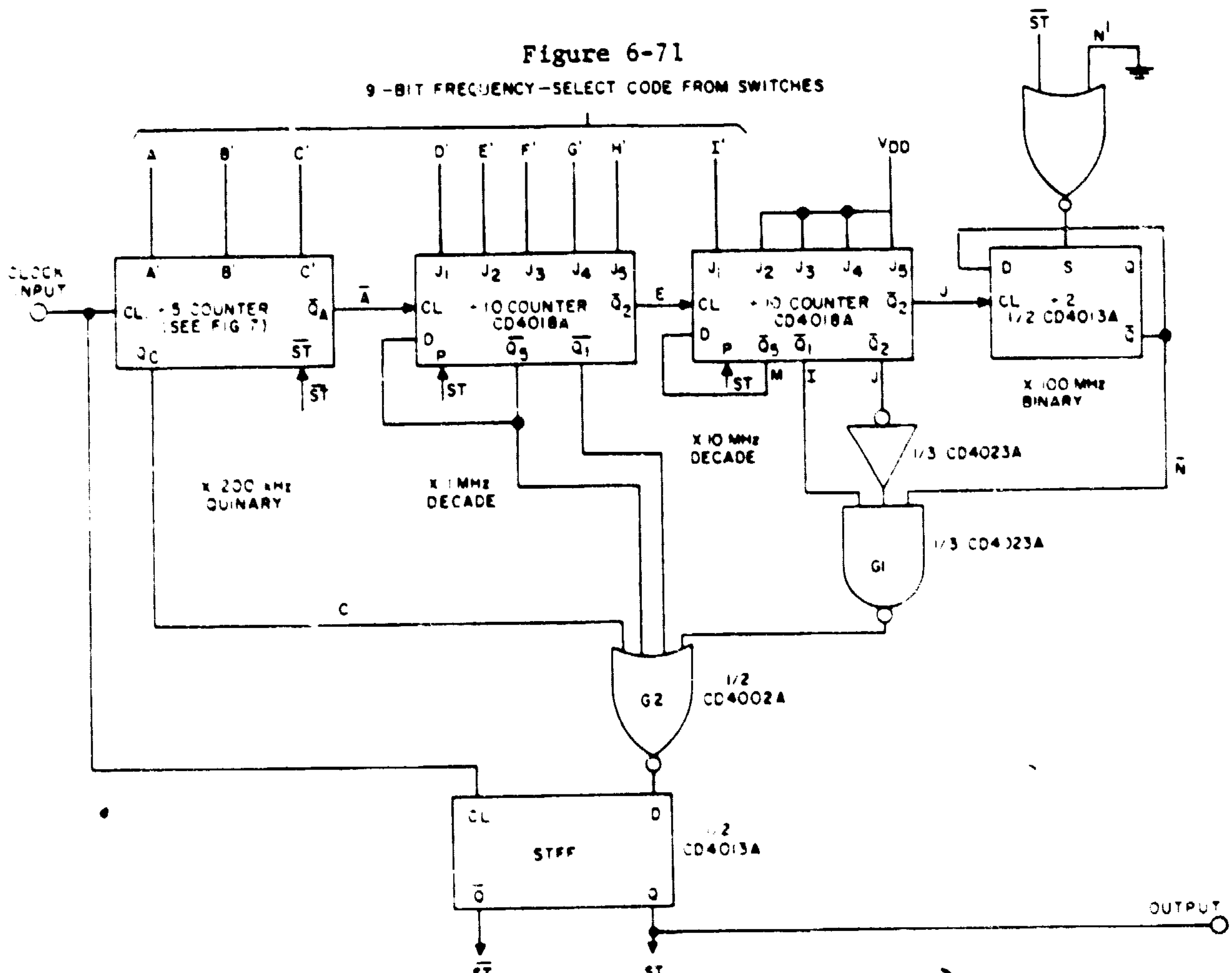
$N\ MIN = \frac{98.8\ MHz}{200\ kHz} = 494$

$R = \frac{2.56\ MHz}{10\ kHz} = 256$

Figure 6-70

FM-band synthesizer using prescaler (RCA)

Figure 6-71



Divide-by-"N" counter logic (RCA)

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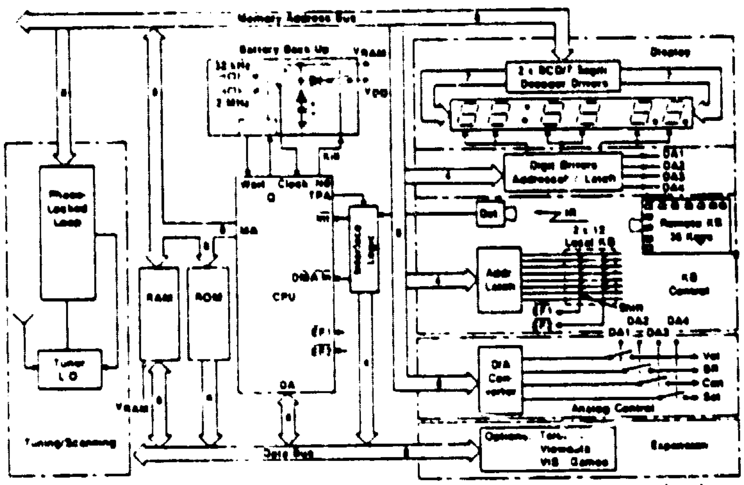
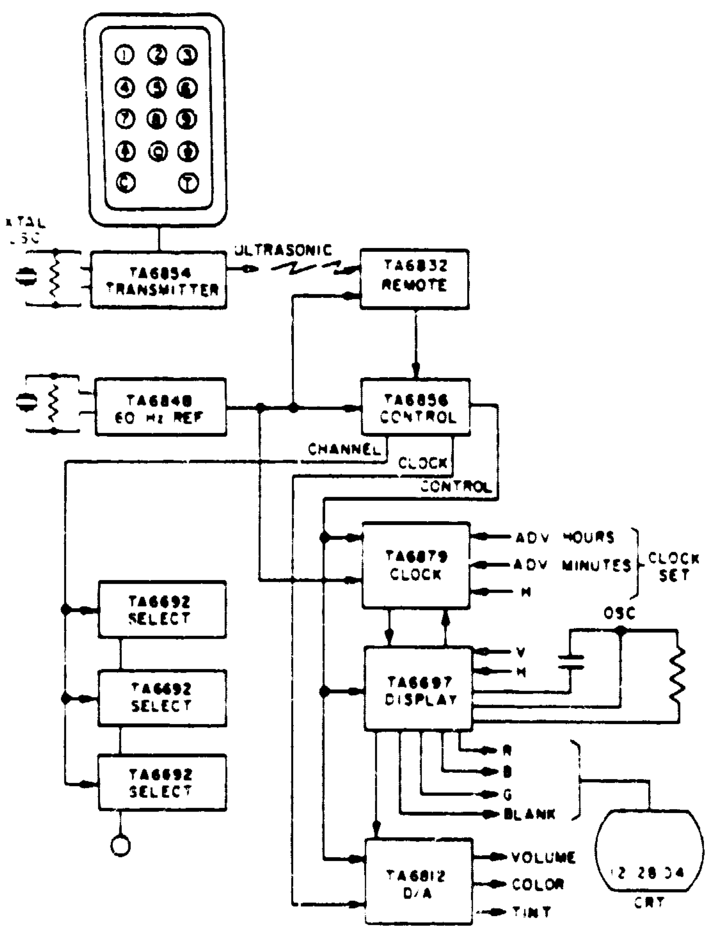


RCA

- The microprocessor-control system. The user interacts with the controller by means of either the local 2 x 12 keyset or the 35-key remote unit. Clock and program information is shown on the six-digit display. Exact tuning is accomplished through the phase-locked loop. The battery back-up system keeps the clock running and stored information intact in the event of a power failure.

Figure 6-72



—Remote-control tuning system. Figure 6-73

6.3.4 TVRO Microwave LNA/Down-Converters

The LNA/down-converter circuit for a TVRO receiving system, for S-band and Ku-band is now receiving considerable attention. Microwave doubly balanced mixers for microstrip circuits have long been available at low cost from various manufacturers (Vari-L, Merrimac, Watkins Johnson, etc.). VCO's are also now available from many manufacturers; see in Figure 6-74, the VTO modules from Avantek which involve VCO's from UHF to C-band and which are packaged in TO-8 cans for case in installation into microstrip. The VTO-8360 (3.03 to 4.13 GHz) for example, is widely used for down-converting reception in the 3.7-4.2 GHz band to 70 MHz IF.

Figure 6-75 shows the new Avantek integrated circuit ACA-4220 series which down-converts 3.7-4.2 GHz to 950-1450 MHz and which includes the LNA. The Merrimac 4 GHz down-converter performs the same function to 880 MHz but does not include the LNA. The Merrimac circuit is advertised as costing around $500 in quantity lots. The C-band circuits are, of course, adaptable to S-band.

At Ku-band, the VITALINK SHF-UHF outdoor unit converter ($3000 including indoor receiver), Figure 6-77, shows the device technology and performance (3.2 dB NF) available for 1980 TVRO receivers.

Figure 6-74

Varactor-Tuned Oscillator Modules

Avantek VTO Series varactor-tuned transistor oscillators feature extremely fast tuning speeds and settling times and minimum post tuning drift. They are packaged in the TO-8 configuration for simple integration into 50 ohm microstripline boards, and can be combined with UTO Series amplifiers for a complete subsystem. For commercial applications such as receiver oscillators and frequency synthesizers, a VTO in a phase—locked loop produces a frequency stability comparable to the crystal controlled reference oscillator, or the VTO can be "free run" for maximum tuning speed and frequency agility.

Specifications @ 25°C Case Temperature

Model	Frequency Range (MHz)	Power Output into 50 Ω Min (mW/dBm)	Power Output Variation Max (dB)	Tuning Voltage Max (VDC)	All Harmonics Typ (dBc)*	FM Noise @ 50 kHz from carrier in 1 kHz BW (dBc)* Typ
VTO-8060	500-1000	20/13	±1.5	+60	-15	-65
VTO 8090	900-1800	20/13	±1.5	+60	15	-60
VTO 8150	1500-2500	10/10	±1.5	+60	18	-55
VTO 8240	2400-3700	10/10	±1.5	+45	18	-55
VTO 8360	3600-4500	10/10	±1.5	+30	25	-50
VTO 8420	4200-5000	10/10	±1.5	+30	25	50
VTO 8490	4900-5900	10/10	±1.5	+30	-25	-50
VTO 8580	5800-6600	5/7	±1.5	+30	25	-45

*dB related to carrier

Avantek

3.7-4.2 GHz
LNA/Downconverter
ACA-4220 Series

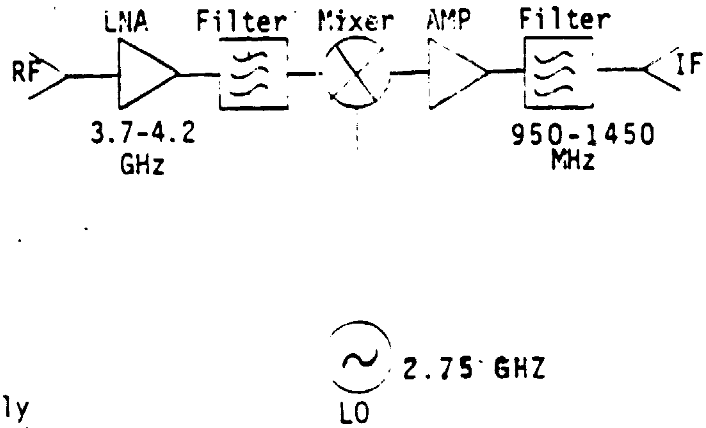
Figure 6-75

Applications

- RF Front-end Earth Terminal

Features

- Integrated Assembly.
- One-piece Cast Weatherproof Case.
- 1.5 db Noise Figure (120°K)
- Single Cable Connection.
- Lower System Cost.
- Wide Dynamic Range.
- Excellent Group Delay/Gain Slope



Description

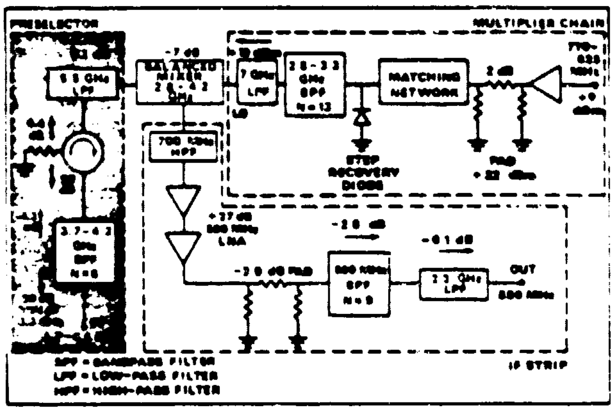
The ACA-4220 Series LNA/Downconverter combines the best features of the widely used 120°K LNA (AWC-4205) with the 880 MHz IF Downconverter (ACA-4200) used in many TVRO receivers and adds internally an Avantek local oscillator. This integrated assembly combines all RF requirements into a single earth terminal subsystem. Additional features or variations in specifications may be readily incorporated, tailoring the design to meet system requirements.

Guaranteed Specifications @ -40°C to +50°C Case Temperature

Frequency (Input)	3.7-4.2 GHz
Frequency (Output)	950-1450 MHz
Noise Figure (db)	1.5
VSWR (In/Out)	1.25/1.25
Gain (Min) (db)	60
Gain variation vs. frequency	±.5 db (max)
Gain slope, db/MHz	0.01 (Max)
Linear group delay, ns/MHz	0.01 (Max)
Parabolic Group Delay, ns/MHz2	0.001 (Max)
Intercept Point, dBm	+20 (Min)
Spurious Outputs	70 dbc (out-of-band) (P_o Ave.=-15 dbm)
Power	+15 28VDC Cable Powered
Phase Noise dbc min. (relative to 200 KHz deviation, measured in 3 KHz BW)	-45 @ 10 KHz decreasing to -66 @ 200 KHz: -66 db, 200 KHz to 4.2 MHz

4-GHz Downconverter Beats Down Costs Too

How do you downconvert a 4-GHz downlink to an 880-MHz IF without going broke? Be thrifty with substrates and semiconductors, bet on microstrip, and invest heavily in innovative filter designs.

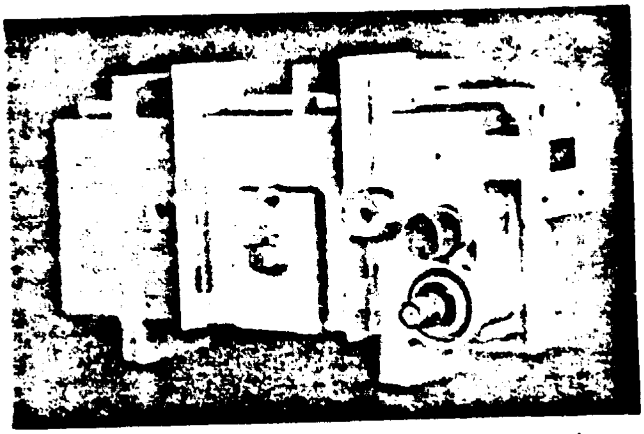


1. Effective filters and thrifty construction techniques are the keys to this downconverter for TVRO sites.

Downconverter specifications

RF input port	
Frequency (GHz)	3.7 to 4.2
Min. return loss (dB)	20
Max. reradiation (dBm)	
3.7 to 4.2 GHz	−86
2.8 to 3.3 GHz	−70
5 to 10 GHz	−60
10 to 18 GHz	−40
LO input port	
Frequency (MHz)	710 to 825
Input power (dBm)	8 to 11
Min. return loss (dB)	13
IF output port	
Frequency (MHz)	880 ± 20
Min. return loss (dB)	20
Min. RF to IF gain (dB)	10
Min. noise figure (dB)	13.5
Gain flatness (dB)	
3.7 to 4.2 GHz	±1.0
any 40-MHz band	0.4 (p-p)
Spurious output (dBm)	
720 to 760 MHz	−110
710 to 825 MHz	−90
2.8 to 10 GHz	−60

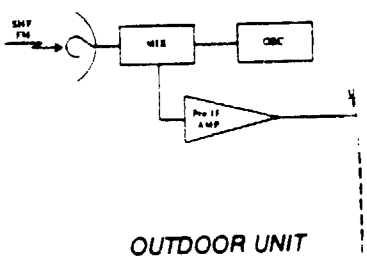
Figure 6-76 (Merrimac)



OUTDOOR UNIT (SHF-UHF Converter)

This two-piece TV Receiver is designed for direct reception from 12 GHz satellites, such as ANIK B and ANIK C. This extremely small unit uses the most advanced solid state technology to achieve the lowest noise figure performance available anywhere.

The indoor unit selects the signal, converts the FM satellite signal into the standard NTSC composite signal and remodulates it onto a VHF TV channel. Operational stability and low cost are realized by the adoption of a newly developed ceramic band-pass filter and a discriminator.



For prices and availability contact
VITALINK CORPORATION

SPECIFICATIONS

SHF-UHF Converter (outdoor unit)

RECEIVING FREQUENCY RANGE:	Between 300 MHz from 11.7 GHz to 12.2 GHz
OUTPUT FREQUENCY: (INTERMEDIATE FREQUENCY)	0.9 GHz - 1.2 GHz
NOMINAL OUTPUT IMPEDANCE:	75Ω Unbalanced
OUTPUT VOLTAGE STANDING WAVE RATIO:	≤1.5
ADMISSIVE IMPUT LEVEL:	-80 dBm
NOISE FIGURE:	3.2 dB
OSCILLATOR FREQUENCY STABILITY:	≤ ±300 kHz
POWER SOURCE:	DC 12V minus Earth Line Powering from Indoor Unit
HOUSING:	JIS C-0920 Weatherproof Housing
APPLICABLE TEMPERATURE:	-20°C - +40°C
MAXIMUM DIMENSIONS:	175mm x 45mm x 80mm
WEIGHT:	1 kg

Figure 6-77

6.3.4.1 12-GHz Low Noise Converters in Japan

Because of the BSE experience and the intense FET developments there, Japan has led the world in 12 GHz LNA and down-converter developments. These developments have included the low noise mixer approach spearheaded by NHK and in particular, Dr. Konishi, and the FET preamplifier and mixer MIC approach spearheaded by SANYO.

Table 6-39 lists the participants in these developments including a listing of the present 16 licencees (plus two U.S. licensees) of the Konishi mixer system, and the six proponents of the MIC FET preamplifier approach.

For completeness, work has been done in this area using special 12 GHz low noise mixers at Westinghouse.

Note in Table 6-39, that KDD is also engaged in FET preamplifier developments.

Figure 6-78 shows the Konishi approach which includes a planar circuit housing a Schottky barrier step recovery diode installed in the feed horn waveguide. This circuit has a conversion loss of 3 dB and with a 7 dB NF IF, has a total noise figure of around 4.2 dB. Figure 6-79 shows Dr. Konishi holding a sheet which includes dozens of planar waveguides. As director for research of the Japan Broadcasting Corporation, Yoshihiro Konishi has a good perspective of both device and systems development, allowing him to point out areas where break-throughs may occur in the 1980's.

"After the satellite project, microwave technology should be very rapidly changed.....by low cost technology", he believes. As inexpensive, standardized components become available, microwaves will make inroads into everyday life.

Figure 6-80 shows the SANYO MIC LNA converter which includes a FET preamplifier, a step recovery diode mixer and a stable local oscillator using a dielectric resonator, with an MIC output at 290-470 MHz where the receiver can tune to the desired channel. This circuit has a noise figure of 3.9 dB which will be reduced if the new MITSUBISHI 1.7 dB FET (device NF) at 12 GHz is used.

Intensive work is being done in the U.S. at Hewlett Packard and Watsons Johnson to further integrate the Ku-band amplifier, mixer converter which converts in response to a tuning voltage. Figures 6-81, 6-82 and the lower portion of Figure 6-83 show innovative work on a Ku-band receiver developed by Dr. Van Tuyl of Hewlett Packard (ISSCC-78) using monolithic gallium arsenide technology, and Figure 6-83 (upper left) shows a 15 GHz circuit by Dr. Crescenzi of Watkins Johnson in which an FET amplifier and a voltage controlled oscillator are combined in a module only 1.7 x 0.65 x 0.25 inches in size. The work by HP and WJ, is an innovative expression of the capability of developing Ku-band circuits which are the manufacturing equivalent of present day UHF MOSFET and bipolar circuits.

TABLE 6-39

Participants in 12 GHz LNA Developments

o **Users and Licencees of Konishi Mixer Down-Converter System:**

- Nippon Electric Co. Ltd.
- Mitsubishi Electric Corp.
- Hitachi Ltd.
- Sumitomo Electric Ind. Ltd.
- Tokyo Shibaura Electric Co. Ltd.
- Matsushita Electric Ind. Co. Ltd.
- Oki Electric Ind. Co. Ltd.
- Sony Corp.
- Daiichi Nippon Cable Ltd.
- Maspro Denkoh Corp.
- DX Antenna Co. Ltd.
- Pioneer Electric Corp.
- Sharp Corp.
- Nippon Antenna Co. Ltd.
- Sanyo Electric Co. Ltd.
- Katoh Electric Inds., and
- Thomson-CSF (Brandt-TV)

o **MIC FET Preamplifeir with Down-Converter to 290-470 MHz:**

- Hitachi
- Mitsubishi
- Sanyo
- Sony
- NEC
- Laboratory for Electronics (France)

o **Special Beam Load Mixer:**

- Sanyo

o **Two Key Japanese 12 GHz Low Noise FET Developments:**

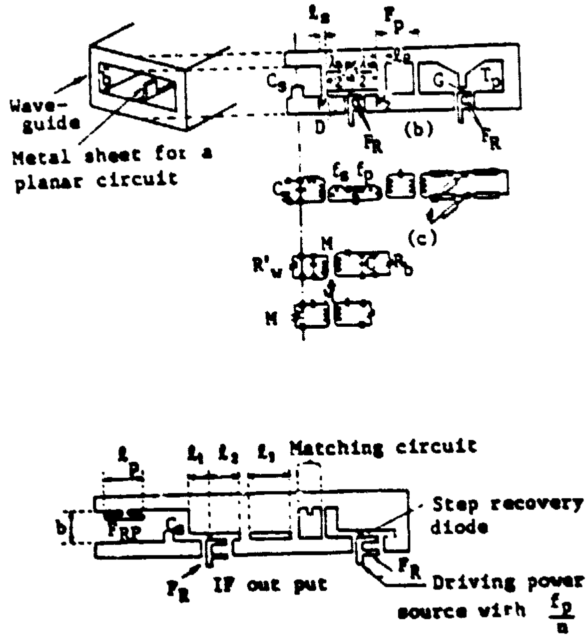
NEC 388	-	2.7 dB NF
Mitsubishi 1403	-	1.7 dB NF
NEC	-	0.7 dB NF (device noise figure)

o **KDD FET Preamplifier Noise Figure Experience using NEC 388 at 12 GHz:**

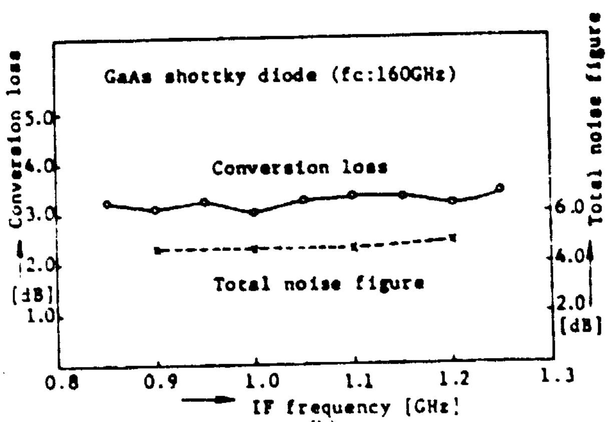
BW	NF
800 MHz	4.2 dB
500 MHz	3.6 dB
300 MHz	3.4 dB

Total FET Amp/Mixer/Low Noise Second Stage Noise Figure:

FET Amplifier	2.7 dB
Second stage contribution	1.3 dB
Waveguide to microstrip	0.2 dB loss
Image rejection filter loss	0.3 dB
Input circulation loss	0.2 dB
LNA Noise Figure	4.7 dB



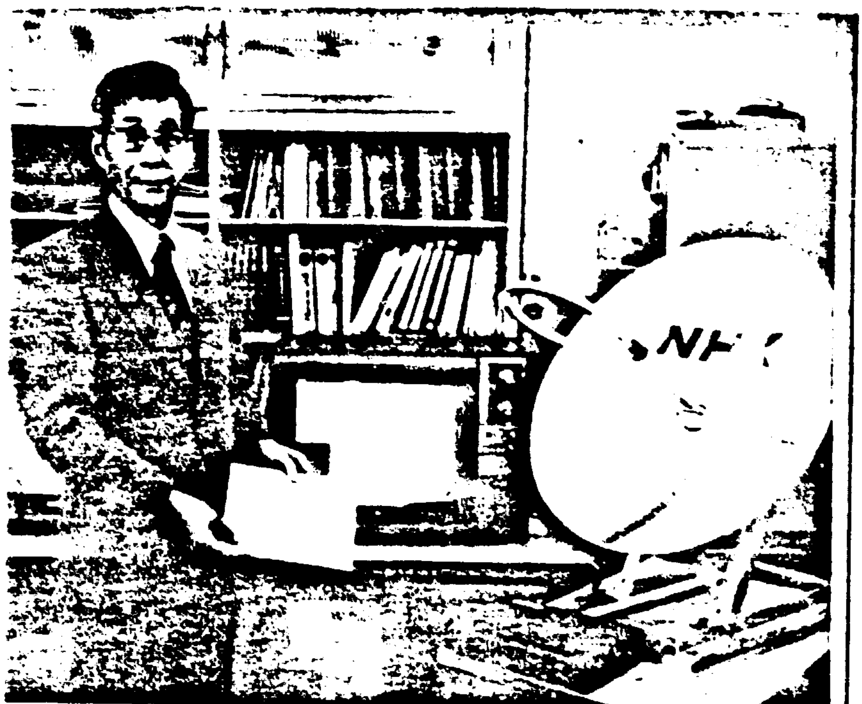
An example of the construction of 12GH
down converter with planar circuit
mounted in waveguide



(b)

Performance of a 12 GHz down converter
with planar circuit mounted in waveguide.

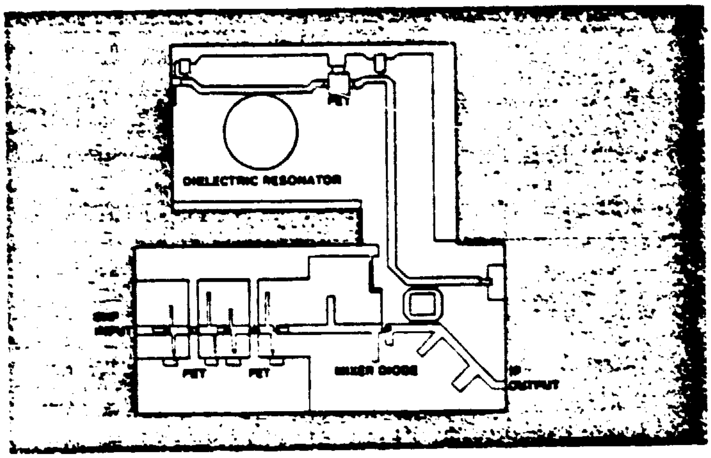
Figure 6-78



A metal sheet in Konishi's hands was chemically etched to produce dozens of planar waveguides, like the one used in the receiver shown picking up a test pattern from the Yuri satellite, at a cost of only forty cents apiece.

Figure 6-79

Integrated SHF Converter Simplifies Satellite Broadcasting



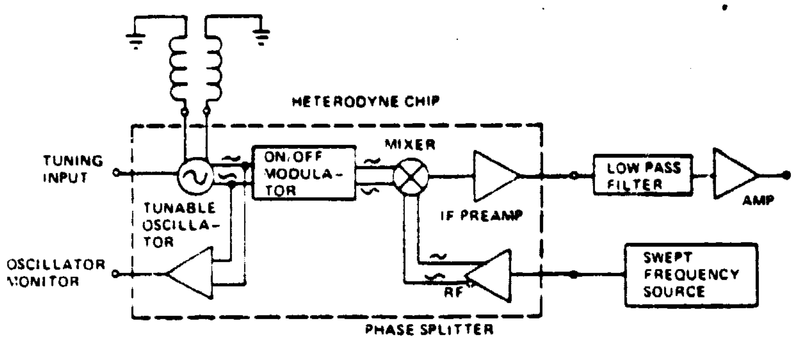
MIC PATTERN: A microwave integrated circuit converts the 11.95–12.13-GHz signal from the Yuri satellite to a 290–470-MHz first IF.

Design Data for Amplifier

GaAs Fet characteristics at 12 GHz		
S11	0.593	−146.2°
S12	−22.99 dB	114.6°
S21	1.11 dB	52.9°
S22	0.693	−55.0°
Stability factor: K		1.73 (Stable)
NF min.		3.9 dB
Γ_s at NF min.	0.529	143.4°
PG at NF min.		7.6 dB
NF at Γ_s =0		5.8 dB
Equivalent noise resistance		26.0 Ω
Input matching gain		1.88 dB
Output matching gain		2.84 dB
Maximum unilateral gain		5.83 dB
RF Filter Characteristics (Mixer Stage)		
Insertion loss of signal band		1.5 dB
Attenuation amount at local frequency		8.5 dB
Attenuation amount at image band		20–25 dB
Total Characteristics of MIC Converter		
Input frequency		11.95–12.13 GHz
IF		290–[illegible] MHz
Local frequency		[illegible] GHz
Noise figure		4.1–4.6 dB
Gain		50 dB
Local stability (−20–+50°C)		±500 kHz
Power consumption		12 V, 200 mA, 2.4 W
Dimensions		54 × 36 × 50 mm³
Weight		150 g

Figure 6-80

Figure 6-81



The monolithic GaAs Fet RF signal chip has its LO's frequency determined by an off-chip resonator and on-chip varactor diodes. An external swept-frequency oscillator provides the low-level input to a doubly balanced mixer through a phase splitter. LO and RF feed-through are kept from saturating the IF amplifier by a doubly balanced mixer. On/off modulation is accomplished with a modulator between LO and mixer. *Hewlett-Packard.*

Figure 6-82

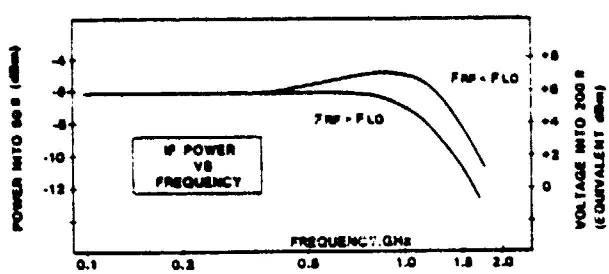
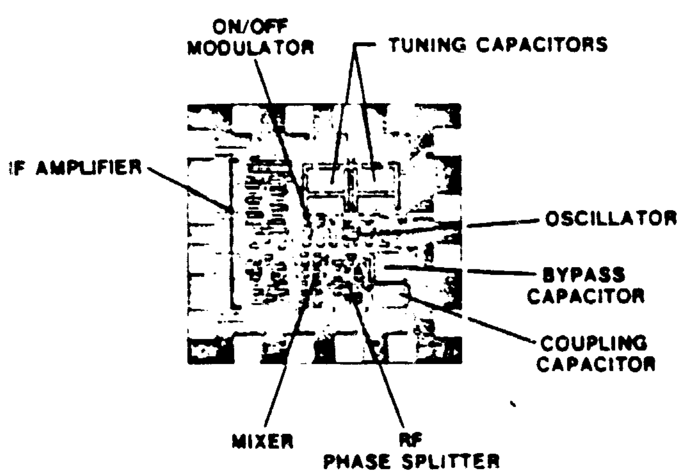
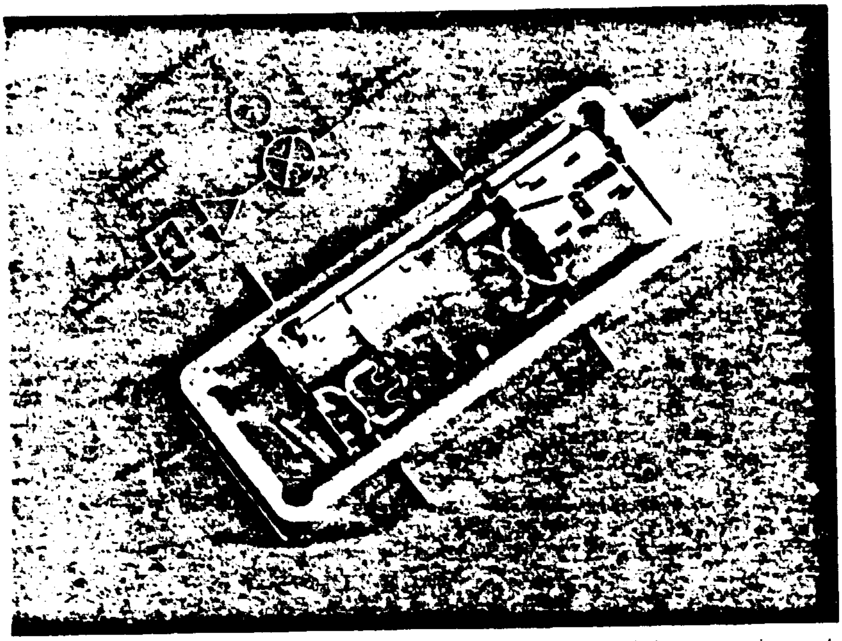


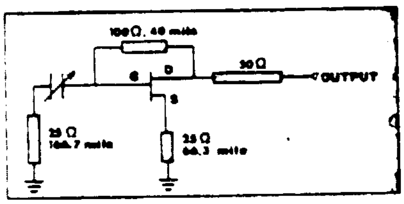
FIGURE 5



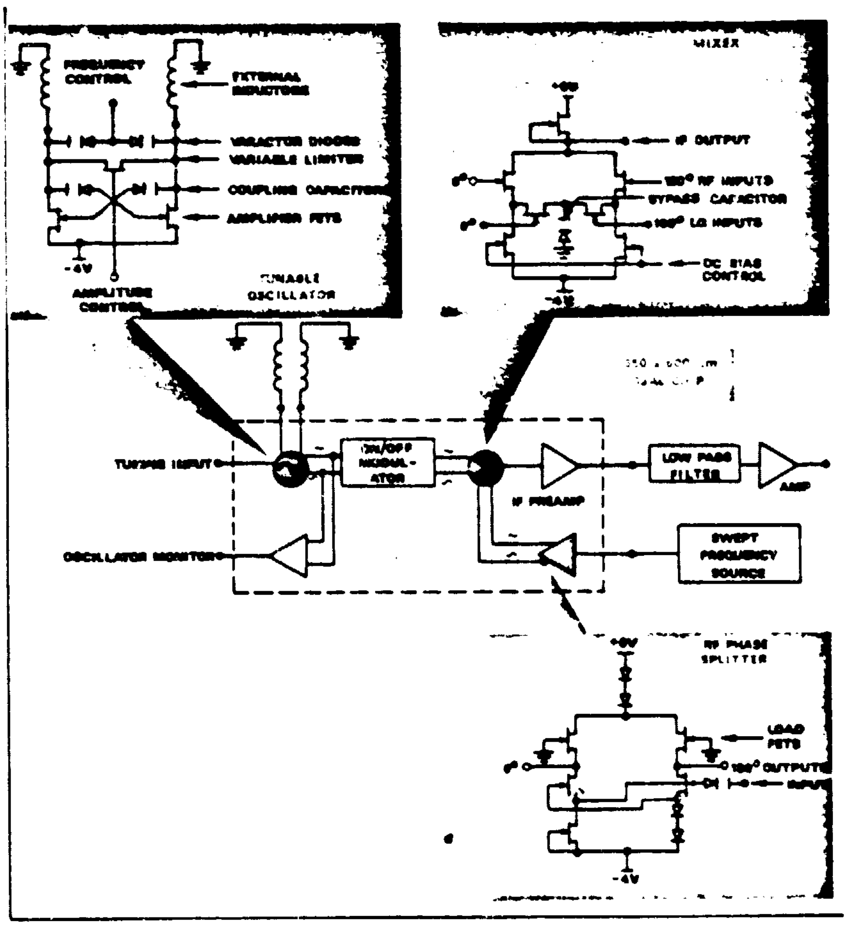


*1. **Four circuit elements** are integrated in a hermetic module measuring only 0.65 x 0.25 x 1.7 inches.*

Figure 6-83



*2. **GaAs FET oscillator** includes the tuning varactor in series with a resonant stub. Line lengths given are for 15-mil thick alumina substrate.*



*1. **A complete subsystem on a chip**, this heterodyne converter provides flat performance up to 1.5 GHz. Details of local oscillator, mixer, and phase-splitting buffer amplifier circuits are shown.*

6.3.5 Integrated Circuits in the TVRO Receiver

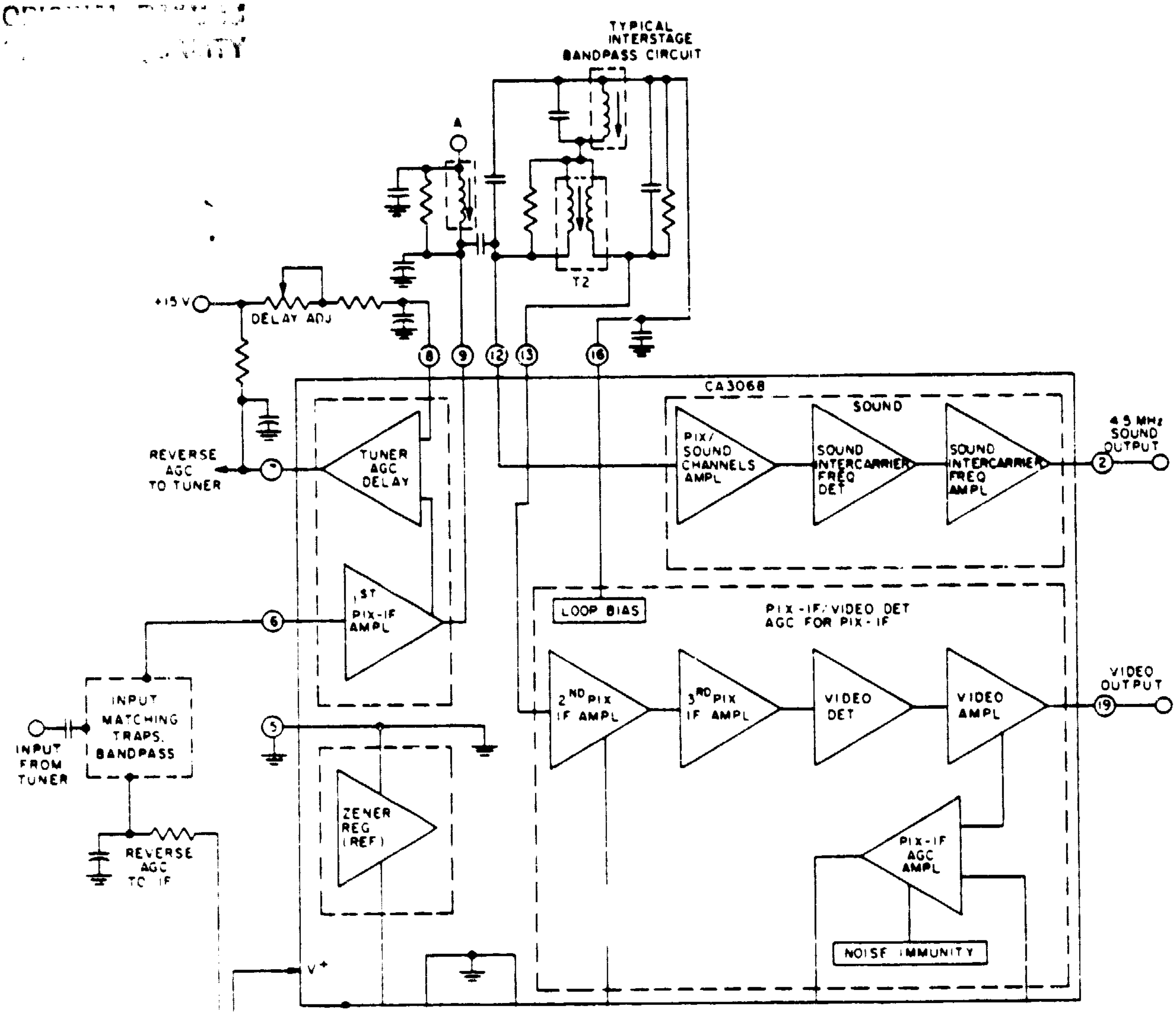
Once the TV FM carrier has been selected by the tuning process and has been developed at IF, then more conventional TV-type circuits can be used for its amplification, AGC, detection and processing.

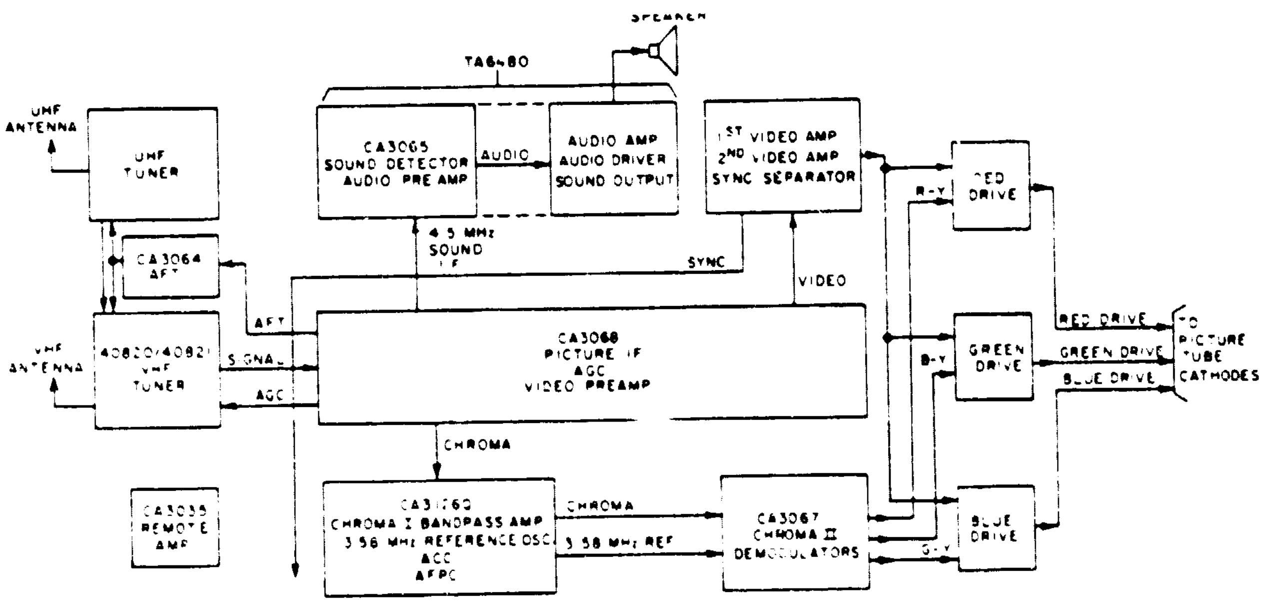
6.3.5.1 Standard Color TV Receiver IC's

Figure 6-84 shows a typical TV receiver circuit, by RCA, which illustrates not only the complex of integrated circuits used by the mid-1970's, but also the circuits included in CA3068 for IF and video detection and processing.

The first IC in TV was the chroma demodulator. Today every color TV has one, usually an LM746 or LM1828 type. In one variation the luminance signal is added to the color difference outputs on the chip (Motorola MC1324). The chroma amplifier and subcarrier regenerator sections have been integrated using a phase-locked loop system with two chips (LM3070 and LM3071 types) and an injection-locked system with one chip (Motorola MC1398). Both of these systems are widely used. Second generation systems which do the phase-locked system with one chip (RCA CA3126 or Motorola MC1399) are gaining acceptance. All of these systems can be used with the above-mentioned demodulators.

According to a NATIONAL application note, Monolithic circuits have been made to work very well at 45 MHz. The first IC IF systems used 2 chips: one for a 2-stage gain-controlled IF amplifier (Motorola MC1349,52) and the second for a video detector with gain (Motorola MC1330). The major obstacle to combining these two chips into a single chip has been stability problems due to internal and/or external coupling output to input. However, a one chip IF amplifier and video detector is now widely used in Europe (Telefunken TDA 440). The AGC system is also often included in these chips. Another IF function used in most color TV receivers today is automatic fine tuning (AFT) which keeps the tuner correctly tuned to the IF frequency (LM3064 type).





Block diagram of typical color-TV signal circuits using the CA3068. (RCA)

Figure 6-84

The first chip to incorporate all of the above functions into a single chip is the National LM1807. The chip uses a phase-locked loop to tune the tuner to the IF frequency set by a local oscillator on the chip. This concept is new to TV and is generating interest.

6.3.5.2 Present Integrated Circuits in TVRO Receivers

Standard color TV IF and video detector IC's cannot be used in TVRO receivers since they are designed to amplify and process a combined vestigial sideband video carrier and an FM sound carrier approximately 4.5 MHz separated from the video carrier frequency. Also, commercial TV IC's use 45 MHz IF's.

TV Receivers must pass an FM carrier which includes both video and audio with a bandwidth from 27 MHz to full 36 MHz, and IF frequencies of 70 MHz or 120 MHz are used to provide amplification compatible with the increased signal carrier bandwidth.

Fortunately, the vast variety of integrated circuits now produced for integrated circuits includes many IC's which can be used for TVRO circuits.

The Signetics NE564-N phase lock loop IC - Figure 6-85A - performs the function of FM demodulation, and Figure 6-85B due to R. Cooper (Radio Electronics Magazine April 1980) shows how this IC is used, with the Signetics NE592, used as a video amplifier. Figure 6-86 shows another circuit implementation of these two IC's for 70 MHz in and video plus audio subcarrier out.

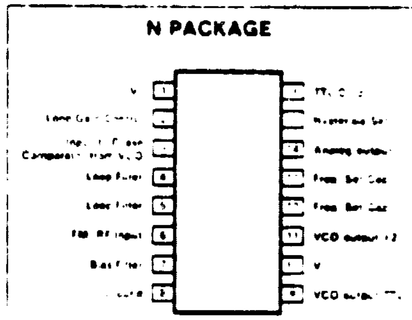
Figures 6-87 and 6-88 show how video de-emphasis (6-87) can be incorporated with transistors or noise eliminator and AGC voltage generator (Figure 6-88) can be incorporated via the RCA CA3120E IC.

NE564-N

FEATURES

- Operation with single 5V supply
- TTL compatible inputs and outputs
- Operation to 50MHz
- External loop gain control
- Reduced carrier feedthrough
- No elaborate filtering needed in FSK applications
- Can be used as a modulator
- Variable loop gain (Externally Controlled)

PIN CONFIGURATION



ABSOLUTE MAXIMUM RATINGS

	PARAMETER	RATING	UNIT
V+	Supply voltage		V
	Pin 1	14	
	Pin 10	6	
P_D	Power dissipation	400	mW
T_A	Operating temperature	0 to 70	°C
T_{stg}	Storage temperature	-65 to 150	°C

BLOCK DIAGRAM

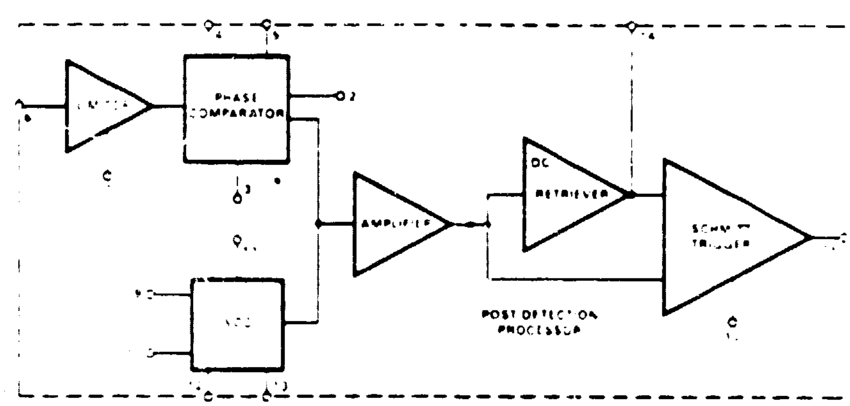


Figure 6-85A. Signetics Phase-Locked Loop IC

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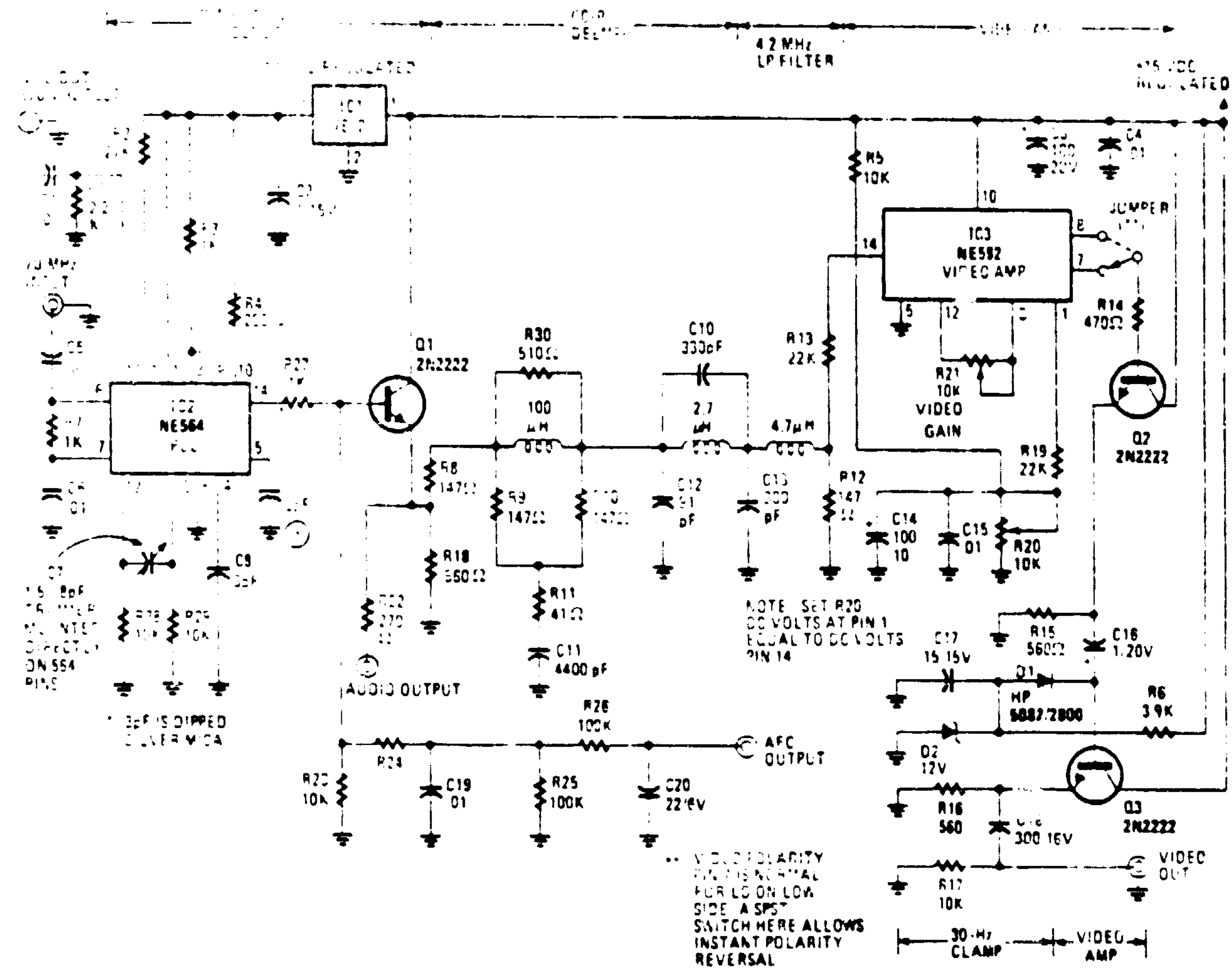


BASEBAND VIDEO AUDIO SYSTEM recovers video and audio signals from the 70-MHz output of the IF strip

Figure 6-85B *

* R. Cooper, Radio Electronics, April 1980

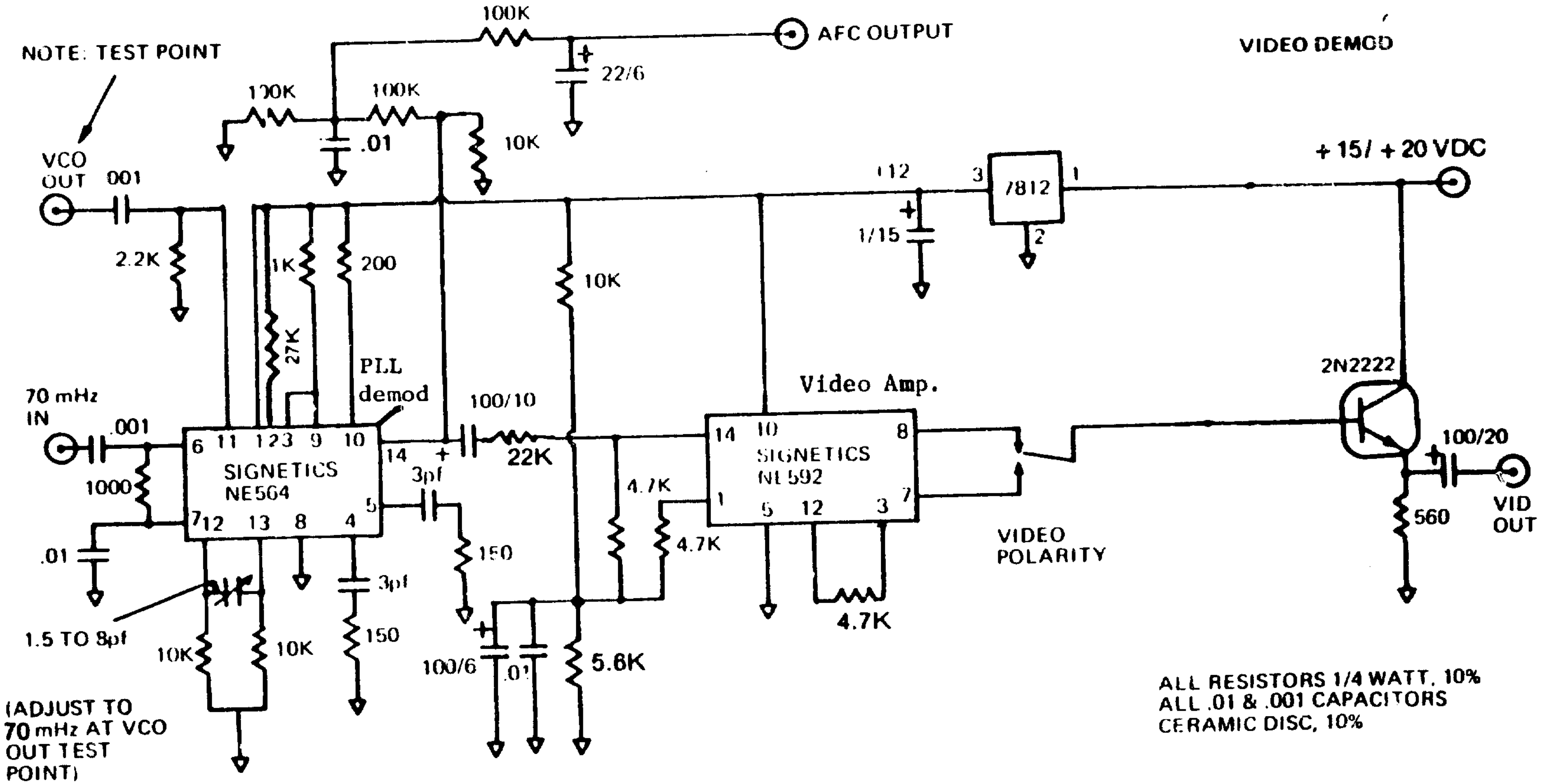
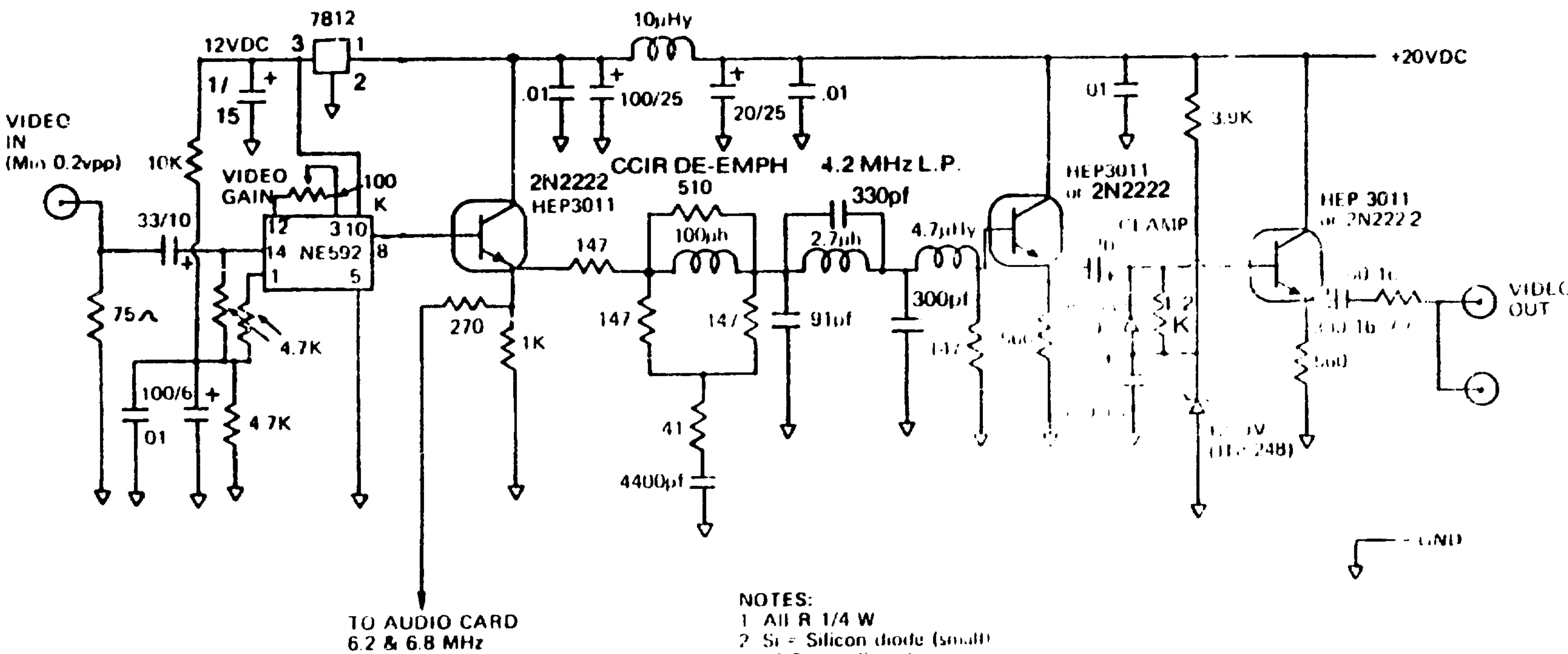
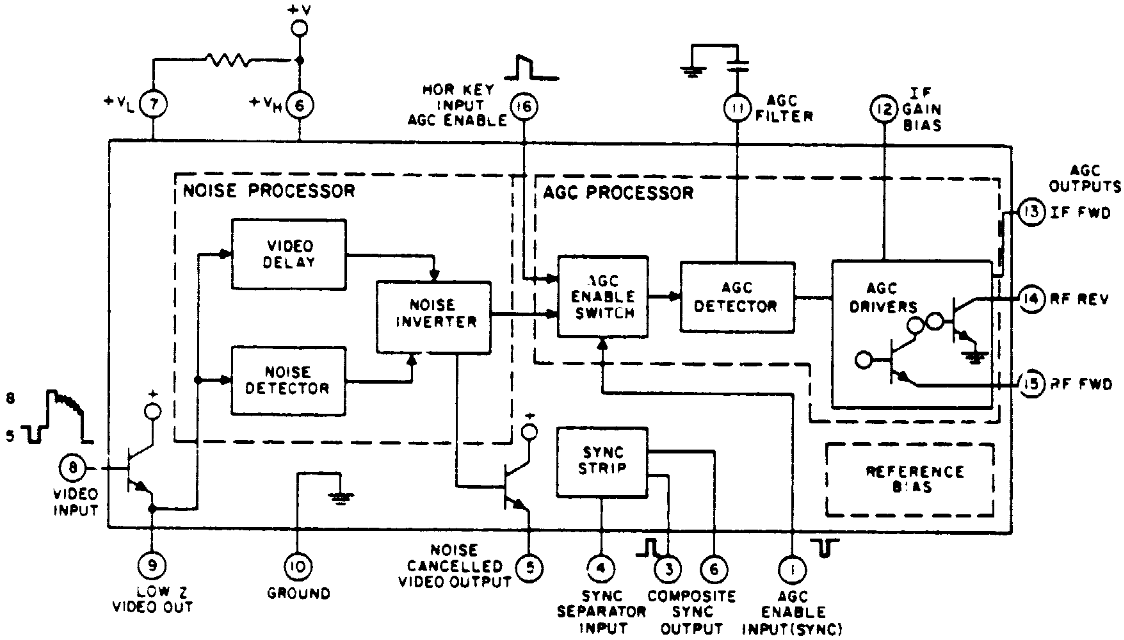

VIDEO DEMOD
NOTE: TEST POINT
VCO OUT
.001
2.2K
100K
100K
100K
.01
10K
22/6
AFC OUTPUT
+15/+20 VDC
12
1/15
7812
1K
27K
200
PLL demod
10K
70 mHz IN
.001
1000
.01
SIGNETICS NE564
100/10
22K
3pf
150
3pf
150
1.5 TO 8pf
10K
10K
(ADJUST TO 70 mHz AT VCO OUT TEST POINT)
100/6
.01
5.6K
4.7K
4.7K
Video Amp.
SIGNETICS NE592
4.7K
VIDEO POLARITY
2N2222
100/20
560
VID OUT
ALL RESISTORS 1/4 WATT, 10%
ALL .01 & .001 CAPACITORS CERAMIC DISC, 10%

Figure 6-86



NOTES:
1 All R 1/4 W
2 Si = Silicon diode (small)
3 pf Cs are dipped mica
4 Circuit board Douglas
5 All inductors molded

Figure 6-87



Simplified block diagram of the CA3120E signal processor. RCA

Figure 6-88

6.3.5.3 Demodulating the Audio Subcarrier

After the video detection process which includes detecting the audio FM subcarrier, this subcarrier must be demodulated and processed. Figure 6-89 shows the variety of detector circuits which have been developed including the historic Foster-Seely discriminator, the AVINS ratio detector, the quadrature detector and the phase-locked loop.

Figures 6-90 and 6-91 show alternate circuit using existing IC's or by modifying a standard module.

6.3.5.4 Remodulation of Video and Audio

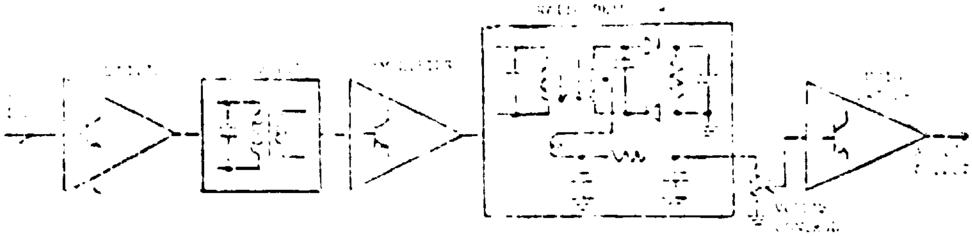
Once the video and the audio signals have been recovered, they can be applied directly to a TV monitor, or they can be remodulated as a pair of vestigial sideband video and FM audio carriers to be available to a standard channel (3,4, or 5) of a standard TV receiver.

The NATIONAL LM1889 IC, shown in Figure 6-92A was designed to perform this function, and is also widely used for TV games. Its cost of less than $10 shows what IC technology and volume production can accomplish with very sophisticated and complex TV circuits.

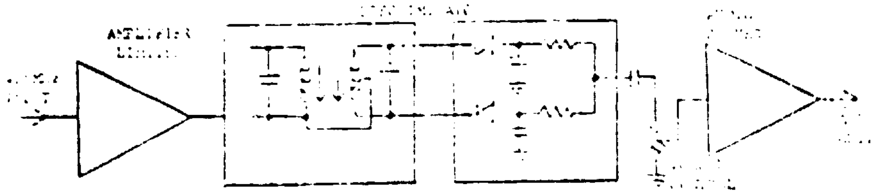
Figure 6-92B shows how an LM1889 can be hooked up to accept the audio and video input, and to produce an NTSC signal for channels 3,4,or 5. (Ref. R. Cooper, Radio Electronics, April 1980).

This circuit is not used for entering a Cable TV since it does not have adequate filtering - which can be accomplished by using a surface wave filter (Anderson Labs).

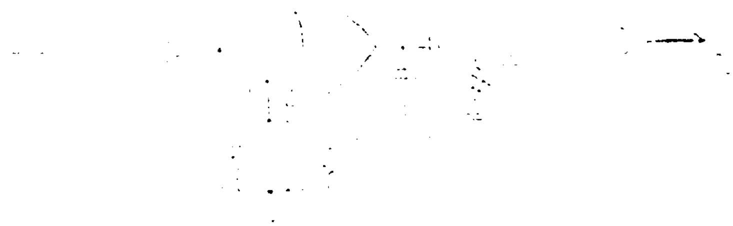
C.



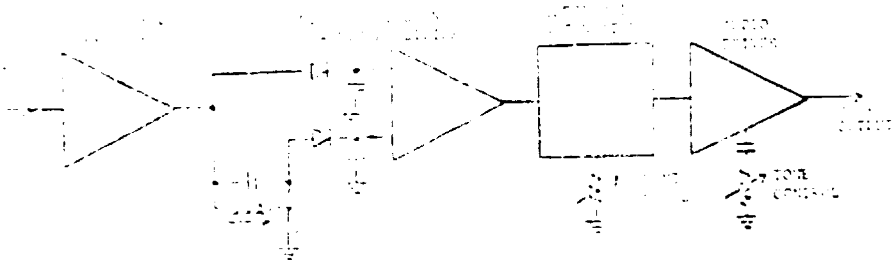
—Ratio Detector, discrete form.



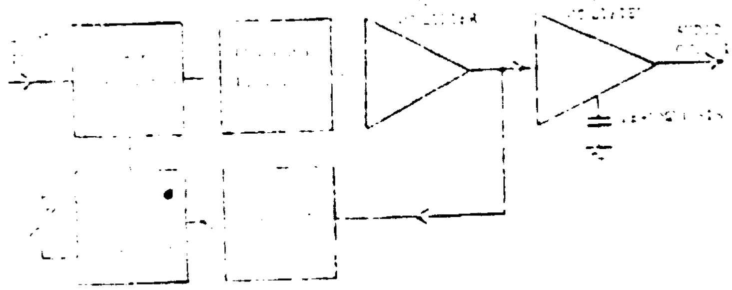
Discriminator, CA 3042.



Quadrature Detector, µA 754

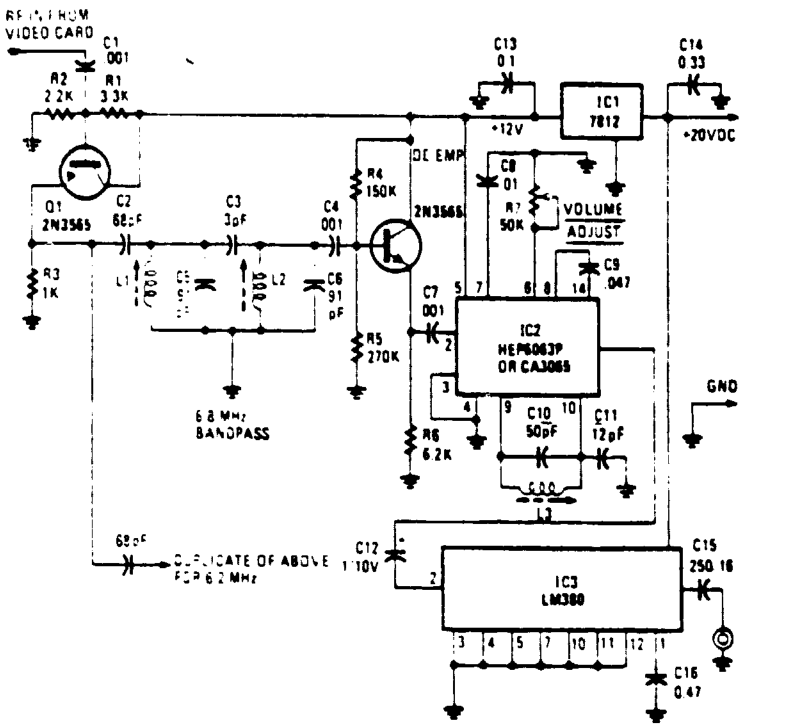


Differential Peak Detector, µA 3065.



Phase-Locked Loop, NE 5605 61B.

Figure 6-89



—6.8-MHZ AUDIO DEMODULATOR. Circuit is duplicated for recovering 6.2-MHz audio signal

Figure 6-90

PARTS LIST
(Audio demodulator.)

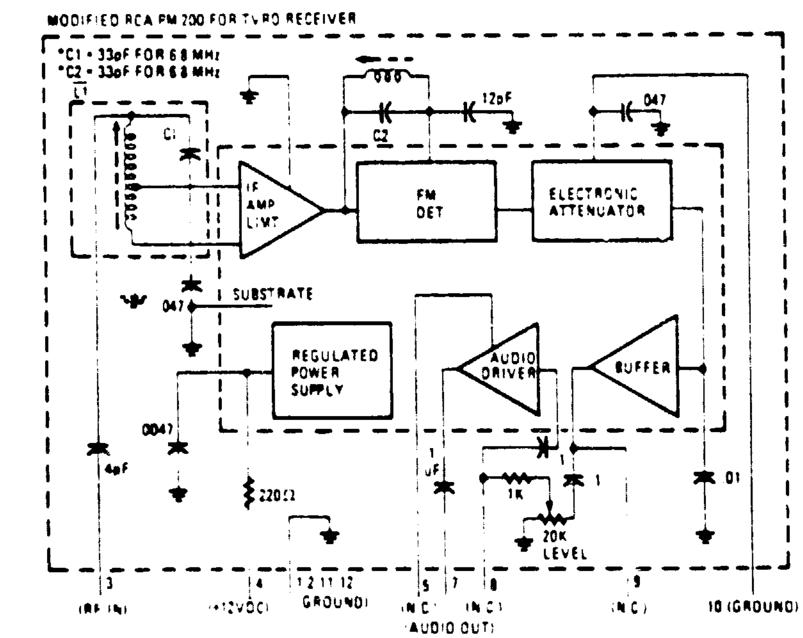
Resistors ¼ watt, 10%, unless otherwise noted

R1—3300 ohms
R2—2200 ohms
R3—1000 ohms
R4—150,000 ohms
R5—270,000 ohms
R6—6200 ohms
R7—50,000 ohms potentiometer

Capacitors

C1, C4, C7—.001 μF
C2—68 pF dipped mica
C3—3 pF dipped mica
C5, C6—91 pF dipped mica
C8—.01 μF
C9—.047 μF
C10—50 pF dipped mica
C11—12 pF dipped mica
C12—1 μF, 10 volts, electrolytic
C13—0.1 μF
C14—.33 μF
C15—250 μF, 16 volts, electrolytic
C16—.47 μF
Q1, Q2—2N3565
IC1—7812 voltage regulator, +12 volts
IC2*—HEP6063P or CA3065
IC3*—LM380
L1, L2—adjustable RF coil, 3—7 μH (J.W. Miller No. 9051)
L3—adjustable RF coil, 7—14 μH (J.W. Miller No. 9052)

***Note: The RCA CA3134GM can replace the CA3065/LM380 combination**



—ALTERNATE APPROACH to subcarrier audio detection uses a standard module from an RC TV receiver

Figure 6-91

DECEMBER 1976

LM1889 TV video modulator

general description

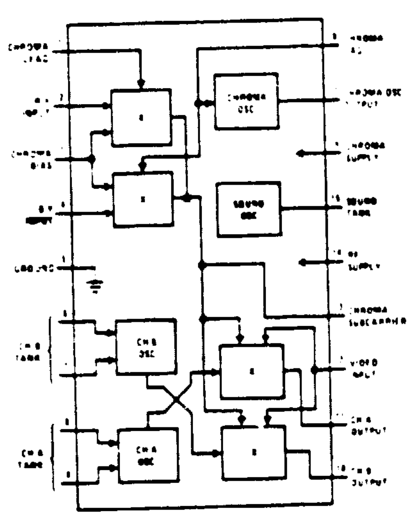
The LM1889 is designed to interface audio, color difference and luminance signals to the antenna terminals of a TV receiver. It consists of a sound subcarrier oscillator, chroma subcarrier oscillator, quadrature chroma modulators, and RF oscillators and modulators for two low-VHF channels.

The LM1889 allows video information from VTR's, games, test equipment, or similar sources to be displayed on black and white or color TV receivers. When used with the MM57100 and MM53104 a complete TV game is formed.

features

- dc channel switching
- 12V to 18V supply operation
- Excellent oscillator stability
- Low intermodulation products
- 5 Vp-p chroma reference signal
- May be used to encode composite video

block diagram



dc test circuit

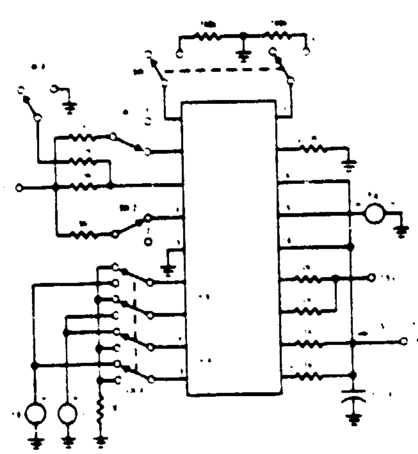
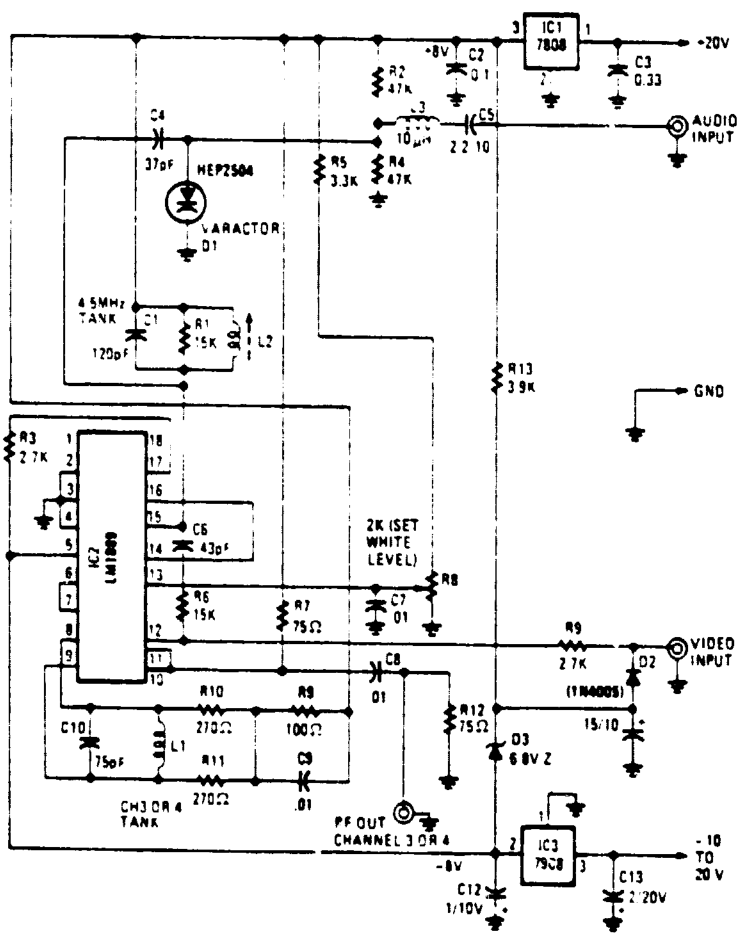


Figure 6-92A



NTSC RF MODULATOR for Channel 3, 4, or 5

Resistors 1/4-watt, 10% unless otherwise specified.

R1, R6—15,000 ohms
R2, R4—47,000 ohms
R3, R9—2700 ohms
R5—3300 ohms
R7, R12—75 ohms
R8—2000 ohms potentiometer
R9—100 ohms
R10, R11—270 ohms
R13—3000 ohms

Capacitors

C1—120 pF dipped mica
C2—0.1 μF ceramic disc
C3—.33 μF ceramic disc
C4—37 pF dipped mica
C5—2.2 μF 10 volts electrolytic
C6—43 pF dipped mica
C7—C9—.01μF ceramic disc
C10—75 pF dipped mica
C11—15 μF 10 volts, electrolytic
C12—1 μF 10 volts electrolytic
C13—20 μF 20 volts, electrolytic
IC1—7808 voltage regulator +8 volts
IC2—LM1889 TV video modulator
IC3—7908 voltage regulator −8 volts
D1—HEP2504 varactor diode (Motorola)
D2—1N4005 diode
D3—Zener diode 6.3 volts
L1—tank coil .08μH (3 turns No. 16 wire air-wound 1/4" ID 3/8" long)
L2—adjustable RF coil 7—14 μH (J. W. Miller type 9052)
L3—10 μH molded RF choke

Figure 6-92B

6.5 Appendix to Section 6 - Interactive TV Systems

The scope of this report cannot consider in depth the full implications of both reception of a digital TV carrier, or interactive systems which provide for a single voice circuit (or digital equivalent) in the up-link.

Accordingly, Tables 6-40 through 6-47 are included since they provide tables of useful data, extracted from CCIR SG 10/11B documents on a summary of uplinks power amplifiers (compiled by the author) in Table 6-41.

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TABLE 6-40

Characteristics of Digital and Frequency-Modulation Television Systems*

System	Digital Television	Frequency-Modulation Television
Modulation	Differentially coded, QPSK modulator, coherent QPSK demodulator	Frequency-modulation, 12 MHz peak-to-peak deviation, with pre- and de-emphasis
Signal Bandwidth (Transmit Filter)	45 MHz (3 pole, low ripple Chebyshev filter)	20 MHz
Receiver Filter	33 MHz, 5 pole, equalized elliptical filter	21 MHz, 6 pole, low ripple Chebyshev
Audio	Multiplexed into data stream	7.5 MHz subcarrier, 25 decibels below video carrier
System Output Signal-to-Noise Ratio (unweighted)	45 decibels**	50 decibels

* Doc. USSG-BC/912

** subjectively measured

TABLE 6-41
HPA'S FOR 14-14.5 GHz

Manufacturer	Tube Type	Power Level (watts)
AEG-Telefunken	TWT	16 W
Hughes	TWT	25-40 W
MCL, Inc.	TWT	25-40 W
Thomson-CSF	TWT	25-40 W
Varian	TWT	25-40 W
AEG-Telefunken	TWT	70 W
Thomson-CSF	TWT	125 W
Hughes	TWT	200-400 W
MCL, Inc.	TWT	200-400 W
Varian	TWT	200-400 W
Aydin	TWT	250 W
Aydin	TWT (in dev.)	400 W
Hughes	TWT	500 W
MCL, Inc.	TWT/klystron	500 W
Thomson-CSF	TWT	500 W
Varian	klystron	500 W
Aydin	TWT (in dev.)	600 W
Aydin	klystron	1-2 kW
MCL, Inc.	klystron	1.5 kW
Varian	klystron	1.5 kW
Aydin	TWT (in dev.)	2 kW
MCL, Inc.	klystron	2 kW
NEC	klystron	2 kW
Thomson-CSF	TWT	2 kW
Varian	klystron	2 kW
NEC	TWT	3-4 kW
Hughes	TWT	5 kW
MCL, Inc.	klystron	10 kW
Varian	klystron	10 kW

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Nippon Electric 1980

Ku, Ka BAND TWT (NOW AVAILABLE)

TUBE TYPE	FREQUENCY (GHz)	BEAM VOLTAGE (kV)	BEAM CURRENT (mA)	POWER (W)	GAIN (dB)
LD4325	14.0-14.5	11.6	220	250	52
LD4219A	14.0-14.5	15.1	550	1000	50
LD4346	14.0-14.5	16.0	1500	3000	50
LD4369	27.55-30.05	17.5	500	700	45
LD4224	34.77-34.89	17.5	500	600	45

Ku, Ka BAND KLYSTRON (NOW AVAILABLE)

TUBE TYPE	FREQUENCY (GHz)	BEAM VOLTAGE (kV)	BEAM CURRENT (mA)	POWER (W)	GAIN (dB)	
LD4215	14.0-14.5	9.5	750	2000	43	
LD4405	27.5-29.0	10.5	430	500	43	
LD4406	28.7-30.1	11.0	460	500	45	
LD4428	27.5-29.0	7.2	250	150	45	
LD4429	28.7-30.1	7.2	250	150	45	
LD4321*	35.5	18.0	030	4000	52	
LD4330*	45.0	10.0	010	1000	51	40 MI

* Pulsed Operation

Nippon Electric

(Doc. USSG BC/829)

TABLE 6-42

TYPICAL 12 GHZ SYSTEM PARAMETERS

Parameter	Unit	Fixed - Satellite Terminal Size Large	Fixed - Satellite Terminal Size Small	Broadcasting - Satellite Community Reception	Broadcasting - Satellite Individual Reception
a. Downlink					
Satellite Transponder					
End-of-life net power to antenna	dBW	16		16	22
Antenna diameter	m	0.26 x 0.52		0.71	0.50 x 1.0
Antenna beamwidth	deg	3.5 x 7		2.3	1.7 x 3.3
Antenna gain	dB	30		36	36
On-axis saturated eirp	dBW	46		52	58
Rf bandwidth	MHz	36		25	18
Earth-Station Receiver					
Antenna diameter	m	9.75	4.88	3.66	0.91
Antenna beamwidth	deg	0.17	0.34	0.45	1.8
Antenna gain	dB	59	53	51	39
System temperature	°K	250	250	500	500
On-axis figure-of merit	dWB/°K	35	29	24	12
Downlink per transponder EG/T	dBW/°K	81	75	76	70
B. Uplink					
Earth-Station Transmitter					
Net Power to antenna	dBW	30[a]	30[a]	30[a]	
Antenna diameter	m	9.75	4.88	4.88	
Antenna beamwidth	deg	0.16	0.32	0.32	
Antenna gain	dB	60.5	54.5	54.5	
On-axis eirp	dBW	90.5[a]	84.5[a]	84.5[a]	
Satellite Transponder					
Antenna diameter	m	0.44 x 0.22		0.44 x 0.22	
Antenna beamwidth	deg	3.5 x 7		3.5 x 7	
Antenna gain	dB	30		30	
System temperature	°K	1200		1200	
On-axis figure-of merit	dBW/°K	-1		-1	
Maximum uplink EG/T	dBW/ K	89.5[a]	83.5[a]	83.5[a]	

[a]Example only. In practice, earth-station power output and eirp are adjusted to match size of carrier.

(Doc. USSG BC/829)

TABLE 6-43

PARAMETERS OF TYPICAL
MOBILE SYSTEM

FREQUENCY RANGE	11.7 to 12.2 GHz (TUNEABLE)
ANTENNA DIAMETER	1.22 m
TRANSMITTED POWER	7 dBW (MAX)
ANTENNA GAIN	41 dB
POLARIZATION	LINEAR (VERTICAL OR HORIZONTAL)
RECEIVE SYSTEM NOISE TEMP.	3000°K
TRANSMISSION	NTSC COLOR TV MOD INDEX = 1.2 RF BANDWIDTH = 20 MHz EMPHASIS/NOISE WEIGHTING = 12.7 dB

TABLE 6-44

PARAMETERS OF SATELLITE SOUND BROADCASTING SYSTEM FOR COMMUNITY RECEPTION

Signal Parameters	
Frequency Band	620-790 MHz
Audio Bandwidth	3100 Hz (300-3400 Hz)
Type of Modulation	FM
Modulation Index	6 (± 20.4 kHz peak frequency deviation)
RF Bandwidth per Sound Channel	47.6 kHz
Downlink Signal-to-Noise Ratio	46.9 dB
Space Station	
Antenna Beamwidth	3.5° by 7°
Antenna Gain	31 dB
EIRP for 42 Channel Aggregate	37.6 dBw
EIRP per Sound Channel	21.6 dBw
Ground Receivers	
Antenna Diameter	3 m
Antenna Gain	24 dB
System Noise Temperature	400 K
Gain-to-Noise Temperature	-2 dBw/K
PFD at Beam Center	-144.5 dBw/m^2/48 kHz

TABLE 6-45

BC/831

Examples of Interactive Community Reception Voice Frequency System Parameters: Uplink

Parameter	1	2	3	4	5	6	7
1. System							
Frequency of carrier (MHz)	700	2600	14000	14000	30000	50000	93000
Carrier-to-noise density ratio (exceeded for 99% of the worst month) (dB-Hz)	54	54	54	54	54	54	54
2. Satellite Receiving Parameters							
Antenna beamwidth at -3dB points (degrees)	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Antenna gain at the edge of service area, relative to an isotropic source (dB)	38	38	38	38	38	38	38
Total receiving system noise temperature (K)	1400	1400	1400	1400	2200	2200	2200
Required flux (edge of beam) 99% of the time) (dBW/m^2)	-162.7	-151.3	-136.7	-136.7	-128.2	-123.7	-118.3

BC/831

TABLE 6-45 (cont'd)

Examples of Interactive Community Reception Voice Frequency System Parameters: Uplink

Parameter[1]	1	2	3	4	5	6	7
Total atmospheric attenuation exceeded for less than 10% of the time (dB)	0	0	1	1			
Additional free-space attenuation (dB)					2	2	2
Additional loss equivalent to down-path noise (dB)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Atmospheric attenuation for 99% of the worst month (dB)			1	1	6	13	19
Required e.i.r.p. from earth station at beam edge (dBW)	0.6	12.0	28.6	28.6	43.1	54.6	66.0
3. Earth Station Transmitter							
Antenna diameter (m)	3.4	3	1.5	3.66	0.8	0.5	0.254
Antenna Gain (dBi)	25	36	44	52	45	46	45
Loss in feed, filters, etc. (dB)	1	1	1	1	1	1	1
Required earth station transmitter power: (dBW)	-23.4	-23.0	-14.4	-22.4	- 0.9	9.6	22.0
(W)	0.005	0.005	0.04	0.006	0.81	9.1	158

BC/531

TABLE 6-46

Examples of Interactive Community Reception Voice Frequency System Parameters: Downlink

Parameter(1)	1	2	3	4(15)	5	6	7
1. System							
Frequency of carrier (MHz)	700	2600	12,000	12,000	22,750	42,000	85,000
Carrier-to-noise density ratio before demodulation (exceeded for 99% of the time)(2) (dB-Hz)	54	54	54	54	54	54	54
2. Receiving installation							
Figure of merit, G/T (dB)(13)	-3.8	7.3	14.3	23.7	12.6	15.1	14.6
System noise factor (dB)(5)	5.6	5.6	5.6	4.4	6.8	5.6	6.1
System noise temperature (K)	750	750	750	500	1100	770	880
Noise power in a 1 Hz radio-frequency bandwidth for the above noise factor (dBW)(6)	-199.9	-199.9	-199.9	-201.6	-198.2	-199.7	-199.2
Carrier power required (dBW)	-145.9	-145.9	-145.9	-147.6	-144.2	-145.7	-145.2
Antenna diameter (m)(7)	3.4	3	1.5	3.66	0.8	0.5	0.254
Receiving antenna gain, relative to an isotropic source (dB)(8)(9)	25	36	43	50.7	43	44	44
Effective area of antenna, S (m^2) 10 log S	7	6	0	7.6	-5.6	-9.6	-15.6

BC/831

TABLE 6-47

Examples of Interactive Community Reception Voice Frequency System Parameters: Downlink

Parameter(1)	1	2	3	4	5	6	7
Required flux (edge of beam) (99% of the time) (dB (W/m^2)	-152.9	-151.9	-145.9	-155.2	-138.6	-136.1	-129.6
Free-space attenuation between isotropic sources 39,000 km apart (dB)	181	192	206	206			
Total atmospheric attenuation exceeded for less than 1% of the time (dB) (10)	0	0	1	1			
Free-space attenuation between isotropic sources 35, 786 km apart (dB)					210.6	217	223
Additional free-space attenuation (dB)					2(14)	2(14)	2(14)
Additional loss equivalent to up-path noise (dB)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Atmospheric attenuation for 99% of the worst month			1	1	4	8	15
Required e.i.r.p. from satellite at beam edge (dBW)	10.4	11.4	19.4	10.1	30.7	37.2	50.7
3. Satellite transmitter							
Antenna beamwidth at -3 dB point. (degrees)	1.4	1.4	1.4	2.3	1.4	1.4	1.4
Antenna gain at the edge of service area, relative to an isotropic source (dB) (12)	38	38	38	33	38	38	38
Loss in feeders, filters, joints, etc. (dB)	1	1	1	1	1	1	1
Required satellite transmitter power: (dBW)	-26.6	-25.6	-17.6	-26.9	-6.3	0.2	13.7
(W)	0.002	.003	.02	0.002	0.23	1.1	23.4

7.0 SYSTEM COST CONSIDERATIONS

7.1 Introduction

This section will address the costs associated with broadcast satellite systems already in operation, or in development, and will include considerations of broadcast satellite systems following the WARC-77 requirements at 12 GHz (EIRP $\approx$ 63-65 dBW, earth terminal G/T = 8 dB/$^{\circ}$K) and at 2.6 GHz and UHF.

Not all types of cost will be considered, i.e., direct-to-user costs, community reception costs, interactive TV system costs, and analog FM vs digital TV costs. Only direct-to-user costs will be addressed.

There are many contributions to costs incurred in both the ground segment and the space segment. The space segment costs can include not only the satellite costs, and the launch vehicle costs but also the on-going costs of operating a TT&C terminal for satellite control. The space segment costs can also include insurance against loss of satellite, and will also include the costs of manufacture incurred on a yearly basis until the delivery of the satellite, the cost of borrowing money where required, costs due to paying orbital incentives, and the costs of maintaining spares either in space or on the ground.

In all areas, space segment costs of broadcast satellites are similar if not identical to space segment costs of fixed service communication satellites and will have similar relationships to spacecraft weight in orbit and spacecraft DC power and EIRP.

In the ground segment, earth terminal costs for the reception of television are much less expensive than the earth terminal counterparts used in fixed service satellite (FSS) systems, TV receive terminals (TVRO and/or receive/transmit terminals) largely interface with the user. Unlike the FSS earth terminal which usually interfaces with a PTT type telephone or data distribution system, the broadcast satellite earth terminal interfaces directly with the user in the case of home-reception TVRO systems, or provides the signal for a cable or direct rebroadcast system. In either case, even if an uplink is also required, the TV receiving earth terminal is much less complicated as has been demonstrated in the preceding section and much less expensive.

One feature relative to broadcast satellite systems over FSS systems is that the use of costly powerful satellites in space - dominated by increasingly costly launch vehicles - makes possible high EIRP's in the 60-65 dBW range at 12 GHz which make possible very inexpensive (less than $1K) earth terminals and in quantities up to 10 million, the cheap individual earth terminal costs makes the space segment cost virtually "disappear" into the total system costs. FSS satellite systems have here-to-fore been built with channel EIRP's in the 30-35 dBW range requiring for many years, 10-meter and 30-meter antennas to receive Intelsat traffic, and 10-meter antennas to receive domestic satellite traffic. This low satellite EIRP is a cost forcing factor for the earth segment.

In recent years, the use of SATCOM II and WESTAR at 4/6 GHz to relay television programs for cable TV and specialized users has given impetus to the widespread use of special 3-meter and 4.5-meter TVRO terminals for commercial television program reception, and with over 3500 TVRO terminals in use in the U.S. as of 7/1/80 at 4 GHz, TVRO terminal costs between $5K and $15K are being realized, and deregulation of the reception from commercial TV distribution satellites has given rise to a "build-your-own" backyard TV terminal at 4 GHz with costs quoted as low as $2K.

7.2 Basic System Costs - An Introduction.

The basic system costs must consider both space and ground segments and the use of money. These aspects were succinctly set forth by W. Pritchard at IAF-30 in Munich, Germany, in September 1979, when he wrote that the general procedure to cost any satellite communication system "starts first with identifying all the elements of cost and the years in which they are going to be incurred. Cost elements are broadly in two categories, the lease or purchase of hardware and the purchase of services, whether these services be for manpower or leased circuits. The effect of these costs is very much determined by when they are incurred. Table 7-1 shows the principal cost elements of a space communication system divided into the aforementioned hardware and service aspects and also among the space, ground and interconnect segments of the system. We proceed by trying to identify the outlay of money in any particular year regardless of whether it is a capital outlay, a periodic payment for service or leasing facilities or an interest payment. In many cases, these costs can be determined on the basis of a published tariff such as for interconnect costs and services, or on the basis of manufacturers' quotations. Maintenance costs are sometimes estimated as a percentage of the hardware cost plus the costs of manpower. Note that a user can supply a service and element himself, in which case he has a capital and cost outlay in particular years, or he can lease the hardware and purchase the service. The numbers entered in any particular year obviously change, but the method of approach is identical. We always start by identifying each expenditure in the year in which it is made. If a cost is to be estimated rather than taken on the basis of firm quotations, it should be estimated in the "present year" dollars and then corrected for a predicted inflation rate. If the inflation rate is 10% per year, then the "in year" cost C_o is related to the current estimate C_e by

$$C_o = C_e (1 + i)^n$$

Occasionally, for purposes of official government estimating or for the pricing of items such as launch vehicles, there are official inflation rates or tables to be used along with Eq. (1) or instead of it. Table 7-2 is a list of inflation factors that have been used by NASA in the United States and other U.S. Government agencies in recent years for calculating U.S. launch vehicle costs. They may change.

The most difficult part of determining the elements (for a fixed service system) is that of estimating the hardware costs. This is necessary for a system planner regardless of whether he proposes to buy this hardware or to lease it from another party, since the lease costs normally also depend on the hardware costs. The costs of all the hardware, whether it be spacecraft or terrestrial, are a function of the requirements, that is the traffic to be carried. The traffic must first be predicted, its type, e.g., telephone data or television, its intensity, that is the number of circuits, and very importantly, the rate at which it is expected to grow.

Pritchard has developed a cost matrix for a 3-satellite program shown in Table 7-3 which includes all aspects of systems costs listed in Table 7-1. As shown, three satellites costing 40 million dollars are acquired; two are launched using launch vehicles each costing 20 million dollars. Earth stations of both 30-meter and 10-meter variety are used.

The satellite and launch vehicle costs used by Pritchard are typical costs based on historical perspective for satellites such as the Intelsat satellite series, WESTAR, described in Tables 7-3 and 7-4. Note that these costs, expanded over a 10-year period, assure a 3-year time-to-build, a satellite life-time of

TABLE 7-1

Estimating Check List

		Hardware	Service
Space	- Satellite	X	
	Transponder		X
	Launch Vehicle		X
	TT&C	X	X
Ground	- Earth Stations	X	X
	Interconnect	X	X

TABLE 7-2

Planning Inflation Rates (NASA Shuttle)

January 1975 (Reference)	1.0
July 1978	1.34
1979	1.45
1980	1.55
1981	1.66
1982	1.77
1983	1.90
1984	2.03
1985	2.17
1986	2.33
1987	2.49
1988	2.66
1989	2.85
1990	3.05

TABLE 7-3

- Program Cost Matrix (3 satellite program)

Year	-3	-2	-1	0	1	2	3	4	5	6	7
Pay to S/C Manufacturer[1,4]	10	10	10	10	1	2	2	2	2	2	2
Launch Vehicle[2]		5		20	20						
Launch Insurance[3]				2	2						
TT & C - Purchase Stat.[5]			5								
O & M				2	2	2	2	2	2	2	2
Earth Sta. (6 Large)[6]				5	10	10	5				
O & M				1	3	5	6	6	6	6	6
Earth Sta. (20 Small)[7]				5	5	5	5				
O & M				1	2	3	4	4	4	4	4
Terrestrial Interconnect				1	1	2	2	3	3	3	3
"In Year" Totals	10	15	15	47	46	29	26	17	17	17	17
Present values	14.8	19.5	17.1	47	40.4	22.3	1.6	10.1	8.8	7.7	6.79
NPV (at 15%)[8]				212.1							
Level Cost					49.5	49.5	49.5	49.5	49.5	49.5	49.5

NOTES FOR TABLE IV

1 Payment to contractor of 40M in 4 equal payments before launch.
2 2 Satellites in orbit - one unlaunched spare.
3 Launch Insurance at 2M/launch for both vehicle and spacecraft.
4 Incentives at 1M/yr. per spacecraft - successful operation after launch.
5 TT & C Sta. - 5M and 2M/yr. operating and maintenance.
6 6 Large Earth Sta. - 5M and 1M/yr./sta. O & M (Incl. microwave relays to central office).
7 20 Small Earth Sta. 1M and .2M/yr./sta. O & M.
8 Net present value or discounted cash flow.

TABLE 7-4

TYPICAL COSTS FOR SYSTEM COMPONENTS

(COSTS IN MILLIONS OF CONSTANT 1975 DOLLARS)

	INTELSAT-IV	COMSTAR	WESTAR
Spacecraft	16.2[1]	16.5[1]	10.3[2,3]
Booster	22.5[1]	22.5[1]	15.0[2]
On-Orbit Cost	38.7	39.0	25.3
Annual Satellite Cost	7.7	7.8	5.1
Annual Channel Cost	.64	.37	.43
Large Terminals (up to 30 meters)	5.0[4]	3.5[4]	
Medium Terminals (10 meters)	3.0[4]		2.0[4]
Small Terminals (4.5 meters)			0.5[4]

1. COMSAT, annual report to the President and Congress, 1974.
2. DCA, "A Digest of Satellite Communications Systems", Vol. IV, September 12, 1973, p. 8-56.
3. "Hughes Let $71.1 Million Indonesia Sat Pacts", Electronic News, February 24, 1975, p. 22.
4. Representative costs derived from manufacturers.

TABLE 7-5

BASIC CHARACTERISTICS OF INTELSAT SATELLITES

(INTELSAT I THROUGH INTELSAT V)

Satellite Type	Launch	Vehicle	Capacity	Average Cost Per Satellite ($ US)	Cost of Launch ($ US)	Total Cost Satellite and Launch ($ US)	Satellite Lifetime (Years)
Intelsat I	4/6/65	Augmented Delta	240 Voice Circuits or TV	$ 7,000,000	$ 4,700,000	$11,700,000	1.5
Intelsat II	10/26/66	Augmented Delta	240 Voice Circuits or TV	$ 3,600,000	$ 4,600,000	$ 8,200,000	3.0
Intelsat III	9/18/68	Augmented Delta	1200 Voice Circuits plus 2 TV Channels	$ 6,250,000	$ 5,750,000	$12,000,000	5.0
Intelsat IV	1/25/71	Atlas-Centaur	4000 Voice Circuits plus 2 TV Channels	$16,200,000	$22,500,000	$38,700,000	7.0
Intelsat IV-A	9/25/75	Atlas-Centaur	6000 Voice Circuits plus 2 TV Channels	$21,500,000	$26,000,000	$47,500,000	7.0
Intelsat V	Late 1979 or Early 1980	Atlas-Centaur, Space Transportation System (STS) or ESA's Ariane	12,000 Voice Circuits plus 2 TV Channels	$28,000,000	$32,000,000	$60,000,000	7.0

7 years, orbital incentive fees, cost of yearly operation and maintenance of both ground and space segments, and the TT&C terminal and terrestrial interconnects. Note too, that even with these costs which represent, by today's standards, the very low satellite and launch costs of the mid 1970's, the satellite and launch vehicle dominate the system costs with the satellite and launch vehicle substantially sharing this cost domination. However, this cost is for a dedicated system with relatively few earth terminals and must be seriously re-structured in a system where terminal-proliferation can be the dominating cost factor. This earth segment cost domination for high volume earth terminal systems will hold true regardless of whether the earth terminals are owned by the systems, or are purchased separately and contribute to paying system costs either by user subscription costs or by transponder leases.

Actually, the impact on satellite system costs by large-volume earth terminals is being felt in the U.S. domestic satellite such as WESTAR and SATCOM systems, which are used for television distribution. As pointed out in Section 6.1, more than 3400 TVRO terminals at 4 GHz with antenna sizes from 3 meters to 10 meters are being used with typical costs ranging from around $15K for a 4.5-meter terminal and $37.5K for a 10-meter terminal. Assuming a $30K per terminal cost, it is evident that 3000 terminals represent an investment of $90M which is comparable to the space segment cost.

However, in a broadcast-to-user broadcast satellite system which will use large, high radiated power satellites and, say a system of earth terminals of the home-user type, purchased at a rate of 200,000 per year, then a surprising result is presented when a cost matrix of the Pritchard type is used. Assume small home-user earth terminals, each costing $1K, a three-satellite system each costing $40M (Intelsat-V bus type), a $50M launch vehicle of the Atlas-Centaur class and a ten year time span with 7 years satellite life, then the cost matrix of Table 7-6 shows that the broadcast satellite system is totally cost-dominated by the earth segment - even with the use of large expensive satellites and launch vehicles.

7.3 Launch Vehicle Costs.

Most studies of broadcast satellite systems before 1978, and the introduction of the STS space transportation system include low launch vehicle costs which make such studies virtually obsolete.

The Space Shuttle and its capability of providing low cost launches into low earth orbits (less than 160 miles) initially led to a virtual discontinuance or early phase-out of the Atlas-Centaur and Delta class launch vehicles which were the backbone of satellite launches in the 1960-1970 period.

With the slippage of the Space Shuttle and the successful development of both Europe's ARIANE sponsored by ESA, and Japan's N-Rocket, the Atlas-Centaur and Delta class rockets are not only being made continuously available with upgrades in load capability, but the Atlas-Centaur upgrade must be considered as a very real answer to the growing economic competitive threat of the ARIANE rocket which is now assured many European payloads and which will carry some Intelsat-V's.

In the early 1970's, the Delta 2914 and the Atlas-Centaur handled the satellite payloads having geosynchronous weights of 800 lbs and 2100 lbs respectively as shown in Table 7-7. These launches cost from \$14M to \$24M. In the mid 1970's, the Delta 3910 (sponsored by RCA for use with SATCOM) and Delta 3914, were also developed and, with the ARIANE and the STS system in the development stage, the spacecraft system design was limited to payloads in the 800-2100 pound class (300-900 Kg) by this launch vehicle availability. Figure 7-1 illustrates the on-orbit mass in Kg and the primary power in watts of most of the satellites

TABLE 7-6

Program Cost Matrix (3 satellite program)

Year	-3	-2	-1	0	1	2	3	4	5	6	7
Pay to S/C Manufacturer[1,4]	30	30	30	30	5	5	5	5	5	5	5
Launch Vehicle[2]		5		50	50				60		
Launch Insurance[3]				10	10				12		
TT&C - Purchase Stat.[5]			5								
O & M				2	2	2	2	2	2	2	2
Earth Sta. (6 Large)[6]				3	6	6	3				
O & M				1	3	5	6	6	6	6	6
Earth Sta. (6 Transportable)[7]				1	1	1	1				
TVRO - 1-meter - (200,000/year)[8]				200	200	200	200	200	200	200	200
Terrestrial Interconnect				1	1	1	1	1	2	2	2
"In Year" Totals	30	35	35	299	280	220	218	214	287	215	215

1. Payment to contractor of 120M in 4 equal payments before launch.
2. 2 satellites in orbit - one spare launched in year 5.
3. Launch Insurance at 10M/launch for both vehicle and spacecraft.
4. Incentives at 5M/yr. per spacecraft - successful operation after launch.
5. TT&C Sta. - 5M and 2M/yr. operating and maintenance.
6. 6 large earth terminals - $3M & 1M/yr/sta. O&M (incl. microwave relays to central broadcasting studios and offices).
7. Transportables for providing remote up-links.
8. 1-meter direct-to-user 12 GHz terminals costing $1K each.

TABLE 7-7

Launch Vehicle Payloads - 1976

Launch Vehicle	Synchronous Transfer Orbit Payload (Lb)	Synchronous Equatorial Orbit Payload (Lb)*	Launch Cost in 1976 Dollars
N-Vehicle (Japan)	550	260	---
Delta 2914	1550	800	$14.2 M
Delta 3914	2000	930	$15.0 M
Ariane (ESA)*	3300	1830	$25.0 M**
Atlas-Centaur	4150	2100	$24.5 M

* Not tested until 1979

** Assumes AKM

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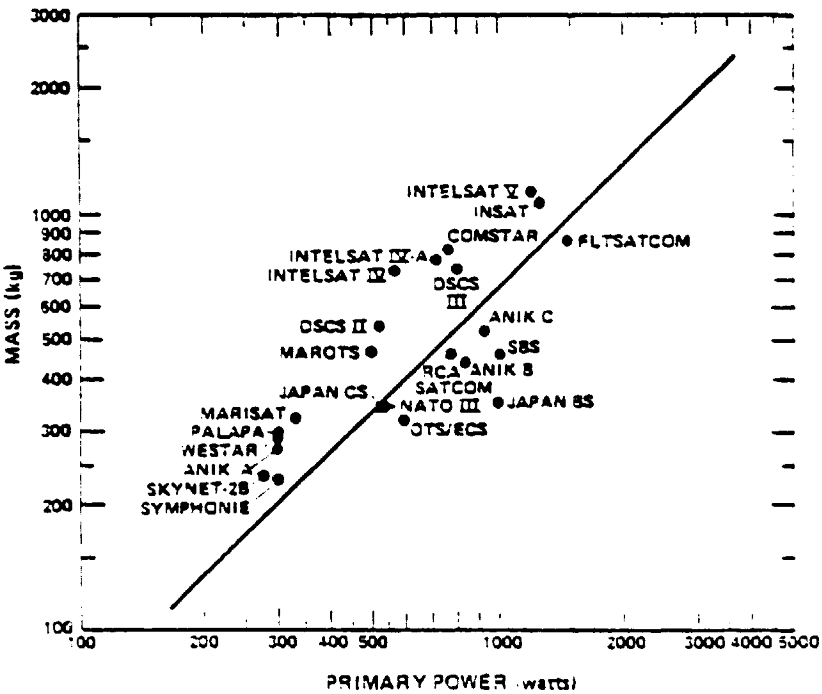


SATELLITE ON ORBIT MASS vs PRIMARY POWER
Figure 7-1

built and launched or designed for launch during the era of the 1970's showing the upper mass level of one thousand kilogram and the dc power level of one KW of these satellites.

Figure 7-2 shows the launch vehicle history and availability during the next six years as set forth by C. L. Cuccia and R. J. Rusch at the AIAA 8th Communication Satellite Systems Conference in April 1980, showing the Atlas-Centaur and Delta 3910, the Delta 3920 which will be available in 1982, and the upgraded Atlas-Centaur whose load capability is being increased to almost 5000 pounds.

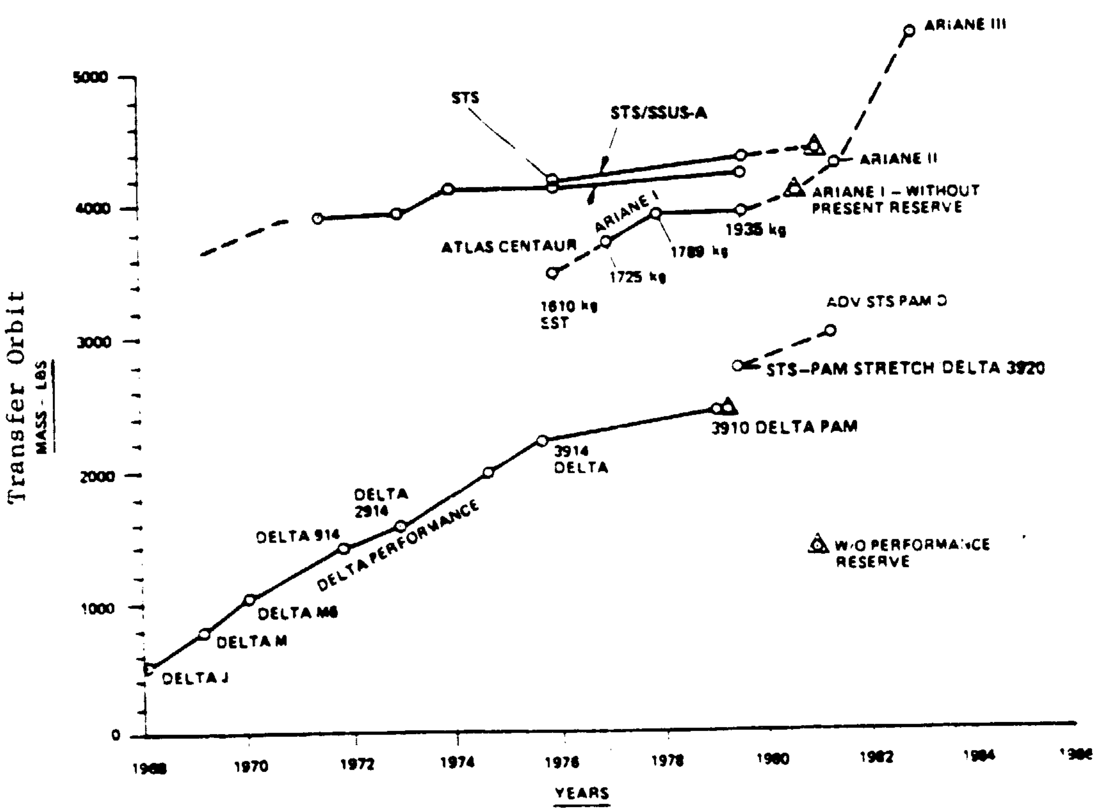
Any new user or designer of a space communication system which requires a launch, simply cannot achieve a reservation on a STS launch until 1986 and must rely on the Delta 3910, Delta 3920, Atlas-Centaur, and the ARIANE vehicles to provide that launch.

On May 30, 1980, a STS Users Conference was held at Cape Kennedy by NASA at which the new costs of the two Delta vehicles, and the Atlas-Centaur were disclosed. These costs plus the costs published in 1980 for ARIANE are listed in Tables 7-8 through 7-11.

Note that the wide disparity between launch vehicles has virtually disappeared. The Delta 3920 cost of \$37.65M is not too far from the Atlas-Centaur cost of \$43M or the ARIANE cost of \$41.2M. Thus a \$40M ± 5M cost for a launch vehicle depending on year of inflation and cost of money will be the baseline for launching any new communication satellite into geostationary orbit until 1987, regardless of the on-orbit satellite weight required. This is an important consideration for broadcast satellites since the size and complexity of such a satellite will not significantly mitigate against its launch cost.

Figure 7-2

Increase in Launch Vehicle Capability



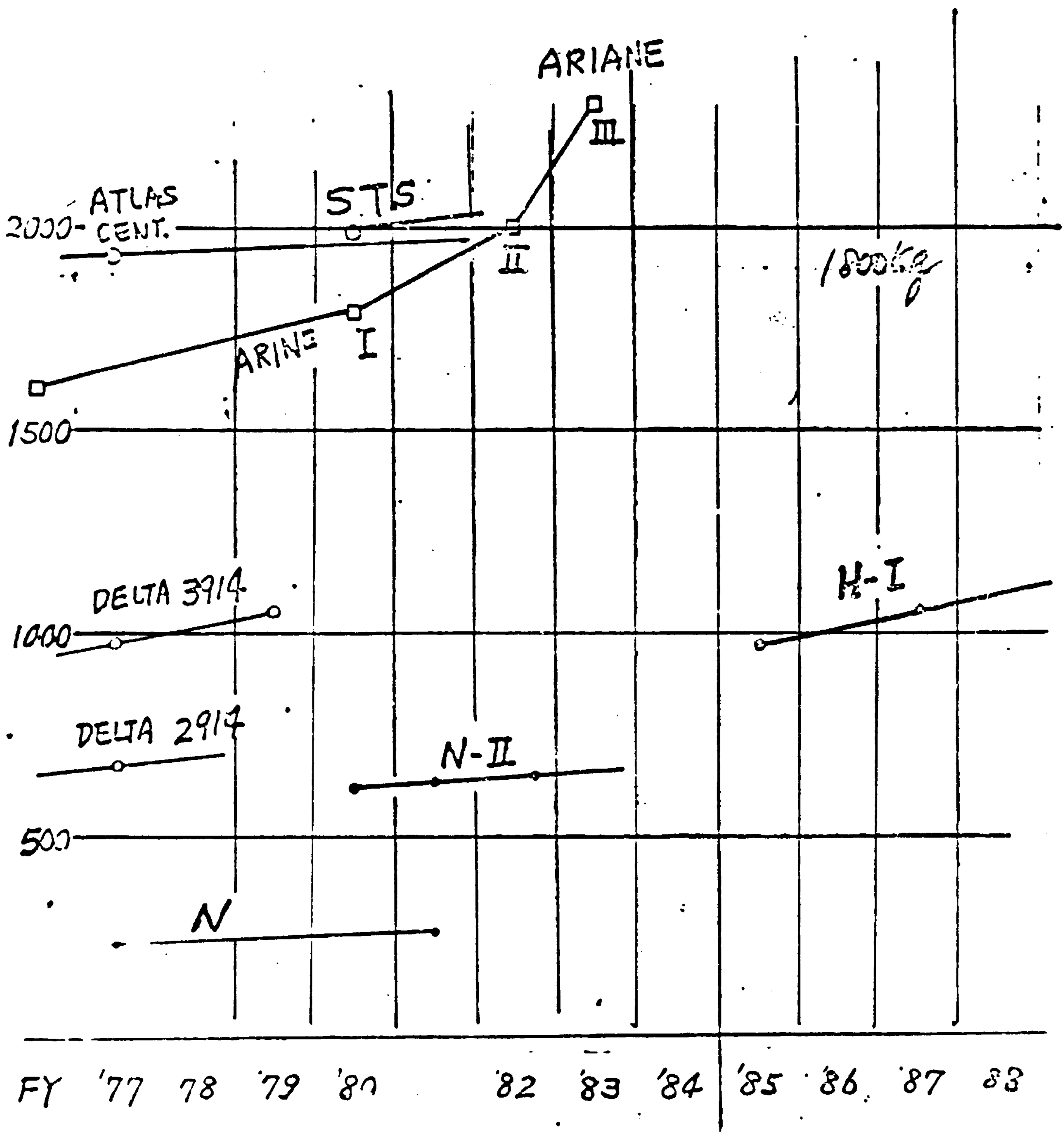


Figure 7-2A Japanese Launch Vehicle Plans

TABLE 7-8

Expendable U.S. Launch Vehicles

1980-1985

	Delta 3910	Delta 3920	Atlas/Centaur
Launch Vehicle	$27.4 M	$32.4 M	$43-45 M
Upgraded Charge	1.25 M	1.25 M	
PAM-D Including Optional Services	4.0 M	4.0 M	
Total Cost	$32.65 M	$37.65 M	$43-45 M
Payload Weight into Synchronous Transfer Orbit	2400 lbs	2750 lbs	4800 lbs
Cost/Lb. into Transfer Orbit	$13,100	$13,250	$9,200

TABLE 7-9

Uprated Delta Launch Vehicle Price by General Dynamics

(Millions of Then Year Dollars

	Launch Year	
	1982	1983-84
Standard Delta 3910	25	27.5 - 28.75
3910 Surcharge	1.25	1.25
PAM-D	2.5	2.75 - 2.88
Uprate Hardware	2.5	2.5
Uprate Non-Recurring	0.5 - 1.5	0.5 - 1.5
Total for STS Users	31.75 - 32.75	34.5 - 36.75
Charge for Non-STS Users	1 - 1.7	1 - 1.7
Total for Non-STS Users	32.75 - 34.45	35.5 - 38.45

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TABLE 7-10

ARIANE Launch Vehicle Price as of 1 July 1980

	1978 Francs (Millions)	1979$ (Millions)*	1980$ (Millions)	1983-84 Launch Cost ($ Millions)
Full ARIANE	140	34	36.7	41.2 - 44.5
Shared ARIANE (ESA finds compatible payload)	75	18	19.4	21.8 - 23.6

* Based on Oct 1979 exchange.

TABLE 7-11

ARIANE Proposed Financing

French financing (60% of launch cost)

- o 40% (of 60%) at 3.5% interest
- o 10 year grace period
- o 25 year amortization
- o Balance at approximately 8%

German financing (40$ of launch cost)

- o No commitment but expected to be equal to or better than French

7.3.1 Considerations of Shuttle Launch Costs.

The Space Shuttle's total capacity in weight and volume is much greater than that required for most geostationary satellite systems. NASA has established a pricing policy that permits the purchase of a part of the Space Shuttle capacity, with the price for sharing the capacity as set forth in the NASA Space Transportation System Reimbursement Guide, JSC-11802 dated May 1980.

The price charged to users for standard Space Shuttle transportation will be based on estimated costs accrued over a 12-year period. This price will be fixed (except to adjust for inflation) for flights in the first 3 full fiscal years of STS operations. Subsequently, the price may be adjusted annually to ensure that total operating costs are recovered over a 12-year period.

The prices listed are based on 1975 dollar values unless otherwise noted. Escalation for inflation will be computed according to the Bureau of Labor Statistics index for the private business sector, all parameters: productivity, hourly compensation, unit labor cost, and prices seasonally adjusted.

A shared-flight user will pay a percentage of the dedicated-flight price. The price for all payloads is based on launch weight or length and is calculated as follows:

1. To calculate a weight load factor, the user should divide the payload weight (including upper stages, flight kits, support equipment, etc.) by the total Shuttle payload weight capability at the desired inclination. Standard orbit inclinations are offered to users for flights originating from the Eastern Test Range (KSC launch). These inclinations and corresponding weight capabilities are listed below:

Launch Site	Inclination, Deg.	Altitude, n.mi.	Weight Capability, Lb (Kg)
KSC	28.5	160	65,000 (29,484)
KSC	57	160	56,000 (25,401)

2. To calculate an approximate length load factor, the user should divide the payload length (including upper stages, airborne support equipment, rotational clearance, etc.), plus 6 inches (15.2 centimeters) nominal for dynamic clearance, by the length of the cargo bay, 720 inches (1829 centimeters). The actual dynamic clearance will be used for final billing.

3. To determine a charge factor, the user should now divide the load factor (length or weight, whichever is greater) by 0.75. However, the effective charge factor is never greater than 1.0.

4. To determine the price for his payload, the user should multiply the price of a dedicated flight (plus a use fee, if applicable) by the calculated charge factor.

The payload-sharing nomographs (Figure 7-3) are provided to help a user quickly determine the approximate price. A standby user will receive a discount of 20 percent of the calculated shared price.

7.4 Spacecraft Costs.

During the past few years cost-estimating models have been developed based on components and/or major subassemblies (Fong, 1977; Bekey, 1978). The advantages of such models are that they give a more accurate description of a given subsystem and that they can take into account the development status of particular components. The disadvantage of these models is that they cannot be applied to advanced concept satellites where there is insufficient information about the subsystems (assuming they agree on subsystem definitions).

Satellite development (non-recurring) costs appear to be the most sensitive to program peculiarities while production (recurring) costs are less sensitive and are much better estimated by all the cost models. Recent studies (Dryden and Large, 1977), suggest that cost models should not be used mechanically.

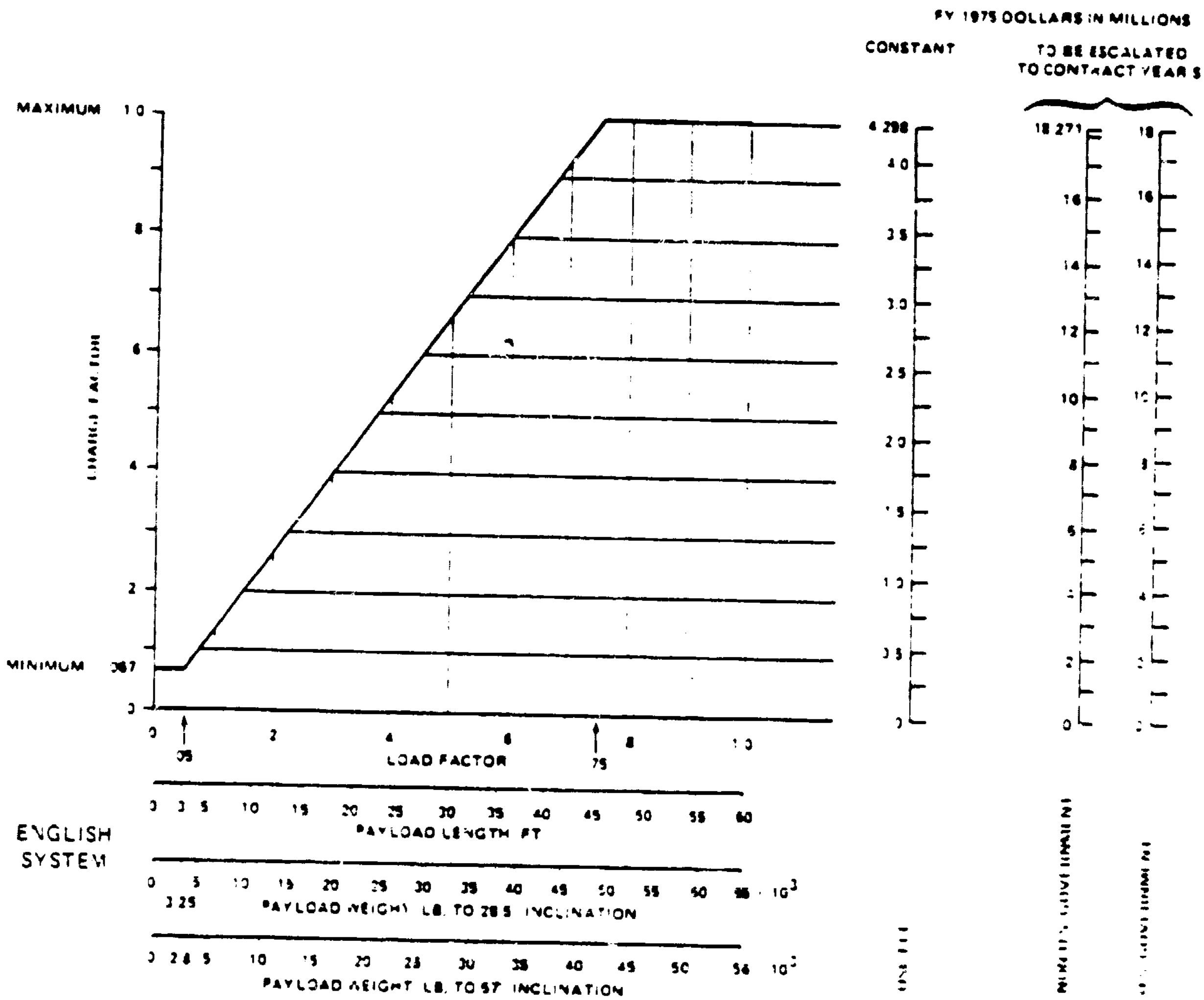

Figure 7-3

Payload-Sharing Nomograph - English System

While the models themselves differ sharply and give different results, nevertheless all appear to agree that the most important variable is weight and that very few other variables are useful.

7.4.1 Simple Cost Model.

It is not possible to determine at satellite costs by a quotation from a manufacturer, particularly in the planning stages. If parametric studies for optimization are to be done, it is important to be able to estimate a satellite's cost from its principal characteristics. Numerous cost models have been developed for calculating costs given weight and power estimates.

On-orbit weight is a good cost driver since all the desired performance features affect S/C weight, including especially primary or radiated power. A simple formula for guessing the on-orbit weight in kg. of a satellite, given its total power in watts is:

$$W = 7.9p^{0.64} \qquad \text{Eq. (2)}$$

This equation is plotted in Figure 7-1 with a number of existing satellites indicated to give an impression about the goodness of fit. The weight then determines the choice of launch vehicle

7.4.2 The SAMSO Cost Model.

One of the most detailed cost models to estimate satellite costs was that of the U.S. Air Force several years ago (SAMSO - Fourth Ed. 1978). Its use requires a knowledge of the weights of the sub-systems, primary powers and a variety of other characteristics. A simplified expression derivable from that model, as presented by W. Pritchard at IAF-30 is:

$$NRE = 6035 + 50(1-u)W + 1367u^{0.51}W^{0.51}$$

$$C_1 = 122 + 66.8(1-u)^{0.81}W^{0.81} + 100.5u^{0.87}W^{0.87}$$

The equation gives the non-recurring costs NRE of a spacecraft of total orbit mass W in kg. and a fraction of this mass u devoted to the communications and antenna. C_1 is the cost of the first production unit of the same spacecraft. These costs are in 1976 dollars. These estimates yield \$55M for NRE and \$22.7M for the first production unit of Intelsat-V - consistent enough with the contract to have been adequate for planning.

The simplified "learning curve" from which the cost of subsequent models can be estimated is that given by T. P. Wright (1936). The cumulative average cost $\overline{C}_n$ for N units is given as:

$$\overline{C}_n = C_1 N^{-b}$$

If one assumes that doubling the quantities results in a reduction in unit cost to pC_1 then the total cost $T_n = \overline{C}_n$ is given as:

$$T_n = \left(C_1 N\right) N^{3.32 \log p} = N C_1 N^{3.32 \log_p}$$

A frequently used, and emperically justified value of p is 0.8 - then:

$$T_n = C_1 N^{0.68}$$

This model yields the manufacturers <u>costs</u>. If the satellite were purchased at the cost to the buyer, it would be augmented by an assumed profit. Many spacecraft are sold virtually at cost with the manufacturer taking a delayed profit in the form of incentive payments spread over the satellite's operation in orbit.

7.4.3 The DCA Cost Model.

An algorithm was generated for the estimation of the costs of communication satellites by DCA* in 1978. This algorithm, based on satellite weight, is plotted for both recurring and non-recurring costs in Figure 7-4 and includes the known costs of many medium satellites, showing the excellent correlation involved. These costs are based on the following equations where C_N and C_R are the non-recurring and recurring costs respectively and W_p is the satellite weight in kilograms.

$$C_N = 4.145 \times 10^4 \, W_p^{1.15}$$

$$C_R = 6.40 \times 10^4 \, W_p^{0.93}$$

These curves were developed by Professor David Staelin and Dr. R. Harvey for NASA Contract 5-25091**.

7.4.4 The Canadian Astronautics Cost Model.

In the April 1980 issue of Satellite Communications, two members of Canadian Astronautics of Canada, i.e., W. Payne and D. T. Tong, published a description of a new computer program for communications satellite cost and mass modeling to aid system engineers to make trade-offs in top system parameters. It is described as differing from previous cost models in that no apriori knowledge of spacecraft configuration is required. It also derives spacecraft cost on a subsystem by subsystem basis rather than a single parameter such as mass or power.

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* DCA, "MILSATCOM System Architecture", Annex G Cost Models, Military Satellite Communication Systems Off[illegible] Defense Communications Agency, Washington, D.C. (March 1976).

**"Future Large Broadband Switched Satellite Communications Networks", Research

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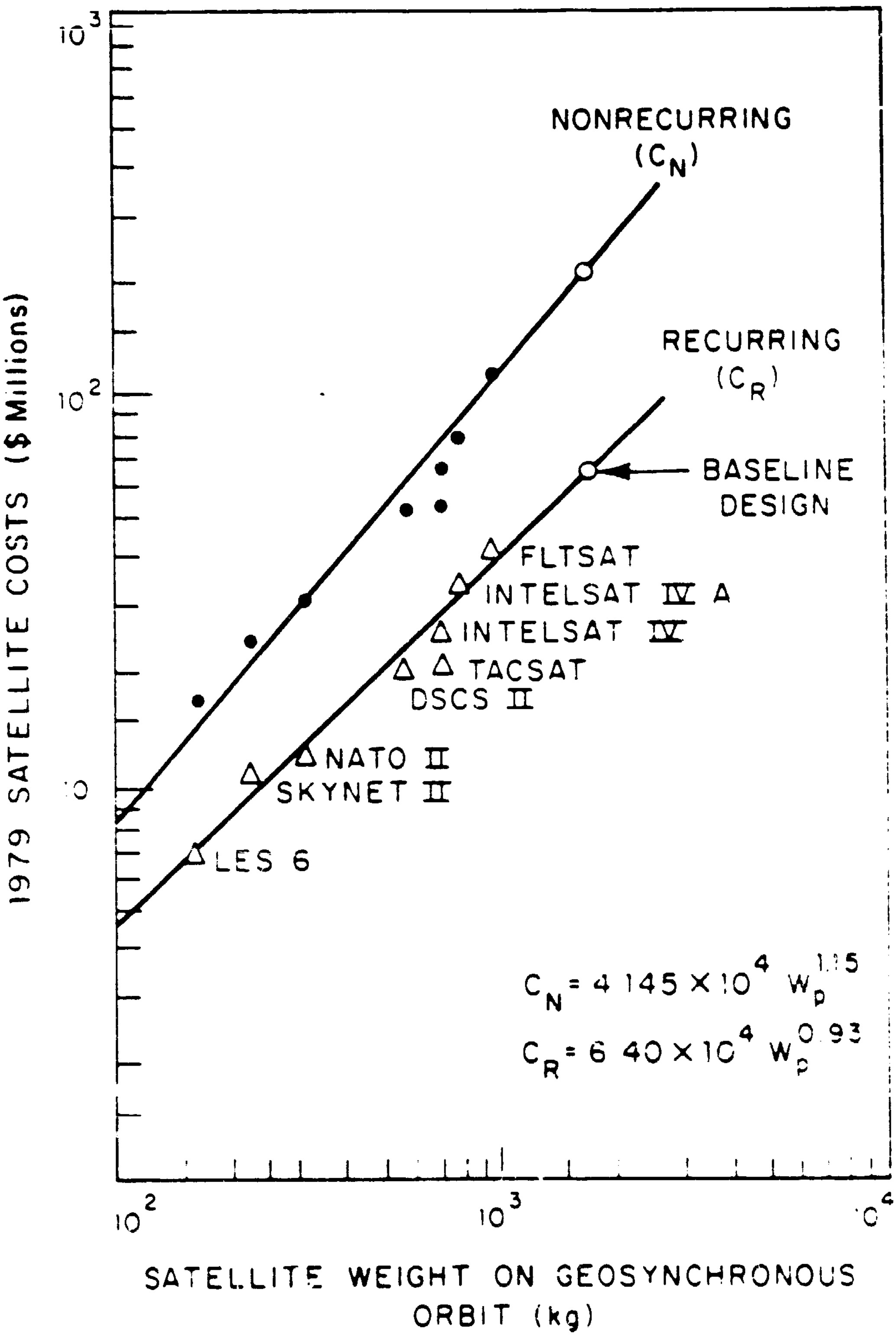

Figure 7-4
DCA Model for Recurring and Non-Recurring Spacecraft
Costs in 1979 Dollars

Tables 7-11 and 7-12 show respectively a cost model derived by Payne and Tong for a hypothetical satellite called "Typicalsat", and typical satellite costs provided by the computer as compared to published costs. The agreement is excellent, and it is evident that this computer model is a useful tool for trade-offs.

7.4.5 The Ford Aerospace and Communications Corporation (FACC) Cost Estimation Model.

In 1978-1980, M. Baker, Jr. and S. Melachrinos of FACC devised a computer program for estimating spacecraft weight and cost based on a modified version of the SAMSO spacecraft cost model. This computer model has been designed to provide systems engineers a tool to estimate S/C sizes and costs, and the effect of increasing or decreasing communications capability on size and cost when performing system level definition and trade-offs. The model is limited to communication payloads or payloads that are equivalent for estimating size and costs although the S/C parameter estimates can be used for sizing any type of spacecraft. The model is limited to 3-axis S/C and the use of the STS as a launch vehicle. The FACC cost estimation model is provided in Appendix A.

The SAMSO statistical base does not include S/C on the 4-7,000 lb. category. There is, therefore, some question to its validity when extended to this category of S/C. FACC has examined relatively detailed S/C designs in this range and has concluded that the SAMSO model can be extended to this range and may be valid within the basic overall validity of the original SAMSO model. Application of this cost model to S/C greater than 7,000 lbs. on orbit and especially those S/C which might be assembled on orbit is not valid.

The estimated S/C subsystem weights and power are re-arranged to fit the SAMSO Cost Estimating Relationship (CER) parameters and Basic Cost Estimates at the subsystem level are generated using an FACC-modified version of the SAMSO

TABLE 7-11

Communication Satellite Cost Model by

Canadian Astronautics, Ltd.

Model Name: Typicalsat

Demonstration run version 02A February, 1980

System Parameters Summary

- Launch in 1982 on a shuttle luanch vehicle with a SSUS-D upper stage
- System has 4 spacecraft comprised of:
  - 2 in orbit operating
  - 1 in orbit spare
  - 1 on ground spare
- Spacecraft design life is 8.0 years
- Spacecraft mass is: 327 KG
  of which payload is: 65 KG
  bus is: 262 KG
- Payload length is 8 ft.
- Program cost is 91.234 million dollars
- 3-axis stabilized spacecraft with extendable rigid solar panels equipped with black solar cells
- Hydrazine monopropellant ausiliary propulsion
- Nickel cadmium battery
- Conventional structure design
- Antenna types used:
  Precision parabola 1.096 diam(M)
- Power requirements (watts):
  - 343 Beginning of Life
  - 269 End of Life
  - 269 Eclipse

Total Cost Summary - 1978 U.S. Dollars - Launch in 1982

Costs (Thousands of $)	Non-Recur.	Recur.	Overall
S/C Program Costs			
Hardware Costs	8244	7794	39421
S/C Integration	1566	1481	7490
Mgmt. and Sys. Engineering	981	928	4691
Mission Analysis	1000	200	1800
T&L	75	250	1075
Profit	1079	1020	5160
Sub-total	12946	11673	59637
Launch Costs			
Upper Stage Costs	1662	2295	10842
Launch Vehicle Costs	320	5109	20755
Sub-total	1982	7404	31597
Program Total	14928	19077	91235

TABLE 7-12

Typical Satellite Costs Provided by

Canadian Astronautics, Ltd.

Program	Mass (kg)	Published Cost	Computer Derived Cost	
			Base Yr.	Cost
ANIK-A	297	35	71	35
ANIK-B	466	24	76	27.6
ANIK-C	548	67	78	64.1
SBS	545	50 + Bonus	78	49.6
MARISAT	326.2	48	77	48.3
Japan BSE	352	?	78	24.5

CER's[1,2]. Weighted complexity factors are then generated and applied to the Basic Estimates to arrive at the cost estimates for the derived S/C. Both non-recurring costs and recurring (First Unit Costs) costs are generated including Management and Support, prototype refurbishment (where required) and total space segment costs including profit and on-orbit incentives, transfer orbit system costs, and STS costs.

Using the payload weight and power as inputs, the model generates estimates for:

- o Structure Weight
- o TT&C Weight and Power
- o Attitude Control Weight & Power
- o Propulsion Weight
- o Electrical/Mechanical Integration Weight
- o Thermal Weight
- o Electrical Power Weight
- o Number of Cells in the Array
- o EOL & BOL Power (equinox)
- o On-Orbit Fuel Weight
- o S/C On-Orbit Weight
- o S/C Launch Weight
- o Transfer Orbit System

These extimates are all based on FACC experience.

An illustrative satellite design for cost estimation has the hypothetical parameters listed in Table 7-13. What is significant is the use of 6 antennas

---

1. Franklin Fong, et al, SAMSO Unmanned Spacecraft Cost Model, Updated Cost Estimating Relationships & Normalization Factors (An Interim Report), Cost Analysis Division, Hq. SAMSO, January, 1977.

2. Christopher J. Rohwer, et al, SAMSO Unmanned Spacecraft Cost Model, Third Edition, Cost Analysis Division, Hq. SAMSO, TR-75-229, August 1975.

TABLE 7-13

Model Parameters

- o Geostationary spaoecraft
- o Number of flight S/C = 3
- o Number of on-orbit S/C = 2
- o Government spacecraft, standard cost
- o Base year = 1984
- o Mission duration = 10 years
- o Average annual inflation rate = 0
- o S/C length = 15 meters
- o Comm S/S weight = 600 pounds
- o Comm S/S power = 2500
- o RF power = 1000 watts total
- o Highest comm frequency = 15 GHz
- o Highest RF power level = >40 watts
- o Number of active power amplifiers = less than 10
- o Number of frequency bands = 2
- o Number of antennas = 6 or more
- o Multiple spot-beam antennas single reflectors
- o 10 feeds/ 1 antenna reflector
- o Basic TT&C
- o Max. TT&C rate = up to 100 kbps
- o No spacecraft processing on memory
- o ACS parameters - model, inertial reference
- o Pointing control - open loop
- o Input pitch pointing accuracy - 0.05 degrees

of the multiple beam variety, the RF power of 1000 watts and a communications subsystem power of 2500 watts. This satellite can use four 250-watt TWTA, or six 150-watt TWT to produce six or four transmit contoured beams respectively. The output of the computer model is listed in Table 7-14 showing a flight model cost of 31 million dollars per spacecraft and an STS cost of 52 million dollars. The total program cost for these spacecraft is around 235 million dollars. The pertinent spacecraft parameters are listed in Table 7-15 as derived from the format of Table 7-16 used for Table 7-14; more complete definitions can be obtained from the Appendix A.

7.4.6 Satellite Cost Versus Various Parameters.

In these paragraphs we will explore the impact of weight, primary power, capacity, antenna complexity, RF power and pointing accuracy on satellite cost. In these considerations, it is important to realize that only three launch vehicles will be available for new spacecraft designs until at least mid 1986 and therefore the spacecraft designer is essentially limited to the launch weights and costs of the Delta launch vehicles 3910 and 3920, Atlas-Centaur, and Ariane I, II, and III. These launchers all cost in the neighborhood of 40 million dollars and therefore the spacecraft designer must largely choose between spacecraft launch mass weights of 2500 lbs or 4800-5000 lbs. The STS with SUSS-A will largely continue the Atlas-Centaur capability.

Given these launch weight capabilities, then we can make the following generalizations relative to spacecraft costs.

7.4.6.1 Satellite Cost vs. Mass Weight.

Each of the computer models previously described showed that spacecraft or satellite weight is a principal cost-determining factor. Figure 7-5 repeats a portion of the DCA computer model output for recurring costs showing how the

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TABLE 7-14

RF Power 1000 watts *

DELTA V1 = 2426.45 M/SEC DELTA V2 = 1830.70 M/SEC
COM WT = 600.0 LBS TTC WT = 49.6 LBS
ACS WT = 171.7 LBS EPS WT = 419.8 LBS
BOL = 4358.2 WATTS BUS WT = 1417.5 LBS
ON-ORBIT FUEL WT = 357.2 LBS
S/C ON-ORBIT WT = 2374.7 LBS S/C LAUNCH WT = 18034.7 LBS
PERIGEE MOTOR 2 WAS CHOSEN

DO YOU WANT A COMPLETE LISTING OF THE BASELINE?
THIS LISTING IS WITHOUT HEADINGS. 1=YES,2=NO
=1

600.0	49.6	293.7	171.7	419.8	71.4
81.6	63.1	266.5	1417.5	357.2	2374.7
10096.2	18034.7	0.0	1763.7	3800.0	2
8.0	15.0	3.0	29054.8	3030.0	4358.2
2500.0	$\boxed{1000.0}$ —RF Power				

See Tables 7-15, 7-16 for Format

STANDARD COSTING FORMAT (DOLLARS IN THOUSANDS)

NUMBER OF S/C = 3 NUMBER OF ON-ORBIT S/C = 2
R+D COST = $ 26643.2 PROTOTYPE COST = $ 39164.6
TOTAL NON-RECURRING COST = $ 65807.8
PROTOTYPE REFURB COST = $10766.3 FIRST UNIT COST = $31331.7
FLIGHT MODEL COST = $ 62663.4 ON-ORBIT INCENTIVES = $ 27847.5
S/C STORAGE COST = $1500.0
TOTAL S/C COST = $168585.0
PM COST = $15000.0 STS COST = $51777.2
TOTAL PROGRAM COST = $235362.2

YEAR 1 COST = $ 36829.3 0 S/C LAUNCHED
YEAR 2 COST = $ 69099.7 0 S/C LAUNCHED
YEAR 3 COST = $ 59540.7 0 S/C LAUNCHED
YEAR 4 COST = $ 19720.7 2 S/C LAUNCHED
YEAR 5 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 6 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 7 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 8 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 9 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 10 COST = $ 2934.8 0 S/C LAUNCHED
YEAR 11 COST = $ 6386.6 0 S/C LAUNCHED
YEAR 12 COST = $ 12338.4 0 S/C LAUNCHED
YEAR 13 COST = $ 12338.4 0 S/C LAUNCHED
YEAR 14 COST = $ 1500.0 1 S/C LAUNCHED

* See Tables 7-22 and 7-23 for RF power comparison.

TABLE 7-15

Parameters Printed by Baker-Melachrino Cost Model*

			Table 7-14
CWT	=	Comm S/S weight	600
EIW	=	Electrical integration weight	81.6
TOTFW	=	Total fuel weight (apogee motor + perigee motor fuel)	10,096
PML	=	Perigee motor length	8
CPWR	=	Comm S/S DC power	2500
TTCW	=	TT&C S/S weight	49.6
SIW	=	Structural integration weight	63.1
SCLWT	=	S/C launch weight	18034.7
SCL	=	S/C length	15
TRFP	=	Total RF power (sum of power amplifiers)	1000
STRW	=	Structure weight	293.7
PRPW	=	Propulsion S/S weight	266.5
XNRT1	=	Inert weight of external apogee motor	0
XSCB	=	Number of batteries	2
ACSW	=	ACS weight	171.7
BSWT	=	Spacecraft bus weight	1417.5
XNRT2	=	Inert weight of perigee motor system	1763
XCLS	=	Number of solar cells	29055
EPSW	=	Eps weight	19.8
OOFW	=	On-Orbit fuel weight	357.2
CLDW	=	STS cradle weight	3800
TBPR	=	Total bus power	3030
THRW	=	Thermal weight	71.4
SCOWT	=	S/C on-orbit weight	2374.7
PMX=	=	Perigee motor indicator	2
BOL	=	Beginning of life solar array output	4358

* Format shown in Table 7-16.

TABLE 7-16

WHEN A COMPLETE LISTING OF PARAMETERS IS PRINTED, THEY ARE IN THE FOLLOWING FORMAT (SEE USER'S GUIDE FOR DEFINITIONS)

CWT	TTCW	STRW	ACSW	EPSW	THRW
EIW	SIW	PRPW	BSWT	OOFW	SCOWT
TOTFW	SCLWT	XNRT1	XNRT2	CLDW	PMX
PML	SCL	XSCB	XCLS	TBPR	BOL
CPWR	TRFP				

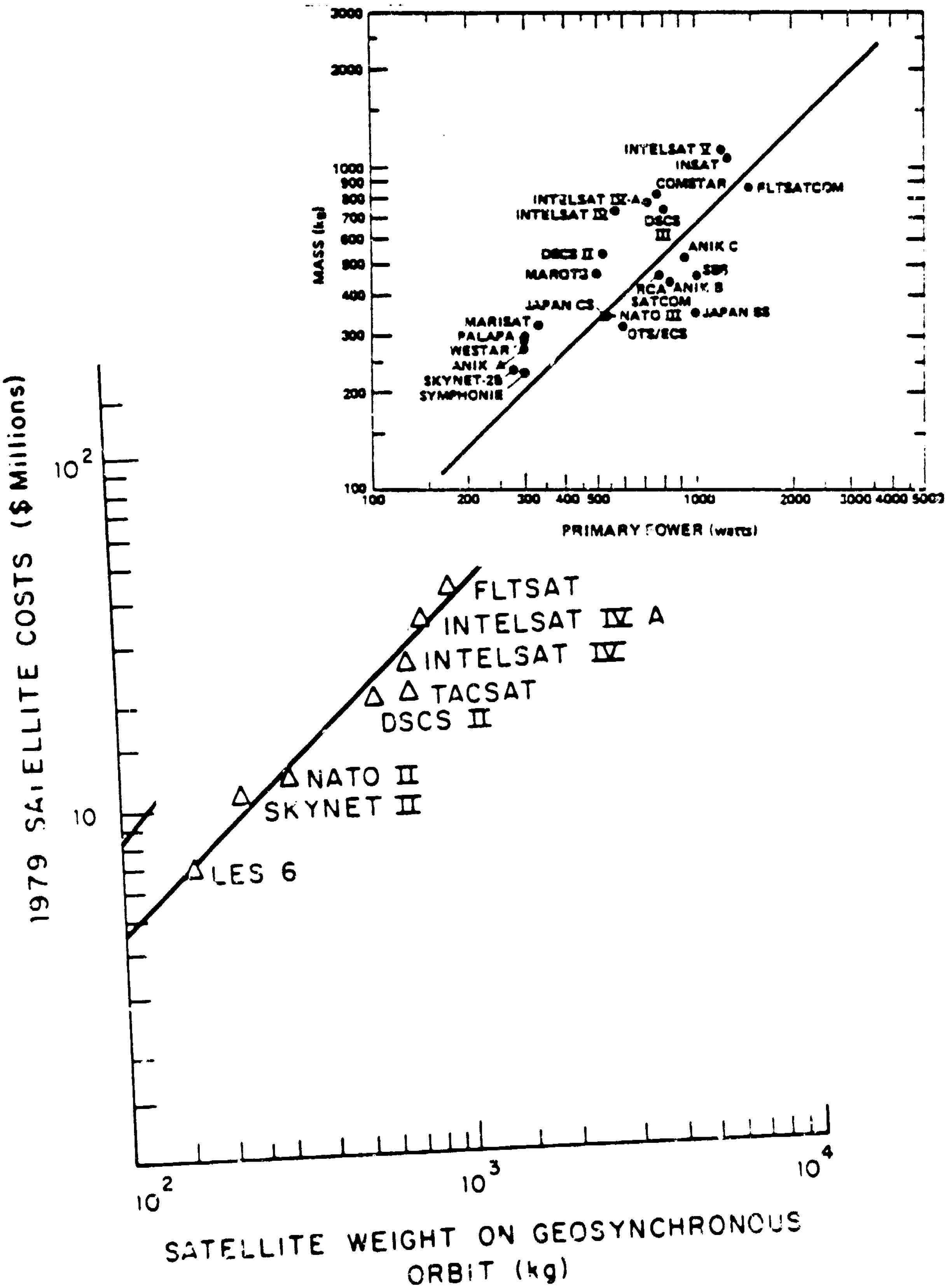


FIGURE 7-5

DCA Model for Recurring Spacecraft Costs in 1979 Dollars.

costs of a number of modern satellites conform to the DCA recurring-cost equation; the Figure 7-5 also repeats the mass vs. primary dc power curve described earlier showing the relatively consistent relationship of almost 1:1 between mass in orbit in thousands of KG's and thousands of primary power in watts for most satellites.

Figure 7-5 predicts that a satellite having an on-orbit dry mass (apogee kick motor expended) of around 1000 KG will cost around 40 million dollars. It It also shows that a large satellite weighing around 2500 KG in orbit will cost around 100 million dollars.

Tables 7-17 and 7-18 illustrate the difference in final orbit weight - which must also include the weight of the burned-out apogee motor in addition to the structure, antenna, communications system, telemetry and controls, electrical power, and mechanical integration weight making up the spacecraft mass. Table 7-17 illustrates the SBS payload weight budget for an STS launch illustrating largely the perigee motor propellant and hardware and the cradle system mass which must also be lifted into orbit. The Intelsat-V weight summary of Table 7-18 shows the breakdown of the 1869 Kg mass weight which the Atlas-Centaur must lift. The final Intelsat-V dry mass in final orbit is a little greater than one thousand kilograms.

Tables 7-19, 7-20 and 7-21 list the weight summaries for Intelsat-V, Japan BSE, and the German TV-SAT showing that the percentage of satellite weight devoted to communication payload is around 20% while the antenna weight is around 8%. In order to increase capacity spacecraft structure and other payload weight must be transferred to antenna and communication payload weight budgets. Figure 7-6 shows how as the spacecraft dry mass increases, the payload percentage of dry mass increases thus giving credence to very large satellites or space platforms and orbiting antenna forms (OAF) as proposed by Jaffe and Fordyce, and Edelson and Morgan in 1977.

TABLE 7-17

Nominal SBS Payload Weight Budget

Satellite in final orbit	1200 lb
Apogee motor propellant	1080
Perigee motor propellant	3700
Perigee motor stage hardware	300
Cradle and airborne support equipment	2200
Total payload in STS cargo bay	8500 lb.

TABLE 7-18

Nominal INTELSAT-V Weight Summary (Kg)
for Atlas-Centaur Launch

Satellite weight in final orbit	749.8
Apogee motor	922.5
Propulsion fuel	172.6
Total spacecraft weight at launch	1869.3

TABLE 7-19

INTELSAT-V Summary for Atlas-Centaur Launch

Subsystem	Mass (Kg)	Ave. Power
Structure/Thermal	183.1	
Propulsion	35.3	
Electrical power	141.9	
Communications transponder	174.6	780
Communications antenna	58.9	
Telemetry, command, and ranging	28.0	43.5
Controls	72.5	
Electrical integration	40.1	
Mechanical integration	15.4	
Total	749.8	1004
Apogee motor	922.5	
Propulsion fuel	172.6	
Total spacecraft		
Launch total	1869.3	
Mass margins	24.4	

TABLE 7-20

BSE Broadcast Satellite Weights

Power	161.1
ACS	59.2
Structure	106.8
RCS	105.2
TT & C	23.4
Mechanisms	60.8
Communications	151.5
Thermal	49.5
Ballast	8.2
Contingency	3.7
	730 lbs.

TABLE 7-21

TV-SAT A3 SYSTEM CHARACTERISTICS

PAYLOAD	3 + 2 (spare) channels with 260 W TWTA s. Separate transmit and receive antennas		
	Total Mass	167.3	kg
	Power requirement	2 238	Watt
	Reliability (5 years)	0.930	
SPACECRAFT	Power BoM/EoM [illegible] y	3 400 / 2 850	W
	System reliability (5 y	0.837	
	Bus reliability (10 y)	0.800	
	Payload Module mass	280.0	kg
	Service Module mass	300.0	kg
	Propulsion Module mass	210.0	kg
	Propellant for transfer, apogee maneuver and acquisition ARIANE: 593 kg,	Shuttle: 825.0	kg
	Propellants for attitude and orbit control	95 (max. 150)	kg
	Mercury for ion thrusters	10.0	kg
	Total mass after separation from		
	ARIANE	1 712.0	kg
	Shuttle + SSUS–A	1 880.0	kg
	Total length with extended arrays	19.25	m
SUBSYSTEMS	Antenna system with two deployable CFC dishes and central tower	56.7	kg
	Repeater with 5 TWTA's of 260 W	110.7	kg
	Power subsystem (50 V bus)	59.5	kg
	ULP solar array	93.5	kg
	Array drive assembly (BAPTA)	14.4	kg
	Data system (TT&C, data handling)	24.9	kg
	Attitude/orbit measurement & control	48.5	kg
	Unified propulsion system	91.5	kg
	RITA–1 electrical thruster package (2)	32.6	kg
	Structure (excl. adapter)	144.7	kg
	Thermal control hardware	63.5	kg
	Bus harness, pyrotechnics	26.4	kg
	Balance mass, miscellaneous	5.0 (A) to 30 (S)	kg

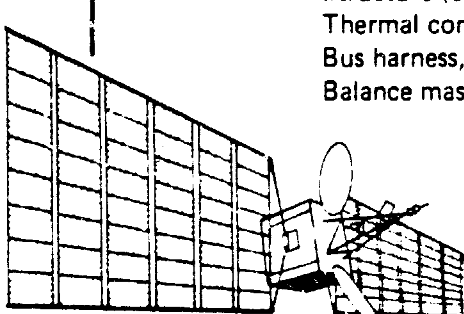
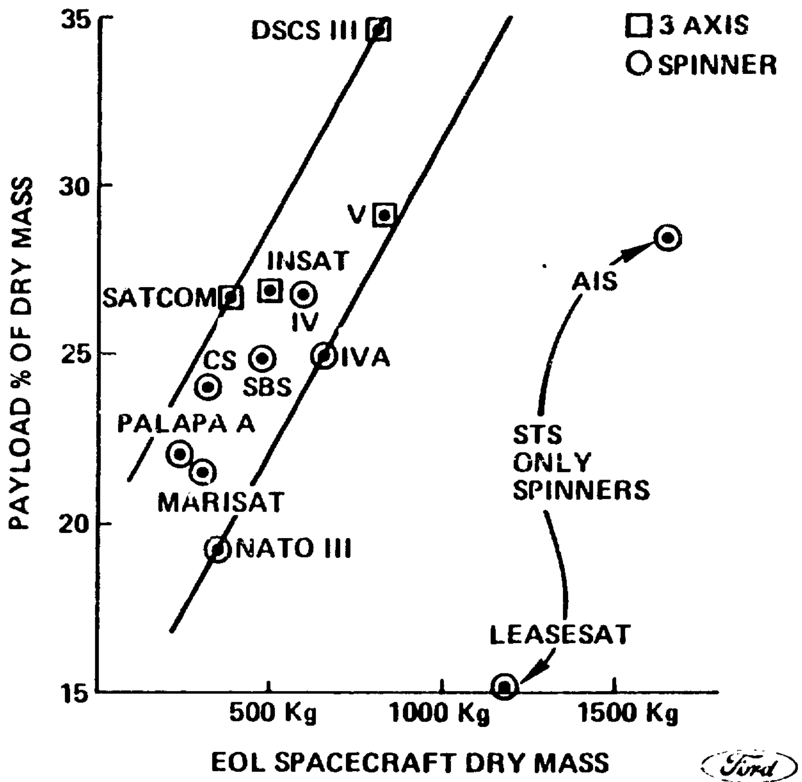


Figure 7-6

SPACECRAFT ECONOMY OF SIZE



Ford Aerospace &
Communications Corporation

7.4.6.2 Satellite Cost vs. Capacity.

One of the unrecognized aspect of satellite design is that relatively large increases in satellite capacity in either bandwidth or in gigabits/second can be achieved with relatively small increases in satellite weight. This relationship between capacity and weight has been plotted by Staelin and Harvey (NAS-5-25091) for satellite weights from 1000 to 20000 pounds for both present day solar cell technology and advanced power technology.

Another illustration of this feature is that Intelsat-V, with launch weight of 1860 Kg will have a useful bandwidth at 4/6 GHz and 11/14 GHz of almost 1600 MHz. By utilizing an additional 500 Kg of launch weight afforded by ARIANE-III, this capacity can be increased to 2500 MHz, a factor of increase of at least 1.6.

7.4.6.3 Satellite Cost vs. Antenna Complexity.

In general, antenna complexity impacts on satellite costs in a different manner than only its weight implication of around 8 to 10% in total satellite weight:

- Complex antennas can greatly increase satellite non-recurring costs depending on the number of antennas involved, and the complexity of the feed horns and driving networks.
- Complex antennas can add to length in the shuttle bay and therefore add to launch cost.
- Complex antennas can add to the attitude control requirements and require additional sensors, ground control, or additional fuel which must be substituted for other payloads.

7.4.6.4 Satellite Cost vs. Power-Amplifier Power.

Power-amplifier power requirements for TV broadcast satellites greatly control satellite costs - particularly when high power tubes are used. In a

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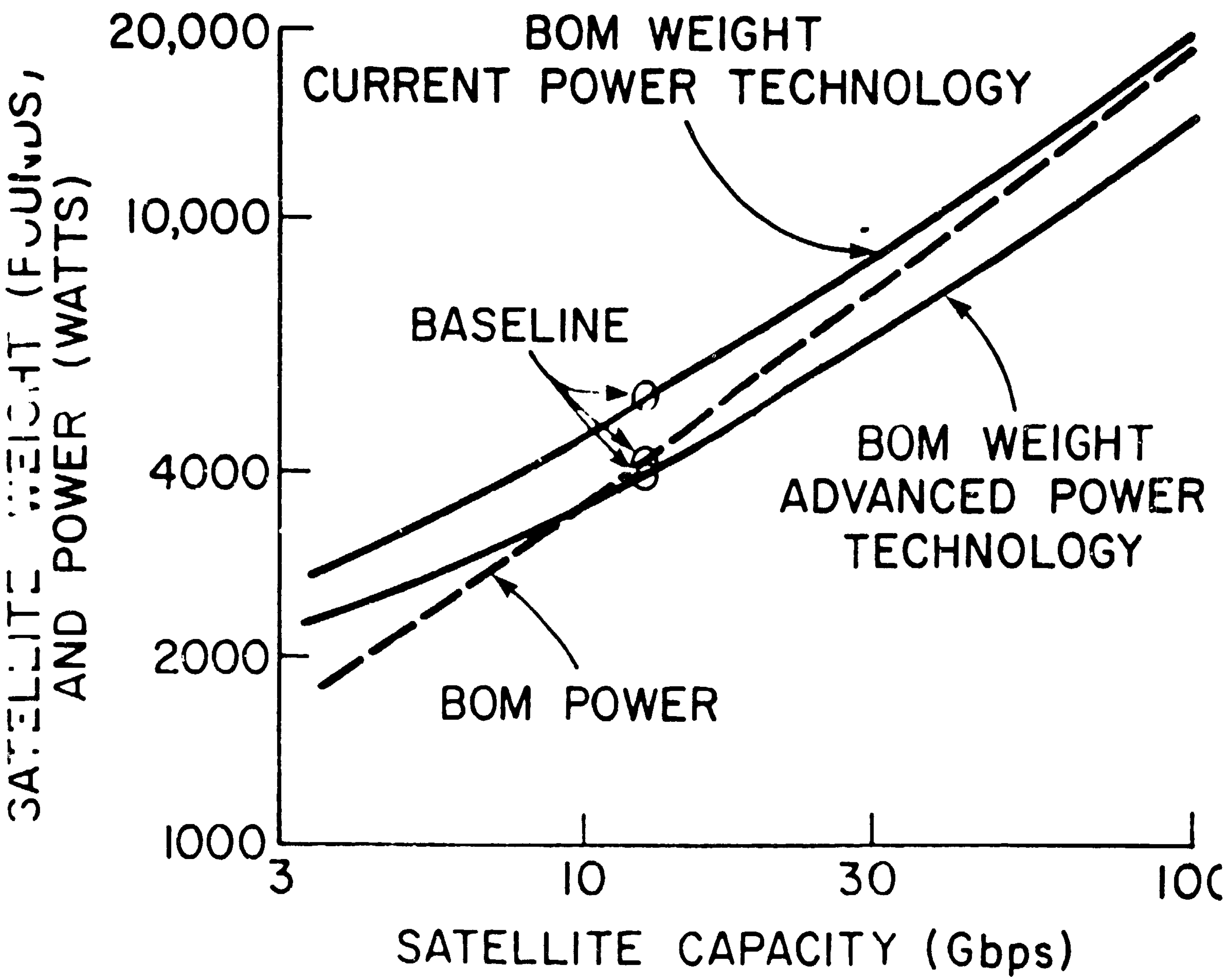

Figure 7-7

Satellite weight and power versus satellite capacity.

fixed satellite system spacecraft such as Intelsat-V, more than 30 TWTA's are used with output powers ranging from 4.5 watts to 10 watts. Intelsat-V has a d.c. power budget of 1000 watts derived from a solar cell system providing up to 1400 watts at beginning of life (BOL).

When TWT such as the Telefunken 450-watt TWTA or the Thomson-CSF 150-watt TWTA are used, the d.c. power requirements of these and therefore the efficiency of tubes operating up to 50% efficiency will be baseline to, and dominate the satellite design. For a satellite having, say 2000 watts available to the power amplifier, then [illegible] two 450-watt TWTA can be accommodated, or eight 125-watt TWTA. For the Canadian-approved 51 dbw satellite design which uses lower power 40 watt TWTA, at least 20 channels can be accommodated - thereby illustrating the advantage of increased satellite capacity as compared to a relatively small increase in ground antenna size.

Tables 7-22A and 7-22B extend Table 7-14 which used a total RF saturated power of 1000 watts produced by its TWTA. Table 7-22 uses 600 watts of RF power (ex: four 150-watt TWTA) and Table 7-23 uses 400 watts of RF power (ex: four 100-watt TWTA). Note that the spacecraft costs decreased from 63 million dollars to 41 million dollars to 33.6 million dollars thus illustrating the pacing nature (with weight) of satellite RF power.

Table 23 summarizes the changes in principal space parameters including cost as a function of total RF power, in the ranges from 400 to 1000 watts of RF power.

The total spacecraft cost varies from $101 million for 400 watts to 169 million dollars for 1000 watts representing an increased in cost by 70%. Note, however, that the spacecraft launch weight increases by a factor of slightly less than 2 for the same RF power increase showing a significant change in launch vehicle requirement.

TABLE 7-22A

(Satellite with RF Power 600 Watts)

```
DELTA V1 = 2428.45 M/SEC  DELTA V2 = 1830.70 M/SEC
COM WT = 400.0 LBS        TTC WT =  49.6 LBS
ACS WT = 171.7 LBS        EPS WT = 277.0 LBS
BOL =  2732.9 WATTS       BUS WT = 1045.2 LBS
ON-ORBIT FUEL WT =   263.4 LBS
S/C ON-ORBIT WT =  1708.6 LBS  S/C LAUNCH WT =  14779.7 LBS
PERIGEE MOTOR 3 WAS CHOSEN

DELTA COM WT = -200.0 LBS        DELTA TTC WT =    0.  LBS
DELTA ACS WT =    0.  LBS        DELTA EPS WT =   -6.6 LBS
DELTA BUS POWER =  -80.0 WATTS   DELTA BUS WT = -153.1 LBS
DELTA ON-ORBIT FUEL WT =  -38.6 LBS  DELTA S/C ON-ORBIT WT =  -391.7 LBS
DELTA S/C LAUNCH WT= -2085.7 LBS

DO YOU WANT A COMPLETE LISTINGS OF PARAMETERS?
THIS LISTING IS WITHOUT HEADINGS,1=YES,2=NO
=1
```

400.0	49.6	195.0	171.7	277.0	47.4
54.4	41.9	208.3	1045.2	263.4	1708.6
7507.4	14779.7	0.	1763.7	0.	3.0
6.5	15.0	2.0	18219.2	1900.0	2732.9
1500.0	$\boxed{600.0}$ RF Power				

See Tables 7-15, 7-16 for Format

```
STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)

NUMBER OF S/C =  3  NUMBER OF ON-ORBIT S/C =  2
R&D COST = $ 25815.5               PROTOTYPE COST = $ 25706.8
TOTAL NON-RECURRING COST = $ 51522.4
PROTOTYPE REFURB COST = $ 8613.1  FIRST UNIT COST = $20565.5
FLIGHT MODEL COST = $ 41131.0     ON-ORBIT INCENTIVES = $ 20253.3
S/C STORAGE COST = $1500.0
TOTAL S/C COST = $123019.7
PM COST = $ 9000.0  STS COST = $37326.6
TOTAL PROGRAM COST = $169346.3

YEAR  1 COST = $ 27534.1     0 S/C LAUNCHED
YEAR  2 COST = $ 49712.0     0 S/C LAUNCHED
YEAR  3 COST = $ 41355.8     0 S/C LAUNCHED
YEAR  4 COST = $ 14224.1     2 S/C LAUNCHED
YEAR  5 COST = $   2175.3    0 S/C LAUNCHED
YEAR  6 COST = $   2175.3    0 S/C LAUNCHED
YEAR  7 COST = $   2175.3    0 S/C LAUNCHED
YEAR  8 COST = $   2175.3    0 S/C LAUNCHED
YEAR  9 COST = $   2175.3    0 S/C LAUNCHED
YEAR 10 COST = $   2175.3    0 S/C LAUNCHED
YEAR 11 COST = $   4663.8    0 S/C LAUNCHED
YEAR 12 COST = $   8652.2    0 S/C LAUNCHED
YEAR 13 COST = $   8652.2    0 S/C LAUNCHED
YEAR 14 COST = $   1500.0    1 S/C LAUNCHED
```

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TABLE 7-22B

(Satellite with RF Power - 400 Watts)

```
DELTA V1 = 2426.45 M/SEC   DELTA V2 = 1830.70 M/SEC
COM WT = 300.0 LBS         TTC WT =  49.8 LBS
ACS WT = 130.1 LBS         EPS WT = 232.6 LBS
BOL =  1956.2 WATTS        BUS WT =  855.5 LBS
ON-ORBIT FUEL WT =    215.6 LBS
S/C ON-ORBIT WT =  1371.0 LBS  S/C LAUNCH WT =   9224.2 LBS
PERIGEE MOTOR 1 WAS CHOSEN

DELTA COM WT = -100.0 LBS        DELTA TTC WT =     0.  LBS
DELTA ACS WT =  -41.8 LBS        DELTA EPS WT =   -44.4 LBS
DELTA BUS POWER = -540.0 WATTS   DELTA BUS WT = -189.7 LBS
DELTA ON-ORBIT FUEL WT =  -47.8 LBS  DELTA S/C ON-ORBIT WT =  -337.6 LBS
DELTA S/C LAUNCH WT= -5555.5 LBS

DO YOU WANT A COMPLETE LISTINGS OF PARAMETERS?
THIS LISTING IS WITHOUT HEADINGS,1=YES,2=NO
=1
```

300.0	49.8	153.4	130.1	232.6	37.3	See Tables 7-15, 7-16 for Format
40.8	33.0	170.7	855.5	215.6	1371.0	
4984.6	9224.2	0.	385.0	2483.8	1.0	
7.0	15.0	2.0	13041.1	1360.0	1956.2	
1000.0	$\boxed{400.0}$ RF Power					

```
STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)

NUMBER OF S/C =  3  NUMBER OF ON-ORBIT S/C =  2
R&D COST = $ 20758.1            PROTOTYPE COST = $ 21027.8
TOTAL NON-RECURRING COST = $ 41785.9
PROTOTYPE REFURB COST = $ 7864.4  FIRST UNIT COST = $16822.2
FLIGHT MODEL COST = $ 33644.5     ON-ORBIT INCENTIVES = $ 16659.0
S/C STORAGE COST = $1500.0
TOTAL S/C COST = $101453.8
PM COST = $11100.0  STS COST = $22573.7
TOTAL PROGRAM COST = $135127.4

YEAR  1 COST = $ 21335.8     0 S/C LAUNCHED
YEAR  2 COST = $ 39626.0     0 S/C LAUNCHED
YEAR  3 COST = $ 32880.4     0 S/C LAUNCHED
YEAR  4 COST = $ 12217.7     2 S/C LAUNCHED
YEAR  5 COST = $   1815.9    0 S/C LAUNCHED
YEAR  6 COST = $   1815.9    0 S/C LAUNCHED
YEAR  7 COST = $   1815.9    0 S/C LAUNCHED
YEAR  8 COST = $   1815.9    0 S/C LAUNCHED
YEAR  9 COST = $   1815.9    0 S/C LAUNCHED
YEAR 10 COST = $   1815.9    0 S/C LAUNCHED
YEAR 11 COST = $   3320.8    0 S/C LAUNCHED
YEAR 12 COST = $   6675.7    0 S/C LAUNCHED
YEAR 13 COST = $   6675.7    0 S/C LAUNCHED
YEAR 14 COST = $   1500.0    1 S/C LAUNCHED
```

4-75

TABLE 7-23

Spacecraft Parameters as a Function of Total RF Power

	Total RF Power in Watts		
	400	600	1000
Comm S/S wt	300 lbs	400 lbs	600 lbs
ACS S/S wt	130 lbs	171 lbs	171.7 lbs
TT&C S/S wt	49 lbs	49.6 lbs	49.6 lbs
EPS wt	232 lbs	277 lbs	420 lbs
Bus wt	855 lbs	1045 lbs	1418 lbs
S/C On-Orbit wt	1371 lbs	1708 lbs	2375 lbs
On-Orbit Fuel	215 lbs	263 lbs	357 lbs
Total Fuel wt:			
(Apogee & Perigee Fuel)	4984 lbs	7507 lbs	10,096 lbs
S/C Launch Weight	9224 lbs	14,779 lbs	18,035 lbs
Number of Solar Cells	13,041	18,214	29,055
BOL Power	1956 Watts	2732 Watts	4358 Watts
Bus Power	1360 Watts	1900 Watts	3030 Watts
COM S/S Power	1000 Watts	1500 Watts	2500 Watts
R&D Cost*	20.7 M	25.8 M	26.6 M
Prototype Cost*	21 M	25.7 M	39.2 M
Total Non-Recurring Cost*	41.8 M	51.5 M	65.8 M
Flight Model Cost* (2 units)	33.6 M	41.1 M	62.7 M
On-Orbit Incentives	16.66 M	20.25 M	27.85 M

*1980 dollars

7.4.6.5 Satellite Cost vs. Pointing Accuracy

It was shown in Section 5 that satellite technology now exists which can now provide pointing accuracies of 0.05° thereby making practical contoured and spot beam operation with antenna beam widths as narrow as 0.125° (3 db). In order to improve this pointing accuracy, as pointed up in Section 5, extraordinary techniques such as the use of star sensors and/or monopulse systems using ground control must be utilized for both spinner and 3-axis body stabilized satellites.

The cost of satellites requiring pointing accuracy better than 0.05° will increase rapidly and require the exchange of much communications payload and antenna payload for ACS payload, and greatly impact a satellite capacity by reducing the number and power levels of transponders which can be accommodated by typical satellites of the 1000-kg weight class.

The case of increased antenna complexity in a larger satellite or on a space platform in order to achieve improved system capacity provided by spatial diversity, will require more precise attitude control components in order to achieve pointing accuracies much better than 0.05°. Such a S/C system can use coarse attitude control for the platform systems or spacecraft and gimballed antennas with very fine attitude control by providing control from the ground using a monopulse system on the spacecraft antenna.

Table 7-23 lists the changes produced in attitude control system (ACS) weight and on-board fuel weight for RF power variation from 400 to 1000 watts. Note the absence of change in ACS weight for larger RF power; the on-orbit fuel, however, increases by a factor of almost 50%.

7.5 Earth Terminal Costs

While satellite costs are primarily dictated by launch vehicle weight capability, earth terminal TVRO costs are dictated by antenna size and receiver LNA noise temperature.

In this section, earth terminal costs for TVRO terminals will be explored for UHF reception from space using a G/T = 0 db/K, for 2.54 GHz community TV reception using a G/T = 0 db/K and for 12 GHz reception for direct-to-user applications using a G/T = 8 dB/K.

The costs will be developed for small quantities, and for quantities of 100,000, 1,000,000, and 10,000,000. The costs derived will be primarily cost-of-sales costs based on materials and labor involved.

It must be appreciated that those costs will be predicated for devices and subsystems which, for the most part, have been manufactured in only relatively small quantities to date (1980). They do not represent costs which can be immediately contracted for but will require the cycle of development, prototype manufacture, and then full manufacture to meet the specifications (i.e., 2 dB NF at 12 GHz) required in large quantities.

Many excellent analyses of terminal costs have been provided in the past based on not only terminal characteristics but also based on Delta 2914 and 3914, Atlas-Centaur and Shuttle costs and launch capabilities. These costs analyses have provided considerable insight into the cost/user and cost/terminal of various earth terminal sizes and costs as associated with various launch vehicles. However, significant changes in launch vehicle availability as discussed in Sect.7.3, coupled with increased launched and satellite costs* and greatly reduced earth

*For example, R. Kelley et al, "Communications Systems Technology Assessment Study, Volume II Results, Contract NAS-3-20364 for NASA Lewis Research Center.

terminal costs, have made a new cost assessment mandatory - particularly for earth terminal quantities well over 100,000.

Many of the earlier analyses also utilized earth terminals at 12 GHz with diameters greater than 1 meter. This section will continue the earth terminal designs of 0 db/^{o}K at UHF and S-band and 8 db/^{o}K at 12 GHz. This will simplify the cost analysis since, at 12 GHz, for example, the 1-meter antenna has been largely associated with 12 GHz direct-to-user down-links as a result of WARC-77 and it is therefore possible to concentrate on specific antenna and receiver designs and associated costs instead of attempting to parametrically relate antenna size G/T, quantity and launch vehicle type over wide range of parameters.

In 1969, the author published new approach to establishing minimum costs of an earth terminal for a particular G/T as a function of antenna size, by recognizing that the antenna costs versus diameter was essentially parabolic with an inverse curve existing for LNA noise temperature versus cost. By combining antenna gain, and system noise temperature derived from antenna noise temperature at a particular elevation and LNA noise temperature, a curve of antenna diameter versus cost for various G/T as shown in Figure 7-8 could be derived.

However, in this report the antenna sizes are sharply limited in range and low noise amplification over wide ranges of noise temperature is both relatively inexpensive and without major cost differential thereby making the G/T versus cost curve of Figure 7-8 of relatively little value since it must be limited to a narrow range of antenna diameters and enjoy the "luxury" of very low noise temperature LNA's in low cost ranges which were not conceivable only a decade ago.

As will be described in the paragraphs to follow, the antennas to be used include Yagi arrays at UHF, 10-ft diameter antennas at 2.64 GHz, and a variety of antenna types having essentially a one square meter aperture at 12 GHz. The LNA's will be transistor or FET amplifiers at UHF and S-band, and FET amplifiers or Schottky barrier diode mixers at 12 GHz, all of which represent low cost techniques at UHF and S-band and potentially low cost techniques at 12 GHz.

Thus, the thrust of this section is to explore true device costs rather than conduct parametric analyses and to determine the feasibility of the long sought-after 1-meter 12GHz TVRO terminal costing around $500.

7.5.1 The Cost Heritage of 4 GHz TVRO Systems.

As pointed out in Section 6, the broadcast satellite small TVRO earth terminal will be able to significantly utilize many new developments made for color TV receivers and in 3, 4.5, and 10 meter TVRO terminals built for TV program distribution using WESTAR and SATCOM satellites.

Domestic satellite distribution of TV-programming was first initiated in the mid 1970's by the broadcast of a Mohamed Ali fight to cable TV users and a major industry was underway. At that time, the first TVRO terminals used 10-meter antennas with uncooled paramps and fairly expensive 4 GHz down converters and TV receivers. Such terminals cost in excess of $100K. As the FET amplifier with its 150°K noise temperature at 4 GHz appeared on the scene circa 1975, both Andrews and Scientific Atlanta advertised a 10-meter TVRO antenna using a GaAs FET LNA and a standard 4 GHz TV Receiver for $60,000.

As competition increased, and the FCC permitted the use of 4.5-meter Receiver only antennas, then 4-5-meter TVRO antennas with uncooled paramps and standard receivers became available for around $35,000.

As the number of antennas manufactured increased (>200/month in Spring 1980) and LNA costs reduced from $5-10K to around $2K, receiver costs also dropped, and by 1980 a high quantity TVRO terminal with a 4.5 meter antenna was available for purchase for costs ranging from $5K to $15K. During this time, the Mutual Broadcasting System purchased 700 small earth terminals (radio receive-only) for its affiliates at less than $5K per unit, and an era of very low cost earth terminals was initiated.

This manufacturing experience at 4 GHz coupled with the development of new integrated circuits for color TV and cable TV systems, and low cost mass produced GaAs receivers directly impacts on the cost of TVRO terminals at UHF, S-band and 12 GHz.

The news of a filing by COMSAT and Sears Roebuck Co. for a TV-broadcast satellite not only created new interest in the potential for TV-broadcast at the 12.2-12.7 GHz frequency, but also, with the FCC de-regulation of TVRO earth terminals, a renewed interest in private TVRO terminals to access the more than 40 channels of television at 4 GHz from the geostationary are serving the U.S.

This interest in 4 GHz TVRO earth terminals not only created a $37.5K TVRO terminal sold as a Christmas present by Nieman Marcus of Dallas, Texas, in 1979, but also started a "bargain" or low cost business in 4 GHz TVRO earth terminals for present users; in Coop's Satellite Digest TI-5180, it was reported that STARVIEW, of Poca Hontas Arkansas, for example, is averaging a shipment of 2-3 TVRO terminals per day.

Table 7-24 lists approximate costs for a home satellite TVRO system at 4 GHz. The deluxe system is the equivalent of a TVRO terminal at the quality purchased by a Cable TV user. The Standard and bargain TVRO's represent the "Lincoln Continental" and "FORD Fairlane" modes, while a "PINTO" quality at lowest possible cost is even now a reality.

Table 7-25 lists the published prices of some available standard and bargain TVRO's as of July 1, 1980. Note that they range from $13K to $4K. Tables 7-26 and 7-27 list typical published antenna, LNA, down-converter and receiver prices, again showing the wide variation between companies depending on the quality and in the case of the antenna, on the actual techniques for construction used. The antenna and LNA costs are high - in the $1500 range for a 10-ft antenna exclusive of mount, and around $1K for an LNA (the NEC FET's still are

TABLE 7-24

Approximate Costs of Components of a Home Satellite System at 4 GHz

	Deluxe Grouping	Standard Grouping	Bargain Prices
Antenna Dish			
15 foot dia.	$7000		
10 foot dia.		$2500	$ 900
Antenna Feed			
Two units	2000		
One unit		1000	500
Low Noise Amplifier			
Two units	6000		
One unit		3000	1000
Microwave Receiver	3000	3000	2300
TV Modulator	1200	400	150
Complete Set of Components*	$19200	$9900	$4850

* to which must be added the cost of shipping, foundations, installation, etc.

TABLE 7-25

Published Prices of Low Cost Complete TVRO Systems for 4 GHz Domestic Satellites such as SATCOM-1

- Microwave Associates, Burlington, Mass.

4.5 meter	$13975
12 foot	$12700
10 foot	$ 9990

- SATELCO, Pico Blvd., Los Angeles

20 ft	$12500
16 ft	$ 7995
10 ft	$ 6995

- Microwave General, Mountain View, Calif.

16.6 ft	$13900
13 ft	$11900
10 ft	$ 9900

- Antenna Dev. & Mfg. Inc., Poplar Bluff, Mo.

11 ft	$6480

- Satellite Television Systems, Poplar Bluff, Mo.

10 ft	$3995

- Starview System, Poca Hontas, Ark.

10 ft Trailer mounted	$7200
10 ft Special	$3995

TABLE 7-26

Published Prices of Low Cost TVRO Antennas for Use at 4 GHz

- Marble Electronics, North Weymouth, Mass

4 ft	$ 98
6 ft	$ 195
8 ft	$ 449
12 ft	$ 695
16 ft	$1195

- Satellite Television Systems, Poplar Bluff, Mo.

13 ft Dish	$2295
10 ft Dish	$1695
10 ft Dish with mount & feed	$1995

- Antenna Dev. & Mfg., Poplar Bluff, Mo.

11 ft	$2765

- Vidiark Electronics, Salem, Ark.

12 ft Spherical Kit	$ 750

- Wagner Industries, Alva, Okla.

10 ft Spherical with horn	$ 925
12 ft Spherical with horn	$1650
16 ft Spherical with horn	$2925

- Prodelin, Highstown, N.J.

2 ft	$ 275
4 ft	$ 485
6 ft	$ 590
8 ft	$ 850
10 ft	$1400

Tilt mount $595 for 8-10 ft

- Andrew, Orland Park, Illinois

4 ft	$ 480
6 ft	$ 590
8 ft	$ 980
10 ft	$1580

Tilt mount $460 for 8-10 ft

- Tristar, Van Epps Rd, Cleveland, Ohio

10 ft Fiberglass	$875

TABLE 7-27

Published Prices of Low Cost 4 GHz LNA's and TVRO Receiver Systems

LNA	
- Avantek LNA plus dc power supplied via RF cable	$1099
- Gillespie Kit (Menlo Park)	$ 125
Requires two NEC 218 FET	$ 110
- DEXCEL LNA	-
- Birkill 4-stage bipolar LNA	$ 175
Down Converters 4 GHz to 70 MHz	
- GHz Engineering (Phoenix)	$ 400
- Satellite Innovations (Winston, Salem)	$ 895
- Telepath (San Jose)	$ 450
- Avantek (IF at 950-1450 MHz)	-
Receivers 4 GHz to Video/Audio - includes remodulation	
- Vitalink Corp (Palo Alto) - includes LNA	$3000
- ICM (Oklahoma City)	$ 995
with remote	$1149
- Satellite Television Systems Avantek LNA + Barker Receiver	$2000
- STT (Arcadia, CA) - Washburn Receiver	≈ $2000
- Microwave Associates - VR-4X Receiver	≈ $2000

a major cost item) .

However, as competition continues to increase, and techniques are developed to address the private user market which will expand as TVRO prices plummet below $5K, these prices will continue to decrease and the development of a "radio amateur" market and mentality will do much to spearhead the cause of low cost TVRO terminals at 700 MHz, and 2.5 GHz and certainly in the direct-to-user marketplace at 12 GHz.

7.5.2 Cost Considerations of G/T.

In 1969, the author published a use of cost versus antenna diameter (gain) and LNA cost versus ^{O}K showing that by combining the two curves, relating cost versus antenna diameter for a fixed value of G/T, a minimum or optimum receive cost can be achieved. This is a result of the antenna cost increasing with size and the LNA cost decreasing with increased noise temperature as shown in Figure 7-8. As the antenna size starts to dominate G/T, one pays primarily for antenna structure since high noise temperature devices are very inexpensive. As the antenna diameter is decreased, at some point, the cost of receiver sensitivity suddenly increases and rises to infinity because a negative noise temperature is impossible to achieve, and the useful ranges of noise temperature below 50^{O}K for the LNA only (included in the system noise temperature which includes antenna noise temperature and losses between the feed and the LNA) require succinctly, an uncooled paramp, a cooled paramp, and a maser - the latter device costing approximately a million dollars.

Figure 7-9 shows actual cost versus antenna gain (instead of size) and receiver (LNA) noise temperature versus cost for TVRO systems in the 0.8 GHz, 2.54 GHz and 12 GHz bands. Note that in each case, the receiver noise temperatures are relatively high (400-600^{O}K) and the antennas small at all three frequencies.

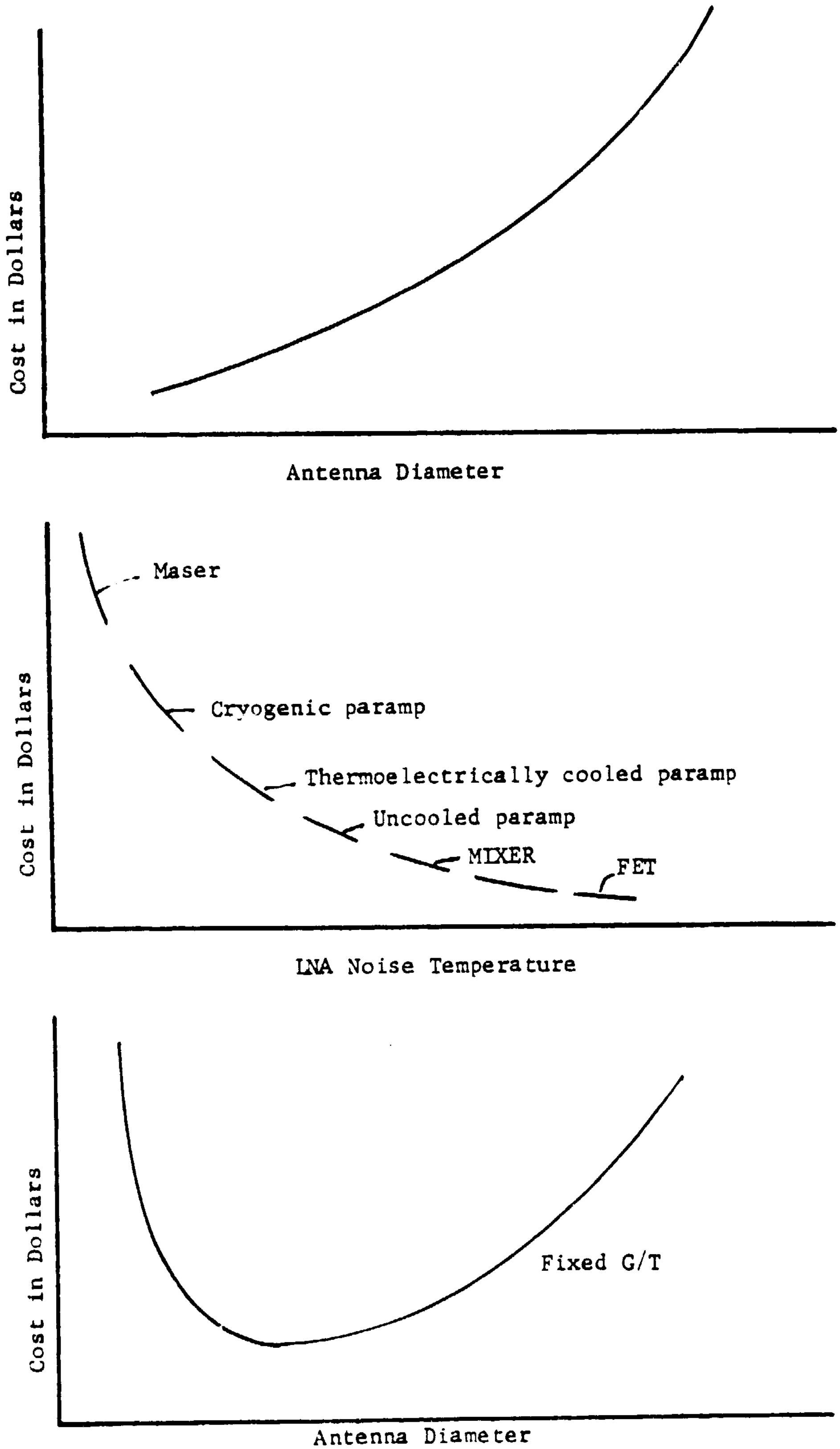
Cost in Dollars
Antenna Diameter
Cost in Dollars
Maser
Cryogenic paramp
Thermoelectrically cooled paramp
Uncooled paramp
MIXER
FET
LNA Noise Temperature
Cost in Dollars
Fixed G/T
Antenna Diameter

Figure 7-8

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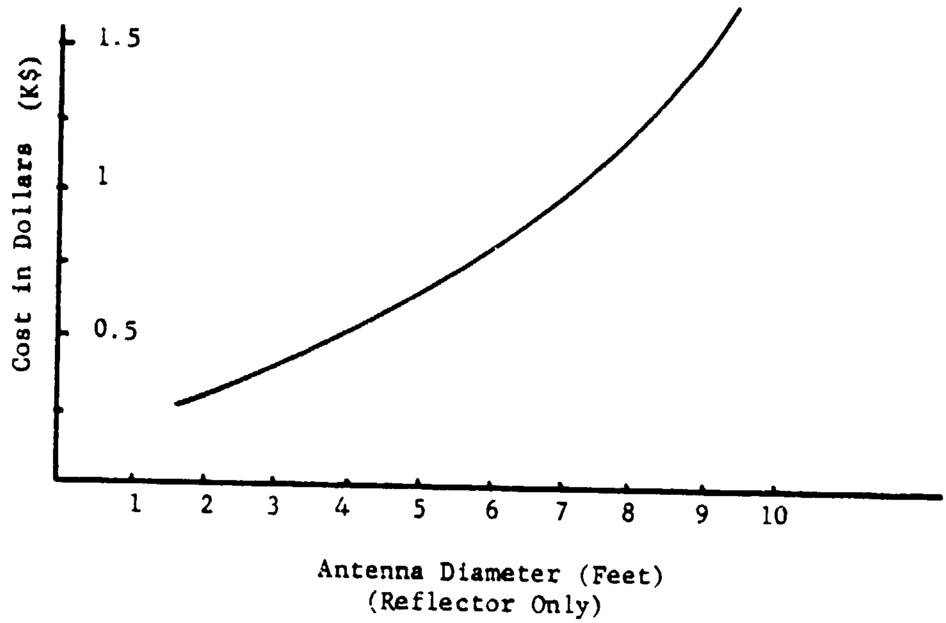

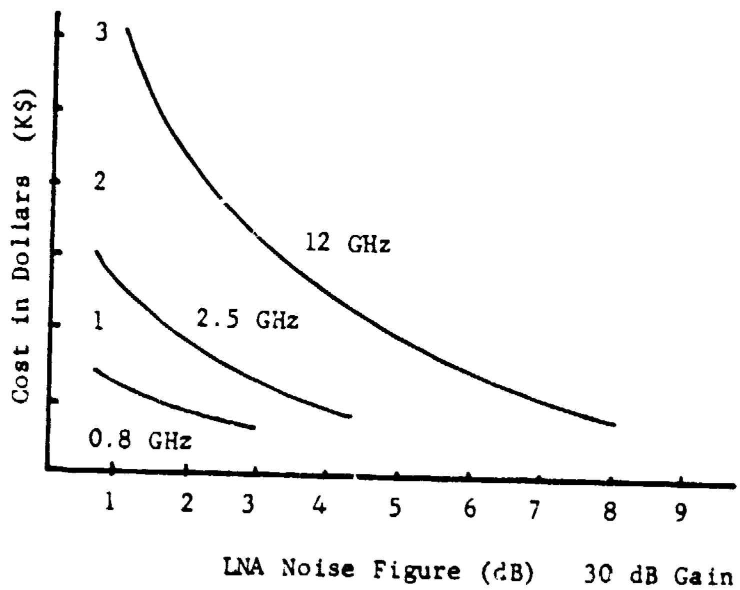

Figure 7-9

At 12 GHz, a G/T = 8, for example, will require a system noise temperature of almost 1000°K to augment an antenna gain of 38 dB. At 2.54 GHz, a G/T = 0 will be provided by an antenna diameter of 1.5 meters and a 28 dB gain and a system noise temperature of around 800°K will be required. At 0.8 GHz, a 3-meter antenna will give a gain of 24 dB and a system noise temperature of 400°K will be required.

An interesting aspect of the present cost analysis is that both the curves of LNA versus cost and the curves of antenna diameter versus cost are in the range of essentially both lowest cost and very low differential cost with respect to diameter change. Thus, full curves of cost versus antenna gain or diameter for large antenna gain ranges and for wide ranges of G/T are rather meaningless, and it is more meaningful to concentrate on the techniques of cost reduction and low cost manufacturing processes for both the antenna and the LNA/receiver.

7.5.3 Considerations of Quantity Production.

As pointed out in USSG BC/851 Rev. 1, Oct. 1, 1975, producing units in large quantities reduces the average cost per unit. The quantity factor in cost reduction can be represented by:

$$Q\ (n) = L^{\mathrm{Log}_2 N}$$

where, Q (n) = quantity cost factor, L = learning factor which typically ranges between .85 to .95 and N = production quantity.

Figure 7-10 shows a plot of Q (n) for several values of L as a function of N. Also shown are several data points for antennas, transistor amplifiers, converters, and paramps. From this it is concluded that as the per unit complexity increases as for the paramps, learning (i.e., through higher production quantities), becomes more significant. In contrast, the antenna, which is not as labor intensive and therefore complex, exhibits a less significant reduction in cost through learning.

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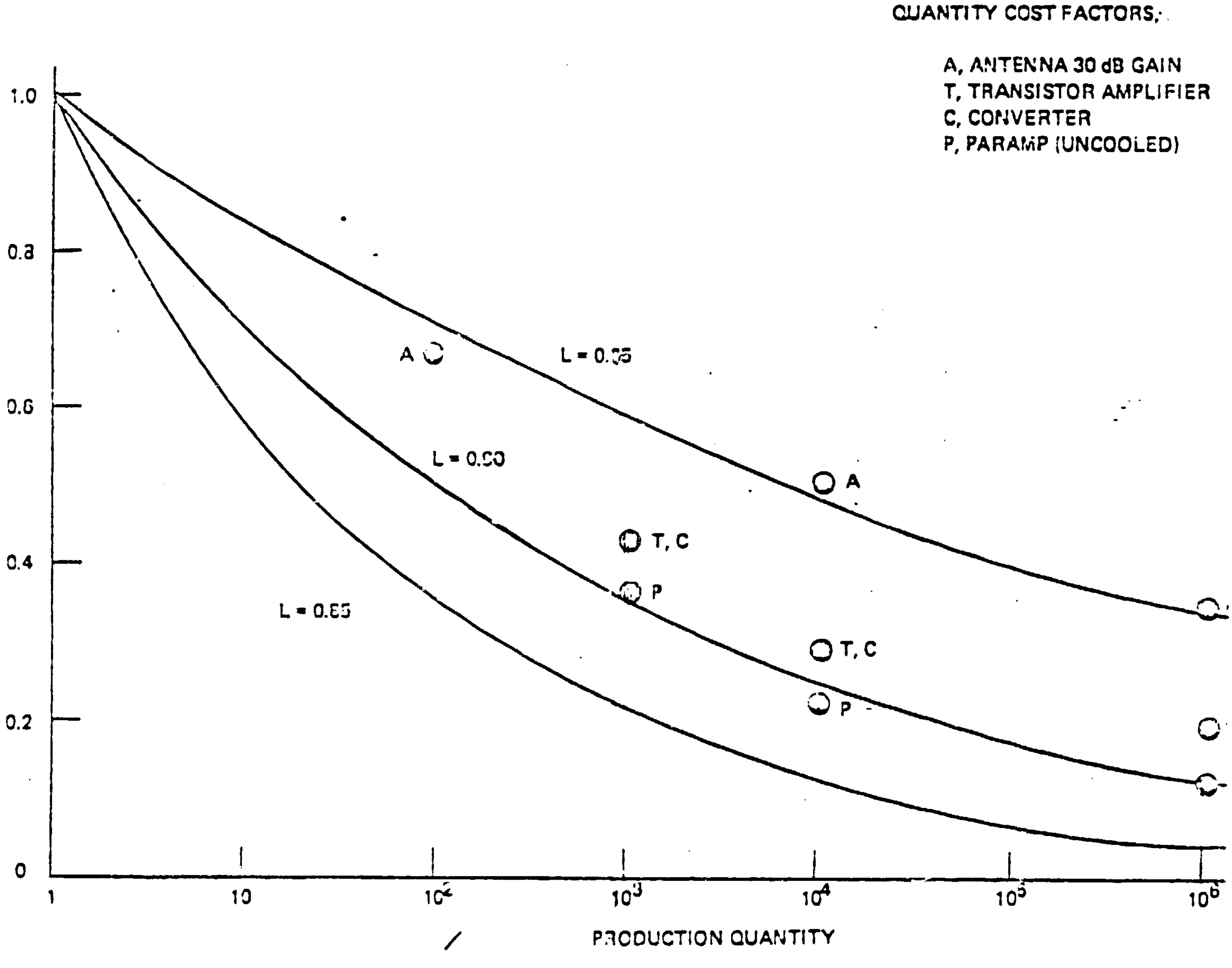

Cost Advantage of Quantity Production

Figure 7-10

Other CCIR study group documents have added insight to the prediction of quantity production costs for TVRO earth terminals. Table 7-25 of Plen/2-USA-4 has predicted a unit cost of $2000 for a TVRO for community reception at 2.6 GHz (in line with present 4 GHz TVRO terminals extended to 10000 units) and only $1400 a piece for 100,000 of such terminals. Note the increasing cost as the frequency is reduced. At 700 MHz, of course, the higher cost comes from antenna structure and materials even though a significant reduction in the cost of the combined LNA and receiver (integrated into one system).

Figure 7-11, derived from a NASA LRC study*, shows a useful display of costs for 12 GHz TVRO terminals as a function of G/T for units from 10 to 1,000,000. Note that at a G/T = 8 db/^{o}K, a unit price for 10 would be around $2000 while for 1,000,000 units, the unit price would be around $450. This is consistent with prices quoted in Japan by SONY and NEC.

7.5.4 Aspects of Mass Production of Antennas and Integrated Circuits.

The TVRO antenna system at any of the three frequencies will be made up of an antenna and a LNA/Receiver; the latter device will be considered as a two-box device interconnected by cable with the LNA box mounted on the feed or integrated with the antenna feed, and the receiver located inside a dwelling or enclosure near to the TV set or the cable input system.

The TVRO system costs in large quantities therefore are dependent on three major cost items which in mass production will each become very low in cost; the antenna and its mount, the low noise amplifier or amplifying down-converter, and the receiver.

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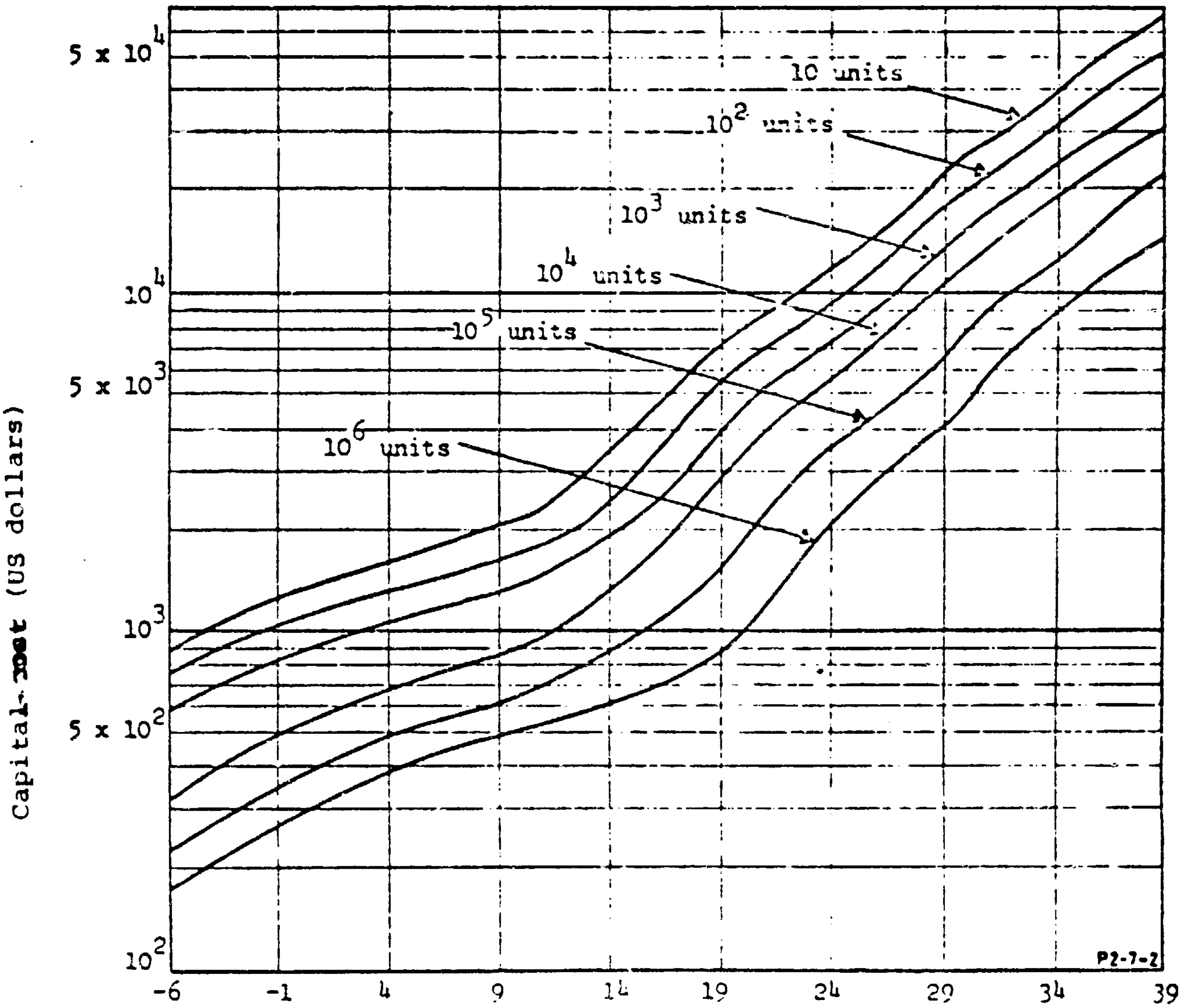
* Results of Communication Systems Technology Assessments Study" (October 1977), Report (Vols. 1 and 2), prepared for the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

TABLE 7-25

Cost Figures Based on Doc. Plen./2- U.S.A. -4 for

TVRO Earth Terminals for Community Reception

Frequency	12 GHz		2.6 GHz		700 MHz	
Number of Video Channels	1	3	1	3	1	3
1. Receiving Terminal Unit Cost (US $) (In production quantities of 10 000 units)	1 650	3 150	2 000	3 500	2 600	4 100
2. Cost of 10 000 Receiving Terminal Units (US $ x 10^6)	16.5	31.5	20.0	35.0	26.0	41.0
3. Receiving Terminal Unit Cost (US $)(In production quantities of 100 000 units)	1 200	2 300	1 400	2 500	1 900	3 000
4. Cost of 100 000 Receiving Terminal Units (US $ x 10^6)	120	230	140	250	190	300



Earth Station Cost vs. G/T (12 GHz band, receive-only terminal)

Figure 7-11. Antenna Gain/System Noise Temperature (dB/K)

The antenna costs will be determined largely by the cost of tooling, handling, assembling, and the cost of materials. Assuming, for example, a $500,000 tooling cost (typical for an automobile fender of about the equivalent size of a 1-meter antenna dish) then at a quantity of 100,000 units, a tooling cost of $0.50 must be added to the material and handling cost.

The LNA, particularly at 2.54 GHz and 12 GHz will depend on transistor cost (S-band) and FET device cost at 12 GHz. FET costs are reducing rapidly at 4 GHz from $200 in 1978 to $50 in 1980, and quantity production of FET's by the million could well bring about the advent of the dollar FET and therefore the very inexpensive FET amplifier (printed on monolithic gallium arsenide).

7.5.4.1 A Note on Integrated Circuit Manufacturing Costs.

A significant reduction in TVRO receiver cost will be achieved when, as in most color TV and FM receivers, the significant receiver circuit functions can be provided by a set of integrated circuits which can be mounted on a single PC-board and powered by a simple d.c. power supply. This note will serve as an introduction to both FACC in having special integrated circuits made for its earth terminals, and recent publications describing how integrated circuit cost is determined.

In a paper by H. Dickens*, a detailed description for establishing factory costs and fair market prices for more traditional integrated circuits such as RAM's and linear operational amplifiers is given. These are typical of most circuits to be used in a TVRO receiver, exclusive of the LNA and mixer which may be antenna mounted at the feed and connected to the receiver by a cable which also supplies d.c. power to the LNA. Table 7-26 lists a cost breakdown of four integrated circuits as provided by Dickens. Note that the cost is determined by wafer costs and yields and not by the circuit. The wafer cost is a function

*H. E. Dickens, "How to Determine Fair Market Prices for Integrated Circuits", Defense Electronics, June 1980.

TABLE 7-26

Typical Integrated Circuit Final Costs
as per H. K. Dicken

	64K RAM (plastic Package) (1981)	16K RAM - Four-Inch Wafer 4-inch wafer ($4\ \mu$)	4-inch wafer ($1.5\ \mu$)	Linear Op Amp
Die size (mils)	160 x 240	145 x 234	75 x 75	72 x 72
Die area (sq. mils)	38,400	33,930	5,625	5,184
Dice per wafer	286	323	2,142	1,300
Wafer probe yield	15%	20%	65%	40%
Good dice per wafer	43	64	1,392	520
Wafer cost (4-in.)	$70	$75	$175	$50
Cost per good die	$1.63	$1.17	$0.126	$0.096
16-pin packaging cost	$1.00	$0.08	$0.08	$0.06
Assembly yield	90%	85%	85%	75%
Total packaged cost	$2.91	$1.47	$0.24	$0.21
Testing cost	$0.75	$0.50	$0.50	$0.05
Final test yield	65%	70%	70%	70%
Total manufacturing cost	$5.65	$2.81	$1.05	$0.37
Estimated volume purchase price	$11.29	$5.50	$2.10	$1.25

of resolution but, as shown in Table 7-27, is dominated by labor and depreciation and yield. According to Dickens, a factory capability of approximately 500 wafers/shift must be reached before an economical IC operation can be achieved.

After wafer cost is determined, the yields of various processing steps must be estimated to arrive at a typical factory cost for an integrated circuit. Industry typically divides the process into four different yield factors. Wafer processing yield ranges from 75 to 90 percent and includes yield losses due to broken wafers, processing errors, and other handling factors that occur before the wafer has finished the process sequence. Automatic handling procedures will increase yield drastically.

The wafer probe yield is the largest variable in calculating cost. The yield is primarily related to random defects due to dust particles or other factors, and is primarily a function of die area. Bipolar devices will have a lower yield than MOS devices primarily because of the added processing steps, such as epitaxial growth. After the wafer has been processed and probed, it must be assembled in a package or chip carrier. There is typically an 80-90 percent yield for this process step, depending primarily on the number of pins in the package.

Selected circuits of the SCT-8 modems were identified as candidates for LSI IC's, and vendors were solicited for their manufacture. Design and layout manuals were obtained from EXAR, INTERNATIONAL MICROCIRCUITS (Master MOS), and INTERDESIGN. The INTERDESIGN manual was far superior to the other two, and gave details and photographs of the local interconnections required between groups of transistors to form digital functions such as multiple-input gates, flip-flops, registers, etc. In addition, large colored layout sheets showing the arrangement of the transistors and underpass connections on the chip (200 times normal size) were provided, together with sets of transparent overlays that furnish the interconnections of transistor arrays to form specific circuit functions.

TABLE 7-27

Future Factory Wafer Costs (MOS)

Resolution	1-2 micron	0.5-1 micron
Wafer (4-in.)	$12.00	$13.00
Supplies	$ 5.00	$ 5.00
Labor	$25.00	$25.00
Depreciation	$17.00	$63.00
Yield	70%	%65
Factory Cost	$84.00	$163.00

The selected circuits were given to Interdesign for an estimate of the costs of partitioning the circuits into LSI chips, performing the layout operation, and fabricating a set of prototype packages. An early Interdesign brochure offered the service of converting the customer's logic diagram to semi-custom interconnection layouts and were costed at \$5K-\$50K, depending on the complexity (average cost \$15K). However, that company now requires a production order for about 10,000 packages before embarking on a layout. This means that for small productions of a few hundred packages, the layout must be done by the customer. If the customer generates the desired interconnection pattern, Interdesign will make the interconnection mask and supply 20 tested prototype packages for \$2,800. If these are found to be satisfactory, the desired production proceeds, and the cost of the production LSI packages depend on the quantity ordered, but is about \$20 each for 100 packages, falling to \$7 each for 5,000 packages.

Table 7-28 lists the non-recurring, recurring, and total costs for both PC circuit boards and semi-custom LSI. Note that the final costs of IC's for what are rather complex circuits are very low, \$10 or less, and that further compactness by reducing the micron size of gates further <u>reduces</u> IC cost rather than increasing it.

FACC has had considerable experience in developing special LSI circuits which include a "receiver on a chip" and uses a wide variety of such special or custom circuits in the modems of the Ford SCT-8 X-band military earth terminal. Some of the FACC experience in developing complex custom LSI IC's has been reported by H. S. Tomlin (Tech Memo 75-5/78-1) and is summarized here for the digital circuits involved. The cost per package at the 5000 unit level of \$5.85 a LSI package compares very advantageously with a PC board cost of \$21.27. As the number of units increases, this cost differential will greatly change in form of the LSI IC's.

TABLE 7-28

COMPLEX DIGITAL CIRCUIT

Non-Recurring Costs

P.C. Boards		Semi-Custom LSI	
Mechanical Engineering	$1,050	Initial Layout	$1,440
Drafting, etc.	2,875	Taping & Prototypes	2,800
Total NRE	$3,925		$4,240

Recurring Costs

P.C. Boards				Semi-Custom LSI
No. of Systems	Fab & Assy of Boards	ICs (MSI)	Boards + ICs	Cost of Packages Chips
1	$ 353	$ 6.17	$ 359	
100	6,195	617	6,812	2,000
1000	22,540	6,170	28,712	15,000
5000	71,590	30,850	102,440	30,000

Total Costs (Non-Recurring + Recurring)

P.C. Boards			Semi-Custom LSI	
No. of Systems		Cost Per Board		Cost Per Package
1	$ 4,284	-	-	
100	10,737	107.37	$ 6,240	$62.40
1000	32,637	32.64	19,240	19.24
5000	106,365	21.27	34,240	5.85

Based on cost of production LSI packages (24 pin)

100 (min. order) . ... $20 each
500 .... $15 each
2500 .... $ 7 each
5000 .... $ 6 each

According to FACC's Lawrence Wilson who heads the modem production for the NATO-III earth terminals being made by FACC, even in simple circuits where LSI is contemplated, an advantage over PC boards is realized due to the fact that, say for an LSI chip with only 20 transistors, the individual transistors may actually cost less than the 20 transistors in the LSI chip, but the labor costs of inserting the individual transistors into an expensive PC board ($50-$500 depending on size), and the testing and inspection cycles will bring the cost of the final PC-board far in excess of that of an LSI IC even for very small quantities.

7.5.4.2 A Note on Antenna System Manufacturing Costs.

The LSI and integrated circuit cost description in the preceding paragraph is primarily material/technology intensive and labor costs per-se play a secondary role.

In the case of antenna costs and LNA costs, the opposite is true; labor is a primary contribution to the total costs, and the following paragraphs will discuss the nature of the labor and material costs contributions to total costs.

Antenna costs are very mature from the standpoint of the learning factor discussed in Figure 7-10. Table 7-29 lists learning factors developed by the Stanford Electronics Laboratories in 1975 showing that all learning factors should be high for the RF portions. At base-band, as would be initially expected in 1975 before the major advent of IC use in color TV receivers, and the development of TVRO receivers, this learning factor would be less. However, the use of IC's changes the learning factor to even higher than that of the RF components.

Historically, antenna and microwave amplifier costs have been dominated by labor costs. A large 10-meter antenna requires much labor in manufacture of panels, support structure, and mount, and in the assembly and installation of

TABLE 7-29

Design Learning Factors

Item	Learning Factor	Reference Reference
o Antenna Reflector	0.93	(Stanford, 1975*)
o Feed	0.93	(Stanford, 1975)
o Receiver	0.94	(Stanford, 1975)
o LO	0.94	(Stanford, 1975)
o Baseband Circuits	0.85(1975) 0.96(1980)	(Assumed) (Assumed)
o Power Supply	0.95	(Assumed)

* Stanford Communications Satellite Planning Center, "Communication Satellite and Earth Station Hardware Review", Vol. 2, Technical Report No. 2, Stanford Electronics Laboratory, Stanford University, August 1975.

such systems. An RF amplifier, assuming the use of production quality microwave devices (not state-of-art experimental, engineering modes, or one-of-a-kind) is also labor intensive, requiring significant assembly, test, checkout, inspection, etc., to meet published or contracted specifications. Yield, of course, contributes an important factor if significant variations in, say, transistor S-parameters, are involved.

Figure 7-12, due to Dr. R. Harvey and Professor D. Staelin of MIT (Contract NAS-5-25091) plots the inflation rates for both labor and materials showing the growth in these rates which significantly affects any attempt to make long-term predictions of high labor content components.

Until recently, antenna costs for even small diameter antennas were high because of the small volume by which antennas were procured thereby requiring considerable individual unit fabrication and making the cost of tooling non-economical. Figure 7-13 lists antenna and mount costs versus reflector diameter of Prodelin antennas for costs from N=1 to N=5000 as of 1976 and the catalog price in 1979. (150 Prodelin 10-ft antennas were procured for the ATS-6 S-band Rocky Mountain Educational TV Experiment). Note that despite the costs of inflation, antenna costs declined by 1979, but even in 1976, the reflector costs for sizes below 5 feet were below $1000. Table 7-26 lists 1980 Prodelin costs showing that antennas with sizes below 6 feet in diameter (without mount) now cost below $500.

Already, volume-manufacturing techniques are being applied to antenna manufacture due to increasing 4-GHz TVRO demands; Scientific Atlanta now manufactures more than 200 3-meter and 4.5-meter antennas (4 GHz) per month using mass-production stamping processes and the advent of the 1-meter 12 GHz precision TVRO antenna costing less than $150 is no longer a distant concept.

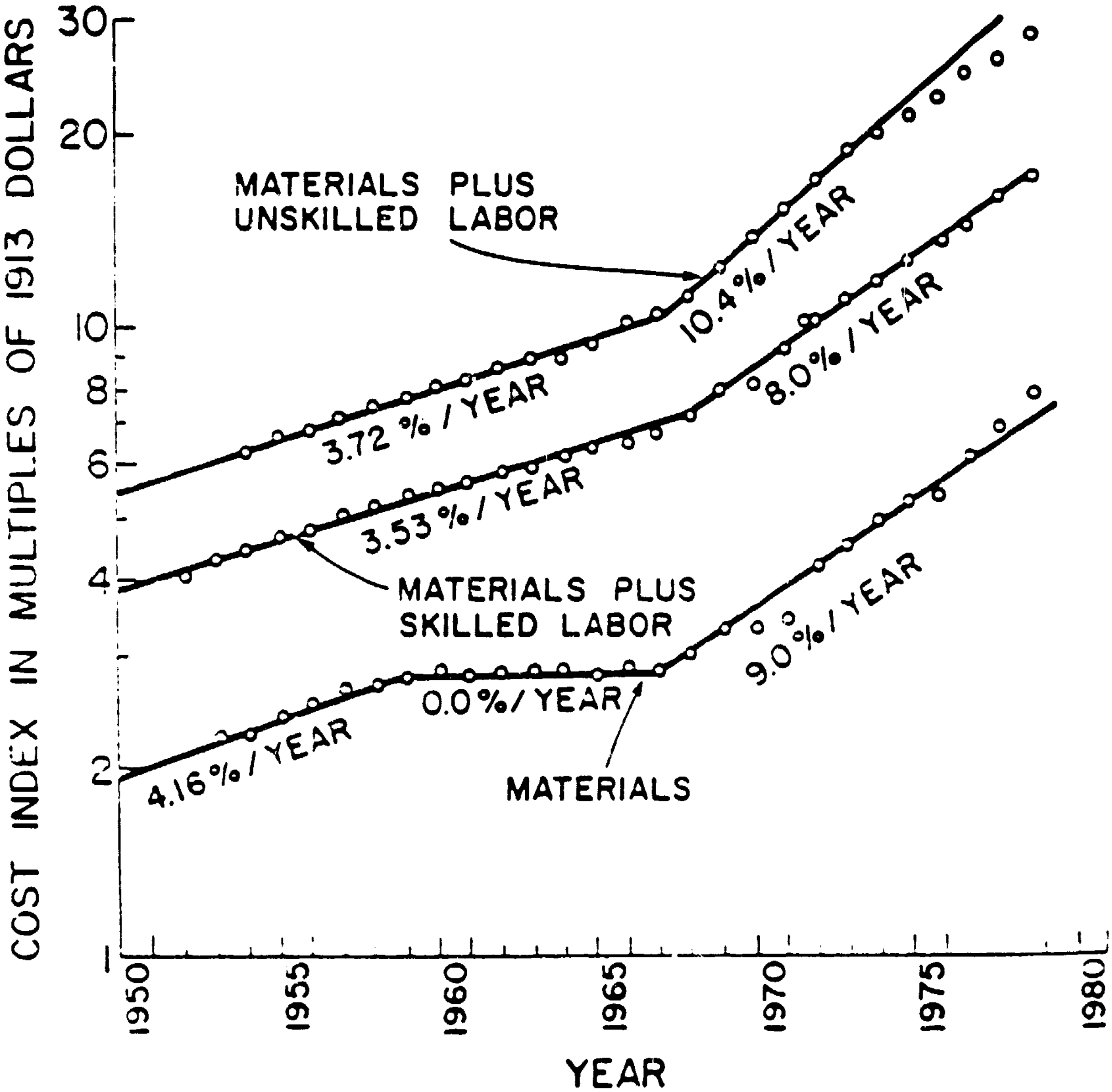


Figure 7-12

Recent inflation rates for labor and materials. (Harvey)

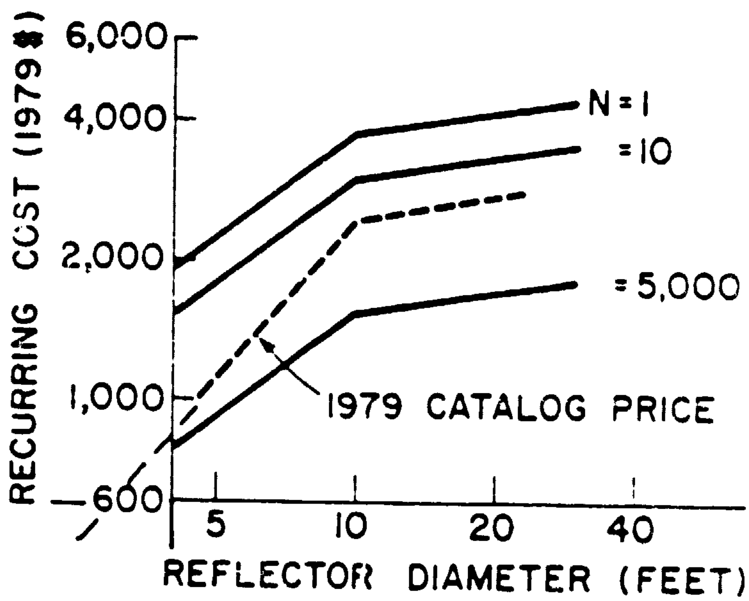


Figure 7-13

Antenna and Mount Cost versus Reflector Diameter of Prodelin Products

(———— 1976
---------- 1979)

Tables 7-30 and 7-31 describe typical cost breakdown approaches, listing both materials and labor and cost of tooling, with Table 7-31 providing an illustrated cost breakdown of a Ku-band 6-meter antenna reflector built in 1977. Note that the individual panels of the 6-meter antenna each is roughly equivalent to twice the aperture of a 1-meter dish, even in 1977; a 1-meter dish could have cost less than $200 (an equivalent structure - a 36-inch circular child's parabolic metal toboggan for snow rides cost less than $15 at Sears at this time). Note that reduction of <u>all</u> labor costs to a minimum and the use of quickly assembled stamped metal parts is the key to cheap precision small antennas at 2.5 and 12.6 GHz and to Yagi or helical spirals at UHF.

Table 7-32 lists typical cost elements of the mount, feed, and LNA of a small aperture antenna. All material elements are presently low volume devices, including LNA castings, and the key to cost reduction is in the LNA microwave device cost and in the assorted labor costs. At present, all costs are dominated by FET costs, which have seen a drop in the per-unit FET cost of $300-$500 in 1975 to $50 in 1980 and will probably be below $10 by 1982. If these FET costs - particularly in monolithic GaAs circuits - can be reduced such that the amplifier-down-converter on-a-chip becomes a low cost reality (see Section 6), then the integrated FEED/LNA, which is a weather-proofed unit, mounted on the 1-meter dish for out-of-doors all-weather operation, is a prime candidate device for costs well below $100 and no longer virtually dominates overall TVRO costs in that this unit now costs at the cost level of either the antenna or the receiver.

7.5.4.3 <u>A Note on Japanese FET Cost.</u>

The prediction of low FET prices in Japan was discussed in the article "Microwaves in Japan" by MSN's Editor in Chief, James Fawcett (Feb. 1980) when he wrote, after interviewing many Japanese semiconductor-company executives,

TABLE 7-30

Antenna Cost Breakdown

Cost Element	Unit Cost	Cost Part 1	Cost Part 2	Cost Part N
Metal Extrusions	.....¢/length	$.....	$.....	$.....
Aluminum Sheet	.....¢/pound	$.....	$.....	$.....
Adhesive	$...../Tube	$.....	$.....	$.....
Rivets	.....¢/Each	$.....	$.....	$.....
Screws	.....¢/Each	$.....	$.....	$.....
Labor	$...../Hour	$.....	$.....	$.....
Cost of Tooling	$.....	$.....	$.....	$.....
Subtotal	$.....	$.....	$.....	$.....
Total (sum of subtotals) Materials and Labor				$.....

TABLE 7-31

Cost Summary (1977) of 10-Panel 6-Meter Parabolic Antenna

Cost Element	Unit Cost	Panel Element	Panel Cost
Aluminum	90¢ per pound	86.45 pounds	$ 77.30
Adhesive	$10.00/Tube	2 Tubes	$ 20.00
Rivets	3¢ each	444 Each	$ 13.32
Labor	$18.00/hour	15.36 Hours	$ 276.48
		Subtotal	$ 387.60
		Number of Panels	10
			$3876.00

TABLE 7-32

Mount, Feed and LNA Cost Breakdown

Cost Element	Unit Cost	Total Cost	Typical 1980 Cost
Feed Casting } can be combined	$..../Feed	$.........	35
LNA Casting } can be combined	$..../Box	$.........	50
Mount	$..../Part	$.........	150
LNA { Option 1:			
FET/Diode (Hybrid Circuit)	$..../Device	$.........	120
Microwave IC	$..../Board	$.........	100
LNA { Option 2:			
GaAs Monolithic IC (Microwave Amplifiers/Converters)	$..../Chip	$.........	In Development
Connectors (RF in, IF out, LO in)	$....	$.........	15
Cable	$..../Foot	$.........	10
Container/Packaging	$..../Subsystem	$.........	20
Labor:			
Assembly	$....	$.........	25 (1 hr)
Initial Test	$....	$.........	10
Inspection and Final Test	$....	$.........	20
Painting/Label/Packaging	$....	$.........	5
Prime Labor/Material Costs			485
Sales Cost (Approx.) using 2.2 factor			1670

"From UHF to 12 GHz, commercially available GaAs FET's due out this year and laboratory devices that hint at the near future indicate the struggle NEC and Mitsubishi are headed for in the 1980s. The most striking example is the simultaneous introduction of very inexpensive sub-2-dB NF FET's for 12 GHz earth terminals. A dual-gate GaAs Mesfet used in TV tuners is manufactured by Matsushita Electronics Ind. Co., Ltd. Their 3SK97 produces 1.3 dB NF, 15 dB MAG, at 1 GHz, but costs only $1.

Government interest is just beginning to spark substantial research, and analog circuits lag digital development. But a wider range of "blue sky" technologies are being tested - including enhancement-mode Mesfets, IGFETs, and Mosfet ICs - than in the USA or Europe. One government contract has already yielded the world's first GaAs LSI of 1000 gate-equivalent circuits, although no details will be revealed until the contract terminates in another year.

NEC, Toshiba, Mitsubishi, and possibly Fujitsu are expected to seek the BSE-2 satellite integration contract. Toshiba and Mitsubishi are both developing phased-array radars. All the companies are expanding outside their traditional military-service alignments, although the entire question of serious military development appears moot unless Article Nine of the constitution is amended.

Much of the projected growth, indeed the entire concept of direct-to-home TV satellites, is dependent on drastic price cuts, which such industry leaders as Toshiaki Irie of NEC are confidently predicting. Irie supervises the Tanagawa plant that already produces 30 million microwave devices annually of both silicon and gallium arsenide.

Growth of the semiconductor and IC division, largest of NEC's five divisions, has been based on high volume production and the shift from discrete silicon to ICs: In the last five years ICs have taken over 40% of sales and are expected to reach 60-65% in the next five. The company is eager to retrace the same route in gallium arsenide. "I believe the GaAs FET will achieve costs as low as the bipolar. We will see similar quantities in the TV market", Irie claims. "I think for GaAs FETs even $5 is too high. Prices must drop two orders of magnitude. Yes. Perhaps to fifty cents".

While home receivers for satellite television offer the largest and most glamorous market, the volumes will begin building even before that field opens with the launch of the BSE-2 in 1983-4. An NHK (Japanese broadcasting corporation) plan to use similar receivers with 12 GHz tower-based transmitters calls for 60-80 thousand units a year to serve 600,000 homes hidden in valleys that do not receive television and Tokyo homes shielded by skyscrapers.

Perhaps surprisingly, television manufacturers are planning to use GaAs FETs in UHF tuners, despite higher noise than bipolars, because of the disappointing intermodulation distortion caused by drastic impedance changes of bipolar forward AGC. Matsushita Electronic Industries Ltd. has already tested a plastic packaged FET which was mentioned on the preceding page with a performance of 1.3 dB NF at 1 GHz; the company has yet to make a commitment to volume manufacture. NEC, however, already has a commercially available FET, the NE218, which reaches 0.9 dB NF at 2 GHz and will work as low as 70 MHz. Some instability may occur at 2 GHz, but ease of matching should preclude this.

7.5.5 <u>TVRO Cost Breakdowns.</u>

Tables 7-33 through 7-41 list typical combined labor and materials costs which have been obtained for various quantities (1-100, 100,000, 1M, and 10M) of TVRO antenna systems having the various G/T figure of merits:

UHF - G/T = 0 dB/^{o}K; S-Band - G/T = 0 dB/^{o}K = 8 dB/^{o}K; 12 GHz - G/T = 8 dB/^{o}K

The cost figures in combined labor and materials costs can be converted to sales cost by the factor 2.2 which is representative of this industry, and Table 7-41 is a total cost summary which includes the use of this factor.

7.5.5.1 UHF TVRO Costs.

Tables 7-33 lists the various candidate UHF antennas which can provide the nearly 24-25 dB of gain necessary to develop a G/T of 0 dB with a low noise receiver with a noise figure of around 1.5 dB. As noted, the parabolic and Torus antennas are very large and therefore very expensive and not really a first-class candidate for the services. On the other hand, the YAGI and helical antennas have a long history of application in this frequency range. The YAGI-UDA antenna is the world's most widely used TV antenna and the helical antennas are used on many satellites and many NASA and military UHF earth terminals. The YAGI is now used in the USSR for the 716 MHz earth terminal to STATSIONAR-T and although one YAGI antenna has been built which achieved 26 dB gain* at 400 MHz, it was so long (80 wavelengths) as to be structurally and economically non-viable. Accordingly, narrow-band arrays are recommended and the antenna L/M cost will be high (around $1000) - even in a matured art which provides sophisticated commercial YAGI antennas and mounts for from $75 to $200.

The UHF TVRO cost of Table 7-34 reflects that essentially this receiver is very inexpensive since it is virtually a counterpart to modern UHF TV receivers - including varactor tuning or synthesizer tuning - using integrated circuits - as has been described in Section 6. The L/M costs of around 38-85 dollars (times 2.2) are similar to stereo tuner costs which are available in the commercial market in a highly competitive environment.

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* P.C. Goldmark and J. Hollywood, "Antennas for improved hf point-to-point reception", CBS Laboratories Project 210, 1963.

TABLE 7-33

UHF TVRO ANTENNA (G/T = 0 dB/K)

Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars) 1-100	100,000	1M	10M
Antenna	Prime focus parabolic or Torus antennas	Frame parabolic dish (4 meters) with mesh surface and prime focus dipole feed	2500	300	200	150
	Array of Yagi Antennas with LNA at each Yagi	4-6 Yagi's in an array. 4 Yagi's used in USSR EKRAN system at 716 MHz to provide 25 dB gain.	1500	200	160	150
	Array of antennafiers (Low noise transistor integrated with dipole element)	Simple antennafiers now in use. Requires devel. use transistor gain as partial substitute for aperture in large array.	800	200	160	150
	Helical Antennas	Used with MARISAT, OSCAR, FLEETSAT	1000	200	160	150
		TOTAL QUANTITY COST		200 to 300	160 to 200	150

TABLE 7-34

UHF TVRO RECEIVER (G/T = 0 dB/K)

Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars)			
			1-100	100,000	1M	10M
LNA	Bipolar Transistor	1-3 dB NF/TV sets	50	IC's		
1.5-3dB	FET (silicon, JFET)	1-3 dB NF/FM Tuners	50			
Down Converter	Integrated Circuit	Similar to use in color TV rec.	300	25	13	10
Oscillator	Varactor Tuned OSC	Similar to use in color TV rec.	250	15	10	7
	Synthesizer IC	In IC's for color TV rec.				
Detector and Video Processor	Integrated Circuit	In use in color TV rec.	25	15	10	7
Remodulator to UHF/VHF	Integrated Circuit	In use in color TV rec.	25	15	10	7
Circuit Boards and Hardware	5-6 layer board Cabinet/P.S./Knobs	Conventional receiver construction	100	15	10	7
		TOTAL QUANTITY COST		85	53	38

7.5.5.2 2.54-GHz TVRO Terminal Costs.

Tables 7-35 and 7-36 list quantity antenna costs for 2.54 GHz antennas in the 23-32 dB gain range. The candidate antennas are parabolic antennas, torus frame antennas, and helical arrays.

There is a long cost history of 2.54 GHz parabolic antennas following the purchase of 150 10-ft diameter plastic antennas from Prodelin (Santa Clara, Ca) for use with the ATS-6 Rocky Mountain Education Experiment in 1975-1976, and small antennas now being developed for TVRO use at 4 GHz can be adapted to community TVRO use.

In considering all candidates, it is not possible to not consider the possible use of phased arrays following the successful Swedish development of a 1.6 GHz phase array (price unknown) for use on shipboard in the MARISAT system.

As noted for both G/T = 0 and G/T = 8, these antennas are costly due to the fact that they are large - from 5-10 feet in diameter for the parabolic dishes, and the costs - in the thousands of dollars - for small quantities reflect large structure/materials/mount and labor costs.

Table 7-26 lists a variety of low quantity antenna costs at 4 GHz by both Prodelin and Andrew which provide the bases of these costs.

The receiver costs listed in Table 7-37 reflect a combination of two costs; (1) a LNA/down-converter box which is weather-proof and mounted with the antenna feed, the assembly is connected by coaxial cable (which also supplies d.c. power) to the receiver which is located in an interior place near the receiver or re-broadcast equipment; and (2) the receiver which accepts an input signal in UHF, provides gain and AGC, demodulates, and remodulates to apply a signal at a desired TV channel into a TV receiver.

TABLE 7-35

2.54 GHz TVRO Antennas (G/T = 0 dB/K)

Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars) 1-100	100,000	1M	10M
Antenna	Prime focus parabolic antenna	5-ft diam dish	600	350	250	200
(Mount included)	Torus frame-antenna using mesh wire surface	3 x 5-foot (approx) rect. frame using one or more prime focus feeds. High side-lobes	600	350	250	200
	Phased array of printed circuit elements or helical elements	Similar to array developed in Scandinavia for 1.6 GHz Marisat system. Very low (35 dB) side-lobes	10000	2500	1000	800
		TOTAL QUANTITY COST		350 to 2500	250 to 1000	200 to 800

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TABLE 7-36

2.54 GHz TVRO Antenna (G/T = 8 dB/K)

COMPONENT	CANDIDATE TECHNOLOGY	DESCRIPTION	NOMINAL COSTS FOR INDICATED QUANTITIES (in U.S. DOLLARS)			
			1-100	100000	1M	10M
ANTENNA (Mount included)	Prime focus parabolic antenna	3 meter dish	1000	500	400	350
	Torus frame antenna using mesh wire surface	4x8 foot (approx) rect. frame using one or more prime focus feeds. High sidelobes	1000	600	500	325
	Phased array of printed circuit elements of helical elements	Similar to array dev. in Scandinavia for 1.6 GHz Marisat system.	20,000	2500	1500	1000
		TOTAL QUANTITY COST		500 to 2500	400 to 1500	325 to 1000

TABLE 7-37

2.54 GHz TVRO Receiver System (G/T = 0 dB/K)

	Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars) 1-100	100,000	1M	10M
Antenna Mounted	LNA	FET Amplifier	1 dB (70K) noise fig.	500	all IC		
		Bipolar transistor amplifier	1.5 dB (120K) noise fig.	400	50	30	25
		Low noise mixer	3 dB conversion loss	400			
	Down Converter	Single conversions	Candidate for monolithic techniques including LNA and oscillator	400			
Interior Installation	Oscillator	VCO	Varactor-tuned oscillator now available	150	15	10	7
		UHF synthesizer IC's plus multiplier	Synthesizer in use, some in color TV rec.	150	25	15	10
	IF, AGC, Detector and Video Processor	Integrated Circuit	In use in color TV rec.	25	15	10	7
	Remodulator to UHF/VHF	Integrated Circuit	In use in CATV systems	25	15	10	7
	Circuit Boards and Hardware	5-6 layer board Cabinet/P.S./Knobs	Conventional receiver construction	100	15	10	7
			TOTAL QUANTITY PRIME COST		110	75	56

The interior "receiver" will be inexpensive - using essentially UHF TV receiver techniques and circuits; the LNA and down-converter for low quantities will be fairly expensive. In 1980, a 1.5-dB NF amplifier is available in TO-5 can modular form and can be procured (Avantek, Amplica, etc.) as a packaged amplifier for around 500-1000 dollars. A down-converter is now marketed by Merrimac (see Section 6) for around $1200 sales cost and around $400 L/M cost. Thus the prime (L/M) cost in quantity will range from 56 to 110 dollars.

7.5.5.3 12-GHz TVRO Costs

Tables 7-28 to 7-40 describe the cost breakdowns for 12 GHz direct-to-user service for the various alternatives associated with the 1-meter antenna (or equivalent), the LNA, and the receiver.

There is a large disparity between various antenna technologies for small quantities. The slotted waveguide array and printed circuit arrays are expensive to make in small quantities, while the small parabolic antennas (including feed, structure and mount) are relatively low cost. However, at high volume, mass production tooling and automatic manufacture of all antenna types will result in very low cost (30 to 100 dollars) depending on type and quantity.

In 1980, the 12-GHz LNA is the pacing item for a 1-meter TVRO terminal cost. This is due to the present high cost of 12 GHz FET's although, at 4 GHz FET's are experiencing a significant cost reduction. 1980 noise figures for production FET's can now be specified at 4 dB. However, within 3 years, such devices will produce 2 dB noise figures due to competition in low-noise GaAs Mesfets at 12 GHz in Japan, i.e., the NE137 from NEC, and the MGF-1403 from Mitsubishi. The NE137 will be commercially available with a noise figure of about 2 dB at 12 GHz based on laboratory devices now providing 1.68 dB NF using a "deep-recessed" half-micron gate which drops source resistance and noise figure. The use of unconventional structure in Mitsubishi's low-noise FET's has produced noise 1.3 dB at

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TABLE 7-38

12 GHz TVRO Antenna (G/T = 8 dB/K)

Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars)			
			1-100	100,000	1M	10M
Antenna	Prime focus feed parabolic antenna	1-meter assembly with first sidelobes in 12-17 dB range	250	50	40	30
	Off-set Fed parabolic antenna	1-meter assembly with first sidelobes in 25-36 dB range	300	50	40	30
	Slotted waveguide array	36 x 36 inch flat plate with sidelobes 40-50 dB range	5000	75	50	40
	Printed Circuit array	36 x 36 inch flat plate with corporate feed-sidelobes in 40-50 dB range	10000	100	60	50
		TOTAL PRIME COST		50 to 100	40 to 60	30 to 50

TABLE 7-39

12 GHz TVRO LNA/First Down Converter
(G/T = 8 dB/K)

Component	Candidate Technology	Description/Heritage	Nominal Costs for Indicated Quantities (in U.S. dollars)			
			1-100	100,000	1M	10M
Low noise amplifier (mounted with or integrated with feed)	FET amplifier *	100-200°NT-presently high cost, developmental only	1500	1 or 2 IC's (monolithic GaAs)		
	Konishi Mixer	400°NT - Wafer assembly in WG	1000	50	30	25
First Down converter and oscillator	Single conversion	Conversion to intermediate freq. 950-1450 MHz	500			
		TOTAL QUANTITY PRIME COST		50	30	25

* 1980 Noise figures for production 12 GHz FET's are at 4 db. Laboratory and developmental FET's are at 2 db. By 1984, production 12 GHz FET's are predicted to give 2 db noise figures, and by 1987, monolithic gallium arsenide FET MIC amplifiers will give 1.5 db NF.

TABLE 7-40

12 GHz TVRO Terminal (G/T = 8 dB/K

Component	Candidate Technology	Description/Heritage	Nominal Cost for Indicated Quantities (in U.S. dollars)			
			1-100	100,000	1M	10M
Second down converter	Single conversion	Input 450-1450 MHz Output 70 MHz	350	Two IC's		
Tuning oscillator	VCO for tuning	Varactor tuned micro-wave FET oscillator-use monolithic techniques	150	40	20	12
	Synthesizer for tuning	Synthesizer IC at UHF/VHF in use	200			
IF, AGC, detector and Video/Audio processor	2-3 Integrated circuits	In use for modern color TV rec.	25	15	10	7
Remodulator to UHF/VHF	Integrated Circuits	In use for modern CATV systems	25	15	10	7
Circuit boards and Hardware	5-6 layer board Cabinet/P.S./Knobs	Conventional receiver construction	100	15	10	7
		TOTAL QUANTITY PRIME COST		85	50	33

12 GHz in the laboratory. More significantly, commercial samples are now available that provide 1.7 dB at 12 GHz, but at a cost that matches their Rolls Royce performance, $283.50 apiece. The battle continues at 4 GHz, where a pair of less expensive devices, the NE218 and MGF-1412, both offer around 0.7 dB NF. However, the eventual advent of the $1 FET as predicted by Japan's Dr. Erie of NEC will cause the FET LNA at 12 GHz to seriously compete with the KONISHI waveguide mounted mixer - and ultimately produce microwave IC's in the 25-50 dollar range (L/M).

Table 7-40 lists the cost ranges for the receiver of the 12 GHz TVRO terminal which is located inside a home next to a TV set and receives a converted signal from 12 GHz to UHF via a cable from the outdoor antenna-mounted LNA. As in the case of the UHF and S-band TVRO terminals, this receiver is essentially a "counterpart" to present UHF TV receivers and a labor and material cost of 33 to 85 dollars for the stated quantities will be realized.

7.5.5.4 TVRO Terminal Summary Cost Ranges.

Table 7-41 summarizes the cost ranges for prime labor/material costs listed in Tables 7-33 through 7-40 and applies the 2.2 factor to these prime costs to achieve representative sales costs for the various terminals at the three frequency ranges and for quantities of 100,000, 1,000,000, and 10 million.

Note that the Ku-band TVRO direct-to-user sales costs range from 462 to 215 dollars depending on quantity which match costs now predicted in Japan and predicted (unofficially) for the Comsat-Sears system.

At lower frequencies, antenna and LNA costs provide much higher terminal costs, with the highest costs occurring at 2.54 GHz due to the combined cost of aperture and sensitivity - the costs at UHF being dominated by aperture costs and at 12 GHz by sensitivity costs.

TABLE 7-41

TVRO Cost Ranges in 1980 Dollars*

Subsystem	Antenna System			Receiver System			TVRO System		
Quantity (M)	0.1	1	10M	0.1	1	10M	0.1	1	10M
	Ave. L/M Costs			Ave. L/M Costs			Ave. Sales Costs**		
UHF (0.8 GHz) Figs.7-33;7-34	250	160	150	8.5	53	38	737	468	413
				Note: includes LNA					
S-Band (2.54 GHz) Figs.7-35;7-37	350	250	200	110	75	56	1012	715	512
				Note: includes LNA					
Ku-Band (12 GHz) Ant.	75	50	40						
LNA	50	30	25						
Total	125	80	65	85	50	33	462	286	215
Figs.7-38;7-39; 7-40									

* G/T = 8 db at 12 GHz, 0 db at 0.8 GHz and 2.54 GHz.

** Sum of Antenna, LNA, and Receiver Costs given as prime labor and materials (L/M) costs in first two columns, and multiplied by 2.2 to get sales cost.

Such costs could not have been predicted even at the time of WARC-77. They are possible now primarily due to the maturation of FET technology and manufacture, the introduction of monolithic GaAs technology for microwave amplifier manufacture, and the development of sophisticated but very inexpensive IC's for commercial UHF TV receivers.

7.5.6 System Costs in Broadcast Satellite Service.

Space segment and earth segment costs have been developed in this section primarily from the standpoint of available technology rather than from a generalized system viewpoint.

As pointed out earlier in this section, it is practical until around 1986 to consider only Delta, Ariane 1, or Atlas-Centaur class launches now predicated as costing in the $40 million dollar range. A satellite capable of providing EIRP in the 60-65 dbw range for at least four channels will cost from 40-50 million dollars each. Thus the space segment cost will range from $150 million to $250 million dollars depending on the number of satellites procured, the launch costs, the TT&C terminal costs, and the cost of money including inflation and insurance.

Table 7-42 lists typical system costs for a 12 GHz direct-to-user system for space segment costs from $150M to $250M, and for 1-meter TVRO costs derived from Table 7-41.

Note that on the basis of an overall system, the space segment cost totally dominates system costs until a quantity between 500K and 1M earth terminals is used. In that range of quantities, the earth segment costs start to dominate and by 10M receivers, totally dominate the system costs.

TABLE 7-42

Typical System Costs - 12 GHz Direct-to-User

Space Segment:	2 Satellites in orbit (60-65 dbw) 1 Spare 7 Year satellite life 1 Tracking Station + maintenance 2 Launch vehicles Cost of money, inflation Cost of Insurance	160-200 M Dollars

Ground Segment:	Quantity	10	100	1K	10K	100K	1M	10M
o 1-meter Antenna TVRO Costs	Nominal Unit Cost ($)	10	5	2	1.2	0.4	0.25	0.2
	Nominal Quantity Costs ($)	100K	500K	2M	5M	40M	250M	2B
o Total Space Segment ($M) Plus Ground Segment Costs								
- $150M Space Segment		150.1	150.5	152	165	190	400	2.15B
- $200M Space Segment		200.1	200.5	202	215	240	450	2.2B
- $250M Space Segment		250.1	250.5	252	265	290	500	2.25B

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APPENDIX A

Technical Memorandum TM-294
March 1980

SYSTEMS ANALYSIS AND SYNTHESIS DEPARTMENT

SPACECRAFT PARAMETER AND COST ESTIMATION MODEL

by S. J. Melachrinos
and
M. W. Baker, Jr.

Performed under:
IR&D Project No. 79010303 "Satellite Communication Sciences"

WORKING PAPER
This is an informal memorandum subject to change

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ABSTRACT

Algorithms are presented for estimating the weight and cost of communications satellites. A computer program called the Spacecraft Parameter and Cost Estimating program or SCPCE is described and presented which implements these algorithms. A user's manual and sample runs are included to allow the reade to run the program.

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PART 1

GENERAL PROGRAM DESCRIPTION

1.0 INTRODUCTION

The spacecraft (S/C) estimating model described herein predicts S/C weights and costs based on derived factors and the use of a modified version of the SAMSO S/C cost model. A computer program has been designed to allow system engineers to estimate S/C sizes and costs and the effect of increasing or decreasing communications capability on size and cost when performing system level definition and trade-offs. The model use is limited to communications payloads (or payloads that are equivalent) for estimating size and costs although the S/C parametric estimates can be used for sizing any type of S/C. Further the model is limited to 3-axis S/C and the use of the Space Transportation System as a launch vehicle. Cost estimates generated are defined as "end-of-program should costs."

2.0 GENERAL MODEL DESCRIPTION

Figure 1-1 depicts the general program flow of the model which consists of four major routines.

2.1 Orbital Parameter Generator

Through the use of simple Keplerian formulas, ΔV's are estimated for the defined S/C orbits. An STS launch vehicle is assumed starting from a parking orbit of 160 nautical miles altitude at an appropriate inclination for ETR or WTR. Model selects minimum inclination change.

2.2 Spacecraft Parameter Generator

3

Using the payload weight and power as inputs, the model generates estimates for:

- o Structure Weight

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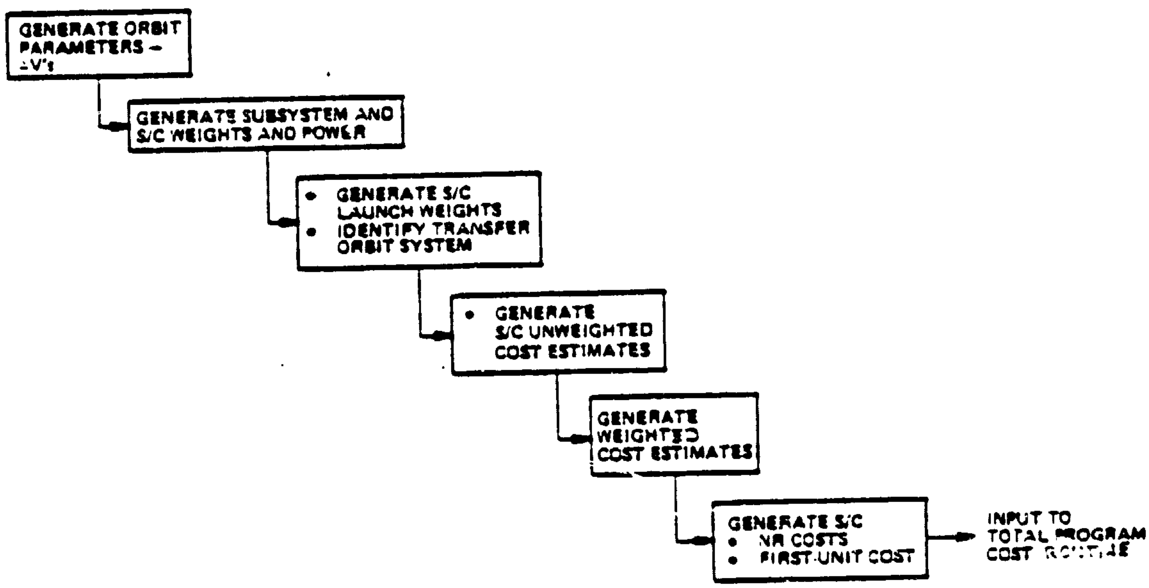

Figure 1-1. General Program Flow

- TT&C Weight and Power
- Attitude Control Weight & Power
- Propulsion Weight
- Electrical/Mechanical Integration Weight
- Thermal Weight
- Electrical Power Weight
- Number of cells in the array
- EOL & BOL Power (equinox)
- On-Orbit Fuel Weight
- S/C On-Orbit Weight
- S/C Launch Weight
- Transfer Orbit System

These estimates are all based on FACC experience.

2.3 Spacecraft Cost Generator

The estimated S/C subsystem weights and power are rearranged to fit the SAMSO Cost Estimating Relationship (CER) parameters and Basic Cost Estimates at the subsystem level are generated using an FACC-modified version of the SAMSO CER's.[1,2] Weighted complexity factors are then generated and applied to the Basic Estimates to arrive at the cost estimates for the derived S/C. Both non-recurring costs and recurring (First Unit Costs) costs are generated including Management and Support, prototype refurbishment (where required) and total space segment costs including profit and on-orbit incentives, transfer orbit system costs, and STS costs.

2

A provision has been provided in the model so that if the user has all of the S/C parameters, the model can be used to generate just the S/C costs.

2.4 Trade Generator

Trade-offs can be accomplished using different spacecraft parameters. The model retains the initial computations as a baseline and recomputes all of

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1. Franklin Fong, et al, SAMSO Unmanned Spacecraft Cost Model, Updated Cost Estimating Relationships & Normalization Factors (An Interim Report), Cost Analysis Division, Hq. SAMSO, January, 1977.
2. Christopher J. Rohwer, et al, SAMSO Unmanned Spacecraft Cost Model, Third Edition, Cost Analysis Division, Hq. SAMSO, TR-75-229, August, 1975.

the S/C weights and costs based on the new inputs. It then prints out the new results and the differences from the baseline. Based on the results of the trades, the user can retain or replace the stored basaline.

3.0 TECHNOLOGY BASE

With the exception of the electrical power subsystem, the technology base for estimating S/C weights is essentially that which would be available for a S/C launched in 1985-87 time period. Although some increases in the technology base can be anticipated post 1985-1987, they would have to be radical in nature for a significant difference to be seen. For the electrical power subsystem, two technology bases are included in the model: one for 1985-87 launch (up to 1984) and one for 1988+ launch (1985). Significant increase in power generating capability per pound of power subsystem weight is anticipated in the post 1985 time period. Where an apogee motor capability is included in the S/C, use of bi-propellant system is factored into the model.

4.0 COST BASE

The cost base provided in the model has been set in terms of 1980 dollars. All computations are presented for that base year. To establish a cost estimate for base years beyond 1980, the generated cost estimates must be spread and appropriate inflation factors applied. The model does include an inflation application which is described in Part II. To achieve this capability, costs of the base year are first spread over the program and then inflation factors applied.

PART II

BASIC ALGORITHMS

1.0 INTRODUCTION

Included in this part of the documentation are the basic computational algorithms used in themodel. They include equations, factors and relationships required to generate required model parameters. The factors used in generating the S/C weights/power are based on a simple averaging (weighted to FACC S/C) of these factors from some 30 different 3-axis S/C designed for many different types of orbits.

2.0 COST MODEL VALIDITY

The SAMSO statistical base does not include S/C in the 4-7,000 lb. category. There is, therefore, some question to its validity when extended to this category of S/C. FACC has examined relatively detailed S/C designs in this range and has concluded that the SAMSO model can be extended to this range and may be valid within the basic overall validity of the original SAMSO model. Application of this cost model to S/C greater than 7,000 lbs. on-orbit and especially those S/C which might be assembled on orbit is not valid.

3.0 EQUATIONS/FACTORS

3.1 Equations

Table 2-1 contains the basic equations contained in the model.

3.2 Factors

Table 2-2 contains the basic factors and factor relationships contained in the model.

3.3 Spreads

Table 2-3 contains the basic cost spread/inflation application relationships contained in the model.

TABLE 2-1

BASIC COMPUTATIONAL EQUATIONS

Note: Acronyms used are defined in Table 2-4.

1.0 <u>Orbital Computations</u>

1.1 <u>At Perigee</u> (ΔV velocity change for transfer orbit insertion)

$$DV1 = \left[\frac{2x2.15227E11xFAR}{FPR\ (FAR + FPR)}\right]^{\frac{1}{2}} - 7727.9$$

Note: FAR & FPR are radii in n. miles; add 3443.9 to altitudes

1.2 <u>At Apogee</u>

1.2.1 Inclination change (STX)

STX = /FINC-X/

Select smallest STX from

x = 28.5 or 55.0 for Eastern Test Range Launch

x = 75.0 or 90.0 for Western Test Range Launch

1.2.2 Circular orbit: any inclination

$$V3 = \left[\frac{2.15227E11}{FAR}\right]^{\frac{1}{2}}$$

$$V4 = \left[\frac{2x2.15227E11xFPR}{FAR(FPR + FAR)}\right]^{\frac{1}{2}}$$

1.2.3 Non-circular orbit: any inclination

$$A1 = (3603.9+FAR)/2 \ ; \ A2 = (FPR+FAR)/2$$
$$E1 = (FAR/A1)-1 \ ; \ E2 = (FAR/A2)-1$$
$$B1 = A1\sqrt{1-E1^2} \ ; \ B2 = A2\sqrt{1-E2^2}$$
$$P1 = B1^2/A1 \ ; \ P2 = B2^2/A2$$
$$V3 = (2.15227E11\ (2/_{P1}-1/_{A1}))^{\frac{1}{2}}$$
$$V4 = (2.15227E11\ (2/_{P2}-1/_{A2}))^{\frac{1}{2}}$$

1.2.4 ΔV at apogee for final orbit acquisition

$$DV2 = \left|V3^2 + V4^2 - 2V3xV4\ \cos\ (STX)\right|^{\frac{1}{2}}$$

TABLE 2-1 (Cont.)

1.0 (Cont.)

1.3 Weight/Fuel

1.3.1 Weight: Weight Final = Weight Initial x $e^{\overbrace{\Delta V/9.807xIsp}^{Z1=Z6}}$

1.3.1.1 At Perigee ΔV = DV1
1.3.1.2 At Apogee ΔV = DV2
1.3.1.3 Isp - See Part 2 of Table 2-2

Note: ΔV = DVMV is maneuver capability specified

1.3.2 Fuel: Weight fuel = weight initial - weight final

2.0 Basic Spacecraft Computations

2.1 S/C on orbit weight
BSWT = ΣBUS subsystem weights
OOFW = FWF x BSWT
PRPW = 0.1 (OOFF + DVMFW) + 56.9 - with AKM
SCOWT = CWT + OOFW + DVMV + BSWT

2.2 S/C Launch Weight

SCLWT = ((SCOWT+XNRT1) x Z_ + XNRT2) x Z_ + CLDW

Note: XNRT's & Z's depend upon perigee motor used.

3.0 Costing

Note: NR = Non-recurring cost; R = Recurring cost

3.1 Communication Subsystem

NR = CNWF(1375.6 + 199.6 x $(CCP)^{.67}$)
R = CRWF(67.6 x $(CCP)^{.75}$ - 91.9)

3.2 TT&C S/S

NR = TNWF(287.7 + 22.2 x TCP)

R = TRWF(91.9 + 13.1 x TCP)

3.3 Structure S/S

NR = SNWF(759.0 + 66.0 x $(SCP)^{.66}$; SNWF = 1.346
R = SRWF(2.4 + 7.5 x $(SCP)^{.75}$) ; SRWF = 1.377

TABLE 2-1 (Cont.)

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3.4 Attitude Control (ACS) S/S

$$NR = ANWF(734.9 + 79.9 \times (ACP)^{.75})$$

$$R = ARWF(25.0 + 40.9 \times (ACP)^{.8})$$

3.5 Electrical Power S/S

$$NR1 = 440.3 + 2.0 \times ECP2$$

$$NR2 = ENWF(50 \times ECP3/1000)$$

$$R1 = 83.5(ECP1 \times ECP2)^{.21128}$$

$$R2 = ERWF(40 \times ECP3/1000)$$

$$NR = NR1 + NR2$$

$$R = R1 + R2$$

3.6 Weighted complexity factors

CN = Sum of individual complexity factors from Section 3.8

CN = Constant

abWF = ((CN + CF) x X) xY

a = C, T, A or E for Comm., TTC, ACS or EPS

b = N or R for Non-recurring or Recurring

3.6.1

	NR			R		
	X	Y	CN	X	Y	CN
COMM	.52	.48	.39	.56	.44	.29
TTEC	.52	.48	.294	.52	.48	.211
ACS	.62	.38	.497	.50	.50	.296
EPS	.56	.44	1.132	.52	.48	.836

3.7 STS Costs

3.7.1 Factor - STSCF

a) LZ = ((SCLWT x 60)/65000) - PML
b) STSCF = SCL + PML/60 IF SCL > LZ
c) STSCF = SCLWT/65000 IF SCL < LZ

3.7.2 STS Cost

STSC = (STSCF x C) + 4300

C = 22722.4 If military program
C = 33806.6 If commercial program

3.8 Basic Complexity Factors

3.8.1 Communications Subsystem

INPUT

CL1 Highest Communications Frequency

1 = 15 GHz
2 = 15-56 GHz
3 = 56 GHz

CL2 Highest P.P. Level at Highest Frequency

	CL1	1	2	3
	CL2	NR/R	NR/R	NR/R
1 = < 5 watts	1	.233/.196	.325/.284	.551/.475
2 = 5 to 10 watts	2	.252/.220	.375/.318	.608/.512
3 = 10 to 20 watts	3	.281/.245	.424/.352	.664/.549
4 = 20 to 40 watts	4	.345/.264	.481/.385	.742/.583
5 = > 40 watts	5	.392/.305	.523/.419	.799/.617

CL3 Type of Transponder

	CL3	NR	R
1 - Translating	1	.100	.109
2 - Regenerative	2	.140	.229
3 - Combination	3	.245	.355

CL4 Number of Active Power Amps

	CL4	NR	R
1 - ≤ 10	1	.067	.073
2 - ≤ 50	2	.086	.080
3 - ≤ 100	3	.112	.088
4 - > 100	4	.137	.089

CL5 Number of Different Frequency Bands

	CL5	NR	R
1 - 1	1	.034	.037
2 - 2	2	.035	.037
3 - 3	3	.039	.040
4 - > 3	4	.040	.041

CL6 Number of RCV/XMIT Antenna Sets

	CL6	NR	R
1 - 1	1	.035	.034
2 - 2,3	2	.039	.039
3 - 4-6	3	.042	.043
4 - > 6	4	.047	.049

TABLE 2-1 (Cont.)

INPUT	DESCRIPTION		COMPLEXITY FACTORS	
CL7	Most Complex Antenna Coverage	CL7	NR	R
	1 - Earth	1	.135	.135
	2 - Single Spot: BW $\geq 1.0^{\circ}$	2	.266	.225
	3 - Single Spot: BW $< 1.0^{\circ}$	3	.332	.281
	4 - Shaped: Single BW $\geq 1.0^{\circ}$	4	.380	.230
	5 - Shaped: Single BW $< 1.0^{\circ}$	5	.475	.288
	6 - Multiple Spot Single BW $> 1.0^{\circ}$	6	.430	.182
	7 - Multiple Spot Single BW $< 1.0^{\circ}$	7	.559	.236
	8 - Scanning $\leq$ 7 BW's	8	.662	.212
	9 - Scanning > 7 BW's	9	.726	.297
CL8	Most Complex Antenna Design	CL8	NR	R
	1 - Horn	1	.100	.100
	2 - Single Reflector	2	.100	.227
	3 - Dual Reflector	3	.248	.248
	4 - Single Lens	4	.271	.328
	5 - Dual Lens/Phased Array	5	.448	.542
CL9	Number of Feed Elements in Most Complex Antenna Design	CL9	NR	R
	1 - 1-10	1	.100	.102
	2 - 11-25	2	.229	.234
	3 - 26-50	3	.458	.455
	4 - 51-75	4	.628	.624
	5 - 76-100	5	.798	.794
	6 - > 100	6	.846	1.172

TABLE 2-1 (Cont.)

3.8.2 TT&C Subsystem

INPUT

TL1	Max. TT&C Bit Rate: CMD or TLM	TL1	NR	R
	1. $\leq 10^5$ BPS	1	.110	.100
	2. $10^5 < 10^9$ BPS	2	.199	.154
	3. $> 10^9$ BPS	3	.279	.176
TL2	Total Number of Commands	TL2	NR	R
	1. ≤ 1000	1	.120	.142
	2. > 1000	2	.144	.183
TL3	Type of Communications Processing	TL3	NR	R
	1. None	1	.303	.304
	2. Centralized	2	.500	.435
	3. Distributed	3	.583	.483
TL4	Processing or TT&C Storage	TL4	NR	R
	1. None	1	.151	.152
	2. $\leq 10^4$ bits	2	.174	.158
	3. $10^4 \leq 10^9$ bits	3	.210	.182
	4. $> 10^9$ bits	4	.274	.234
TL5	Processing Memory	TL5	NR	R
	1. None	1	.151	.152
	2. Mag. Core	2	.160	.160
	3. Tape	3	.165	.165
	4. Other	4	.250	.251

TABLE 2-1 (Continued)

3.8.3 AC Subsystem

INPUT	DESCRIPTION	COMPLEXITY FACTOR		
AL1	Attitude Reference	AL1	NR	R
	1. Inertial or Other	1	.256	.282
	2. Celestial	2	.357	.321
AL2	Pointing Control	AL2	NR	R
	1. Open Loop	1	.190	.206
	2. Closed Loop	2	.255	.332
AL3	Pitch Axis Pointing Accuracy	AL3	NR	R
	1. $\geq \pm 1.0^{o}$	1	.294	.302
	2. $0.25^{o} < 1.0^{o}$	2	.356	.365
	3. $0.1^{o} < 0.25^{o}$	3	.482	.429
	4. $< 0.1^{o}$	4	.835	.544

3.8.4 EP Subsystem

		NR	R
1. TBPR $\leq$ 750	1	.432	1.978
2. TBPR $\leq$ 1250	2	.437	2.747
3. TBPR $<$ 1750	3	.442	3.846
4. TBPR $\leq$ 2250	4	.447	4.945
5. TBPR $<$ 2750	5	.452	6.044
6. TBPR $\leq$ 3250	6	.457	7.143
7. TBPR $>$ 325	7	.462	9.066

Note: No user input is required.

TABLE 2-2

BASIC SPACECRAFT SIZING PARAMETERS

1.0 Spacecraft

1.1 On-orbit Fuel Weight

FWF = .252 of .073 (geostationary orbit vs. non-geostationary)

1.2 EPS Factors

1.2.1 Basic Factors

	<1982	>1982
ARYWF	13.0	17.5
BWTF	70.0	42.5
XCLSF	0.11	0.15

1.2.2 Sizing: EPSW = ARYW + BATW + SHWT + PCUW

ARYW = BOL/ARYWF
BATW = BWTF x XSCB
XCLS = BOL/XCLSF
SHWT = 4.8 x XSCB
PCUW = 20.8 + (2.7 x XSCB)
XSCB = TBPR/1000.0 rounded up.

1.3 Bus Subsystem: BSWT=TTCW+ACSW+EPSW+STRW+THRW+EIW+SIW+FRPW

FW5 = EPSW+CWT
STRW = 0.288xFW5 or 0.367xCWT whichever is greater
THRW = 0.07xFW5
EIW = 0.136xCWT
SIW = 0.215xSTRW
PRPW = 1.016xSTRW (Initial sizing)

1.4 Array

EOL = 1.05xTBPR
BOL = EOL/0.73

1.5 TT&C

1 = 49.6 lbs. 0.0 watts: base subsystem
2 = 79.6 lbs. 60.0 watts W/crypto
3 = 109.1 lbs. 80.0 watts W/crypto & SSMA

TABLE 2-2 (Continued)

1.0 Spacecraft (continued)

1.6 ACS

1.6.1	CHWT < 1300 lbs.	ACSW = 131.1 lbs. PAA > .1°
		ACSW = 151.7 lbs. PAA > 0.05
1.6.2	CHWT 1300 lbs.	ACSW = 151.7 lbs. PAA > .1°
		ACSW = 171.7 lbs. PAA > 0.05

Add 35 lbs. & 25 watts for PAA

2.0 Perigee Motor Factors

2.1 PAM-D (PMX = 1)

XNRT = 385; PMC = 3700
CLDW = 2483.6 PML = 7.0
I_{sp} = 293

2.2 PAM-A (PMX = 2)

XNRT = 1333; PMC = 5000
CLDW = 3800; PML = 8.0
I_{sp} = 293

2.3 SPS-1 (PMX = 3)

XNRT = 1763.7; PMC = 3000
CLDW = 0.0 PML = 6.5
I_{sp} = 305.4 @ per; 310 @ apogee

2.4 I.U.S. (PMX = 5)

XNRT = 2180.6; PMC = 5500
CLDW = 0.0 PML = 16.5
I_{sp} = 290, 296

2.5 SPS-1 M1 (PMX = 5)

XNRT = 2180.6; PMC = 5500
CLDW = 0.0 PML = 13.0
I_{sp} = 305.4, 310

4.0 Program Costing Alternatives

Built into the model are three basic programs which are significantly different in character. All the basic costs for these programs are generated by the model.

4.1 Standard

For all three program cost formats the model first generates non-recurring and recurring hardware estimates. For the standard program the model computes the program cost as follows:

a. Total non-recurring cost = hardware non-recurring x 1.3
b. First unit cost = hardware recurring x 1.25
c. Prototype cost = 1.25 x first unit cost
d. R&D cost = a -c
e. Prototype refurbishment cost = 0.2 x first unit cost + 4500.
f. Flight Model Cost = (# of S/C - 1) x first unit cost
g. Profit and on-orbit incentives = 0.2 x (a + e + f)
h. Total S/C costs = a + e + f + g
i. Total Program Cost = h + STS and transfer orbit system costs

4.2 DoD Fly-Before-Buy

This program consists of a prototype and a number of flight demonstration models, plus the required number of flight S/C. The prototype is not flown.

a. Total non-recurring cost = hardware non-recurring x 1.3
b. First Unit Cost = hardware recurring x 1.25
c. Demonstration S/C cost = First Unit Cost x Number of Demo S/C
d. Profit = .1 x (a + c)
e. Demo Program Cost = a + c + d + STS + Transfer Orbit System Costs
f. Production start-up cost = .15 x a
g. Flight Model Recurring Cost = 1.1 x b x Number of Flight Model S/C

h. Profit and On-orbit Incentives = .2 x (f + g)

i. Flight Model Program Cost = f + g + h + STS + transfer orbit system costs

j. Total Program Cost = e + i

4.3 Minimum Non-recurring Costs

There are S/C programs which can use another program's S/C bus with minimal changes. For such a program, prototype costs are eliminated and R&D costs are significantly less than those generated by the other costing formats.

a. Factor Cost = 2 x hardware recurring

b. Non-recurring Cost = .36 x factor cost

c. Management and Support = 10% of b

d. Total Non-recurring Cost = b + c

e. First Unit Cost = 1.25 x hardware recurring

f. Flight Model Cost = (# of S/C) x first unit cost

g. General and Administrative Costs = .15 x (d + f)

h. Profit and On-orbit Incentives = .12 x (d + f + g)

i. Total S/C Cost = d + f + g + h

j. Total Program Cost = i + STS cost + transfer orbit system cost

TABLE 2-3

COST SPREAD FACTORS AND INFLATION APPLICATION

1.0 Cost Spread Factors (Fraction of Total Cost Per Year)

1.1 Non-recurring .35 .45 .2 (in first three years, respectively)
DoD FBB Start Up Cost .5 in each of first two years following demonstration program.

1.2 Recurring

1.2.1	$XSC \leq 2$	.2	.4	.4	(in first three years)			
	$2 < XSC \leq 9$	.1	.3	.4	.2	(in first four years)		
	$9 < XSC$	.1	.25	.25	.25	.15	(in first five years)	

1.3 STSC .2 .4 .4 (starting three years before launch)

1.4 PMC .5 .5 (starting two years before launch)

1.5 POOIC .1 (in each of ten years following first launch)

Note: The program assumes that there are four STS launches per year, and that each launch can carry one or two spacecrafts depending on the selected perigee motor system.

2.0 Inflation Application

2.1 Program Costs

$A = (1 + XIR)^{(BYR-1980 + 1.5)}$ $B = (1 + XIR)^{(BYR-1980 + 5)}$

2.1.1 Standard/Minimum Recurring Costing

Total Inflated S/C Cost = Ax Total S/C Cost

2.1.2 DoD FBB

Total Inflated S/C Cost = A x Demo S/C Cost + B x Flight Model S/C Cost

TABLE 2-3 (Continued)

2.0 Inflation Application (Continued)

2.2 STSC/PMC Costs

$C = (1 + XIR)^{(BYR-1980 + x)}$, X = Number of years beyond BYR when first cost incurred

2.2.1 STSIC = C x STSC

2.2.2 PMIC = C x PMC

TABLE 2-4

GLOSSARY OF ACRONYMS

ACP	-	ACS costing parameter
ACSW	-	ACS weight
AL1-AL3	-	ACS complexity factor inputs
ANWF	-	ACS Non-recurring weighted complexity factor
ARWF	-	ACS recurring weighted complexity factor
ARYW	-	Solar array weight
ARYWF	-	Solar array weight factor
A1, A2	-	Intermediate results in calculating $\Delta V2$
BATW	-	Battery weight
BOL	-	Beginning-of-life solar array output
BSWT	-	Spacecraft bus weight
BWTF	-	Battery weight factor
B1, B2	-	Intermediate results in calculating $\Delta V2$
BYR	-	Base year of program
CCP	-	Communication subsystem costing parameter
CHWT	-	Spacecraft check weight
CLDW	-	STS cradle weight
CL1-CL9	-	Communication subsystem complexity factor inputs
CNWF	-	Comm. non-recurring weighted complexity factor
CRWF	-	Comm. recurring weighted complexity factor
CWT	-	Comm. subsystem weight
DPC	-	Demonstration program cost
DSCC	-	Demonstration S/S cost
DVMFW	-	Maneuver fuel weight
DVMV	-	S/C maneuverability requirement
ECP1,2,3	-	EPS costing parameters
EIW	-	Electrical integration weight
ENWF	-	EPS non-recurring weighted complexity factor
EOL	-	End-of-life solar array output
EPSW	-	EPS weight
ERWF	-	EPS recurring weighted complexity factor
E1, E2	-	Intermediate results in calculating $\Delta V2$
FAR	-	Final apogee radius

TABLE 2-4 (Continued)

GLOSSARY OF ACRONYMS

FINC	-	Final inclination
FMC	-	Flight model cost
FMPC	-	Flight model program cost
FPR	-	Final perigee radius
FUC	-	First unit cost
FWF	-	Fuel weight factor
FW5	-	Sizing parameter for STRW
GAC	-	General and administrative cost
I_{sp}	-	Specific impulse of fuel
LZ	-	Sizing parameter for STS
OOFW	-	On-orbit fuel weight
OOIC	-	On-orbit incentive cost
PAA	-	Pitch axis pointing accuracy
PCUW	-	Power control unit weight
PMC	-	Perigee motor cost
PMIC	-	Perigee motor inflated cost
PML	-	Perigee motor length
PMX	-	Perigee motor indicator
PROF	-	Profit
PRORFC	-	Prototype refurbishment cost
PROTC	-	Prototype cost
PRFW	-	Propulsion S/S weight
P1, P2	-	Intermediate results in calculating DV2
RDC	-	Research and development cost
SCL	-	S/C length
SCLWT	-	S/C launch vehicle
SCOWT	-	S/C on-orbit weight
SCP	-	Structure costing parameter
SHWT	-	Shunt weight
SIW	-	Structural integration weight
SNWF	-	Structural non-recurring weighted complexity factor
SRWF	-	Structural recurring weighted complexity factor
STRW	-	Structure weight

TABLE 2-4 (Continued)

GLOSSARY OF ACRONYMS

STSC	-	STS cost per launch
STSCF	-	STS co[illegible]
STSIC	-	STS inflated c.st
STX	-	Inclination change
SUC	-	Start-up cost
TBPR	-	Total bus power
TCP	-	TT&C costing parameter
TFMC	-	Total flight model cost
THRW	-	Thermal weight
TL1-TL5	-	TT&C S/S complexity factor inputs
T[illegible]RC	-	Total non-recurring cost
TNWF	-	TT&C Non-recurring weighted complexity factor
TPC	-	Total program cost
TPMC	-	Total perigee motor cost
TSCC	-	Total S/C cost
TSTSC	-	Total STS cost
TRWF	-	TT&C Recurring weighted complexity factor
TTCW	-	TT&C S/S weight
V3,V4	-	Intermediate result in calculating DV2
XCLS	-	Number of solar cells
XCLSF	-	Solar cell factor
XIR	-	Average annual inflation rate
XNRT1	-	Inert weight of external apogee motor system
XNRT2	-	Inert weight of perigee motor system
XSC	-	Total number of S/C in program
XSCB	-	Number of batteries
Z1-Z6	-	Fuel weight fractions for different AM/PM systems

PART III

FLOW DIAGRAM

Figure 3-1 is a flow diagram for non-computer use of the model. By following this diagram, the user without access to the computer program can exercise the model by band. The diagram also indicates the flow of the computer program.

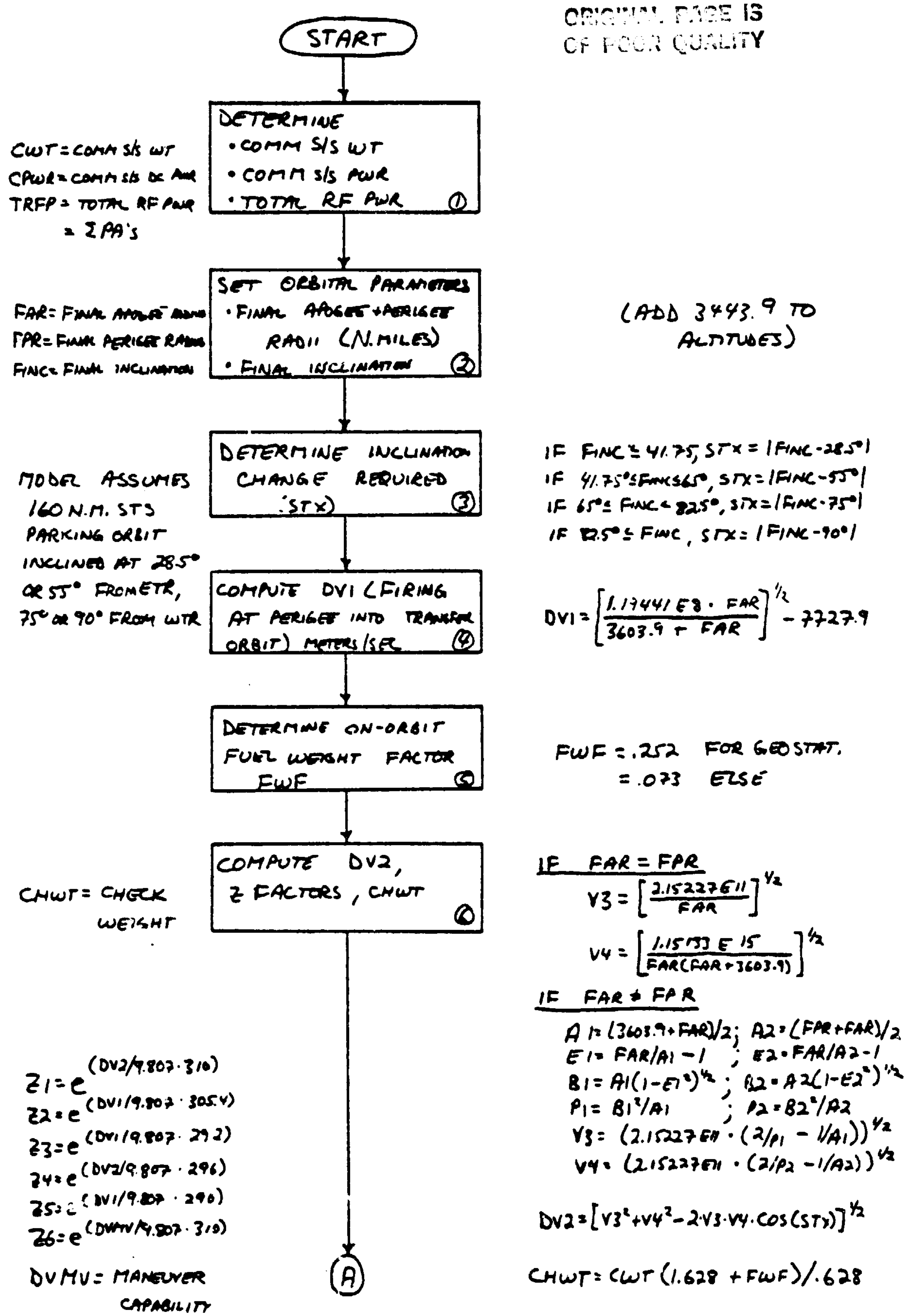

Figure 3-1. Flow Diagram

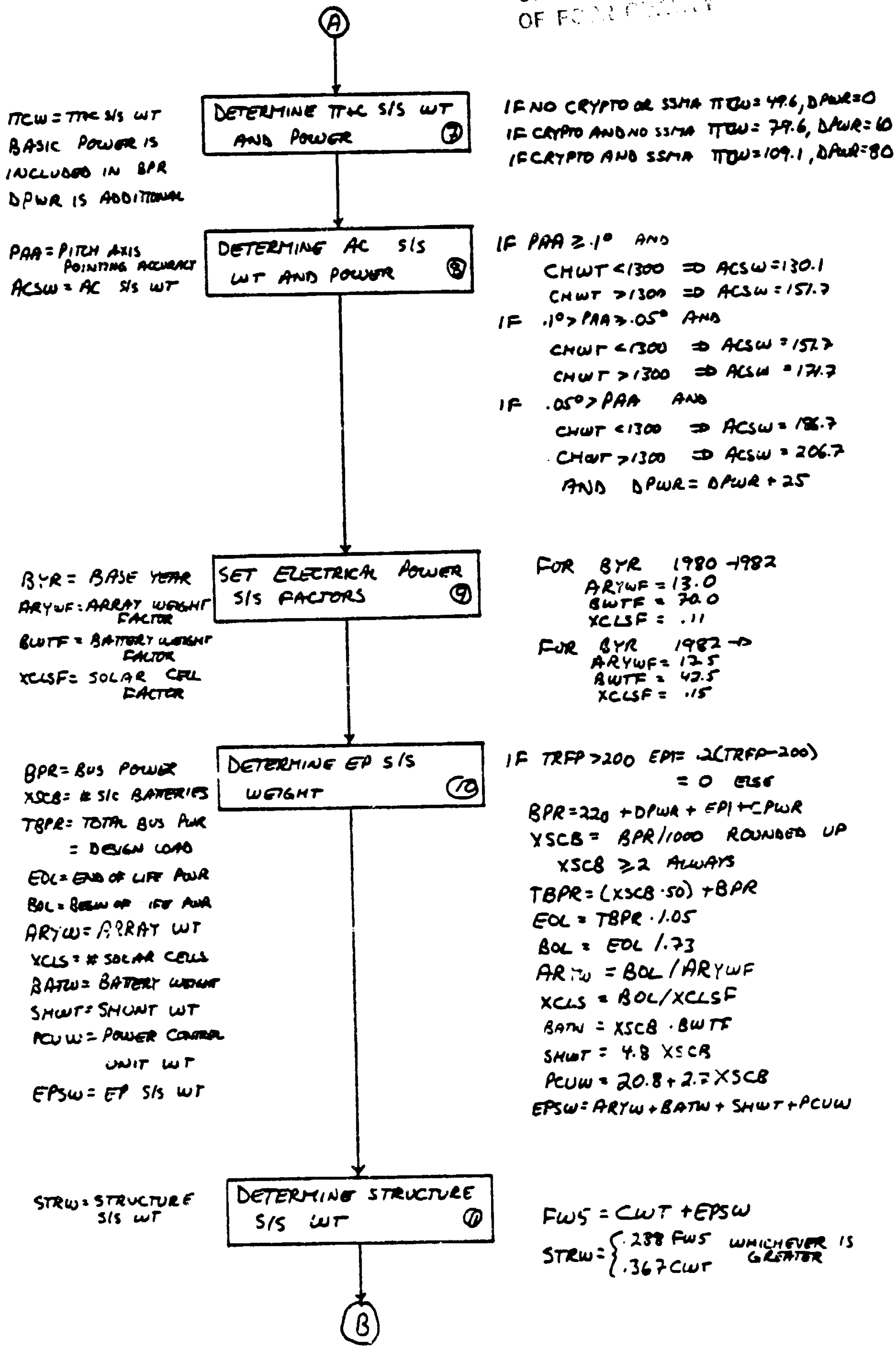

Figure 3-1 (Continued)

(B)

THRW = THERMAL WT
EIW = ELEC INTEG WT
SIW = STR. INT WT
PRPW = PROPULS. S/S WT
BSWT = TOTAL S/C BUS

DETERMINE OTHER S/C BUS WEIGHTS AND TOTAL S/C BUS WEIGHT (12)

THRW = .07 FWS
EIW = .136 CWT
SIW = .215 STRW
PRPW = 1.016 STRW
BSWT = TTCW + ACSW + EPSW + STRW + THRW + EIW + SIW + PRPW

OOFW = ON-ORBIT FUEL WT
PWI = NEW PROP S/S WT.

DETERMINE ON-ORBIT FUEL WEIGHT, NEW PRPW, NEW BSWT (13)

OOFW = BSWT · FWF
PWI = .1 OOFW + 56.9
BSWT = BSWT + PWI − PRPW
PRPW = PWI

SCOWT = S/C ON-ORBIT WT
DVMFW = MANEUVER FUEL WT.

DETERMINE INITIAL S/C ON-ORBIT WT AND MANEUVER FUEL WTS. COMPARE WITH CHWT. (14)

SCOWT = CWT + BSWT + OOFW
DVMFW = SCOWT · Z6 − SCOWT
PWI = .1(DVMFW + OOFW) + 56.9
BSWT = BSWT + PWI − PRPW
PRPW = PWI
OOFW = FWF (BSWT + $\frac{DVMFW}{2}$)
SCOWT = CWT + BSWT + DVMFW + OOFW
IF SCOWT > 1300 AND CHWT < 1300
OR SCOWT < 1300 AND CHWT > 1300
SET CHWT = SCOWT AND REDO
BLOCK (8) AND (12) ON

AMFW = APOGEE MOTOR FUEL WT
PMFW = PERIGEE MOTOR FUEL WT
TOF1 = S/C WT PRIOR TO APOGEE KICK
TOF2 = S/C WT PRIOR TO TRANSFER ORBIT KICK
TOTFW = TOTAL TRANSFER ORBIT FUEL WT
XNRT2 = INERT WT OF PM = 1763.7
XNRT1 = INERT WT OF AM/PM SYSTEM ... APOGEE KICK = 0
SCLWT = S/C LAUNCH WT.
CLDW = CRADLE WT = 0

DETERMINE S/C LAUNCH WT AND AM/PM FUEL WTS (15)

AMFW = SCOWT · Z1 − SCOWT
PWI = .1(DVMFW + OOFW + AMFW) + 56.9
BSWT = BSWT + PWI − PRPW
PRPW = PWI
OOFW = FWF (BSWT + $\frac{DVMFW}{2}$)
SCOWT = CWT + BSWT + DVMFW + OOFW
TOF1 = (SCOWT + XNRT1) · Z1
TOF2 = (TOF2 + XNRT2) · Z2
AMFW = TOF1 − (SCOWT + XNRT1)
PMFW = TOF2 − (TOF1 + XNRT2)
TOTFW = AMFW + PMFW
SCLWT = TOF2 + CLDW

(C)

Figure 3-1 (Continued)

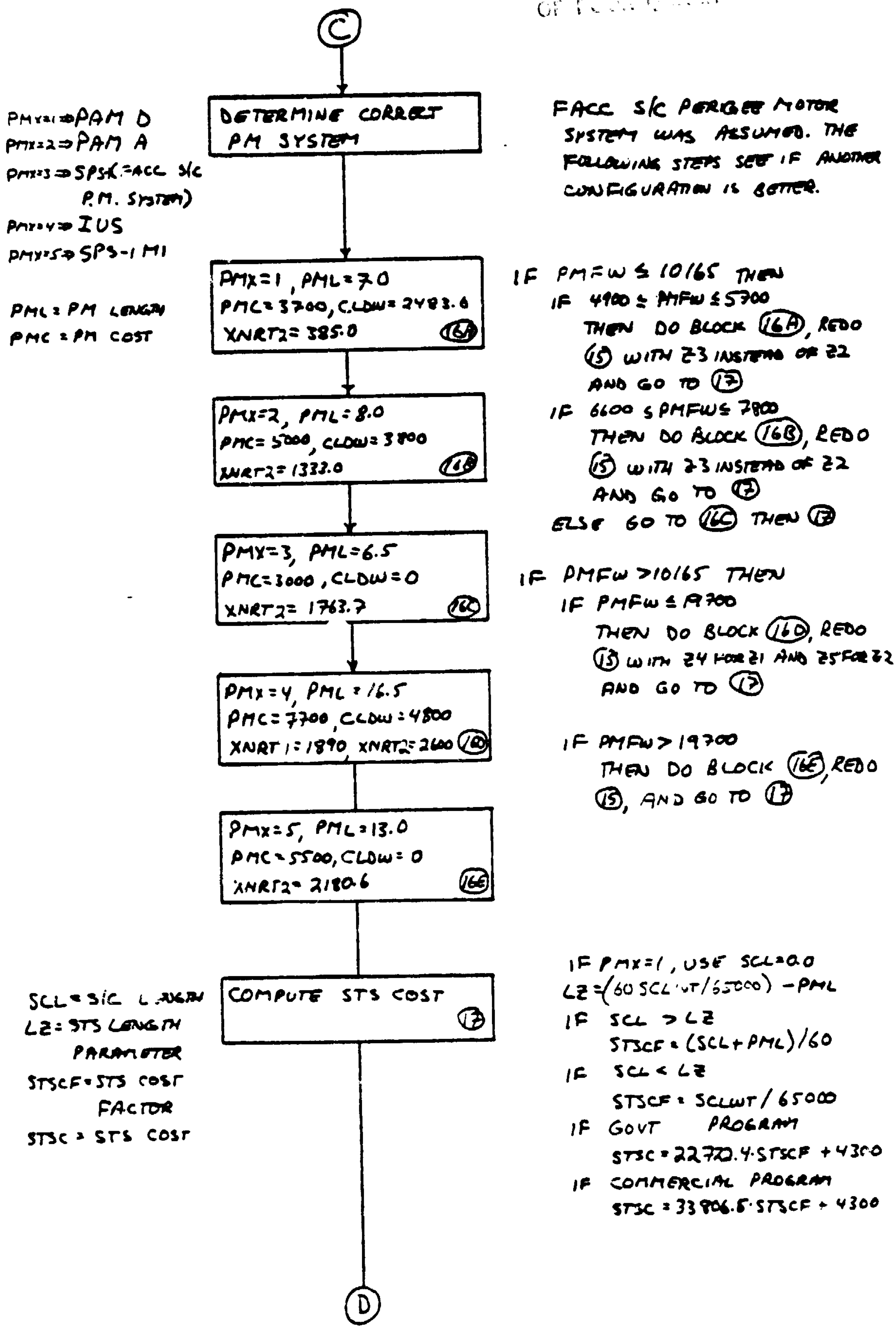

Figure 3-1 (Continued)

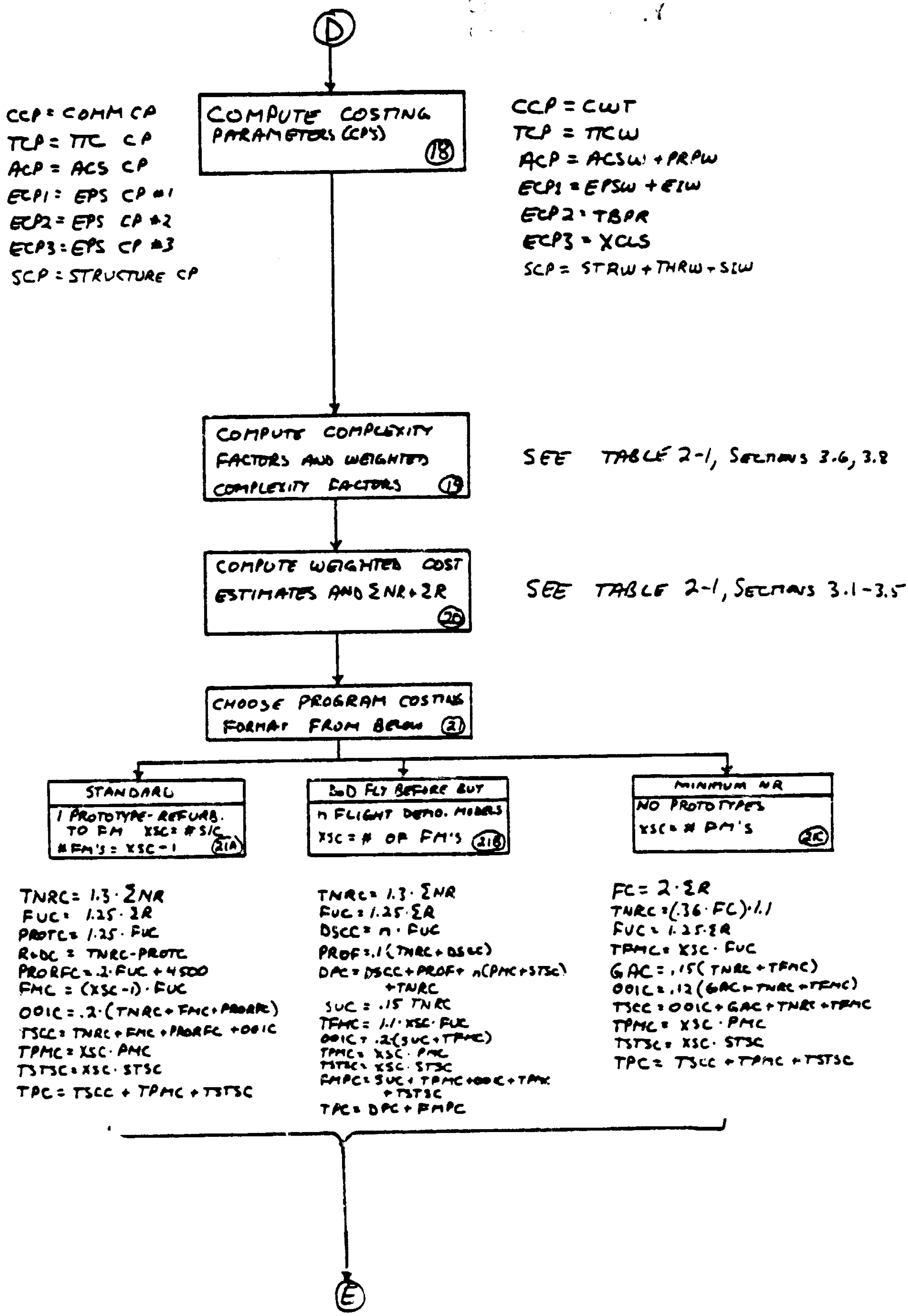

Figure 3-? (Continued)

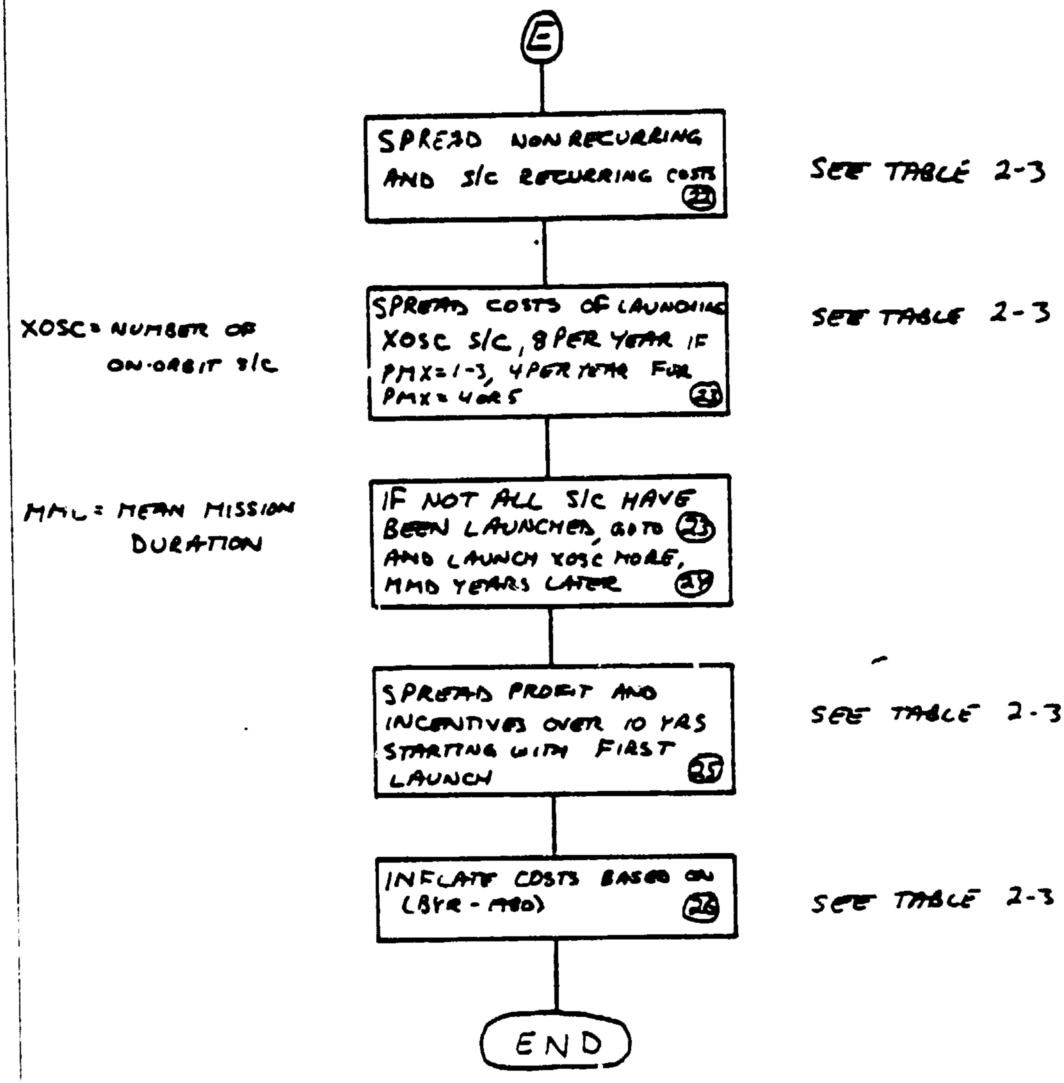

Figure 3-1 (Continued)

PART IV

CONCLUSIONS AND COMMENTS

The SCPCE program is a useful tool for evaluating various spacecraft designs and configurations. Its flexibility and modular program format allow for easy expansion and updating as the data base for the S/C design parameters or the SAMSO model is updated. Its interactive nature makes it easy to use by someone without extensive computer experience.

The model as presented here has not been fully verified against current spacecraft programs. Some comparisons have been made, but a complete verification against a fully-costed current program has not been done. This step should be done to assure confidence in the model.

In addition, there are several limitations inherent in the algorithms as presented, e.g., an STS launch is assumed. A further version of this model should include:

1. An expendable launch vehicle capability
2. An on-ground spare option
3. Inclusion of launch insurance costs

APPENDIX A

USER'S MANUAL

1.0 INTRODUCTION

The model is very easy to use, due to the interactive data input. No previous computer experience is required to run the program, however the user must know enough about communication satellites to answer the questions. The final outputs are all labeled and are presented to the user in a well-organized manner. All acronyms used are defined in Tables 2-4 and B-1.

2.0 THE HELP SUBROUTINE

At the beginning of a run, the user is asked if he needs help. An affirmative answer will result in a listing of a description of the program, its modes of operation and an explanation of all acronyms appearing in questions. This is to acquaint the first-time user with the program and will enable him to gain facility with it more quickly.

3.0 MODES OF OPERATION

As mentioned in Part I, the program can be run in two modes: full program, or cost only.

The full program mode performs the spacecraft size and weight estimation and then estimates the associated costs. Having designed a spacecraft, the user can then modify his input specifications, design a new spacecraft and make tradeoff comparisons between the two. He then can select one of the two to save for future comparisons.

The cost only mode is a one-time-through option for a user who already has a spacecraft design. More specific inputs are required then, to describe the spacecraft design to the model. Hardware recurring and non-recurring costs are estimated, but there is no direct option for tradeoffs.

4.0 INPUT REQUIREMENTS

The input requirements for the two modes are different, and are listed below.

4.1 Full Program Mode

a. Orbital Information - Final apogee and perigee radii and final inclination, if not geostationary.
b. Number of S/C to be manufactured, number of on-orbit S/C, (number of flight demonstration S/C for DoD FBB).
c. Base program year, program type (government or commercial), program costing format, mean mission duration, average annual inflation rate.
d. Estimated S/C length, maneuver capability.
e. Communication subsystem weight, DC power, and total RF power.
f. Type of TT&C system.
g. Complexity factor inputs - Specific questions are asked about each of the subsystems and weighted complexity factors are internally generated.

In addition, there are provisions for direct input of subsystem parameters if use of the model's estimations is not desired.

4.2 Cost Only Mode

a. Communications Subsystem - Weight in pounds; includes transponder and antennas.
b. TT&C Subsystem - Weight in pounds; includes antennas.
c. Attitude Control Subsystem - Includes ACS + Propulsion subsystem weight; does not include fuel weight.
d. Structure Subsystem - Weight in pounds; includes thermal and mechanical integration weights
e. Electrical Power Subsystem - Weight in pounds including electrical integration, beginning-of-life array power (watts @ equinox), number of batteries.

f. S/C length, perigee motor cost and length, and S/C launch weight including transfer orbit system and its cradle.

g. Type of program (government or commercial) and program costing format.

h. Total number of S/C, number of orbiting S/C for operating system, and number of flight demonstration S/C for DoD FBB.

i. Base year of program (contract award date), mean mission duration and average annual inflation rate.

j. Complexity Factor Inputs - Questions are asked about the subsystems and weighted complexity factors are internally generated.

5.0 PROGRAM OUTPUTS

5.1 Full Program Mode

a. Delta V1 and Delta V2 (velocity changes for orbit injections)

b. Communication S/S weight, TTC S/S weight, AC S/S weight, EP S/S weight, beginning-of-life array output and S/C bus weight.

c. On-orbit fuel weight, S/C on-orbit weight, S/C launch weight, and perigee motor indicator.

d. Program costs depending on the specific costing format chosen (in 1980 dollars).

e. Per-year costs (after inflation) and number of S/C launched per year.

In addition, there is an optional printout of either the baseline S/C or the current S/C design parameters available.

Once there is a baseline S/C (i.e., after the first time through) delta parameters are printed. These are the differences in weights and costs between the baseline S/C and program and the current S/C and program.

5.2 Cost Only Mode

a. Program costs (in 1980 dollars) depending on the specific costing format chosen.

b. Per-year cost (after inflation) and number of S/C launched per year.

There is no provision for tradeoff comparisons in the cost only mode.

6.0 SAMPLE RUNS

6.1 Full Program Mode (Figure A-1)

The baseline S/C is a TDMA, Direct-to-User system, with 25 - 25w spot beams in K_a-band. An inflation rate of zero was chosen for simplicity. General and administrative costs are included in R&D cost and "First Unit Costs," but profit is not; profit is included with "On-Orbit Incentives." The "First Unit Cost" is an estimate of the actual cost of building one flight model. For a unit selling or buying price, divide the "Total S/C Cost" by the number of spacecraft, resulting in, in this case, $74M.

In the trades mode, the communications payload is changed to reflect the replacement of the 25w TWT's with 15w TWT's. This results in a lower payload weight, DC power requirement, and RF power output. In addition, one of the answers to a complexity factor question must be changed; the other inputs are zero to indicate no change.

The resulting spacecraft has a 256-pound-less on-orbit weight, and a 1051.2-pound-less launch weight. The new unit cost is then $68.5, and the cost savings are realized in years 1 through 13 as indicated.

6.2 Cost Only Mode (Figure A-2)

The HELP subroutine is first exercised to guide the user. The example is a typical domsat spacecraft, with C-band CONUS beams and K_u-band spot beams. Again, a zero inflation rate was chosen. Because of the simplicity of the system, spacecraft costs are much lower than the previous example. For this three spacecraft system, the unit co-t is $37.5M, the average of three S/C including prorated R&D costs.

C 8

```
*RUN SCPCE

THIS IS THE SPACECRAFT PARAMETER AND COST
ESTIMATING PROGRAM DEVELOPED AT FACC WDL.

DO YOU NEED HELP? 1=YES,2=NO
=2
INPUT PROGRAM MODE : 1=COST ONLY, 2=FULL PROGRAM
=2
IS ORBIT GEOSTATIONARY? 1=YES,2=NO
=1
INPUT XSC,XOSC,PROGT,PROGF,BYR,MMD,XIR
=2,2,1,1,1985,10,0
INPUT SCL,DVMV
=15,0
INPUT PARAMETERS:CWT,CPWR,TRFP. USE CWT=0 FOR NO CHANGE IN TRADES MODE
=958,2594,825
INPUT HIGHEST COMMUNICATIONS FREQUENCY. 1=<15GHZ,2=<58GHZ,3=>58GHZ
=2
INPUT HIGHEST POWER LEVEL AT HIGHEST FREQUENCY.
1=<5W,2=5-10W,3=10-20W,4=20-40W,5=>40W
=4
INPUT TYPE OF TRANSPONDER. 1=TRANSLATING,2=REGENERATING,3=COMBINATION
=2
INPUT NUMBER OF ACTIVE POWER AMPS,1=10 OR LESS,2=50 OR LESS
3=100 OR LESS,4=MORE THAN 100
=2
INPUT NUMBER OF DIFFERENT FREQUENCY BANDS. 1=1,2=2,3=3,4=4 OR MORE
=1
INPUT NUMBER OF RCV/XMIT ANTENNA SETS.1=1,2=2 OR 3,3=4 TO6,4=7 OR MORE
=2
INPUT MOST COMPLEX ANTENNA PATTERN. 1=EARTH
2=SINGLE SPOT: BW.GE.1.0,3=SINGLE SPOT: BW<1.0
4=SHAPED: SINGLE BW.GE.1.0,5=SHAPED: SINGLE BW.LT.1.0
6=MULTIPLE SPOT:SINGLE BW.GE.1.0,7=MULTIPLE SPOT:SINGLE BW.LT.1.0
8=SCANNING,LE.7BW'S,9=SCANNING>7BW'S
=6
INPUT MOST COMPLEX ANTENNA DESIGN. 1=HORN,2=SINGLE REFLECTOR
3=DUAL REFLECTOR,4=SINGLE LENS,5=DUAL LENS/PHASED ARRAY
=2
INPUT NUMBER OF FEEDS IN MOST COMPLEX ANTENNA DESIGN
1=1 TO 10,2=11 TO 25,3=26 TO 50,4=51 TO 75,5=76 TO 100,6=MORE THAN 100
=2
INPUT SOURCE OF TT&C PARAMETERS. 1=DIRECT INPUT,2=MODEL
=2
INPUT TYPE OF TT&C S/S. 1=BASIC,2=CRYPTO,3=CRYPTO AND SEMA
=1
INPUT MAXIMUM TT&C BIT RATE,CMD OR TLM. 1=UP TO 100 KBPS
2=UP TO 1 GBPS,3=MORE THAN 1 GBPS
=1
INPUT TOTAL NUMBER OF CHANNELS. 1=UP TO 1000,2=MORE THAN 1000
=1
INPUT TYPE OF COMMUNICATIONS PROCESSING. 1=NONE,2=CENTRALIZED
3=DISTRIBUTED
=2
INPUT PROCESSING OR TT&C STORAGE. 1=NONE,2=UP TO 10 KB,3=UP TO 1 GB
4=MORE THAN 1 GB
=1
INPUT TYPE OF MEMORY. 1=NONE, 2=MAGNETIC CORE,3=TAPE,4=OTHER
=1
```

Figure A-1. Full Program Mode Terminal Session

```
INPUT SOURCE OF ACS PARAMETERS 1=DIRECT INPUT,2=MODEL.
=2
INPUT ATTITUDE REFERENCE. 1=INERTIAL OR OTHER,2=CELESTIAL
=1
INPUT POINTING CONTROL. 1=OPEN LOOP,2=CLOSED LOOP
=1
INPUT PITCH AXIS POINTING ACCURACY (DEGREES)
=.1
INPUT SOURCE OF EPS PARAMETERS. 1=DIRECT INPUT,2=MODEL.
=2

DELTA V1 = 2428.45 M/SEC  DELTA V2 = 1830.70 M/SEC
COM WT = 958.0 LBS          TTC WT =  49.6 LBS
ACS WT = 151.7 LBS          EPS WT = 421.4 LBS
BOL  =  4385.5 WATTS        BUS WT = 1652.8 LBS
ON-ORBIT FUEL WT =   416.4 LBS
S/C ON-ORBIT WT =  3027.0 LBS  S/C LAUNCH WT =  18392.3 LBS
PERIGEE MOTOR 3 WAS CHOSEN

STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)

NUMBER OF S/C =  2  NUMBER OF ON-ORBIT S/C =  2
R&D COST = $ 34711.8-             PROTOTYPE COST = $ 42926.9
TOTAL NON-RECURRING COST = $ 77638.7
PROTOTYPE REFURB COST = $11388.3  FIRST UNIT COST = $34341.8
FLIGHT MODEL COST = $ 34341.8      ON-ORBIT INCENTIVES = $ 24869.7
TOTAL S/C COST = $148018.3
PM COST = $ 6000.0  STS COST = $24884.4
TOTAL PROGRAM COST = $178902.7

YEAR  1 COST = $ 40692.4      0 S/C LAUNCHED
YEAR  2 COST = $ 64975.1      0 S/C LAUNCHED
YEAR  3 COST = $ 45565.4      0 S/C LAUNCHED
YEAR  4 COST = $  5467.0      2 S/C LAUNCHED
YEAR  5 COST = $  2467.0      0 S/C LAUNCHED
YEAR  6 COST = $  2467.0      0 S/C LAUNCHED
YEAR  7 COST = $  2467.0      0 S/C LAUNCHED
YEAR  8 COST = $  2467.0      0 S/C LAUNCHED
YEAR  9 COST = $  2467.0      0 S/C LAUNCHED
YEAR 10 COST = $  2467.0      0 S/C LAUNCHED
YEAR 11 COST = $  2467.0      0 S/C LAUNCHED
YEAR 12 COST = $  2467.0      0 S/C LAUNCHED
YEAR 13 COST = $  2467.0      0 S/C LAUNCHED

DO YOU WANT A COMPLETE LISTING OF THE BASELINE?
THIS LISTING IS WITHOUT HEADINGS. 1=YES,2=NO
=1
    958.0       49.8      397.3      151.7      421.4       96.6
    130.3       85.4      320.3     1652.8      416.4     3027.0
  11601.6    18392.3         0.     1763.7         0.        3.0
      6.5       15.0        3.0    29237.0     3048.0     4385.5
   2594.0      625.0
DO YOU WANT TO MAKE TRADES? 1=YES,2=NO
=1
DO YOU WANT TO CHANGE ORBIT PARAMETERS? 1=YES,2=NO
=2
DO YOU WANT TO CHANGE THE PROGRAM COSTING PARAMETERS?1=YES,2=NO
=2
DO YOU WANT TO CHANGE SCL OR DVMV? 1=YES,2=NO
=2
DO YOU WANT TO CHANGE THE COMM S/S PARAMETERS?1=YES,2=NO
=1
```

Figure A-1 (Continued)

```
INPUT PARAMETERS:CWT,CPWR,TRFP. USE CWT=0 FOR NO CHANGE IN TRADES MODE
=900,1780,375
AN INPUT OF ZERO ON THE NEXT NINE QUESTIONS INDICATES NO CHANGE.
INPUT HIGHEST COMMUNICATIONS FREQUENCY. 1=<15GHZ,2=<56GHZ,3=>56GHZ
=0
INPUT HIGHEST POWER LEVEL AT HIGHEST FREQUENCY.
1=<5W,2=5-10W,3=10-20W,4=20-40W,5=>40W
=3
INPUT TYPE OF TRANSPONDER. 1=TRANSLATING,2=REGENERATING,3=COMBINATION
=0
INPUT NUMBER OF ACTIVE POWER AMPS,1=10 OR LESS,2=50 OR LESS
3=100 OR LESS,4=MORE THAN 100
=0
INPUT NUMBER OF DIFFERENT FREQUENCY BANDS. 1=1,2=2,3=3,4=4 OR MORE
=0
INPUT NUMBER OF RCV/XMIT ANTENNA SETS,1=1,2=2 OR 3,3=4 TO6,4=7 OR MORE
=0
INPUT MOST COMPLEX ANTENNA PATTERN. 1=EARTH
2=SINGLE SPOT: BW.GE.1.0,3=SINGLE SPOT: BW<1.0
4=SHAPED: SINGLE BW.GE.1.0,5=SHAPED: SINGLE BW.LT.1.0
6=MULTIPLE SPOT:SINGLE BW.GE.1.0,7=MULTIPLE SPOT:SINGLE BW.LT.1.0
8=SCANNING.LE.7BW'S,9=SCANNING>7BW'S
=0
INPUT MOST COMPLEX ANTENNA DESIGN. 1=HORN,2=SINGLE REFLECTOR
3=DUAL REFLECTOR,4=SINGLE LENS,5=DUAL LENS/PHASED ARRAY
=0
INPUT NUMBER OF FEEDS IN MOST COMPLEX ANTENNA DESIGN
1=1 TO 10,2=11 TO 25,3=26 TO 50,4=51 TO 75,5=76 TO 100,6=MORE THAN 100
=0
DO YOU WANT TO CHANGE TT&C PARAMETERS? 1=YES,2=NO
=2
DO YOU WANT TO CHANGE ACS PARAMETERS? 1=YES,2=NO
=2
DO YOU WANT TO CHANGE EPS PARAMETERS? 1=YES,2=NO
=2

DELTA V1 = 2428.45 M/SEC  DELTA V2 = 1830.70 M/SEC
COM WT = 900.0 LBS        TTC WT =  49.8 LBS
ACS WT = 151.7 LBS        EPS WT = 346.7 LBS
BOL =  3114.0 WATTS       BUS WT = 1494.4 LBS
ON-ORBIT FUEL WT =   378.8 LBS
S/C ON-ORBIT WT =  2771.0 LBS  S/C LAUNCH WT =  15341.2 LBS
PERIGEE MOTOR 3 WAS CHOSEN

DELTA COM WT =  -58.0 LBS        DELTA TTC WT =    0.  LBS
DELTA ACS WT =    0.  LBS        DELTA EPS WT =  -72.7 LBS
DELTA BUS POWER = -884.0 WATTS  DELTA BUS WT = -158.2 LBS
DELTA ON-ORBIT FUEL WT =  -39.9 LBS  DELTA S/C ON-ORBIT WT =  -258.0 LBS
DELTA S/C LAUNCH WT= -1051.2 LBS

DO YOU WANT A COMPLETE LISTINGS OF PARAMETERS?
THIS LISTING IS WITHOUT HEADINGS,1=YES,2=NO
=1
    900.0      49.6     359.8     151.7     348.7      87.4
    122.4      77.3     297.8    1494.4     378.8    2771.0
  10806.5   15341.2        0.    1763.7        0.       3.0
      8.5      15.0       3.0   20760.3    2185.0    3114.0
   1760.0     375.0
```

Figure A-1 (Continued)

```
STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)

NUMBER OF S/C =  2  NUMBER OF ON-ORBIT S/C =  2
R&D COST = $ 31209.3                 PROTOTYPE COST = $ 40051.7
TOTAL NON-RECURRING COST = $ 71281.0
PROTOTYPE REFURB COST = $10908.3  FIRST UNIT COST = $32041.3
FLIGHT MODEL COST = $ 32041.3      ON-ORBIT INCENTIVES = $ 22842.1
TOTAL S/C COST = $137052.7
PM COST = $ 6000.0  STS COST = $24884.4
TOTAL PROGRAM COST = $167937.1

YEAR  1 COST = $ 37908.1      0 S/C LAUNCHED
YEAR  2 COST = $ 61001.0      0 S/C LAUNCHED
YEAR  3 COST = $ 43185.8      0 S/C LAUNCHED
YEAR  4 COST = $  5284.2      2 S/C LAUNCHED
YEAR  5 COST = $  2284.2      0 S/C LAUNCHED
YEAR  6 COST = $  2284.2      0 S/C LAUNCHED
YEAR  7 COST = $  2284.2      0 S/C LAUNCHED
YEAR  8 COST = $  2284.2      0 S/C LAUNCHED
YEAR  9 COST = $  2284.2      0 S/C LAUNCHED
YEAR 10 COST = $  2284.2      0 S/C LAUNCHED
YEAR 11 COST = $  2284.2      0 S/C LAUNCHED
YEAR 12 COST = $  2284.2      0 S/C LAUNCHED
YEAR 13 COST = $  2284.2      0 S/C LAUNCHED


DELTA COST YEAR  1 =$ -2784.3
DELTA COST YEAR  2 =$ -3874.1
DELTA COST YEAR  3 =$ -2379.7
DELTA COST YEAR  4 =$  -182.8
DELTA COST YEAR  5 =$  -182.8
DELTA COST YEAR  6 =$  -182.8
DELTA COST YEAR  7 =$  -182.8
DELTA COST YEAR  8 =$  -182.8
DELTA COST YEAR  9 =$  -182.8
DELTA COST YEAR 10 =$  -182.8
DELTA COST YEAR 11 =$  -182.8
DELTA COST YEAR 12 =$  -182.8
DELTA COST YEAR 13 =$  -182.8

DO YOU WANT TO CHANGE THE BASELINE? 1=YES,2=NO
=2
DO YOU WANT A COMPLETE LISTING OF THE BASELINE?
THIS LISTING IS WITHOUT HEADINGS. 1=YES,2=NO
=2
DO YOU WANT TO MAKE TRADES? 1=YES,2=NO
=2

*
```

Figure A-1 (Continued)

```
*RUN SCPCE

THIS IS THE SPACECRAFT PARAMETER AND COST
ESTIMATING PROGRAM DEVELOPED AT FACC WDL.

DO YOU NEED HELP? 1=YES,2=NO
=1

THIS PROGRAM WAS WRITTEN BY S.MELACHRINOS AT FACC WDL.
THIS IS VERSION 1.1 - 4 MARCH 1980

THIS PROGRAM ESTIMATES THE SIZE AND COST OF A COMMUNICATION
SATELLITE GIVEN SOME BASIC PARAMETERS. IT USES SPACECRAFT SIZING
RULES BASED ON FACC EXPERIENCE AND COSTING RULES BASED ON A MOD-
IFIED VERSION OF THE SAMSO SPACECRAFT COSTING MODEL.

THERE ARE TWO MODES OF THIS PROGRAM, THE COST ONLY MODE
AND THE FULL PROGRAM MODE. IN THE COST ONLY MODE, PROGRAM
COSTS ARE ESTIMATED FOR A GIVEN SPACECRAFT. IN THE FULL
PROGRAM MODE, THE MODEL CAN ESTIMATE SUBSYSTEM WEIGHTS AND
POWERS IF THEY ARE NOT GIVEN (BASED ON GENERAL INPUTS)
BEFORE ESTIMATING COSTS. THE USER CAN THEN ENTER A TRADES
MODE AND CHANGE ANY OR ALL OF THE PARAMETERS. ALL WEIGHTS
ARE IN POUNDS AND DOLLARS IN THOUSANDS.

THIS MODEL IS LIMITED TO 3-AXIS STABILIZED S/C AND STS LAUNCH.

INPUTS FOR THE COST ONLY MODE ARE:
CCP=COMM COSTING PARAMETER=COMM WT (INCLUDING ANTENNAS)
TCP=TTC COSTING PARAMETER=TTC WT.
SCP=STRUCTURE COSTING PARAMETER=STRUCTURE WT (INCLUDING
     THERMAL)
ACS=ACS COSTING PARAMETER=AC S/S WT + PROPULSION S/S WT
ECP1=EP COSTING PARAMETER=EP S/S WT
BOL=BEGINNING-OF-LIFE SOLAR ARRAY OUTPUT (WATTS)
BYR=BASE YEAR OF PROGRAM
XSCB=NUMBER OF S/C BATTERIES
SCLWT=S/C LAUNCH WEIGHT
XSC=NUMBER OF FLIGHT S/C IN PROGRAM
XOSC=NUMBER OF ON-ORBIT S/C
XFDSC=NUMBER OF FLIGHT DEMONSTRATION SPACECRAFT (NOT
     INCLUDED IN XSC) FOR DOD FLY BEFORE BUY COSTING-1 OR 2
SCL=S/C LENGTH
PROGT=PROGRAM TYPE - 1 IF GOVERNMENT-MILITARY,2 IF COMMERCIAL
PROGF=PROGRAM COSTING FORMAT - 1 IF STANDARD, 2 IF DOD FLY
     BEFORE BUY, 3 IF MINIMUM NON-RECURRING COST (NO PROTOTYPE)
PMX=PERIGEE MOTOR INDICATOR-SEE BELOW
PMC=PERIGEE MOTOR COST-SEE BELOW
PML=PERIGEE MOTOR LENGTH-SEE BELOW
                        PMX               PMC             PML
        PAM-D            1                3700            7.0
        PAM-A            2                5000            8.0
        SPS-1            3                3000            6.5
        IUS              4                7700            18.5
        SPS-1 M1         5                5500            13.0
MMD=MEAN MISSION DURATION (YEARS)
XIR=AVERAGE ANNUAL INFLATION RATE (%)
THE OTHER INPUTS ARE SELF EXPLANATORY.

INPUTS FOR THE FULL PROGRAM MODE ARE:
FAR=FINAL APOGEE RADIUS
FPR=FINAL PERIGEE RADIUS
FINC=FINAL INCLINATION
CWT=COMM S/S WT
```

Figure A-2. Cost Only Mode Terminal Session

```
CPWR=COMM S/S DC POWER (WATTS)
TRFP=TOTAL RF POWER (WATTS)

THE OTHER INPUTS ARE EITHER SELF EXPLANATORY OR ARE EXPLAINED ABOVE IN
THE COST ONLY MODE SECTION.

IN THE COST ONLY MODE, PROGRAM COSTS AND PER YEAR COSTS
ARE PRINTED. IN THE FULL PROGRAM MODE, ESTIMATED SPACE-
CRAFT PARAMETERS ARE PRINTED BEFORE THE COSTS. IF IN THE
TRADES SECTION OF THE FULL PROGRAM MODE, THE CHANGES
IN SPACECRAFT PARAMETERS AND COSTS FROM A PREVIOUSLY
COMPUTED BASELINE ARE ALSO PRINTED.

WHEN A COMPLETE LISTING OF PARAMETERS IS PRINTED, THEY ARE
IN THE FOLLOWING FORMAT (SEE USER'S GUIDE FOR DEFINITIONS)
         CWT       TTCW      STRW      ACSW      EPSW      THRW
         EIW       SIW       PRPW      BSWT      OOFW      SCOWT
         TOTFW     SCLWT     XNRT1     XNRT2     CLDW      PMX
         PML       SCL       XSCB      XCLS      TSPR      BOL
         CPWR      TRFP

INPUT PROGRAM MODE : 1=COST ONLY, 2=FULL PROGRAM
=1
INPUT PARAMETERS:CCP,TCP,SCP,ACP,ECP1,BOL,XSCB
=301,49.3,215.2,276.8,389,1996.9,2
INPUT PARAMETERS:SCLWT,SCL,PMX,PMC,PML
=6252.2,8,1,3700,7
INPUT PARAMETERS:BYR,XSC,XCSC,XFDSC,PROGT,PROGF,MMD,XIR
=1981,3,3,0,2,1,7,0
AN INPUT OF ZERO WILL CAUSE THE QUESTION TO BE ASKED AGAIN
INPUT HIGHEST COMMUNICATIONS FREQUENCY. 1=<15GHZ,2=<56GHZ,3=>56GHZ
=1
INPUT HIGHEST POWER LEVEL AT HIGHEST FREQUENCY.
1=<5W,2=5-10W,3=10-20W,4=20-40W,5=>40W
=3
INPUT TYPE OF TRANSPONDER. 1=TRANSLATING,2=REGENERATING,3=COMBINATION
=1
INPUT NUMBER OF ACTIVE POWER AMPS,1=10 OR LESS,2=50 OR LESS
3=100 OR LESS,4=MORE THAN 100
=2
INPUT NUMBER OF DIFFERENT FREQUENCY BANDS. 1=1,2=2,3=3,4=4 OR MORE
=2
INPUT NUMBER OF RCV/XMIT ANTENNA SETS,1=1,2=2 OR 3,3=4 TO6,4=7 OR MORE
=2
INPUT MOST COMPLEX ANTENNA PATTERN. 1=EARTH
2=SINGLE SPOT: BW.GE.1.0,3=SINGLE SPOT: BW<1.0
4=SHAPED: SINGLE BW.GE.1.0,5=SHAPED: SINGLE BW.LT.1.0
6=MULTIPLE SPOT:SINGLE BW.GE.1.0,7=MULTIPLE SPOT:SINGLE BW.LT.1.0
8=SCANNING.LE.7BW'S,9=SCANNING>7BW'S
=6
INPUT MOST COMPLEX ANTENNA DESIGN. 1=HORN,2=SINGLE REFLECTOR
3=DUAL REFLECTOR,4=SINGLE LENS,5=DUAL LENS/PHASED ARRAY
=2
INPUT NUMBER OF FEEDS IN MOST COMPLEX ANTENNA DESIGN
1=1 TO 10,2=11 TO 25,3=26 TO 50,4=51 TO 75,5=76 TO 100,6=MORE THAN 100
=1
INPUT MAXIMUM TT&C BIT RATE,CMD OR TLM. 1=UP TO 100 KBPS
2=UP TO 1 GBPS,3=MORE THAN 1 GBPS
=1
INPUT TOTAL NUMBER OF CHANNELS. 1=UP TO 1000,2=MORE THAN 1000
=1
INPUT TYPE OF COMMUNICATIONS PROCESSING. 1=NONE,2=CENTRALIZED
3=DISTRIBUTED
=2
```

Figure A-2. (Continued)

```
INPUT PROCESSING OR TT&C STORAGE. 1=NONE,2=UP TO 10 KB,3=UP TO 1 GB
4=MORE THAN 1 GB
=2
INPUT TYPE OF MEMORY. 1=NONE, 2=MAGNETIC CORE,3=TAPE,4=OTHER
=4
INPUT ATTITUDE REFERENCE. 1=INERTIAL OR OTHER,2=CELESTIAL
=1
INPUT POINTING CONTROL. 1=OPEN LOOP,2=CLOSED LOOP
=1
INPUT PITCH AXIS POINTING ACCURACY (DEGREES)
=.05

STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)

NUMBER OF S/C =  3  NUMBER OF ON-ORBIT S/C =  3
R&D COST = $ 20702.5             PROTOTYPE COST = $ 22085.1
TOTAL NON-RECURRING COST = $ 42797.6
PROTOTYPE REFURB COST = $ 8035.2  FIRST UNIT COST = $17876.1
FLIGHT MODEL COST = $ 35352.1     ON-ORBIT INCENTIVES = $ 17237.0
TOTAL S/C COST = $103422.0
PM COST = $11100.0  STS COST = $24732.2
TOTAL PROGRAM COST = $139254.2

YEAR  1 COST = $ 23814.3      0 S/C LAUNCHED
YEAR  2 COST = $ 46368.0      0 S/C LAUNCHED
YEAR  3 COST = $ 39557.4      0 S/C LAUNCHED
YEAR  4 COST = $ 14001.2      3 S/C LAUNCHED
YEAR  5 COST = $   1723.7     0 S/C LAUNCHED
YEAR  6 COST = $   1723.7     0 S/C LAUNCHED
YEAR  7 COST = $   1723.7     0 S/C LAUNCHED
YEAR  8 COST = $   1723.7     0 S/C LAUNCHED
YEAR  9 COST = $   1723.7     0 S/C LAUNCHED
YEAR 10 COST = $   1723.7     0 S/C LAUNCHED
YEAR 11 COST = $   1723.7     0 S/C LAUNCHED
YEAR 12 COST = $   1723.7     0 S/C LAUNCHED
YEAR 13 COST = $   1723.7     0 S/C LAUNCHED
```

Figure A-2 (Continued)

APPENDIX A-2

PROGRAM LISTING

Table ?-1 is a glossary of variables that are internal to the computer program that are not listed in Table 2-4. Figure B-1 is a listing of the computer program.

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TABLE B-1

GLOSSARY OF COMPUTER PROGRAM VARIABLES

(Those not included in Table 2-4)

AMFW	-	Apogee motor fuel weight
AWX	-	ACS parameter change indicator
AW2	-	Alternate ACS weight
AX	-	Dummy variable for Z's
AY	-	Dummy variable for Z's
BATR	-	Basic bus power
BL(26)	-	Baseline array
BLCST(30)	-	Baseline cost
BLIMAX	-	IMAX for baseline
BLPI	-	Baseline print indicator
BPX	-	Basic program parameter change indicator
CFAC(8)	-	Complexity factor array
CHBLX	-	Baseline change indicator
CL12(3,5,2)	-	Complexity factor array
CL7(9,2)	-	Complexity factor array
CL8(5,2)	-	Complexity factor array
CL9(6,2)	-	Complexity factor array
CN(4,2)	-	Complexity factor array
CNT	-	First time through indicator
CSX	-	Comm. parameter change indicator
CTA(4,6,2)	-	Complexity factor array
CTL313 (3,3,2)	-	Complexity factor array
DACSW	-	Delta ACSW
DBSWT	-	Delta BSWT
DCNT	-	Delta CNT
DEPMC	-	Demonstration program PMC
DEPSW	-	Delta EPSW
DESTSC	-	Demonstration Program STSC
DLCST(30)	-	Delta cost (per year)
DLIMAX	-	IMAX for delta cost
DOOFW	-	Delta OOFW

TABLE B-1 (Continued)

GLOSSARY OF COMPUTER PROGRAM VARIABLES

DPWP1,2	-	Intermediate power terms
DSCLWT	-	Delta SCLWT
DSCOWT	-	Delta SCOWT
DTBPR	-	Delta TBPR
DTTCW	-	Delta TTCW
EL	-	EPS Complexity factor term
EPSF(7,2)	-	Complexity factor array
EPX	-	EPS parameter change indicator
EP1	-	Sizing parameter for DPWR
FACTOR	-	Profit factor
FLAG	-	Name of CNT in subroutines
FW6	-	Sizing parameter for STRW
IHELP	-	HELP subroutine indicator
II	-	Counter for cost spreading
III	-	Counter for demo program cost spreading
IMAX	-	Last year in which costs are incurred
INPUT	-	Input variable in subroutine
IORB	-	Geostationary orbit indicator
LNCHC	-	Launch cost
LPY(30)	-	S/C launched per year array
MMO	-	Near mission duration
NR(5)	-	Non-recurring costs
OPX	-	Orbit change indicator
PICF	-	Program inflation factor
PLX	-	Parameter listing indicator
PMFL	-	Perigee motor trade indicator
PMFW	-	Perigee motor fuel weight
POOC	-	Profit and on-orbit incentive cost
PROG	-	Program mode indicator
PROGF	-	Program costing format
PROGT	-	S/C program type
PW1	-	Intermediate propulsion S/C weight
R(5)	-	Recurring costs

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TABLE B-1 (Continued)

GLOSSARY OF COMPUTER PROGRAM VARIABLES

RC	-	Recurring cost for spreading
STORC	-	Storage cost
SUMNR	-	Sum of non-recurring costs
SUMR	-	Sum of recurring costs
TAL212	-	Complexity factor array
TCX	-	TT&C parameter change indicator
TEST	-	Input testing function
TOF1	-	S/C weight prior to apogee motor kick
TOF2	-	S/C weight prior to transfer orbit kick
TRDX	-	Trades indicator
TTCD	-	TT&C S/C type indicator
UACSW	-	New ACSW
UAWX	-	ACS parameter source indicator
UCPWR	-	New CPWR
UCWT	-	New CWT
UDPWR1	-	New DPWR1
UDPWR2	-	New DPWR2
UEWX	-	EPS parameter source indicator
UPAA	-	New PAA
UTRCP	-	New TRFP
UTTCD	-	New TTCA
UTTCW	-	New TTCW
UTWX	-	TT&C parameter source indicator
XA(4,2)	-	Complexity factor array
XFDR	-	Number of flight demonstration replenishment S/C
XFDSC	-	Number of flight demonstration S/C
XFERC	-	Total transfer orbit and STS cost
XFRCST(30)	-	Transfer orbit and STS cost per year
XCPY	-	Number of STS launches per year
XOSC	-	Number of on-orbit S/C
XOSCNT	-	Counter for XOSC
XSCL	-	Number of S/C launches
XSCPL	-	Number of S/C per STS launch

OF POOR QUALITY

TABLE B-1 (Continued)

XSCPT	-	Number of S/C launched per year
Y(4,2)	-	Complexity factor array
YRCST(30)	-	Program cost per year

```
C      PROGRAM SCPCE: S/C PARAMETER/COST ESTIMATOR
C      VERSION 1.1 - MODIFIED 4 MAR 1980 - S. J. MELACHRINOS
       INTEGER IHELP,PROG,BYR,XOSC,XSC,XFDSC,PROGT,PROGF,PMX,CNT,OPX,BPX,
      &IORB,CSX,TCX,UTWX,UTTCD,TTCC,AWX,UAWX,EPX,UEWX,PMFL,EL,MMD,IMAX,
      &BLIMAX,DLIMAX,CHBLX,BLPI,TRDX,PLX
       REAL CCD, TCP,SCP,ACP,ECP1,ECP2,ECP3,BOL,SCLWT,SCL,PMC,PML,DV1,
      &DV2,FWF,STX,V3,V4,FAR,FPR,FINC,A1,A2,P1,P2,Z1,Z2,Z3,Z5,Z6,AY,AX,
      &DVMV,CWT,VCWT,CPWR,UCPWR,UTRFP,TRFP,CHWT,UTTCW,TTCW,UDPWR1,DPWR1,
      &UACSW,UDPWR2,ACSW,DPWR2,PAA,EPSW,AW2,ARYWF,AWTF,XCLSF,XCLS,TBPR,
      &BATR,EP1,XSCB,BPR,EOL,ARYW,BATW,SHWT,PCUW,FW5,FW6,STRW,THRW,EIW,
      &SIW,PRPW,OOFW,AMFW,PMFW,BST,PW1,SCOWT,DVMFW,XNRT1,XNRT2,TOF1,
      &TOF2,TCTFW,CLDW,LZ,STSCF,STSC,DCWT,DTTCW,DACSW,DEPSW,DBSWT,
      &DTBPR,DOOFW,DSCOWT,DSCLWT,BL(26),SUMNR,SUMR,XIR,YRCST(30),
      &BLCST(30),DLCST(30),LPY,DSCL
        LOGICAL TEST
       COMMON /BPAR/XSC,XOSC,XFDSC,PROGF,MMD,XIR,BYR
       COMMON /CST/TPC,PMC,STSC,TNMC,PMX
       TEST(A,B)=(A.EQ.0.).AND.(B.EQ.1)
C      HERE STARTS THE PROGRAM
       PRINT," "
       PRINT,"THIS IS THE SPACECRAFT PARAMETER AND COST"
       PRINT,"ESTIMATING PROGRAM DEVELOPED AT FACC WDL."
       PRINT," "
       PRINT,"DO YOU NEED HELP? 1=YES,2=NO"
       READ,IHELP
       IF(IHELP.LE.1)CALL HELP
       CNT=1
       PRINT,"INPUT PROGRAM MODE : 1=COST ONLY, 2=FULL PROGRAM"
       READ, PROG
       GO TO (10,15),PROG
 10     PRINT,"INPUT PARAMETERS:CCP,TCP,SCP,ACP,ECP1,BOL,XSCB"
       READ,CCP,TCP,SCP,ACP,ECP1,BOL,XSCB
       PRINT,"INPUT PARAMETERS:SCLWT,SCL,PMX,PMC,PML"
       READ,SCLWT,SCL,PMX,PMC,PML
       PRINT,"INPUT PARAMETERS:BYR,XSC,XOSC,XFDSC,PROGT,PROGF,MMD,XIR"
       READ,BYR,XSC,XOSC,XFDSC,PROGT,PROGF,MMD,XIR
       ECP2=BCL*.73/1.05
       ECP3=BOL/.11
       IF(BYR.GT.1982)ECP3=BOL/.15
       PRINT,"AN INPUT OF ZERO WILL CAUSE THE QUESTION TO BE ASKED AGAIN"
       CALL CCMCF(1)
       CALL TTCCF(1)
       CALL ACSCF(1,PAA)
       GO TO 335
 13     CNT=2
       PRINT,"DO YOU WANT TO CHANGE ORBIT PARAMETERS? 1=YES,2=NO"
       READ,OPX
       GO TO (15,50),OPX
 15     PRINT,"IS ORBIT GEOSTATIONARY? 1=YES,2=NO"
       READ,IORB
       GO TO (20,25),IORB
 20     DV1=2426.45
```

Figure B-1. Computer Program Listing

```
520        FWF=.252
530        STX=28.5
540        FAR=22755.3
550 22      V3=SQRT(2.15227 E11/FAR)
560        V4=SQRT(1.55133E15/FAR/(3963.9+FAR))
570        GO TO 30
580 25      PRINT,"INPUT ORBIT PARAMETERS:FAR,FPR,FINC. GEOSTATIONARY RADIUS=
590        &22755.3 MILES"
600        READ,FAR,FPR,FINC
610        DV1=SQRT(1.19441E8 *FAR/(3963.9+FAR))-7727.9
620        IF(FINC.LT.41.75) STX=ABS(28.5-FINC)
630        IF((41.75.LE.FINC).AND.(FINC.LT.65.0)) STX=ABS(55.0-FINC)
640        IF((65.0.LE.FINC).AND.(FINC.LT.82.5)) STX=ABS(75.0-FINC)
650        IF(82.5.LE.FINC) STX=90.0-FINC
660        FWF=.073
670        IF(FAR.EQ.FPR) GO TO 22
680         A1=(3963.9+FAR)/2.0
690        A2=(FAR+FPR)/2.0
700        P1=FAR*(2-FPR/A1)
710        P2=FAR*(2-FPR/A2)
720        V3=SQRT(2.15227E11*(2.0/P1-1.0/A1))
730        V4=SQRT(2.15227E11*(2.0/P2-1.0/A2))
740 30      DV2=SQRT(V3**2+V4**2-2*V3*V4*COS(STX/57.2958))
750        Z1=EXP(DV2/3040.2)
760        Z2=EXP(DV1/2995.1)
770        Z3=EXP(DV1/2863.5)
780        Z4=EXP(DV2/2902.9)
790        Z5=EXP(DV1/2844.0)
800 50      GO TO (60,55),CNT
810 55      PRINT,"DO YOU WANT TO CHANGE THE PROGRAM COSTING PARAMETERS?1=YES
820        &,2=NO"
830         READ,BPX
840         GO TO (60,70),BPX
850 60      PRINT,"INPUT XSC,XOSC,PRDCT,PROGF,BYR,MMD,XIR"
860        READ,XSC,XOSC,PRDCT,PROGF,BYR,MMD,XIR
870        XFSDC=0
880        IF(PROGF.NE.2) GO TO 68
890        PRINT,"INPUT XFDSC"
900        READ,XFDSC
910        GO TO 70
920 68     XFDSC=0
930 70      GO TO (78,75),CNT
940 75      PRINT,"DO YOU WANT TO CHANGE SCL OR DVMV? 1=YES,2=NO"
950        READ,SCLX
960        GO TO (78,80),SCLX
970 78      PRINT,"INPUT SCL,DVMV"
980        READ,SCL,DVMV
990        Z6=EXP(DVMV)
1000 80     GO TO (90,85),CNT
1010 85     PRINT,"DO YOU WANT TO CHANGE THE COMM S/S PARAMETERS?1=YES,2=NO"
1020        READ,CSX
1030        GO TO (90,110),CSX
```

Figure B-1. (Continued)

```
1040 93    PRINT,"INPUT PARAMETERS:CWT,CPWR,TREP. USE CWT=0 FOR NO CHANGE IN
1050      & TRADES MODE"
1060       READ,UCWT,UCPWR,UTREP
1070       IF (TEST(UCWT,CNT)) GO TO 90
1080       IF(UCWT.EQ.0.0) GO TO 95
1090       CPWR=UCPWR
1100       CWT=UCWT
1110       TREP=UTREP
1120 95    GO TO (100,97),CNT
1130 97    PRINT,"AN INPUT OF ZERO ON THE NEXT NINE QUESTIONS INDICATES NO C
1140      &HANGE."
1150 100   CALL COMCF(CNT)
1160 110   CHWT=CWT*(1.628+FWF)/.628
1170C      NOW WE INPUT PARAMETERS FOR TT&C AND ACS
1180 200   GO TO (206,202),CNT
1190 202   PRINT,"DO YOU WANT TO CHANGE TT&C PARAMETERS? 1=YES,2=NO"
1200       READ,TCX
1210       GO TO (206,220),TCX
1220 206   PRINT,"INPUT SOURCE OF TT&C PARAMETERS. 1=DIRECT INPUT,2=MODEL"
1230       READ,UTWX
1240       GO TO (209,208),CNT
1250 208   PRINT,"AN INPUT OF ZERO ON THE NEXT SIX QUESTIONS INDICATES NO CH
1260      &ANGE."
1270 209   GO TO (210,212),UTWX
1280 210   PRINT,"INPUT TT&C S/S WEIGHT,DELTA POWER (OVER BASIC)"
1290       READ,UTTCW,UDPWR1
1300       IF (TEST(UTTCW,CNT)) GO TO 210
1310       IF (UTTCW.EQ.0.0) GO TO 215
1320       TTCW=UTTCW
1330       DPWR1=UDPWR1
1340       GO TO 215
1350 212   PRINT,"INPUT TYPE OF TT&C S/S. 1=BASIC,2=CRYPTO,3=CRYPTO AND SSMA"
1360       READ,UTTCD
1370       IF(TEST(UTTCD,CNT)) GO TO 212
1380       IF(UTTCD.EQ.0) GO TO 215
1390       TTCD=UTTCD
1400 215   CALL TTCCF (CNT)
1410 220   GO TO (226,222),CNT
1420 222   PRINT,"DO YOU WANT TO CHANGE ACS PARAMETERS? 1=YES,2=NO"
1430       READ,AWX
1440       GO TO (226,240),AWX
1450 226   PRINT,"INPUT SOURCE OF ACS PARAMETERS 1=DIRECT INPUT,2=MODEL."
1460       READ,UAWX
1470       GO TO (230,233),UAWX
1480 230   GO TO (232,231),CNT
1490 231   PRINT,"AN INPUT OF ZERO ON THE NEXT FOUR QUESTIONS INDICATES NO C
1500      &HANGE"
1510 232   PRINT,"INPUT ACS WT,DELTA POWER (OVER BASIC)"
1520       READ,UACSW,UDPWR2
1530       IF(TEST(UACSW,CNT)) GO TO 232
1540       IF(UACSW.EQ.0.0) GO TO 236
1550       ACSW=UACSW
```

Figure B-1. (Continued)

```
      DPWR2=UDPWR2
      GO TO 236
233   GO TC (236,234),CNT
234   PRINT,"AN INPUT OF ZERO CN THE NEXT THREE QUESTIONS INDICATES NO
     &CHANGE."
236   CALL ACSCF(CNT,PAA)
C     NOW WE INPUT EPS PARAMETERS
240   GO TO (246,242),CNT
242   PRINT,"DO YOU WANT TO CHANGE EPS PARAMETERS? 1=YES,2=NO"
      READ,EPX
      GO TO (246,260),EPX
246   PRINT,"INPUT SOURCE OF EPS PARAMETERS. 1=DIRECT INPUT,2=MODEL."
      READ,UEWX
      GO TO (250,260),UEWX
250   PRINT,"INPUT EPS WEIGHT,BOL,# S/C BATTERIES"
      READ,EPSW,BOL,XSCB
C     NOW THAT WE HAVE ALL THE INPUTS,WE DO THE CALCULATIONS
260   GO TC (270,262),UTWX
262   GO TO (264,266,268),TTCD
264   TTCW=49.6
      DPWR1=0.0
      GO TO 270
266   TTCW=79.6
      DPWR1=60.0
      GO TO 270
268   TTCW=109.1
      DPWR1=80.0
270   GO TO (280,272),UAWX
272   IF (PAA.LT.0.1) GC TO 274
      ACSW=130.1
      AW2=151.7
      DPWR2=0.0
      GO TO 278
274   IF (PAA.LT..05) GO TO 276
      ACSW=151.7
      AW2=171.7
      DPWR2=0.0
      GO TO 278
276   ACSW=186.7
      AW2=206.7
      DPWR2=25.0
278   IF(CNT.GT.1300.) ACSW=AW2
280   DPWR=DPWR1 + DPWR2
      IF(BYR.GT.1982) GO TO 282
      ARYWF=13.0
      BWTF=70.0
      XCLSF=.11
      GO TO 285
282   ARYWF=17.5
      BWTF=42.5
      XCLSF=.15
285   GO TC (286,290),UEWX
```

Figure B-1. (Continued)

```
286   XCLS=BOL/XCLSF
      TBPR=BOL*.73/1.05
      BATR=TBPR-DPWR-CPWR-50.0*XSCB
      GO TO 300
290   EP1=TNFP-200.0
      IF(EP1.LT.0.0) GO TO 292
      DPWR=DPWR+.2*EP1
292   BATR=220.0
      BPR=BATR+DPWR+CPWR
      XSCB=BPR/1000.0
      IF(XSCB.GE.2.0) GO TO 294
      XSCB=2.0
      GO TO 296
294   XSCB=AINT(XSCB)+1.0
296   TBPR=BPR+50.0*XSCB
      EOL=TBPR*1.05
      BOL=EOL/.73
      ARYW=BOL/ARYWF
      XCLS=BOL/XCLSF
      BATW=XSCB*BWTF
      SHWT=4.8*XSCB
      PCUW=20.8+2.7*XSCB
      EPSW=ARYW+SHWT+PCUW+BATW
300   FWS=CWT+EPSW
      FW6=.367*CWT
      STRW=.288*FWS
      IF(STRW.LE.FW6) STRW=FW6
      THRW=.07*FWS
      EIW=.136*CWT
      SIW=.215*STRW
      PRPW=1.016*STRW
      BSWT=TTCW+ACSW+EPSW+STRW+THRW+SIW+PRPW+EIW
      OOFW=BSWT*FWF
      PW1=.1*OOFW+56.9
      BSWT=BSWT+PW1-PRPW
      PRPW=PW1
      SCOWT=CWT+BSWT+OOFW
      DVMFW=SCOWT*Z6-SCOWT
      PW1=.1*(DVMFW+OOFW)+56.9
      BSWT=BSWT+PW1-PRPW
      PRPW=PW1
      OOFW=FWF*(BSWT+(DVMFW/2))
      SCOWT=CWT+BSWT+DVMFW+OOFW
      IF((((CHWT.GT.1300.0).AND.(SCOWT.GT.1300.0)).OR.((CHWT.LE.1300.0).
     &AND.(SCOWT.LE.1300.0))).OR.(UAWX.EQ.1)) GO TO 305
      CHWT=SCOWT
      GO TO 272
305   XNRT2=1765.7
      AX=Z1
      AY=Z2
      PMFL=1
      XNRT1=0.0
```

Figure B-1. (Continued)

```
      AMFW=SCOWT+AX-SCOWT
      PW1=.1*(DVMFW+OOFW+AMFW)+56.9
      BSWT=BSWT+PW1-PRPW
      PRPW=PW1
      OOFW=FWF*(BSWT+DVMFW/2)
      SCOWT=CWT+BSWT+DVMFW+OOFW
307   TOF1=(SCOWT+XNRT1)*AX
      TOF2=(TOF1+XNRT2)*AY
      AMFW=TOF1-(SCOWT+XNRT1)
      PMFW=TOF2-(TOF1+XNRT2)
      TOTFW=AMFW+PMFW
      SCLWT=TOF2+CLDW
      IF(PMFL.NE.1) GO TO 330
      PMFL=2
      IF(PMFW.LE.19700) GO TO 310
      PMX=5
      PML=13.0
      PMC=5500.0
      CLDW=0.0
      XNRT2=2180.6
      GO TO 307
310   IF (PMFW.LE.10165) GO TO 315
      PMX=4
      PML=16.5
      PMC=3000.0
      CLDW=4800.0
      XNRT2=2600.0
      XNRT1=1690
      AX=24
      AY=25
      IF(DVMW.GT.0.0)GO TO 307
      PW1=1.016*STRW
      BSWT=BSWT+PW1-PRPW
      PRPW=PW1
      OOFW=BSWT*FWF
      PW1=.1*OOFW+31.3
      BSWT=BSWT+PW1-PRPW
      PRPW=PW1
      SCOWT=CWT+BSWT+OOFW
      GO TO 307
315   IF((6600.GT.PMFW).OR.(PMFW.GT.7800.)) GO TO 320
      PMX=2
      PML=8.0
      PMC=5000.0
      CLDW=3800.0
      XNTR2=1333.0
      AY=23
      GO TO 307
320   IF((PMFW.LT.4900.).OR.(5700..LT.PMFW)) GO TO 325
      PMX=1
      PML=7.0
      PMC=3700
```

Figure B-1. (Continued)

```
      CLDW=2663.6
      XNRT2=385.0
      AY=23
      GO TO 307
325   PMX=3
      PML=6.5
      PMC=3000.0
      CLDW=0.0
330   PRINT," "
      PRINT 800,DV1,DV2
800   FORMAT ('DELTA V1 = ',F7.2,' M/SEC  DELTA V2 = ',F7.2,' M/SEC')
      PRINT 801,CWT,TTCW
801   FORMAT ('COM WT = ',F5.1,' LBS        TTC WT = ',F5.1,' LBS')
      PRINT 802,ACSW,EPSW
802   FORMAT ('ACS WT = ',F5.1,' LBS        EPS WT = ',F5.1,' LBS')
      PRINT 803,BOL,BSWT
803   FORMAT ('BOL = ',F7.1,' WATTS       BUS WT = ',F6.1,' LBS')
      PRINT 900,OOFW
900   FORMAT('ON-ORBIT FUEL WT = ',F7.1,' LBS')
      PRINT 804,SCOWT,SCLWT
804   FORMAT('S/C ON-ORBIT WT = ',F7.1,' LBS  S/C LAUNCH WT = ',F8.1,
     &' LBS')
      PRINT 901,PMX
901   FORMAT('PERIGEE MOTOR ',I1,' WAS CHOSEN')
      GO TO (332,331),CNT
331   DCWT=CWT-BL(1)
      DTTCW=TTCW-BL(2)
      DACSW=ACSW-BL(4)
      DEPSW=EPSW-BL(5)
      DBSWT=BSWT-BL(10)
      DTBPR=TBPR-BL(23)
      DOOFW=OOFW-BL(11)
      DSCOWT=SCOWT-BL(12)
      DSCLWT=SCLWT-BL(14)
      PRINT," "
      PRINT 805,DCWT,DTTCW
805   FORMAT ('DELTA COM WT = ',F6.1,' LBS       DELTA TTC WT = ',F6.1,
     &' LBS')
      PRINT 806,DACSW,DEPSW
806   FORMAT ('DELTA ACS WT = ',F6.1,' LBS       DELTA EPS WT = ',F6.1,
     &' LBS')
      PRINT 807,DTBPR,DBSWT
807   FORMAT ('DELTA BUS POWER = ',F6.1,' WATTS  DELTA BUS WT = ',F6.1,
     &' LBS')
      PRINT 808,DOOFW,DSCOWT
808   FORMAT('DELTA ON-ORBIT FUEL WT = ',F6.1,' LBS  DELTA S/C ON-ORBIT
     & WT = ',F7.1,' LBS ')
      PRINT 809,DSCLWT
809   FORMAT('DELTA S/C LAUNCH WT= ',F7.1,' LBS')
      PRINT," "
      PRINT,"DO YOU WANT A COMPLETE LISTINGS OF PARAMETERS"'
      PRINT,"THIS LISTING IS WITHOUT HEADINGS,1=YES,2=NO"
```

Figure B-1. (Continued)

```
      READ,PLX
      GO TO (810,332), PLX
810   PRINT 811,CWT,TTCW,STRW,ACSW,EPSW,THRW
      PRINT 811,EIW,SIW,PRPW,BSWT,OOFW,SCOWT
      PRINT 811,TOTFW,SCLWT,XNRT1,XNRT2,CLDW,FLOAT(PMX)
      PRINT 811,PML,SCL,XSCU,XCLS,TBPR,BOL
      PRINT 811,CPWR,TRFP
811   FORMAT (6F10.1)
812   FORMAT (5F10.1,I10)
332   CCP=CWT
      TCP=TTCW
      ACP=ACSW+PRPW
      SCP=STRW+THRW+SIW
      ECP1=EPSW+EIW
      ECP2=TBPR
      ECP3=XCLS
335   LZ=SCLWT*60.0/65000.0-PML
      DSCL=SCL
      IF (PMX.EQ.1) DSCL=0.0
      IF(DSCL.GT.LZ) STSCF=(DSCL+PML)/60.0
      IF(DSCL.LE.LZ)STSCF=SCLWT/65000.0
      GO TO (336,338),PROGT
336   STSC=STSCF*22722.4 + 430C.
      GO TO 340
338   STSC=STSCF*33806.3 + 430C
      EL=INT(TBPR/500.0)
      IF (TBPR.GT.3250.0)EL=7
      IF (TBPR.LE.500.0) EL=1
340   CALL WCF(EL)
      CALL COST (CCP,TCP,SCP,ACF,ECP1,ECP2,ECP3,SUMNR,SUMR)
      CALL PRGCST(SUMNR,SUMR)
      CALL CSTSPD (YRCST,IMAX)
      IF (PROG.EQ.1) GO TO 450
      GO TO (390,350),CNT
350   DLIMAX=BLIMAX
      IF (IMAX.GT.DLIMAX) DLIMAX=IMAX
      PRINT," "
      DO 360 I=1,DLIMAX
      DLCST(I)=YRCST(I)-BLCST(I)
360   PRINT 370,I,DLCST(I)
370   FORMAT ('DELTA COST YEAR ',I2,' =$ ',F7.1)
      PRINT,' '
380   PRINT,'DO YOU WANT TO CHANGE THE BASELINE? 1=YES,2=NO'
      READ,CHBLX
      GO TO (390,405),CHBLX
390   DO 400 I=1,30
400   BLCST(I)=YRCST(I)
      BL(1)=CWT
      BL(2)=TTCW
      BL(3)=STRW
      BL(4)=ACSW
      BL(5)=EPSW
```

Figure B-1. (Continued)

```
      BL(6)=THRW
      BL(7)=EIW
      BL(8)=SIW
      BL(9)=PRPW
      BL(10)=BSWT
      BL(11)=UOFW
      BL(12)=SCOWT
      BL(13)=TOTFW
      BL(14)=SCLWT
      BL(15)=XNRT1
      BL(16)=XNRT2
      BL(17)=CLDW
      BL(18)=FLOAT(PMX)
      BL(19)=PML
      BL(20)=SCL
      BL(21)=XSCB
      BL(22)=XCLS
      BL(23)=TBPR
      BL(24)=BOL
      BL(25)=CPWA
      BL(26)=TRFP
      BLIMAX=IMAX
405   PRINT,'DO YOU WANT A COMPLETE LISTING OF THE BASELINE? '
      PRINT,'THIS LISTING IS WITHOUT HEADINGS. 1=YES,2=NO'
      READ,BLPI
      GO TO (410,440),BLPI
410   PRINT 420,BL
420   FORMAT (6F10.1)
440   PRINT,"DO YOU WANT TO MAKE TRADES? 1=YES,2=NO"
      READ,TRDX
      GO TO (13,450),TRDX
450   STOP
      END
      SUBROUTINE COMCF(FLAG)
      LOGICAL TEST
      INTEGER CL(9),FLAG,INPUT,TL(5),AL(3)
      COMMON/CTAL/CL,TL,AL
      TEST(INPUT,FLAG)=INPUT.EQ.0.AND.FLAG.EQ.1
1000  PRINT,"INPUT HIGHEST COMMUNICATIONS FREQUENCY. 1=<15GHZ,2=<56GHZ,
     &3=>56GHZ"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 1000
      IF(INPUT.EQ.0) GO TO 1010
      CL(1)=INPUT
1010  PRINT,"INPUT HIGHEST POWER LEVEL AT HIGHEST FREQUENCY."
      PRINT,"1=<5W,2=5-10W,3=10-20W,4=20-40W,5=>40W"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 1010
      IF(INPUT.EQ.0) GO TO 1020
      CL(2)=INPUT
1020  PRINT,"INPUT TYPE OF TRANSPONDER. 1=TRANSLATING,2=REGENERATING,3=
     &COMBINATION"
```

Figure 3-1. (Continued)

```
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 1020
      IF(INPUT.EQ.0) GO TO 1030
      CL(3)=INPUT
 1030 PRINT,"INPUT NUMBER OF ACTIVE POWER AMPS,1=10 OR LESS,2=50 OR LESS
     &"
      PRINT,"3=100 OR LESS,4=MORE THAN 100"
      READ,INPUT
      IF (TEST(INPUT,FLAG)) GO TO 1030
      IF (INPUT.EQ.0) GO TO 1040
      CL(4)=INPUT
 1040 PRINT,"INPUT NUMBER OF DIFFERENT FREQUENCY BANDS. 1=1,2=2,3=3,4=4
     & OR MORE"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 1040
      IF(INPUT.EQ.0) GO TO 1050
      CL(5)=INPUT
 1050 PRINT,"INPUT NUMBER OF RCV/XMIT ANTENNA SETS,1=1,2=2 OR 3,3=4 TO
     &6,4=7 OR MORE"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 1050
      IF(INPUT.EQ.0) GO TO 1060
      CL(6)=INPUT
 1060 PRINT,"INPUT MOST COMPLEX ANTENNA PATTERN. 1=EARTH"
      PRINT,"2=SINGLE SPOT: BW.GE.1.0,3=SINGLE SPOT: BW<1.0"
      PRINT,"4=SHAPED: SINGLE BW.GE.1.0,5=SHAPED: SINGLE BW.LT.1.0"
      PRINT,"6=MULTIPLE SPOT:SINGLE BW.GE.1.0,7=MULTIPLE SPOT:SINGLE BW.
     &LT.1.0"
      PRINT,"8=SCANNING.LE.7BW'S,9=SCANNING>7BW'S"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 1060
      IF(INPUT.EQ.0)GO TO 1070
      CL(7)=INPUT
 1070 PRINT,"INPUT MOST COMPLEX ANTENNA DESIGN. 1=HORN,2=SINGLE REFLECT
     &OR"
      PRINT,"3=DUAL REFLECTOR,4=SINGLE LENS,5=DUAL LENS/PHASED ARRAY"
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 1070
      IF(INPUT.EQ.0)GO TO 1080
      CL(8)=INPUT
 1080 PRINT,"INPUT NUMBER OF FEEDS IN MOST COMPLEX ANTENNA DESIGN"
      PRINT,"1=1 TO 10,2=11 TO 25,3=26 TO 50,4=51 TO 75,5=76 TO 100,6=MO
     &RE THAN 100"
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 1080
      IF(INPUT.EQ.0)GO TO 1090
      CL(9)=INPUT
 1090 RETURN
      END
      SUBROUTINE TTCCF(FLAG)
      LOGICAL TEST
      INTEGER TL(5),FLAG,INPUT,CL(9),AL(3)
```

Figure B-1. (Continued)

```
      COMMON/CTAL/CL,TL,AL
      TEST(INPUT,FLAG)=INPUT.EQ.0.AND.FLAG.EQ.1
 2000 PRINT,"INPUT MAXIMUM TT&C BIT RATE,CMD OR TLM. 1=UP TO 100 KBPS"
      PRINT,"2=UP TO 1 GBPS,3=MORE THAN 1 GBPS"
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 2000
      IF(INPUT.EQ.0)GO TO 2010
      TL(1)=INPUT
 2010 PRINT,"INPUT TOTAL NUMBER OF CHANNELS. 1=UP TO 1000,2=MORE THAN 1
     &000"
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 2010
      IF (INPUT.EQ.0)GO TO 2020
      TL(2)=INPUT
 2020 PRINT,"INPUT TYPE OF COMMUNICATIONS PROCESSING. 1=NONE,2=CENTRALI
     &ZED"
      PRINT,"3=DISTRIBUTED"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 2020
      IF(INPUT.EQ.0)GO TO 2030
      TL(3)=INPUT
 2030 PRINT,"INPUT PROCESSING OR TT&C STORAGE. 1=NONE,2=UP TO 10 KB,3=U
     &P TO 1 GB"
      PRINT,"4=MORE THAN 1 GB"
      READ,INPUT
      IF (TEST(INPUT,FLAG))GO TO 2030
      IF(INPUT.EQ.0)GO TO 2040
      TL(4)=INPUT
 2040 PRINT,"INPUT TYPE OF MEMORY. 1=NONE, 2=MAGNETIC CORE,3=TAPE,4=OTH
     &ER"
      READ,INPUT
      IF (TEST(INPUT,FLAG))GO TO 2040
      IF(INPUT.EQ.0)GO TO 2050
      TL(5)=INPUT
 2050 RETURN
      END
      SUBROUTINE ACSCF(FLAG,PAA)
      LOGICAL TEST
      INTEGER AL(3),INPUT,FLAG,CL(9),TL(5)
      COMMON/CTAL/CL,TL,AL
      TEST(INPUT,FLAG)=INPUT.EQ.0.AND.FLAG.EQ.1
 3000 PRINT,"INPUT ATTITUDE REFERENCE. 1=INERTIAL OR OTHER,2=CELESTIAL"
      READ,INPUT
      IF(TEST(INPUT,FLAG))GO TO 3000
      IF(INPUT.EQ.0)GO TO 3010
      AL(1)=INPUT
 3010 PRINT,"INPUT POINTING CONTROL. 1=OPEN LOOP,2=CLOSED LOOP"
      READ,INPUT
      IF(TEST(INPUT,FLAG)) GO TO 3010
      IF(INPUT.EQ.0) GO TO 3020
      AL(2)=INPUT
 3020 PRINT,"INPUT PITCH AXIS POINTING ACCURACY (DEGREES)"
```

Figure 3-1. (Continued)

```
      READ,UPAA
      IF(TEST(UPAA,FLAG)) GO TO 3020
      IF(UPAA.EQ.0.0) GO TO 3030
      PAA=UPAA
      AL(3)=4
      IF (PAA.GE..1) AL(3)=3
      IF(PAA.GE..25)AL(3)=2
      IF(PAA.GE.1.0) AL(3)=1
 3030 RETURN
      END
      SUBROUTINE WCF(EL)
      INTEGER CL(9),TL(5),AL(3),EL,I1,I2,I3,I4,I,J,J1
      REAL CL12(3,5,2)/.223,.325,.351,.252,.375,.608,.281,.424,.664,
     &.345,.481,.742,.392,.523,.7 ),.196,.284,.475,.220,.318,.512,.245,
     &.352,.549,.264,.385,.583,.3 5,.419,.617/
      REAL CTL313(3,3,2)/.1,.14(,.245,.110,.199,.279,.303,.500,.583,
     &.109,.229,.355,.1,.154,.176,.304,.435,.483/
      REAL CTA(4,6,2)/.067,.085,.112,.137,.034,.035,.039,.04,.035,.039,
     &.042,.047,.151,.174,.210,.274,.151,.160,.165,.250,
     &.294,.356,.482,.835,.073,.080,.088,.089,.037,.037,.040,.041,.034,
     &.039,.043,.049,.152,.158,.182,.234,.152,.160,.165,.251,.302,.365,
     &.429,.544/
      REAL CL7(9,2)/.135,.266,.332,.380,.475,.430,.559,.662,.726,.135,
     &.225,.281,.230,.288,.102,.236,.212,.297/
      REAL CL8(5,2)/.1,.1,.248,.271,.448,.1,.227,.248,.328,.542/
      REAL CL9(6,2)/.1,.229,.458,.628,.798,.846,.102,.234,.455,.624,
     &.794,1.172/
      REAL TAL212(2,3,2)/.12,.144,.256,.357,.190,.255,.142,.183,.282,
     &.321,.206,.332/
      REAL EPSF(7,2)/.432,.437,.442,.447,.452,.457,.462,1.978,2.747,
     &3.846,4.945,6.044,7.143,9.066/
      REAL X(4,2)/2*.52,.62,2*.56,.52,.50,.52/
      REAL Y(4,2)/2*.48,.38,2*.44,.48,.50,.48/
      REAL CN(4,2)/.39,.294,.497,1.132,.29,.211,.296,.836/
      REAL CFAC(8)
      COMMON/CTAL/CL,TL,AL
      COMMON/WCOMF/CFAC
      DO 4010 I=1,2
      I1=4*I-3
      I2=4*I-2
      I3=4*I-1
      I4=4*I
      CFAC(I1)=CL12(CL(1),CL(2),I)+CTL 313(CL(3),1,I)+CTA(CL(4),1,I)
     &+CTA(CL(5),2,I)+CTA(CL(6),3,I)+CL7(CL(7),I)+CL8(CL(8),I)+
     &CL9(CL(9),I)
      CFAC(I2)=CTL313(TL(1),2,I)+TAL212(TL(2),1,I)+CTL313(TL(3),3,I)
     &+CTA(TL(4),4,I)+CTA(TL(5),5,I)
      CFAC(I3)=TAL212(AL(1),2,I)+TAL212(AL(2),3,I)+CTA(AL(3),6,I)
      CFAC(I4)=EPSF(EL,I)
      DO 4000 J=1,4
      J1=4*(I-1)+J
 4000 CFAC(J1)=(CFAC(J1)+CN(J,I))* X(J,I)* Y(J,I)
```

Figure B-1. (Continued)

```
 6310  CONTINUE
       RETURN
       END
       SUBROUTINE COST (CCP,TCP,SCP,ACP,ECP1,ECP2,ECP3,SUMNR,SUMR)
       INTEGER I
       REAL  CCP,TCP,SCP,ACP,ECP1,ECP2,ECP3,SUMNR,SUMR
       COMMON/WCONF/CNWF,TNWF,ANWF,ENWF,CRWF,TRWF,ARWF,ERWF
       REAL NR(5),R(5)
       NR(1)=CNWF*(1375.6+199.6*(CCP**.67)
       R(1)=CRWF*(67.6*CCP**.75-51.2)
       NR(2)=TNWF*(287.7+22.2*TCP)
       R(2)=TRWF*(91.9+13.1*TCP)
       NR(3)=1.346*(759.0+66.0*SCP**.66)
       R(3)=1.377*(2.4+7.5*SCP**.75)
       NR(4)=ANWF*(734.9+79.9*ACP**.75)
       R(4)=ARWF*(25.0+40.9*ACP**.3)
       NR(5)=440.3+2.0*ECP2+ENWF*ECP3/20.0
       R(5)=83.5*(ECP1*ECP2)**.21128+ERWF*ECP3/25.0
       SUMNR=0.0
       SUMR=0.0
       DO 5000 I=1,5
       SUMNR=SUMNR+NR(I)
 5000  SUMR=SUMR+R(I)
       RETURN
       END
       SUBROUTINE PRGCST(NR,R)
       INTEGER XSC,XOSC,XFDSC,PRCGF,BYR,PMX,MMD
       REAL NR,R,STSC,PMC,STORC,TSTSC,TPMC,TNRC,FUC,PROTC,RDC,PRORFC,FMC,
      &OOIC,TSCC,TPC,DSCC,DEPMC,DESTSC,PROF,DPC,SUC,TFMC,FMPC,GAC
       COMMON/WFAR/XSC,XOSC,XFDSC,PROGF,MMD,XIR,BYR
       COMMON/CST/TPC,PMC,STSC,TNRC,PMX
       PRINT," "
       FUC=1.25*R
       STORC=0.0
       IF(XOSC.LT.XSC)STORC=1500.0
       TPMC=XSC*PMC
       TSTSC=XSC*STSC
       TNRC=1.3*NR
       GO TO (6100,6200,6300),PRCGF
 6100  PROTC=1.25*FUC
       RDC=TNRC-PROTC
       PRORFC=.2*FUC+4500
       FMC=(XSC-1)*FUC
       OOIC=.2*(TNRC+FMC+PRORFC)
       TSCC=TNRC+FMC+PRORFC+OOIC+STORC
       TPC=TSCC+TPMC+TSTSC
       PRINT 6110
 6110  FORMAT ('STANDARD COSTING FORMAT  (DOLLARS IN THOUSANDS)')
       PRINT," "
       PRINT 6111,XSC,XOSC
 6111  FORMAT ('NUMBER OF S/C = ',I2,2X,'NUMBER OF ON-ORBIT S/C = ',I2)
       PRINT 6112,RDC,PROTC
```

Figure 3-1. (Continued)

```
6112  FORMAT ('R&D COST = $',F8.1,14X,'PROTOTYPE COST = $',F8.1)
      PRINT 6113,TNRC
6113  FORMAT ('TOTAL NON-RECURRING COST = $',F8.1)
      PRINT 6114,PRORFC,FUC
6114 FORMAT ('PROTOTYPE REFURB COST = $',F7.1,2X 'FIRST UNIT COST = $',
     &F7.1)
      PRINT 6115,FMC,OOIC
6115  FORMAT('FLIGHT MODEL COST = $',F8.1,5X,'ON-ORBIT INCENTIVES = $',
     &F8.1)
      IF(STORC.NE.0.0)PRINT 6116,STORC
6116  FORMAT('S/C STORAGE COST = $',F6.1)
      PRINT 6117,TSCC
6117  FORMAT ('TOTAL S/C COST = $',F8.1)
      PRINT 6118,TPMC,TSTSC
6118  FORMAT ('PM COST = $',F7.1,2X,'STS COST = $',F7.1)
      PRINT 6119,TPC
6119  FORMAT ('TOTAL PROGRAM COST = $',F8.1)
      GO TO 6400
6200  DSCC=XFDSC*FUC
      DEPMC=XFDSC*PMC
      PROF=.1*(TNRC+DSCC)
      DESTSC=XFDSC*STSC
      DPC=DSCC+PROF+TNRC+DEPMC+DESTSC
      SUC=.15*TNRC
      TFMC=1.1*XSC*FUC
      OOIC=.2*(SUC+TFMC)
      FMPC=SUC+TFMC+OOIC+TPMC+TSTSC+STORC
      TPC=DPC+FMPC
      PRINT 6210
6210  FORMAT ('DOD FBB COSTING FORMAT  (DOLLARS IN THOUSANDS)')
      PRINT," "
      PRINT6211,XFDSC
6211  FORMAT ('NUMBER OF FLIGHT DEMONSTRATION S/C = ',I2)
      PRINT 6111,XSC,XOSC
      PRINT 6113,TNRC
      PRINT 6212,FUC,DSCC
6212  FORMAT ('FIRST UNIT COST = $',F7.1,2X,'DEMO S/C COST = $',F7.1)
      PRINT 6213,PROF
6213  FORMAT ('PROFIT = $',F6.1)
      PRINT 6118,DEPMC,DESTSC
      PRINT 6214,DPC
6214  FORMAT ('DEMONSTRATION PROGRAM COST = $',F8.1)
      PRINT 6215,SUC
6215  FORMAT ('START UP COST = $',F7.1)
      PRINT 6115,TFMC,OOIC
      PRINT 6118,TPMC,TSTSC
      IF(STORC.NE.0.0) PRINT 6116,STORC
      PRINT 6216,FMPC
6216  FORMAT ('FLIGHT MODEL PROGRAM COST = $',F8.1)
      PRINT 6119,TPC
      GO TO 6400
6300  TNRC=.796*R
```

Figure B-1. (Continued)

```
      TFMC=XSC+FUC
      GAC=.15*(TNMC+TFMC)
      OOIC=.12*(GAC+TNMC+TFMC)
      TSCC=OOIC+GAC+TFMC+TNMC+STORC
      TPC=TSCC+TPMC+TSTSC
      PRINT 6310
6310  FORMAT ('MINIMUM NON-RECURRING COST COSTING FORMAT (DOLLARS IN TH
     &OUSANDS)')
      PRINT," "
      PRINT 6113,TNMC
      PRINT 6311,FUC,GAC
6311  FORMAT ('FIRST UNIT COST = $',F7.1,8X,'GEN & ADMIN COST=$',F7.1)
      PRINT 6115,TFMC,OOIC
      IF(STORC.NE.0.0)PRINT 6116,STORC
      PRINT 6117,TSCC
      PRINT 6118,TPMC,TSTSC
      PRINT 6119,TPC
6400  RETURN
      END
      SUBROUTINE HELP
      PRINT," "
      PRINT,"THIS PROGRAM WAS WRITTEN BY S.MELACHRINOS AT FACC WDL."
      PRINT,"THIS IS VERSION 1.1 - 4 MARCH 1980"
      PRINT," "
      PRINT,"THIS PROGRAM ESTIMATES THE SIZE AND COST OF A COMMUNICATION
     &"
      PRINT,"SATELLITE GIVEN SOME BASIC PARAMETERS. IT USES SPACECRAFT S
     &IZING"
      PRINT,"RULES BASED ON FACC EXPERIENCE AND COSTING RULES BASED ON A
     & MOD-"
      PRINT,"IFIED VERSION OF THE SAMSO SPACECRAFT COSTING MODEL."
      PRINT," "
      PRINT,"THERE ARE TWO MODES OF THIS PROGRAM, THE COST ONLY MODE "
      PRINT,"AND THE FULL PROGRAM MODE. IN THE COST ONLY MODE, PROGRAM"
      PRINT,"COSTS ARE ESTIMATED FOR A GIVEN SPACECRAFT. IN THE FULL"
      PRINT,"PROGRAM MODE, THE MODEL CAN ESTIMATE SUBSYSTEM WEIGHTS AND"
      PRINT,"POWERS IF THEY ARE NOT GIVEN (BASED ON GENERAL INPUTS)"
      PRINT,"BEFORE ESTIMATING COSTS. THE USER CAN THEN ENTER A TRADES"
      PRINT,"MODE AND CHANGE ANY OR ALL OF THE PARAMETERS. ALL WEIGHTS"
      PRINT,"ARE IN POUNDS AND DOLLARS IN THOUSANDS."
      PRINT," "
      PRINT,"THIS MODEL IS LIMITED TO 3-AXIS STABILIZED S/C AND STS LAUN
     &CH."
      PRINT," "
      PRINT,"INPUTS FOR THE COST ONLY MODE ARE:"
      PRINT,"CCP=COMM COSTING PARAMETER=COMM WT (INCLUDING ANTENNAS)"
      PRINT,"TCP=TTC COSTING PARAMETER=TTC WT."
      PRINT,"SCP=STRUCTURE COSTING PARAMETER=STRUCTURE WT (INCLUDING"
      PRINT,"      THERMAL)"
      PRINT,"ACP=ACS COSTING PARAMETER=AC S/S WT + PROPULSION S/S WT"
      PRINT,"ECP1=EP COSTING PARAMETER=EP S/S WT"
      PRINT,"BOL=BEGINNING-OF-LIFE SOLAR ARRAY OUTPUT (WATTS)"
```

Figure B-1. (Continued)

```
7770      PRINT,"BYR=BASE YEAR OF PROGRAM"
7780      PRINT,"XSCB=NUMBER OF S/C BATTERIES"
7790      PRINT,"SCLWT=S/C LAUNCH WEIGHT"
7800      PRINT,"XSC=NUMBER OF FLIGHT S/C IN PROGRAM"
7810      PRINT,"XOSC=NUMBER OF ON-CRUIT S/C"
7820      PRINT,"XFDSC=NUMBER OF FLIGHT DEMONSTRATION SPACECRAFT (NOT"
7830      PRINT,"     INCLUDED IN XSC) FOR DOD FLY BEFORE BUY COSTING-1 OR 2"
7840      PRINT,"SCL=S/C LENGTH"
7850      PRINT,"PROGT=PROGRAM TYPE - 1 IF GOVERNMENT-MILITARY,2 IF COMMERCI
7860     &AL"
7870      PRINT,"PROGF=PROGRAM COSTING FORMAT - 1 IF STANDARD, 2 IF DOD FLY"
7880      PRINT,"     BEFORE BUY, 3 IF MINIMUM NON-RECURRING COST (NO PROTOTY
7890     &PE)"
7900      PRINT,"PMX=PERIGEE MOTOR INDICATOR-SEE BELOW"
7910      PRINT,"PMC=PERIGEE MOTOR COST-SEE BELOW"
7920      PRINT,"PML=PERIGEE MOTOR LENGTH-SEE BELOW"
7930      PRINT,"                        PMX             PMC             PML"
7940      PRINT,"        PAM-D           1               3700            7.0"
7950      PRINT,"        PAM-A           2               5000            8.0"
7960      PRINT,"        SPS-1           3               3000            6.5"
7970      PRINT,"        IUS             4               7700           16.5"
7980      PRINT,"        SPS-1 M1        5               5500           13.0"
7990      PRINT,"MMD=MEAN MISSION DURATION (YEARS)"
8000      PRINT,"XIN=AVERAGE ANNUAL INFLATION RATE (%)"
8010      PRINT,"THE OTHER INPUTS ARE SELF EXPLANATORY."
8020      PRINT," "
8030      PRINT,"INPUTS FOR THE FULL PROGRAM MODE ARE:"
8040      PRINT,"FAR=FINAL APOGEE RADIUS"
8050      PRINT,"FPR=FINAL PERIGEE RADIUS"
8060      PRINT,"FINC=FINAL INCLINATION"
8070      PRINT,"CWT=COMM S/S WT"
8080      PRINT,"CPWR=COMM S/S DC POWER (WATTS)"
8090      PRINT,"TRFP=TOTAL RF POWER (WATTS)"
8100      PRINT,"THE OTHER INPUTS ARE EITHER SELF EXPLANATORY OR ARE
8110     & EXPLAINED ABOVE IN THE COST ONLY MODE SECTION."
8120      PRINT," "
8130      PRINT,"IN THE COST ONLY MODE, PROGRAM COSTS AND PER YEAR COSTS "
8140      PRINT,"ARE PRINTED. IN THE FULL PROGRAM MODE, ESTIMATED SPACE-"
8150      PRINT,"CRAFT PARAMETERS ARE PRINTED BEFORE THE COSTS. IF IN THE  "
8160      PRINT,"TRADES SECTION OF THE FULL PROGRAM MODE, THE CHANGES"
8170      PRINT,"IN SPACECRAFT PARAMETERS AND COSTS FROM A PREVIOUSLY "
8180      PRINT,"COMPUTED BASELINE ARE ALSO PRINTED."
8190      PRINT," "
8200      PRINT,"WHEN A COMPLETE LISTING OF PARAMETERS IS PRINTED, THEY ARE"
8210      PRINT,"IN THE FOLLOWING FORMAT (SEE USER'S GUIDE FOR DEFINITIONS)"
8220      PRINT,"          CWT      TTCW     STRW     ACSW     EPSW     THPW"
8230      PRINT,"          EIW      SIW      PRPW     BSWT     OOFW     SCUWT"
8240      PRINT,"          TOTF=    SCLWT    XNRT1    XNRT2    CLDW     PMX"
8250      PRINT,"          PML      SCL      XSCB     XCLS     TBPR     BOL"
8260      PRINT,"          CPWR     TRFP"
8270      PRINT," "
8280       RETURN
```

Figure B-1. (Continued)

```
      END
      SUBROUTINE CSTSPD(YRCST,I)
      INTEGER XSC,XOSC,XFDSC,PROGF,MMD,IND,I,II,III,PMX,XFDR,BYR
      REAL YRCST(30),FACTOR,XIR,TPC,PMC,STSC,TNRC,STORC,TPMC,TSTSC,LNCHC
     &,POOIC,XFRCST(30),XSCPL,XLPY,XSCL,XOSCNT,STSIC,PMIC,PICF,
     &XFERC,RC,LPY(30),XSCPY,FUC
      REAL NRCSF(3)/.35,.45,.2/,RCSF(3,5)/.2,2*.1,.4,.3,.25,2*.4,.25,
     &0.0,.2,.25,2*0.0,.15/
      COMMON/BPAR/XSC,XOSC,XFDSC,PROGF,MMD,XIR,BYR
      COMMON/CST/TPC,PMC,STSC,TNRC,PMX
      DO 8000  I=1,30
      LPY(I)=0.0
      XFRCST(I)=0.0
 8000 YRCST(I)=0.0
      STORC=0.0
      IF ((XSC+XFDSC).GT.XOSC)STORC=1500.0
      XSCPL=2.0
      IF (PMX.GT.3) XSCPL=1.0
C     THE NEXT LINE DEFINES THE MAXIMUM NUMBER OF LAUNCHES PER YEAR.
C     CHANGING IT EASILY LIMITS THE NUMBER OF S/C LAUNCHED.
      XLPY=4.0
      XSCL=0.0
      IND=1
      IF(XSC.GT.2) IND=2
      IF(XSC.GT.9) IND=3
      PICF=(1+XIR*.01)**(BYR-1978.5)
      GO TO (8010,8500,8010),PROGF
 8010 TPMC=XSC*PMC
      TSTSC=XSC*STSC
      LNCHC=1500.0*XSC
      FACTOR=.2
      IF (PROGF.EQ.3) FACTOR=.12
      POOIC=(TPC-TSTSC-TPMC-STORC)* FACTOR/(1+FACTOR)
      IF (PROGF.EQ.3) TNRC=1.15*TNRC
      RC=TPC-TPMC-TSTSC-STORC-POOIC-TNRC-LNCHC
      DO 8015  I=1,3
 8015 YRCST(I)=NRCSF(I)*TNRC
      DO 8020 I=1,5
 8020 YRCST(I)=YRCST(I)+RC*RCSF(IND,I)
      DO 8030 I=4,13
 8030 YRCST(I)=YRCST(I)+.1*POOIC
      II=4
      XSCPY=XSCPL*XLPY
 8040 I=II
      XOSCNT=XOSC
      IF(XOSCNT.GT.(XSC-XSCL))XOSCNT=XSC-XSCL
 8050 STSIC=STSC*(1+XIR*.01)**(BYR+I-1984)
      PMIC=PMC*(1+XIR*.01)**(BYR+I-1983)
      IF (XOSCNT.LE.XSCPY)GO TO 8060
      YRCST(I)=YRCST(I)+XSCPY*1500.0
      XFRCST(I-3)=XFRCST(I-3)+XSCPY*.2*STSIC
      XFRCST(I-2)=XFRCST(I-2)+XSCPY*(.4*STSIC +.5*PMIC)
```

Figure B-1. (Continued)

```
      XOSCNT=XOSCNT-XSCPY
      XSCL=XSCL+XSCPY
      LPY(I)=XSCPY
      I=I+1
      GO TO 8050
 8060 YRCST(I)=YRCST(I)+XOSCNT*1500.0
      XFRCST(I-3)=XFRCST(I-3)+XOSCNT*.2*STSIC
      XFRCST(I-2)=XFRCST(I-2)+XOSCNT*(.4*STSIC+.5*PMIC)
      XFRCST(I-1)=XFRCST(I-1)+XOSCNT*(.4*STSIC+.5*PMIC)
      XSCL=XSCL+XOSCNT
      LPY(I)=XOSCNT
      IF(XSCL.GE.XSC) GO TO 8070
      II=II+MMD
      GO TO 8040
 8070 IF (XOSCNT.EQ.0.0) I=I-1
      IF (STORC.LT.1000.) GO TO 8085
      DO 8080  J=4,I-1
 8080 YRCST(J)=YRCST(J)+STORC/(I-4)
 8085 IF (I.LT.13) I=13
      DO 8090  J=1,I
 8090 YRCST(J)=YRCST(J)*PICF+XFRCST(J)
      GO TO 5800
 8500 XFERC=(XFDSC+XSC)*(PMC+STSC)
      FUC=(TPC-XFERC-1.28*TNRC)/(1.1*XFDSC+1.32*XSC)
      RC=(FUC-1500.)*XFDSC
      DO 8510 I=1,3
 8510 YRCST(I)=(NRCSF(I)*TNRC+RCSF(1,I)*RC)*PICF
      III=4
      YRCST(4)=XFDSC*1500.*PICF
      LPY(4)=XFDSC
      YRCST(1)=YRCST(1)+XFDSC*.2*STSIC
      YRCST(2)=YRCST(2)+XFDSC*(.4*STSIC+.5*PMIC)
      YRCST(3)=YRCST(3)+XFDSC*(.4*STSIC+.5*PMIC)
      YRCST(5)=.075*TNRC
      YRCST(6)=.075*TNRC
      RC=XSC*(FUC-1500.)
      DO 8520 I=1,5
 8520 YRCST(4+I)=YRCST(4+I)+RC*RCSF(IND,I)
      POOIC=.13*TNRC+(.1*XFDSC+.32*XSC)*FUC
      DO 8530 I=8,17
 8530 YRCST(I)=YRCST(I)+.1*POOIC
      II=8
 8540 XOSCNT=XOSC-XFDSC
      I=II
      IF (XOSCNT.GT.(XSC-XSCL)) XOSCNT=XSC-XSCL
 8550 STSIC=STSC*(1+XIR*.01)**(BYR+I-1984)
      PMIC=PMC*(1+XIR*.01)**(BYR+I-1983)
      IF (XOSCNT.LE.XSCPY) GO TO 8560
      YRCST(I)=YRCST(I)+XSCPY*1500.
      XFRCST(I-3)=XFRCST(I-3)+XSCPY*.2*STSIC
      XFRCST(I-2)=XFRCST(I-2)+XSCPY*(.4*STSIC+.5*PMIC)
      XFRCST(I-1)=XFRCST(I-1)+XSCPY*(.4*STSIC+.5*PMIC)
```

Figure B-1. (Continued)

```
      XOSCNT=XOSCNT-XSCPY
      XSCL=XSCL+XSCPY
      LPY(I)=XSCPY
      I=I+1
      GO TO 8550
 8560 YRCST(I)=YRCST(I)+XOSCNT*1500.0
      XFRCST(I-3)=XFRCST(I-3)+XOSCNT*.2*STSIC
      XFRCST(I-2)=XFRCST(I-2)+XOSCNT*(.4*STSIC+.5*PMIC)
      XFRCST(I-1)=XFRCST(I-1)+XOSCNT*(.4*STSIC+.5*PMIC)
      XSCL=XSCL+XOSCNT
      LPY(I)=XOSCNT
      IF (XSCL.GE.XSC) GO TO 8600
      II=II+MMO
      III=III+MMO
      XFDR=XFDSC
      IF(XFDSC.GT.(XSC-XSCL)) XFDR=1
      YRCST(III)=YRCST(III)+XFDR*1500.0
      LPY(III)=XFDR
      XSCL=XSCL+XFDR
      STSIC=STSC*(1+XIR*.01)**(BYR+III-1984)
      PMIC=PMC*(1+XIR*.01)**(BYR+III-1983)
      XFRCST(III-3)=XFRCST(III-3)+XFDR*.2*STSIC
      XFRCST(III-2)=XFRCST(III-2)+XFDR*(.4*STSIC+.5*PMIC)
      XFRCST(III-1)=XFRCST(III-1)+XFDR*(.4*STSIC+.5*PMIC)
      IF(XSCL.LT.XSC) GO TO 8540
 8600 IF(XOSCNT.EQ.0.0) I=I-1
      IF(III.GT.I) I=III
      DO 8610 J=8,I-1
 8610 YRCST(J)=YRCST(J)+1500./(I-8)
      PICF=(1+XIR*.01)**(BYR-1975)
      IF (I.LT.17) I=17
      DO 8620 J=5,I
 8620 YRCST(J)=YRCST(J)+PICF*XFRCST(J)
 8800 DO 8805  J=I+1,30
 8805 YRCST(J)=0.0
      PRINT," "
      DO 8820 J=1,I
 8820 PRINT 8830,J,YRCST(J),IFIX(LPY(J))
 8830 FORMAT('YEAR ',I2,' COST = $',F8.1,4X,I2,' S/C LAUNCHED')
      PRINT," "
      RETURN
      END
```

Figure B-1 (Continued)

APPENDIX - A-3

COMMUNICATIONS SUBSYSTEM ESTIMATION

Estimates of the communications subsystem weight and D.C. power are required to use this model. To demonstrate this, a 24-channel 6/4 GHz spacecraft communications subsystem is presented as an example. Figure C-1 is a detailed block diagram, and Table C-1 is the weight/power summary. The total subsystem weight (256.6 lbs), total subsystem power (739.2 watts) and total RF power (210 watts) are the basic inputs for the full program mode.

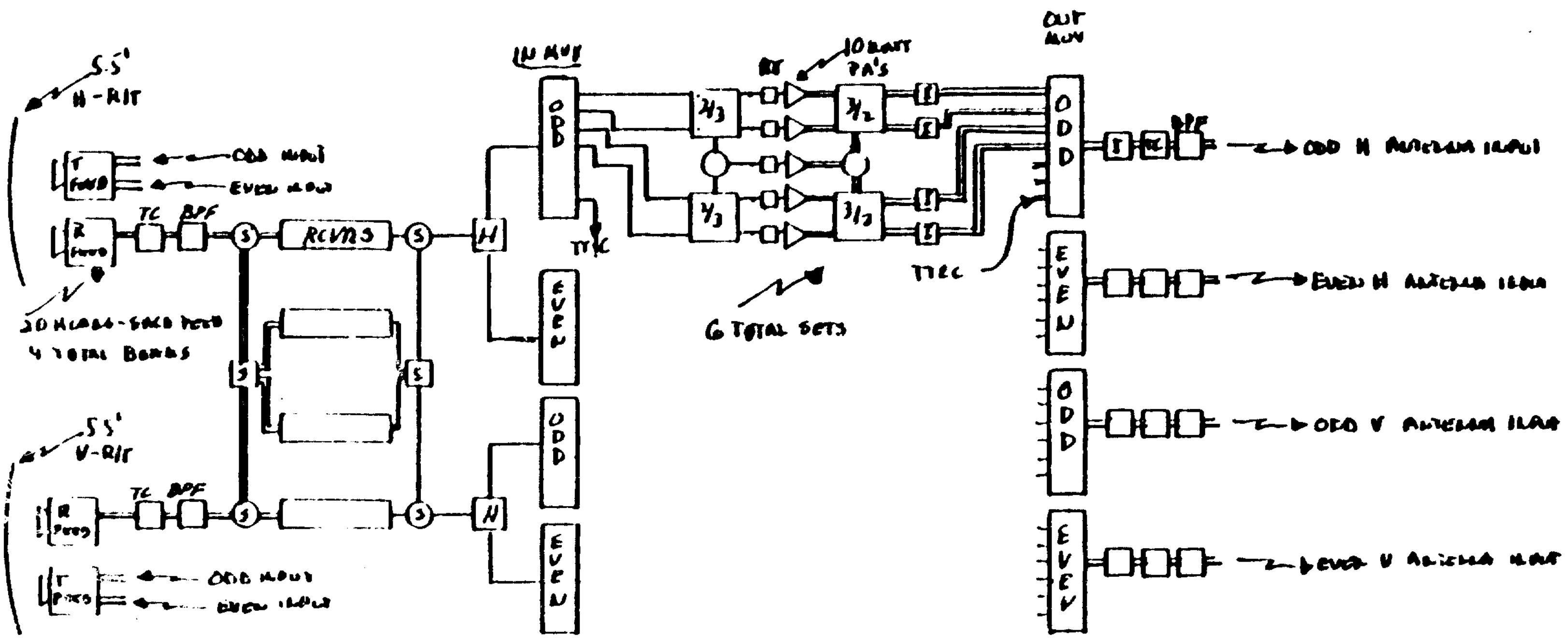

Figure C-1. Communications Subsystem Block Diagram

TABLE C-1

SAMPLE COMMUNICATIONS SUBSYSTEM WEIGHT/POWER

	# Total	# Active	Unit Weight	Unit Power	Total Weight (Lbs.)	Total Power (Watts)
A. Transponder						
1. Test Coupler	6		0.2	-	1.2	-
2. Bandpass Filter	6		0.7	-	4.2	-
3. RCVRS/DWN CNVTRS	4	2	3.3	6.0	13.2	12.0
4. Hybrids 1/2	2		0.1	-	0.2	-
5. In-Mux Channels	25		0.8/CH	-	20.0	-
6. 2/3 - 3/2 Switches	12		0.2	-	2.4	-
7. 2/3 -3/2 W/G Switches	12		0.4	-	4.8	-
8. Attenuators	30		0.02	-	0.6	-
9. 10 Watt PA's	30	24	3.3	30.3	99.0	727.2
10. Isolators	28		0.2	-	5.6	-
11. Out Mux Changes	25		0.7/CH	-	17.5	-
12. Switches	9		0.1	-	0.9	-
13. W/G Switches	9		0.3	-	2.7	-
Subtotal					172.3	739.2
14. Transponder Misc.			0.75 x subtotal		12.9	-
Total Transponder					185.2	739.2
B. Antennas						
1. Reflectors 5.5 ft. dia.	2		15.4	-	30.8	-
2. Feeds	4		8	-	32.0	-
3. Ant. Misc			8.6	-	8.6	-
Total Antenna					71.4	-
C. Total Subsystem					256.6	739.2

APPENDIX B

ADVANCES IN MULTIBEAM SATELLITE ANTENNA TECHNOLOGY

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Abstract

This paper surveys the state of the art in multibeam antenna development as applicable to communication satellites. It defines three basic forms of multibeam antennas -- those providing space diversity, polarization diversity, and variable-shaped beams. The use of lenses, reflectors, and phased arrays in multibeam configurations is described. Finally, hardware developments in the field are surveyed, including the LES-7 waveguide lens, more recent experimental TEM and waveguide lenses, a dual K-band reflector, and offset-fed reflectors for the INTELSAT IV-A and V satellites.

I. Multibeam Antennas - Forms and Functions

Multiple beam antennas have been considered for nearly a decade now as one answer to the bandwidth constraints affecting multiple users of a common radiating communications system, particularly involving a satellite. If the users (or groups of users) are separated geographically, each may reuse the same frequency band by accessing the satellite through a different antenna beam. Space limitations on a satellite, however, call for a single antenna structure capable of radiating many simultaneous beams which are sufficiently isolated that individual beams do not interfere with each other. This is known as frequency reuse through space diversity.

Additionally, two users (or groups of users) in the same geographical area may both use the same frequency band without interference by employing orthogonal polarizations (right and left circular, or horizontal and vertical). This is known as frequency reuse through polarization diversity, and is limited to a single reuse since only two orthogonal polarizations exist. Space diversity allows considerably more flexibility, being limited only by the number of individual beams implemented in the antenna and by the antenna's resulting size.

A third form of multibeam antenna needs to be recognized and distinguished from the above two; this is actually a variable-shaped beam antenna, such as proposed for the Defense Satellite Communication System (DSCS-III) program, as discussed in another session. This antenna type may be implemented as a multibeam antenna with space diversity, but differing from the above types in that the beams are interconnected to a single common port. The shape of the resulting single beam may be controlled by means of the interconnection network, thus providing two advantageous features: first, available power can be concentrated only in the areas actually in use at a given time, resulting in increased EIRP and G/T; and second, areas where interference is being experienced (jamming) can be discriminated against by forming nulls in the net antenna pattern in those directions, either by command or adaptively.

II. Types of Multibeam Antennas

Three distinct types of multibeam antennas are examined - lenses, reflectors, and arrays. Each type is discussed, their operating principles and subtypes described, and their relative merits compared.

A. Multibeam Lens Antennas

Multiple beams in space may be created by focusing the energy from a primary array of feed horns through a microwave lens. The axial symmetry of such a configuration allows low aberration for scanned beams, thus resulting in low sidelobes and cross-polarization components, which are important considerations for frequency reuse applications. Two types of lenses have been considered for microwave use.

Refractive Lenses. The classic solid dielectric lens shown in Fig. 1 was studied for multibeam use by Lockheed[1] and Hughes.[2] For a 30 dB sidelobe specification, it was shown[2] that random variations of refractive index must be controlled to within 0.8% around a nominal value of 2.0. Since lightweight low-loss materials of this uniformity were not available, no further effort was applied.

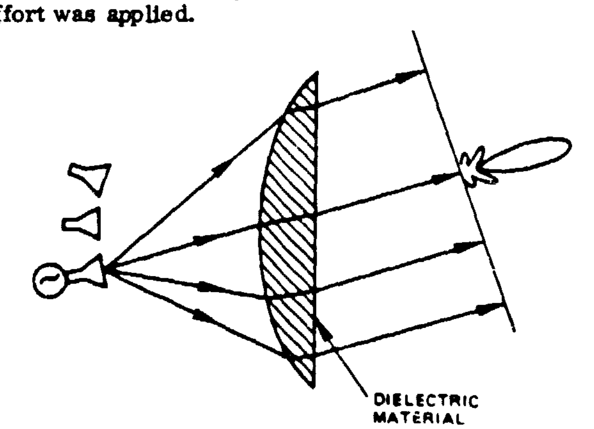


Fig. 1 Refractive Lens

Constrained Lenses. A constrained lens is a form of space-fed array, as shown in Fig. 2. A ray path through the lens is constrained to follow an RF transmission line, interconnecting small pickup and reradiating elements. Optimum low-aberration beam control

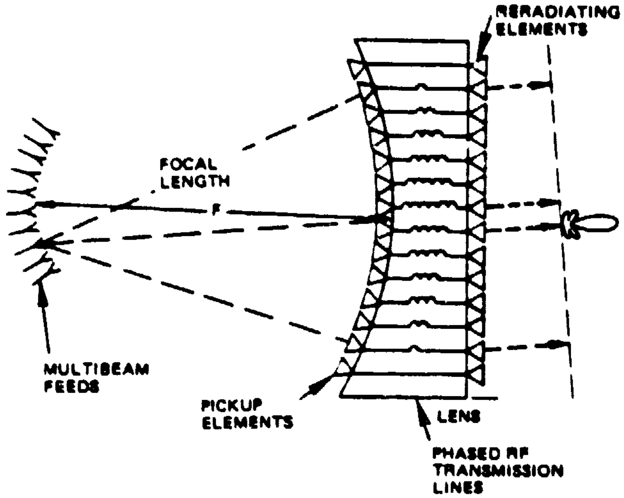


Fig. 2 Constrained Lens

is established by proper choice of line length and element positioning. Characterization of this lens type is generally in terms of the type of wave carried by the RF lines, i.e., waveguide or TEM (bootlace). The latter are non-dispersive and as such usually exhibit greater bandwidths; they may utilize coaxial, microstrip, or similar types of delay lines, generally much smaller in cross-sectional dimensions than waveguides. As a consequence, this type of interconnection allows more freedom in choosing the lens optical design to achieve minimum aberrations. The TEM lens should thus be capable of lower sidelobe performance than the waveguide, although it may be somewhat more lossy due to the dissipation in its lines.

B. Multibeam Reflector Antennas

Reflector-type multibeam antennas are potentially attractive because of their design simplicity, inherent bandwidth, ease of construction, light weight, and low cost. However, studies have shown that the usual large multibeam feed structures cause excessive blockage and consequent high sidelobe levels for all configurations except offset-fed types, such as shown in Fig. 3. These designs usually consist of a section of a larger parabola, whose focal point is located such that the feed does not block directly reflected rays from the section. Feed energy is constrained to illuminate the parabolic section, with proper amplitude taper for desired low sidelobes. Offset-fed types are less well known than symmetrically fed types (including cassegrainian), and are subject to rapid deterioration of sidelobes and cross-polarization properties for off-axis scanned beams unless special techniques are used to compensate for the usual phase errors, such as reflector shaping and dual-focus designs.

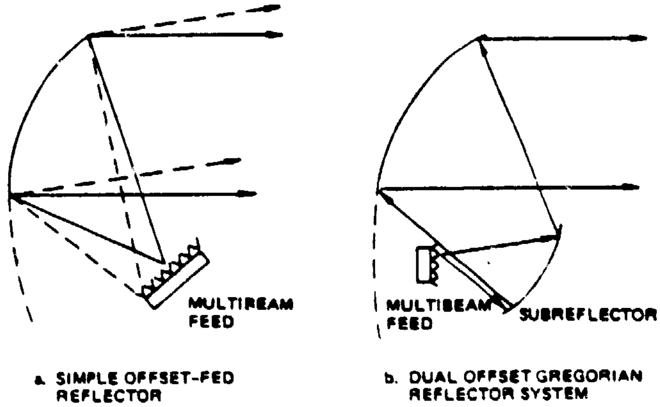


Fig. 3 Reflector Antennas

To illustrate what performance can be expected from an offset-fed reflector system, calculations were run for an 8 GHz design with a reflector diameter of 8 feet (64 wavelengths) and a focal length of 10 feet, producing a 1.3° half-power beamwidth. A parabolic amplitude taper with -28 dB edge illumination was assumed, with constant phase. Scanning was accomplished by displacing the feed from the focal point and readjusting feed orientation to maintain the same illumination pattern over the reflector. Patterns for scans up to ±10° in the plane of scan are shown in Fig. 4; patterns for

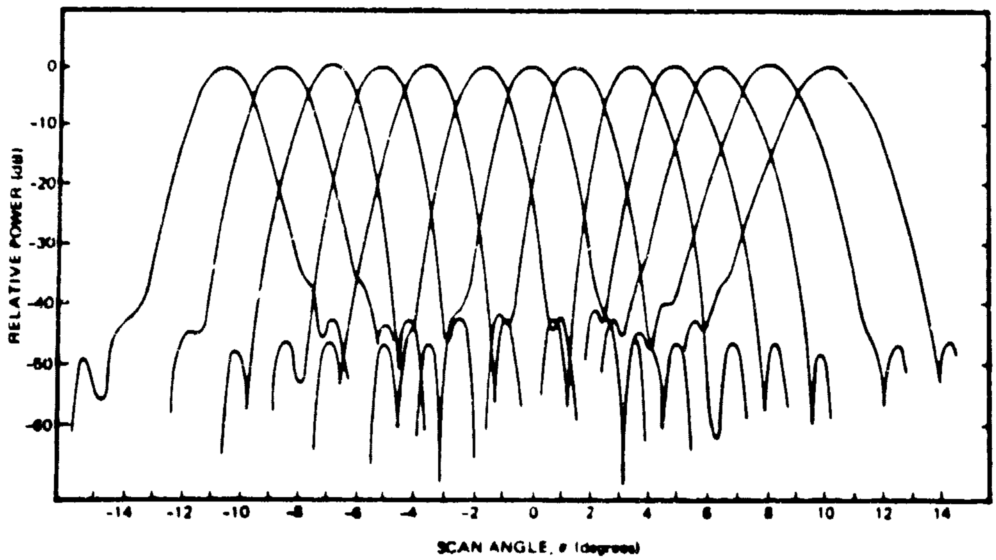
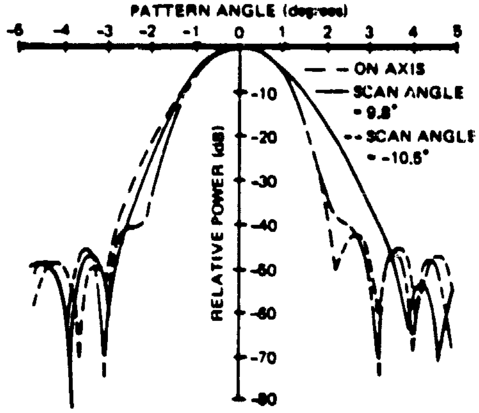
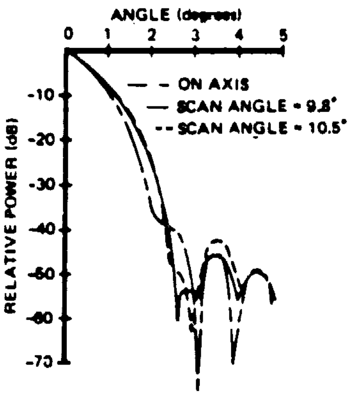


Fig. 4 Computed Vertical Plane Scan Patterns of Offset Paraboloid

orthogonal and 45° cuts through the on-axis beam, as well as those for the extreme scan positions, are shown in Fig. 5. These figures show sidelobes generally maintained below −40 dB over the entire scan range, with little change in gain, and a gradual broadening of the mainlobe for the scanned beams, as shown in Fig. 6. This broadening may actually be more harmful for frequency reuse applications than degraded sidelobes, since the broadened beam will increase the minimum spacing between beams required to maintain a given degree of isolation, which is roughly equal to the distance between nulls of the main beams.



a. 45° Plane



b. Horizontal Plane

Fig. 5 Vertical Plane Patterns for Central and Extreme Angle Scan Positions

The Gregorian dual-reflector system, shown in Fig. 3b and described by Fitzgerald,[3] represents a potential improvement in offset-fed reflector performance, since the second reflector allows an additional degree of freedom available for optimizing off-axis scanning characteristics. Two versions have been studied -- the true Gregorian with multiple individual displaced feeds, and the near-field Gregorian with a small planar array feed, which scans the secondary beam by tilting the phase front of the array feed. The advantage of the array feed is that continuous control of the scanned beam is available with a modest-sized array, whose size is reduced from the radiating aperture diameter by the ratio of the focal lengths (magnification) of the two reflectors.

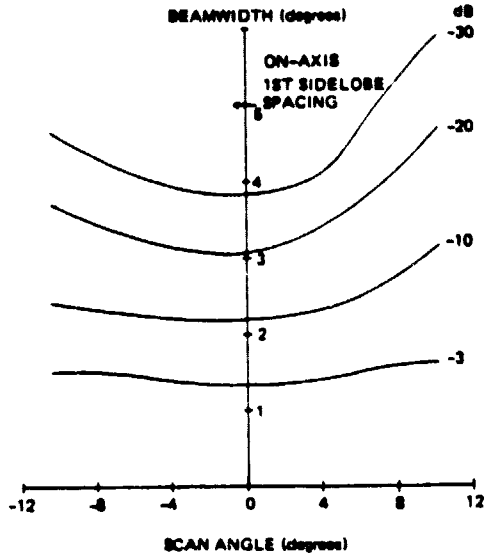


Fig. 6 Beamwidth Scan Broadening

However, this size reduction also requires the array to scan over proportionately wider limits, which becomes difficult for earth-coverage applications with any substantial degree of magnification. Furthermore, true multibeam applications (as contrasted with shaped beams) require multiple phasing networks for the array feeds, as will be mentioned in the next section. Apparently the true Gregorian system has received little study, although its potential for multiple beam use is attractive.

In the array-fed reflector each feed element separately illuminates the reflector to generate a component beam in the far field. By properly exciting feed elements, and thus summing individual component beams, a desired shaped beam may be achieved to serve a specific ground coverage area. Depending on the feed-array element, this system can be operated for any linear or circular polarization. Circular polarization (CP) is attractive for an offset reflector when polarization diversity is used since an offset parabolic reflector does not generate a cross-polarized signal when the feed has perfect CP pattern. Thus for CP beams, good polarization isolation and axial ratio can be obtained by properly designing the element and array configuration.

C. Multibeam Phased Array Antennas

A conventional planar phased array consisting of identical low-gain, uniformly spaced radiators can be adapted for multiple beam use by providing separate beam forming and steering networks for each individual beam, and combining their outputs at each array element, as depicted in Fig. 7. Separate sets of networks separated by diplexers are also required for receive and transmit; or different arrays (or array elements) can be used for the two functions. The weight and complexity of such a system increase in proportion to the number of simultaneous beams, and become a major factor against the choice of such a system for any significant number of beams. The possible use of a Butler matrix to passively form multiple beams in space from

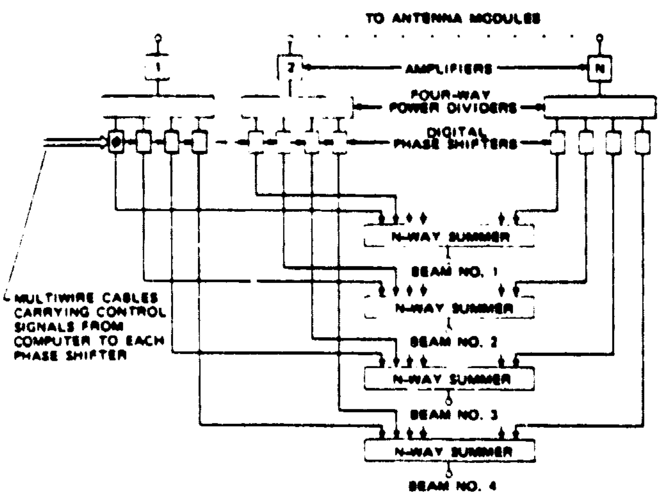


Fig. 7 Typical Multibeam Array Antenna System Schematic Using Four Active Beams

a common array seems appealing, but introduces too great a degree of inflexibility in beam positioning to be of general use.

Another factor weighing heavily against phased array multibeam transmit antennas is the need to provide individual power amplifiers at each radiating element, each of which must handle simultaneous signals from all of the multiple beams. To avoid excessive intermodulation generation, AM/PM conversion, and signal suppression effects due to the presence of the multiple signals, great care must be taken to avoid saturation within these devices, forcing them to operate in their low-efficiency linear regions. This penalizes the overall transmitter efficiency available by a factor of 5 to 10 dB, and thus further increases weight and prime power requirements severely.

As an example of the extent of such compromises, we quote a summary of the characteristics of several alternate multiple-beam phased array antennas configured by Hughes[4] for a general purpose Armed Forces satellite. The antennas were to operate at X-band (7-8 GHz), and have the ability to position 10 to 30 simultaneous beams anywhere on earth from synchronous altitude (±8.7° field of view). The number of discretely driven elements is determined by the minimum beamwidth required to avoid excessive gain loss when scanning to the edge of the earth, and meanwhile maintaining grating lobes outside the earth. This results in a maximum element spacing of about 5 inches, with the total number of elements required for a 5-foot-diameter array being around 91, and a corresponding increase to 472 for a 10-foot array. Other characteristics of these two sizes are summarized in Table 1, based on an assumed radiated power requirement of 10 W per beam, and using TWT power amplifiers with saturated power levels 10 dB greater than actually required, thus assuring linear operation. FET preamplifiers at each receive antenna element were assumed, with 20 to 30 dB gain, and 4-bit diode phase shifters consuming 0.5 W each. Totals for even the smallest 10-beam 5-foot array show an estimated weight of over 700 lb and a prime power requirement of 4.5 kW, for net radiated power of only 100 W. The design would require 910 phase shifters to form the 10 separate beams, and 91 10-watt TWT's each operating at about 10% of

Table 1. Projected Characteristics of an X-Band Multibeam Array Antenna

Parameter	Characteristics			
Array diameter, ft	5		10	
Number of elements	91		472	
Beamwidth, degrees	2		1	
Gain on axis, dB	40		46	
Maximum sidelobe, dB				
On axis	25		25	
9° scan	22		23	
Number of simultaneous beams	10	30	10	30
Weight, lb				
Transmitters	560	900	1250	2300
Receivers	28	33	120	130
BFN's	120	575	330	1640
Totals	708	1508	1700	4170
Power, kW				
Transmitters	4.0	12	4.0	12
Receivers	0.04	0.075	0.14	0.16
BFN's	0.45	1.4	2.3	7.1
Totals	4.5	13.5	6.4	19.3

rated power, with a net efficiency of only 2.5%. In contrast, a TEM waveguide lens of the same size, with a 10-beam feed network and ten 100-watt TWT's, would weigh less than 125 lb.

A more attractive use for a phased-array multibeam antenna is in producing shaped beams, rather than multiple simultaneous beams, as specified for the DSCS-III antenna. A single beam as narrow as 2° is desired anywhere on earth from synchronous altitude, or a variable pattern up to full earth coverage, with the additional ability to produce nulls within this pattern to discriminate against jammers. The phased array is well suited to this application, since it is able to produce high-gain low-sidelobe beams individually or in various combinations merely by adjusting phases over the aperture. With tapered amplitude illumination and careful phase control (typical 5° tolerances), sidelobes as low as -35 dB can be achieved.[5] Multiple phasing networks for multiple beams are not required, since only a single beam of variable shape is to be produced. The overall array size is determined by the narrowest beam desired, resulting in a 5-foot diameter for tapered low-sidelobe illumination at X-band. The number of array elements required is a function of the grating lobe condition as well as the sidelobe level and beam pointing accuracy desired. The 5-foot aperture can be filled with 91 elements, each 3 wavelengths in diameter, arranged in triangular fashion, which will maintain 30 dB sidelobes for scanning to the edge of earth, while eliminating grating lobes from the earth's field of view. Careful control of the transmit array power amplifiers on each element would still be necessary to avoid phase changes with signal levels, and consequent beam squint, but the problem would be considerably eased since multiple users in the same bands would not be present. Furthermore, at least 6-bit digital phase shifters would be necessary to achieve phase accuracies consistent with the low sidelobe requirements. The resulting design would have as much beam and null control capabilities as a 91-beam lens antenna, as shown by corresponding calculated patterns for the two cases.

III. Multibeam Antenna Applications

A. Multibeam Lenses

A true multibeam antenna for spatial frequency reuse produces many separate beams from one common aperture. Typically, 30 dB sidelobes are needed and from 5 to 10 or more beams may be desired. Use of a 7-element feed cluster is necessary to form each low-sidelobe pencil beam while retaining approximately one-beamwidth switched beam positioning resolution. The complete feed array may contain 50 to 100 feed radiators, followed by a set of 7-to-1 BFN's (beam forming networks), one for each beam port (Fig. 8). Each BFN may be switched to different sets of feed elements, if desired, thereby providing each beam with a range of pointing directions to be chosen by ground command. The excellent low-aberration optics of the TEM lens permits the excitation sets for all BFN's to be the same (invariant with beam position), thus permitting a vast simplification in ground command requirements for low-sidelobe beam pointing control.

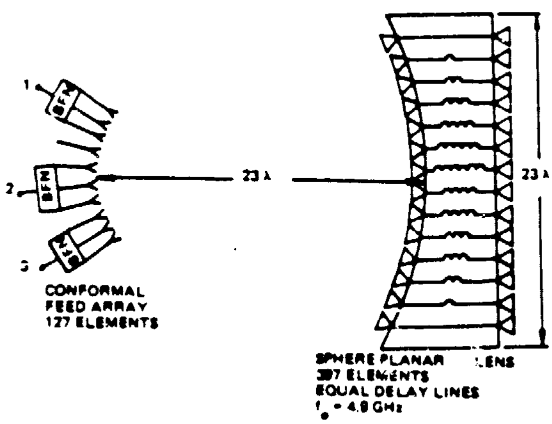


Fig. 8 Multibeam TEM Lens Diagram

Experimental TEM Lens. This application has been the focus of extensive development of low-sidelobe TEM lenses at Aeronutronic Ford. The particular TEM line lens has a spherical inner (S_1) surface and a planar outer (S_2) surface, with all interconnection lines of equal length. Such geometry provides excellent small-angle scan focusing necessary to maintain low sidelobes for all beam positions over the lens FOV (field of view). The use of RF printed circuit techniques (such as open microstrip) for interconnecting lines offers the advantages of low weight (thin PC cards), high reliability (no connectors), and ease of quantity precision production (photo-etching).

The preliminary design of such a lens for simultaneous 4 and 6 GHz operation (Fig. 9) has been described previously.[6] Each triad (consisting of one S_1 radiator, one microstrip line, and the corresponding S_2 radiator) is photoetched onto the two sides of a thin (0.020 inch thick) flat copper-clad dielectric card. Each card is mated with a second orthogonal card into a crossed-card configuration so as to produce lens operation independent of polarization. A collection of such card pairs is mounted through slots in a pair of circular metallic sheets (the S_2 sheet being planar and the S_1 sheet spherical) so that each radiator protrudes "outward" beyond its respective sheet, which acts as a ground plane for the radiators. In effect, the S_1 and S_2 sheets are slotted racks serving to hold card pairs in a circular array matrix. This collection of cards and conducting sheets is the TEM lens (Fig. 9).

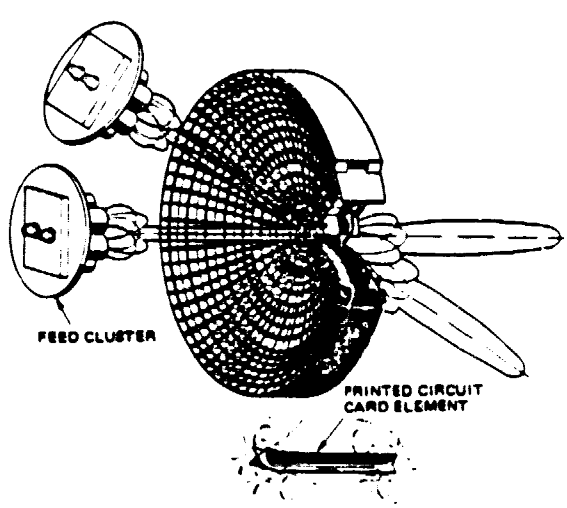


Fig. 9 Printed Circuit Card, TEM Lens, and Feed Clusters

The feed array was designed to consist of small radiators in a nearly triangular lattice on a spherical focal scan surface. To produce each low-sidelobe pencil beam, a symmetrical cluster of feed elements was driven as an array, using 7 elements at 6 GHz and 13 elements at 4 GHz (Fig. 10). A computerized synthesis technique was developed to calculate optimized phase and amplitude excitation coefficients of the individual clusters.[7]

An electrical test model of this antenna was constructed for experimental pattern testing at C-band (Fig. 11). This model has a diameter of 5 feet, as well as a 5-foot focal length, and uses 396 card pairs in the TEM lens. It includes a 19-element linearly polarized feed cluster on a mechanical mount that permits positioning the cluster to any position within the earth coverage FOV. Either a 7-way (6 GHz band) or 13-way (4 GHz band) power divider could be connected to the 19-element feed cluster for tests, with unconnected elements terminated in matched loads.

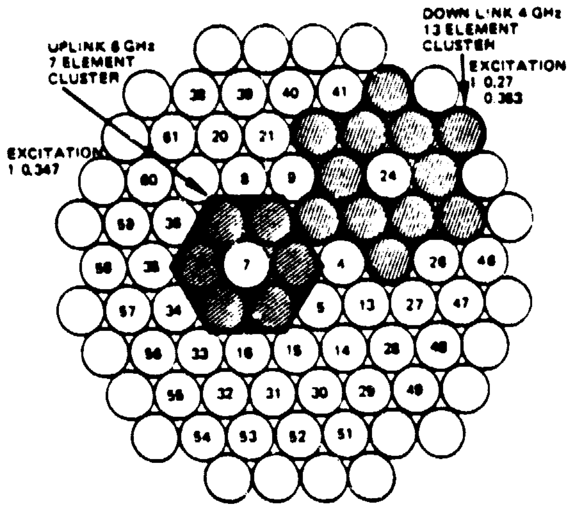


Fig. 10 Feed Cluster Geometry for TEM Lens

Figure 12 shows an H-plane (relative to feed cluster polarization) secondary pattern measured at 4.9 GHz with a single on-axis feed element energized to produce a basic singlet pattern of the lens. Also shown is a calculated pattern for this case, with good agreement. Figure 13 shows similar patterns using a 7-element cluster feed with the synthesized excitations for low sidelobes. For beam positions over the earth's FOV (0 to 8.6° scan), the on-earth sidelobes remained below -30 dB.

Subsequent tests verified wideband performance and indicated that smaller lens elements would be necessary to achieve best efficiency for both transmit (3.7 to 4.2 GHz) and receive (5.9 to 6.4 GHz) operation in the one multibeam antenna. Currently, such smaller elements are being developed via active impedance measurement subarray techniques.

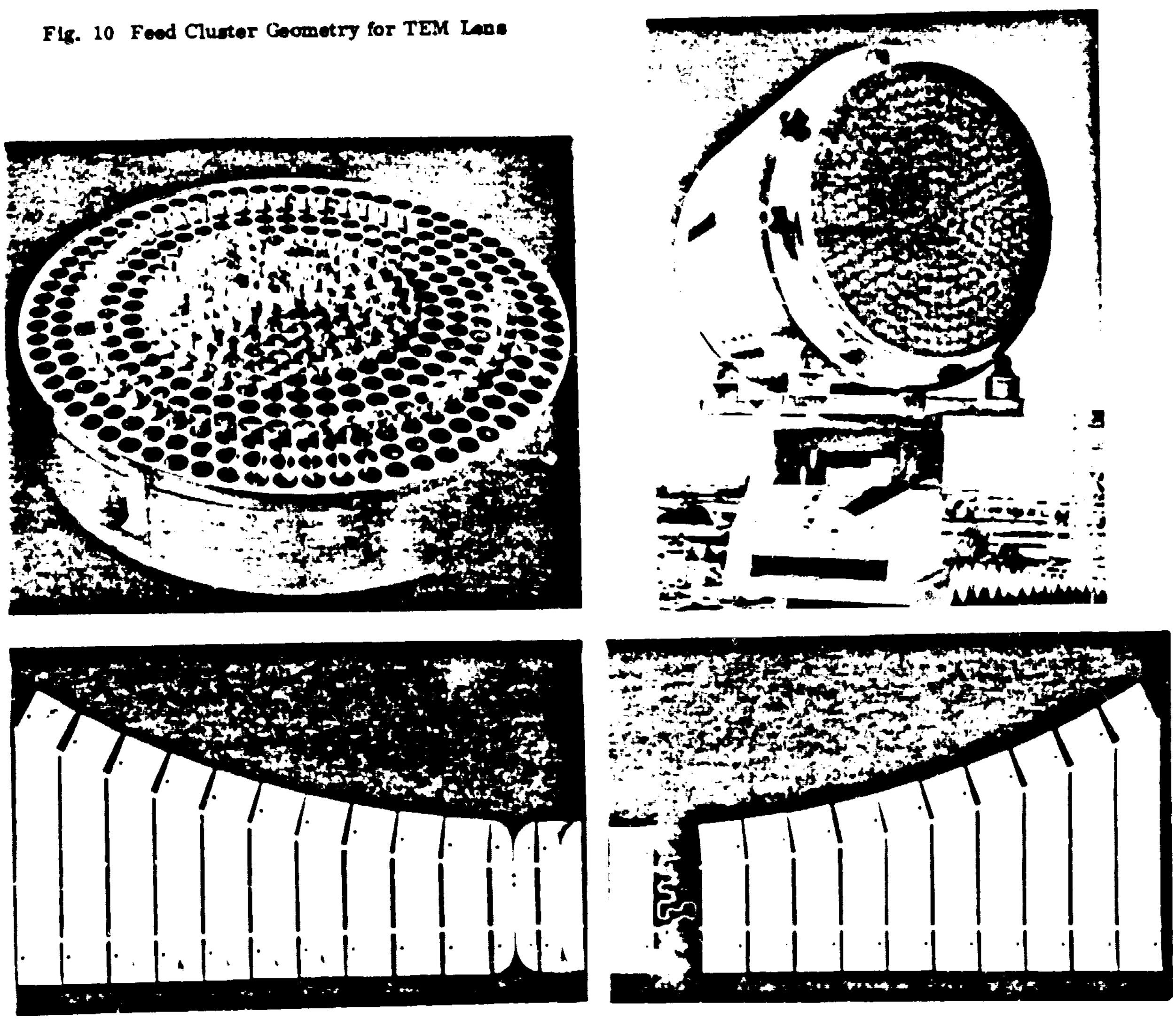


Fig. 11 TEM Lens Model

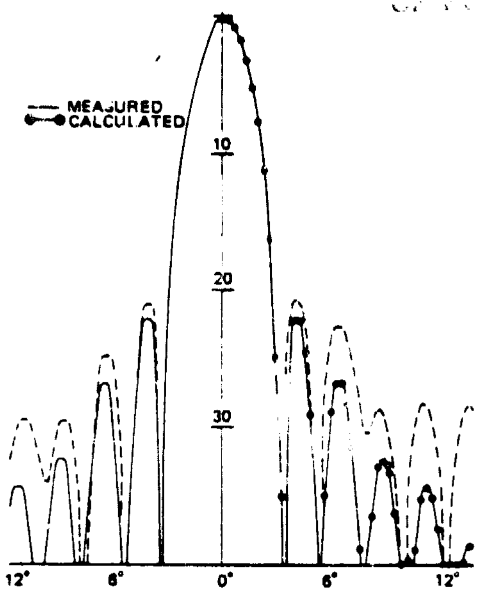


Fig. 12 Measured vs Calculated 4.9 GHz Pattern of TEM Lens with Single Element Feed

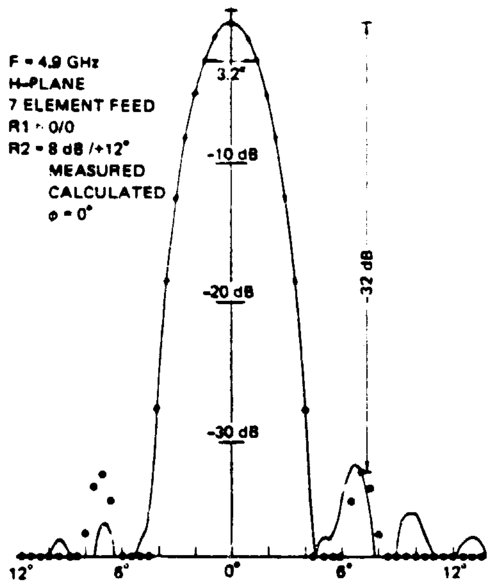


Fig. 13 Measured vs Calculated 4.9 GHz Pattern of TEM Lens with 7-Element Feed Cluster (On-Axis)

TEM Lens Beam Isolation Characteristics. In order to explore the system capabilities of the TEM lens antenna, a computer-calculated design was devised, providing the capability of generating 61 low-sidelobe dual-polarized beams over a 17° FOV at both 4 and 6 GHz. The general requirements of isolation between beams, as well as the total coverage provided by the beams, invoke certain restrictions in the design of a multibeam antenna. These generally fall into the following areas:

a. Antenna beamwidths and beam separation angles must be chosen to provide the required isolation as well as coverage.

b. Characteristics of the individual beams, including both beam shape and sidelobe levels, must be properly selected. Sidelobe levels of at least -35 dB are generally required, while a steep falloff of the main beam allows closer spacing of individual beams without interference.

c. Use of polarization diversity requires (for CP) that axial ratios of the individual beams be maintained under 0.5 dB to prevent excessive leakage into the cross-polarized channel.

d. Feed networks that provide excitations for individual beams to achieve the desired shapes and low sidelobes, as well as necessary switching, should be as simple as possible to avoid excessive losses.

Limits on interbeam isolation may be established by any of the following coupling criteria: (1) main beam coupling, (2) sidelobe levels, or (3) cross-polarized levels. These levels must ordinarily be below the desired isolation level between beams, over the entire coverage area of each beam, with sufficient margin to allow for all contributions to the total isolation from other beams. The minimum beam separation to meet typical isolation requirements is usually established by the null-to-null beamwidth of the downlink (broader) beam.

After extensive study of calculated patterns, it was established that a maximum of six beams of the available 61 dual-polarized beams could be excited simultaneously while maintaining an isolation of 27 dB between beams, for a total of 12 times frequency reuse.[8]

B. Variable-Shaped Beam Lenses

An alternate use of a multibeam antenna lies in combining all beams through a ground-controlled RF variable power combiner (or variable power divider),[9] thus producing a single composite beam whose shape may be varied from a single narrow pencil beam to a much wider, flattop composite of up to N beams. N is usually chosen so that the widest flattop conical beam provides full coverage of the earth. Another feature of the variable beam concept is the ability to control the BFN so that a narrow null is placed in a previously established broad coverage beam in the direction of a discrete source of strong interference, thereby improving an otherwise unacceptable signal-to-noise ratio. Both waveguide and TEM lenses have been considered for the variable beam application.

LES-7 Lens. Dion and Ricardi[10] of MIT's Lincoln Laboratory have developed a laboratory model variable beam antenna using a 30-inch-diameter stepped waveguide lens with a 19-horn feed array and a BFN tree of two-to-one ferrite waveguide variable power combiners. They have developed a scalar computer program[11] for calculating radiation patterns of this lens, and have studied application of up to 61-element feed arrays with lens diameters up to 50 inches at X-band.[12, 13]

The 30-inch-diameter lens model is illustrated in Fig. 14 consisting of over 700 square waveguide cells with one ring step in its outer surface. The 19-element linearly polarized feed array is mounted on

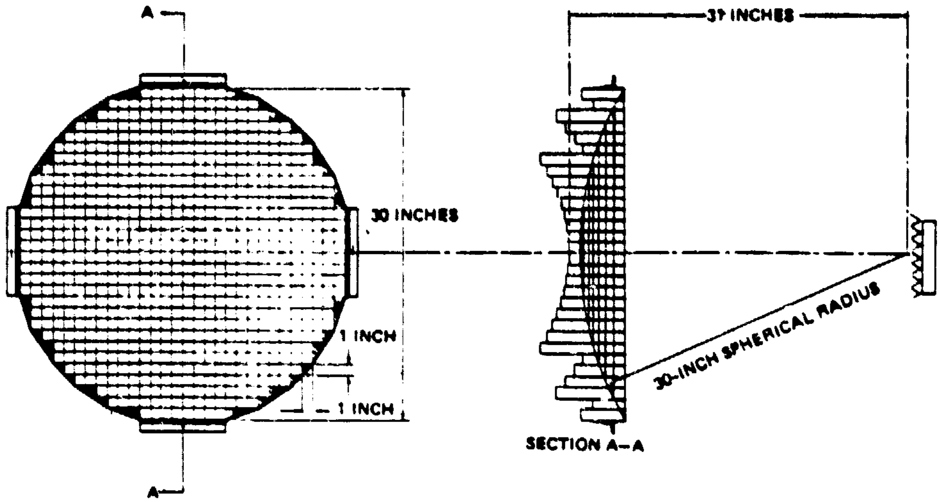


Fig. 14 LES-7 Experimental Waveguide Lens Antenna Design

a flat surface centered at the lens focal point (f/D = 1). Figure 15 shows a set of five singlet beams, each produced by separate excitation of one feed horn at a time. Figure 16 shows the composite earth coverage pattern obtained by uniform coherent excitation of all 19 feeds. Figure 17 shows a typical compound coverage contour pattern obtained by excitation of four horns, illustrating the wide flexibility of this concept.

Figure 18 shows a measured earth coverage contour pattern plot with one feed turned off so as to create a narrow deep interference rejection null. The dashed contours are the calculated -6 dB and -12 dB contours for comparison. The dotted area has a null depth of 15 dB or greater. A similar result is obtained when two adjacent feeds are turned off (Fig. 19).

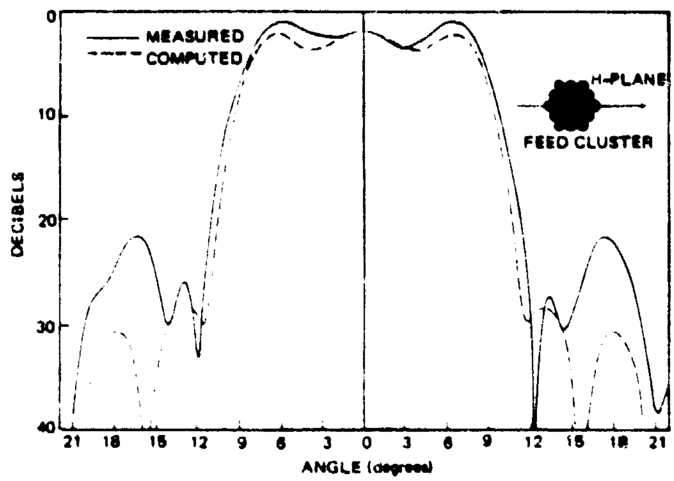


Fig. 16 Earth-Coverage Patterns at Design Frequency

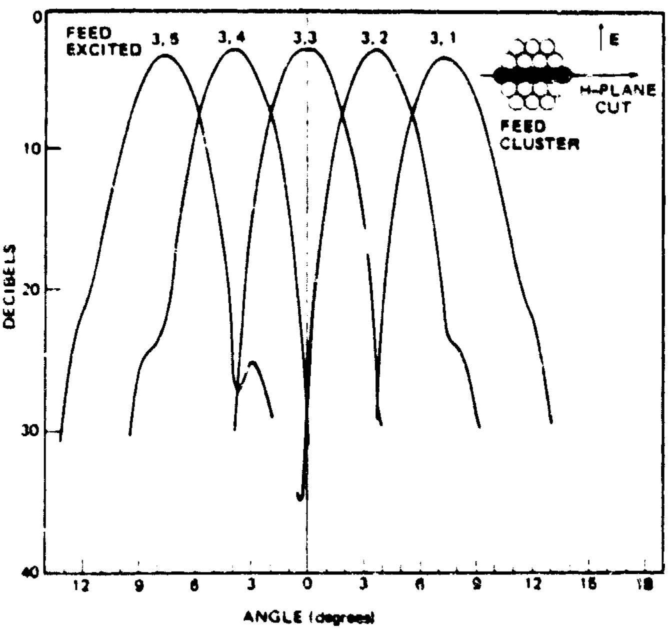


Fig. 15 Superimposed H-Plane Patterns of Center Row Beams Measured at Design Frequency

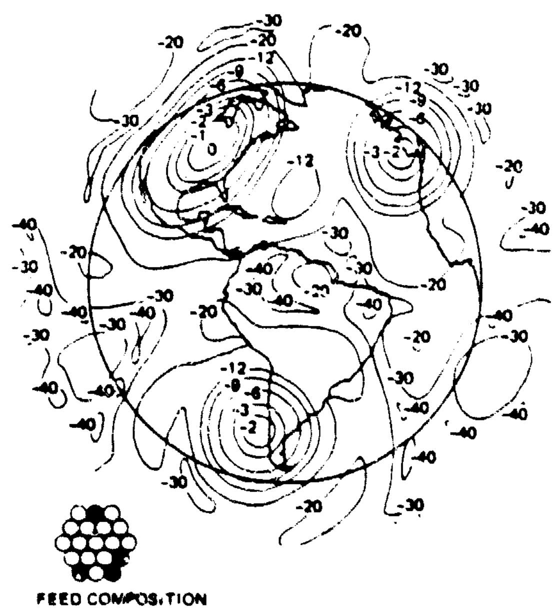


Fig. 17 Compound Coverage Contour Pattern (Measurements in Decibels)

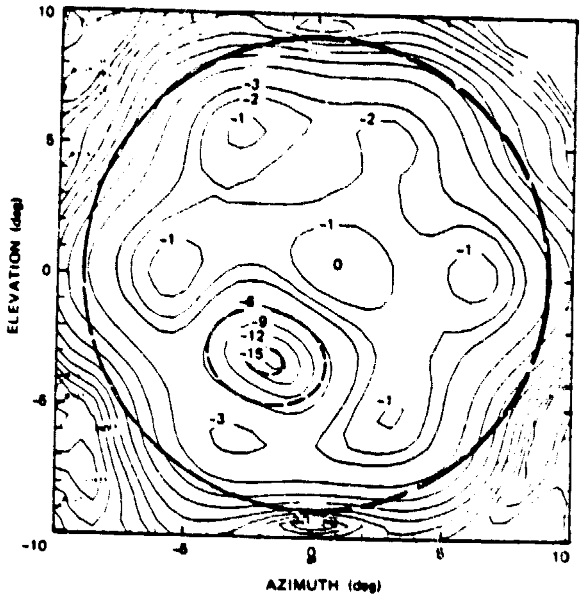


Fig. 18 Measured Earth-Coverage Contour With Feed 22 Off

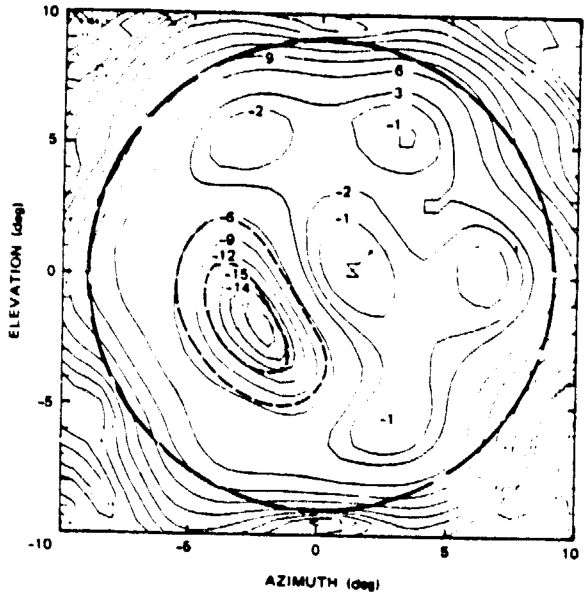


Fig. 19 Measured Earth-Coverage Contour With Feeds 22 and 32 Off

Recent Experimental Waveguide Lenses. Modifications of the Dion and Ricardi waveguide lens have been designed and constructed by Lockheed (48 inch diameter) and by Aeronutronic Ford (46 inch diameter), wherein model antennas with 61 circularly polarized feed elements have been tested. In the Aeronutronic Ford antenna, the lens is a matrix of square hollow metallic waveguides forming a metallic "eggcrate" structure. S_1 is spherical, with the sphere centered at the lens focal point (f/D = 1) as in the TEM lens. S_2 is elliptical, with three ring steps (setbacks) to prevent excessive lens edge thickness and unacceptably narrow frequency bandwidth. The usable bandwidth of the stepped lens is about 5% to 10%. This X-band design has 1528 waveguide cells arranged in a square grid. The 46-inch-diameter lens produces a 2° half-power pencil beam that may be positioned over an 18° conical FOV. It exhibits 20 dB sidelobes for singlet beam excitation.

For experimental testing the feed array for this antenna was excited from a 61-to-1 variable BFN formed of variable power dividers, attenuators, and phase shifters. The test model is illustrated in Fig. 20. The feed array is positioned on a spherical surface (Fig. 21) for simplifying shaped beam excitations (no phase corrections are needed for off-axis beams, in contrast to requirements for a flat array). Figure 22 shows the measured circularly polarized patterns of five adjacent beams, energized and measured one at a time.

Figure 23 shows a right hand circularly polarized (RHCP) measurement of the on-axis singlet beam at midband. Main beam axial ratio remained below 1.5 dB for all positions over a bandwidth of 5.5%.

Figure 24 illustrates measured beam scanning between adjacent singlet positions by gradual change of the BFN feeding the two beam feeds. Figure 25 shows the measured RHCP earth coverage pattern with all 61 feeds equally excited. Axial ratio remained below 1.5 dB

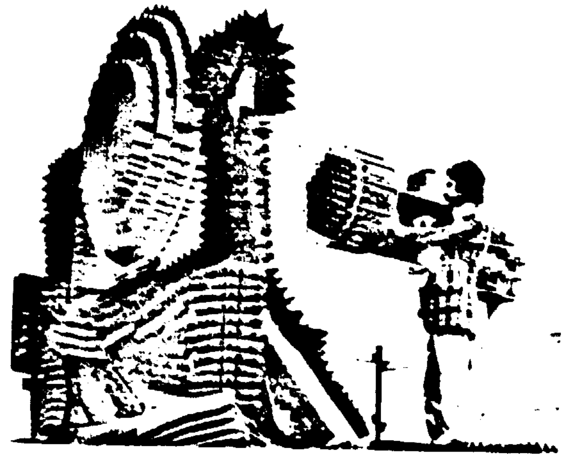


Fig. 20 Multiple Beam Waveguide Lens Antenna

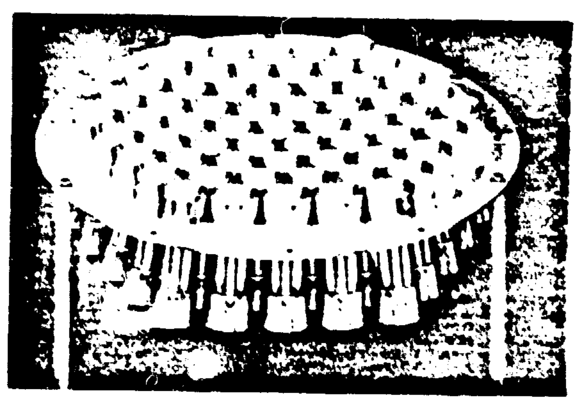


Fig. 21 61-Element Spherical Feed Array

OF POOR QUALITY

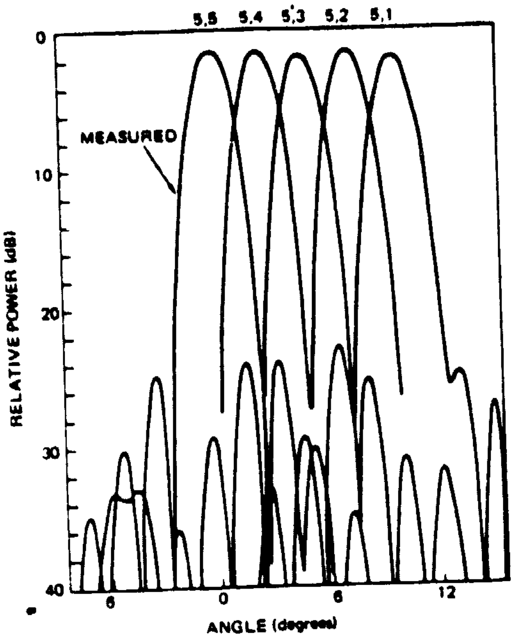


Fig. 22 Adjacent Scanned Beam Patterns, f_o, RHCP

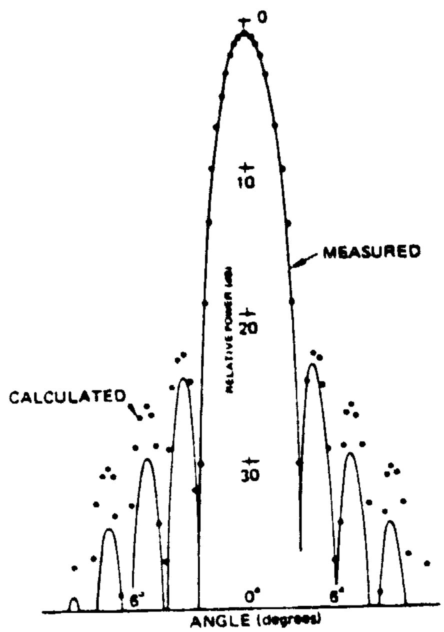


Fig. 23 Singlet Beam Pattern, Central Beam, f_o, RHCP, $\phi = 0°$

across the 5.5% band for this case. The insertion of a deep null into the earth coverage beam was accomplished by phase reversal and appropriate amplitude control of one feed (Figs. 26 and 27). For the simple turnoff and subtraction null techniques, the null bandwidth was found to be small (due primarily to the dispersive lens defocusing phenomena), about 1% for a -20 dB null.

A 30-inch-diameter, 19-beam transmit antenna similar to the Lincoln Labs model was constructed by Lockheed for initial evaluations of the antenna and its control network. More recently, Lockheed built a 48-inch-diameter receive lens, with 61 feeds and a number of design

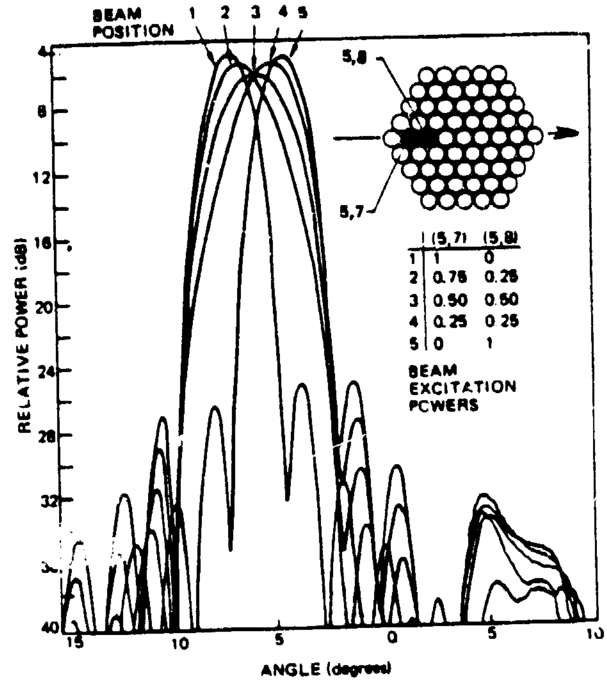


Fig. 24 Scanned Doublet Beam Pattern, (5,7), (5,8), f_o, RHCP, $\phi = 0°$

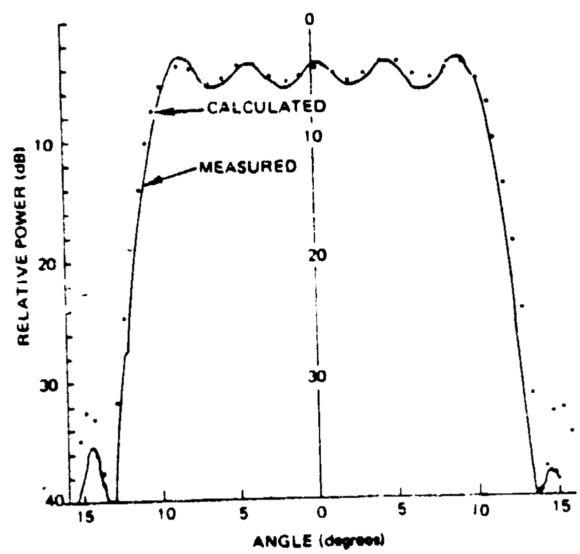
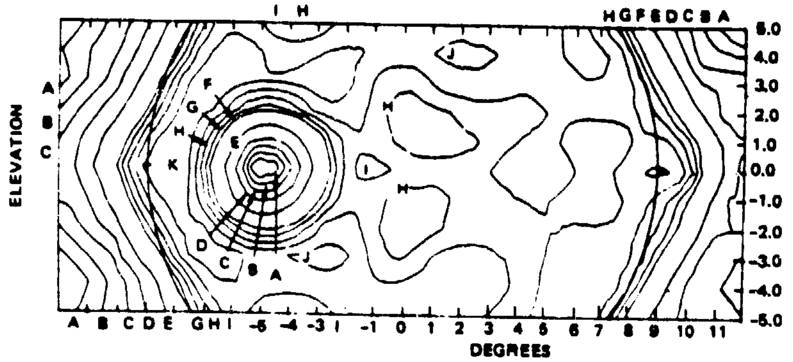


Fig. 25 Earth Coverage Beam Pattern, 61 Feeds, Equal Excitation, f_o, RHCP, $\phi = 45°$

optimizations. This lens employs more than 2200 waveguide elements in a two-zone configuration. Although no measured data have been published, results are reported to have been excellent.[14]

One major advantage of using a waveguide lens is the ability to employ unique manufacturing techniques that greatly reduce the weight tolerances required to build a structure that can withstand space applications with no degradation of electrical properties. A considerable amount of research has been done on the use of a variety of carbon-composite structures in forming very strong but lightweight square waveguides.



CONTOUR DATA

SYMBOL	dB
A	-30.00
B	-25.00
C	-20.00
D	-15.00
E	-10.00
F	-5.00
G	-4.00
H	-3.00
I	-2.00
J	-1.00
K	0.00

Fig. 26 Earth Coverage Null, Singlet Beam (5,7) Subtraction Digitized Contour Plot, Measured at f_0, RHCP

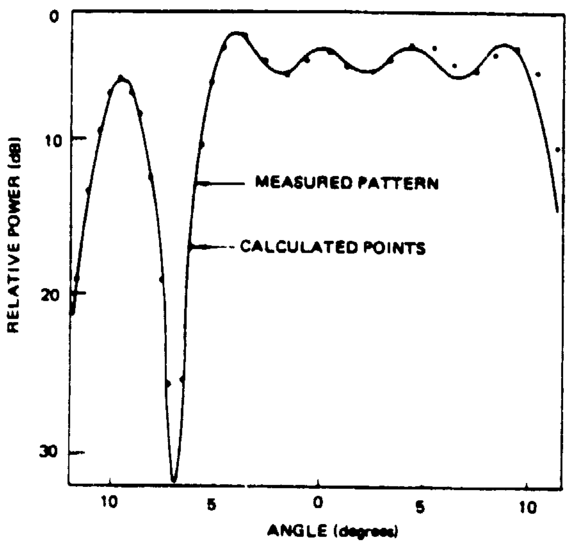


Fig. 27 Earth Coverage Null, Singlet Null Beam Pattern, (5,8), f_0, RHCP

Lockheed also reports development of a unique power divider assembly and beam-forming network which greatly reduces the number of levels required in the network, thus reducing beam-forming network loss while providing a much greater degree of precision in the setting of power at individual beam ports.

Variable-shaped beam lens antennas are currently under investigation by two contractors (Hughes and General Electric) for the Air Force (SAMSO) as part of contract definition studies for DSCS-III.

TEM Variable Beam Lens. An application of a TEM lens to the variable beam concept was studied by Binz and Waineo.[15] The lens was formed of multiple flat sheets of layered form and printed circuit boards, each board containing a row of many balanced stripline delay lines, pickup, and reradiator dipoles. Single-sense circular polarization is achieved from this linearly polarized lens by placing a form of sheet polarizer over the lens aperture, which converts linear to circular polarization. Four-percent-bandwidth waveguide polarizers based on ferrite faraday rotators were proposed for use in the 64-to-1 BFN. A feature of this lens was the calculated 30 dB sidelobe level performance of the pencil beam formed from a properly excited cluster of feed elements. No test model has been reported.

C. Multibeam Reflector Antennas

Symmetrical Six-beam K-Band Model. Since aberrations due to offset-fed reflectors generally increase as the number of beamwidths of scan increase, it is especially attractive to utilize a symmetrical feed structure for higher-frequency narrow beam applications, such as a domestic satellite system. If the number of simultaneous beams is limited, feed structure blockage may be tolerable without producing excessive sidelobes. Turrin[16] has proposed a novel structure to minimize such blockage by extending the feed horns through holes in an auxiliary plane reflector, thus eliminating most of the support and feed network structures from the blockage region. His design was for a spherical reflector accommodating six simultaneous beams, pointing within a 13° area (to cover ground stations from Hawaii to Puerto Rico), for use at both 20 and 30 GHz. The basic antenna layout is shown in Fig. 28, with feed

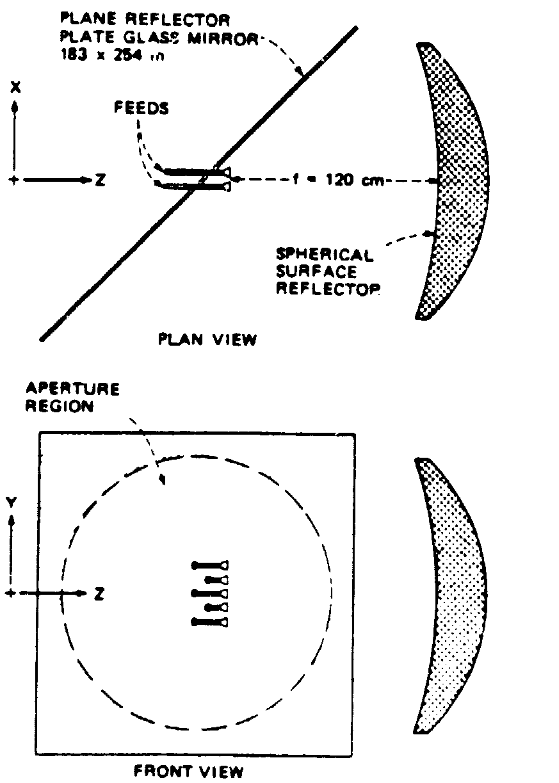


Fig. 28 Multibeam Spherical/Planar Reflector

locations as in Fig. 29. Orthogonal linear polarizations were used for the two bands, obtained from a novel finned feed horn design. A 5-foot-diameter (150 cm) model was built and tested. Beamwidths of approximately 0.7° were obtained in both bands, principally because of different feed illumination tapers. Measured gain and first-sidelobe levels are shown in Fig. 30 as a function of beam pointing direction off-axis; on-axis gains were 47.0 dB at 19 GHz and 49.2 dB at 30.2 GHz, some 3 to 4 dB below theoretical maxima for a 5-foot aperture. Isolation between beams was more than 28 dB, except for two adjacent co-polarized beams designed to cover New York and Atlanta, only 1.3° apart, where isolation was 24 to 26 dB.

INTELSAT IV-A Antenna. The most representative multibeam antennas in use today are of the offset-fed reflector type as employed on the INTELSAT IV-A, the

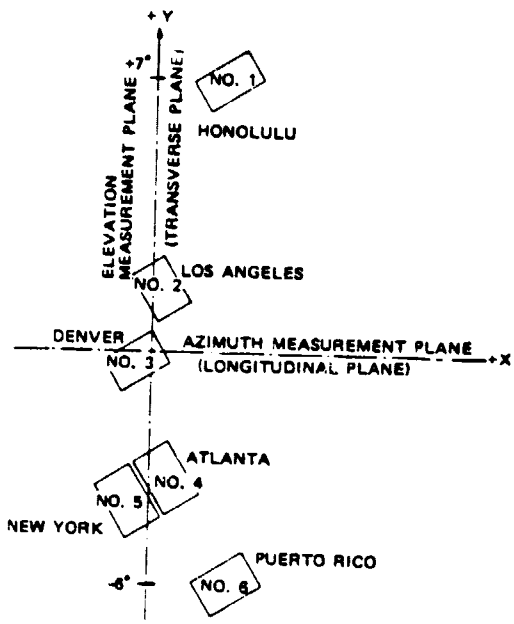


Fig. 29 Feed Horn Positions

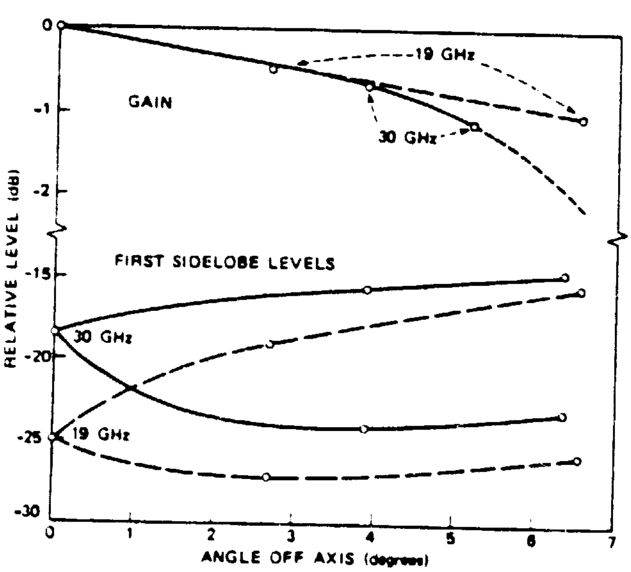


Fig. 30 Single-feed Measurements of Off-axis Performance

second of the INTELSAT IV series of communication satellites. Increased channel capacity in the IV-A is achieved by reuse of the 500 MHz bands at both 4 and 6 GHz by means of antenna beamshaping, which produces two spatially isolated beams covering eastern and western hemispherical areas, as depicted in Fig. 31.[17] Both Atlantic and Pacific regions are shown, with coverage areas determined by locations of INTELSAT ground stations. Reduced coverage is also required at secondary regions shown as rectangles. The 6 GHz receive beams (LHCP) each cover an entire hemisphere. The 4 GHz transmit beams (RHCP) are further divided into northern and southern quadrants, which are individually available for even- or odd-numbered channels on command.

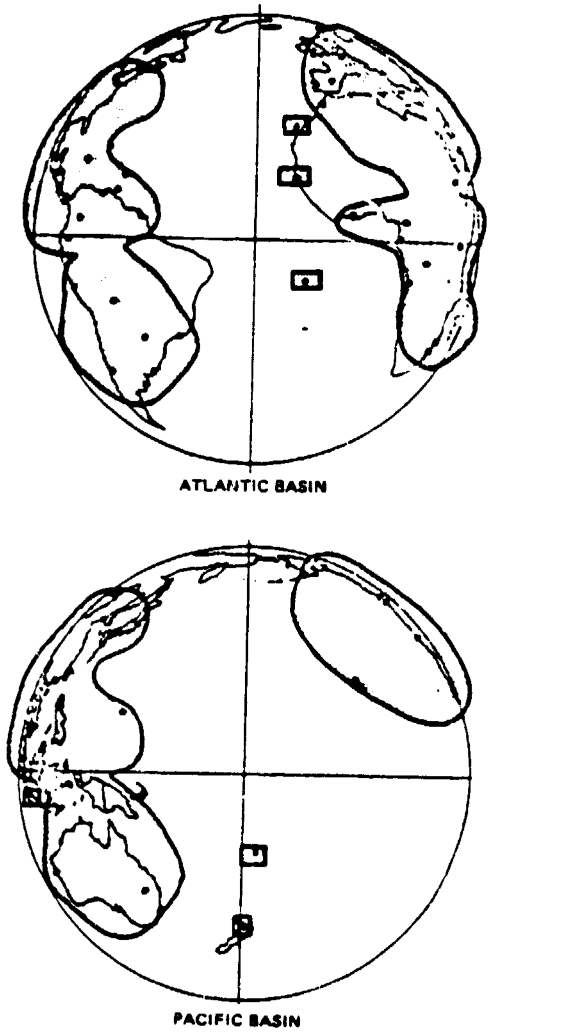


Fig. 31 INTELSAT IV-A Shaped Beam Coverage

The general arrangement of antenna hardware on the IV-A spacecraft mast is shown in Fig. 32. The two 53-inch-square parabolic reflectors at the base of the mast form the even-odd north-south transmit beams, while the east-west beams are provided by separate sets of feeds for each reflector. The shaped-beam receive reflector is located above the two transmit structures. A biconical global-coverage antenna appears at the tip of the mast. Performance characteristics of the antenna system are summarized in Table 2, as extracted from the Hughes report.[17]

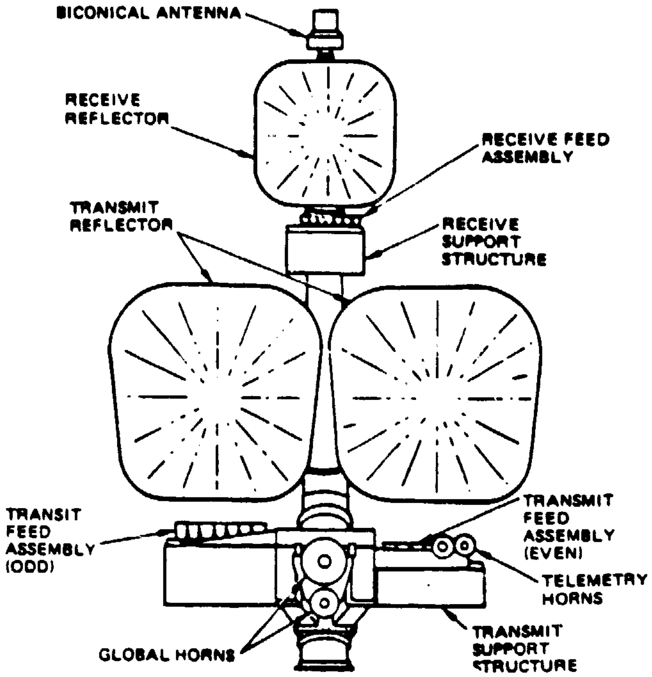


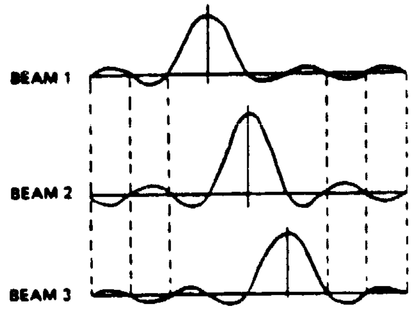
Fig. 32 General Arrangement of Antenna Hardware, INTELSAT IV-A

Table 2. INTELSAT IV-A Antenna Performance Characteristics

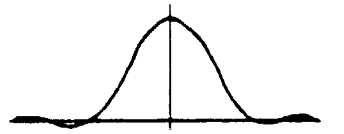
Coverage:	All stations plus major land mass in Atlantic and Pacific basins (Fig. 31)
Frequencies:	Receive 5932 to 6378 MHz Transmit 3707 to 4153 MHz
Polarization:	LHCP on receive RHCP on transmit Ellipticity $\leq$ 3 dB
Gain:	Receive 22 dB Transmit 24 dB (sector) 21 dB (T mode)
Sidelobe level:	C/I $\leq$ 27 dB
Slope:	$\leq$ 3 dB/degree

The two dominant features of the shaped-beam antenna are the multihorn feed array and the highly offset square reflectors. Both features contribute to achieving the required sidelobe isolation. A feed horn located at the focal point of a parabolic reflector produces a secondary pattern coincident with the antenna boresight. An identical feed horizontally displaced from the focal point produces a secondary pattern displaced in azimuth from the boresight. If the reflector f/D ratio is sufficiently large, these two secondary patterns will have very similar shapes.

Three such feed horns, horizontally arrayed about the focal point, will thus produce three secondary patterns staggered in azimuth about the antenna boresight. If the relative beam displacement is equal to the nominal sidelobe width, the beam arrangement shown in Fig. 33 will be realized. In this configuration, the sidelobes of beams 1 and 3 are in phase with each other but are 180° out of phase with sidelobes of the middle beam. This sidelobe cancellation can be maximized, yielding the pattern shown in Fig. 33b, if the outer beams are reduced in amplitude relative to the center beam. This reduction can be accomplished by a feed network power splitter which provides the required unequal power levels to the feed horns.



a. Component Beams for Three Adjacent Feed Horns



b. Composite Shaped Beam

Fig. 33 Shaped Beam Superposition Concept

The particular arrangement shown in Fig. 33 is a case of three horns with a symmetric power distribution. For applications such as INTELSAT IV-A, where sidelobes on only one side of the main beam need be low, asymmetric power distributions may be used. The number of horns may also be varied so long as the power distribution is reoptimized for each case. The result is a series of two-horn, three-horn, and four-horn arrays, each with low sidelobe properties but different beamwidths. Several such arrays can be stacked vertically to achieve the coverage requirements of INTELSAT IV-A, yet still retain sidelobe performance in the azimuth direction.

The reflector associated with this feed network is also designed to enhance sidelobe performance. A focal length of 50 inches was selected to minimize phase errors and maximize sidelobe performance. In addition, sidelobes produced by aperture blockage are eliminated by using a highly offset parabolic reflector with the bottom edge of the reflector located 12 inches above the focal axis. Finally, the reflector cross section is designed to be nearly square. This arrangement minimizes sidelobe interference between the NW and SE and the NE and SW portions of the coverage regions.

A typical feed-horn array for the odd-channel transmit antenna consists of 37 horns with integral polarizers (Fig. 34). This array is energized by quadrants from a TEM transmission line power division network.

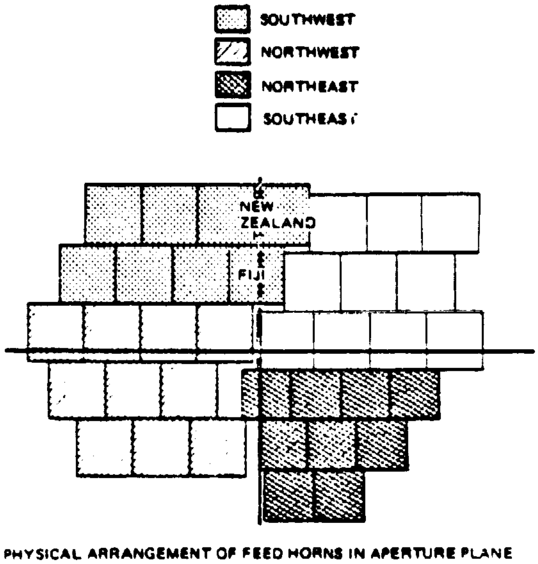


Fig. 34 INTELSAT IV-A Odd-Channel Transmit Antenna Feed System

INTELSAT V Antenna. The INTELSAT V requirements are similar to those of INTELSAT IV-A except that polarization diversity is also required to provide simultaneous coverage of two overlapping regions in each hemisphere. A configuration common to the Atlantic, Pacific, and Indian Ocean theaters is desired, with a minimum amount of switching in the feed networks to accommodate differences between areas. Steerable spot beams for the 11/14 GHz bands are also required. This satellite is scheduled for development for delivery in 1979.

Offset-fed reflectors are also being considered for INTELSAT V, with considerably tighter control of individual shaped beams necessary to maintain low axial ratios (under 0.75 dB) to achieve at least 27 dB isolation between beams. Aeronutronic Ford has built a 9 GHz (3 ft diameter) scale model of this C-band antenna (Fig. 35). Phase and amplitudes for the 48-horn feed array shown were determined by computer optimization to yield the desired coverage pattern.[18]

A measured contour plot of the Western Hemisphere beam from this model is shown in Fig. 36a for the principal RHCP polarization; ground stations to be covered are indicated by "+" signs (representing the Indian Ocean area). Pattern shaping to conform to this desired coverage area is evident, as are the low sidelobe levels in the Eastern Hemisphere (affording at least 27 dB isolation from the Eastern Hemisphere beam). A measured cross-polarized (LHCP) radiation contour plot of the same beam is given in Fig. 36b; the reference level for this plot is 30 dB below that of the principal-polarized plot. Results show that axial ratios in the Western Hemisphere coverage area are below the desired 0.75 dB.

Similar results have been reported by TRW[19] in which a 60-inch offset-fed reflector with a 45-element feed was tested at 4 GHz. Dual circularly-polarized cup-dipole feed elements were used because of their inherent low axial ratios and because of their adjustability to compensate for mutual coupling in an array environment, as

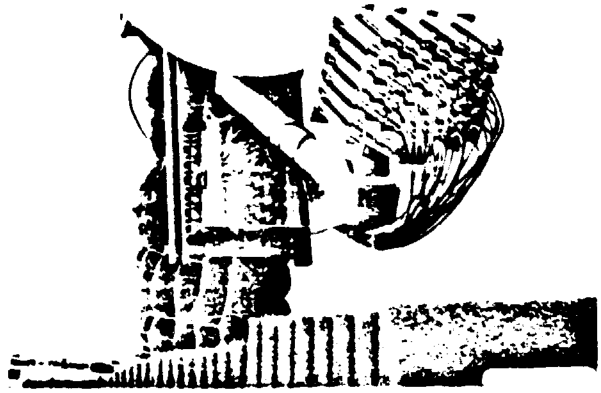


Fig. 35 Antenna Assembly on Test Range

determined by near-field testing. Calculated and measured hemispherical beam contour patterns by TRW show remarkably good agreement, good sidelobes, and low cross-polarized levels.

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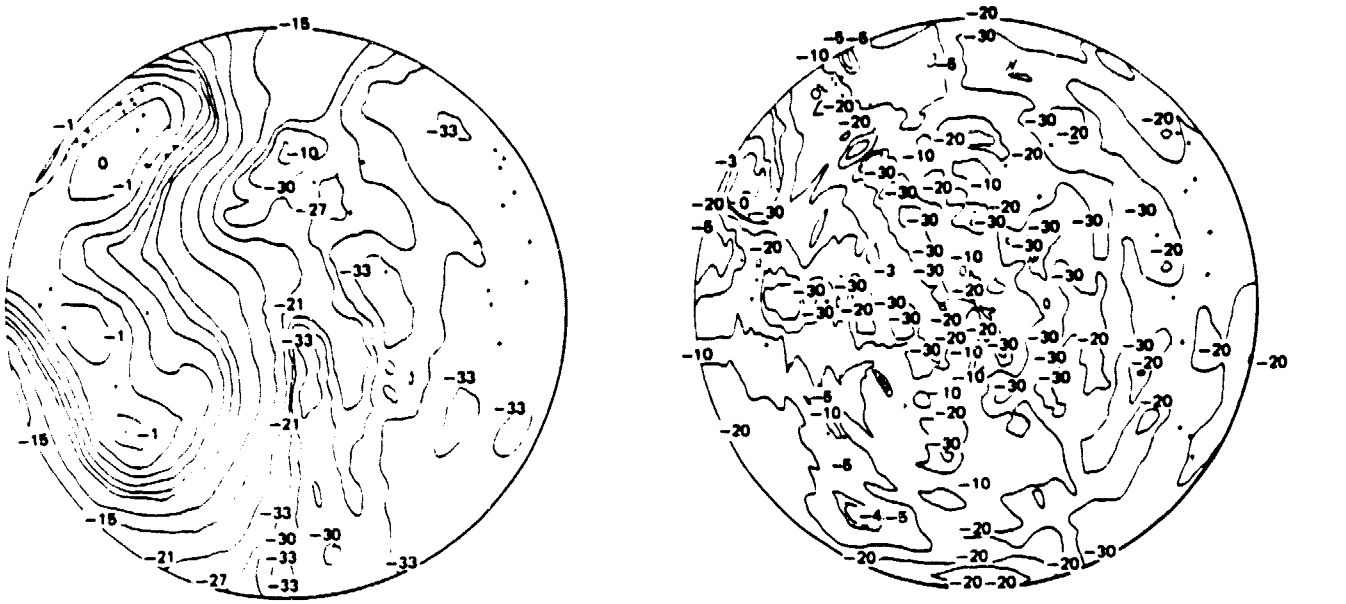

a. Principal Polarization

b. Cross Polarization

Fig. 36. Contour Data (Frequency = 9.54 GHz)

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APPENDIX C

INTELSAT V SPACECRAFT DESIGN SUMMARY

78-528

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Abstract

This paper describes the technical aspects of the Ford Aerospace & Communications Corporation's current design of INTELSAT V, the largest commercial communications satellite ever designed and built for the International Telecommunications Satellite Organization (INTELSAT). The spacecraft system design concept is described, with emphasis on the key technologies utilized to configure the total spacecraft. Key systems aspects include a design summary with discussion of the communications, controls, telemetry, command and ranging, power, propulsion, and thermal subsystems as well as spacecraft-peculiar operational characteristics. Key technologies include use of graphite-fiber-reinforced plastic, contiguous band output multipliers, dual-polarization multiple-shaped antennas, dual-collector 11 GHz traveling wave tubes, and electrothermal thrusters.

Spacecraft Design Summary

The INTELSAT V spacecraft is a high-capacity, commercial communications satellite. Each satellite will be a radio-frequency relay, the space links in the vast INTELSAT communications network. INTELSAT spacecraft growth is illustrated in Fig. 1. As many as 6 INTELSAT V satellites will be operated simultaneously to interconnect more than 300 INTELSAT earth terminals. Depending on the operational configuration employed at INTELSAT, each satellite will carry up to 12,000 two-way telephone circuits and two color-television transmissions.

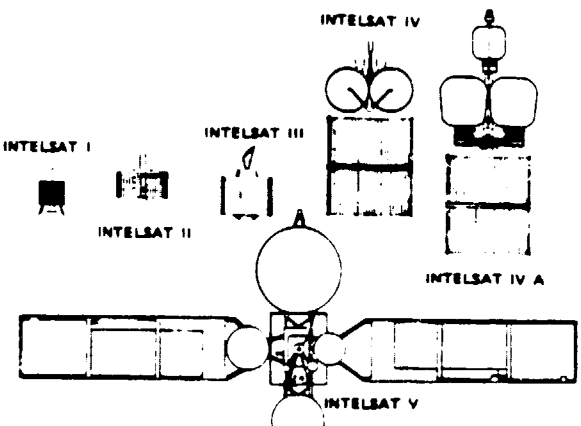

Fig. 1 INTELSAT spacecraft growth.

The powerful communications transmitters, sensitive communications receivers, and rf upconverters require nearly 800 watts of electrical power. Consequently, a large solar array area of nearly 20 square meters is required to provide electrical power for the communications and supporting subsystems. The solar array area necessitates a body-stabilized spacecraft configuration with deployable, sun-oriented solar panels.

The spacecraft three-axis-stabilized design is composed of a box-shaped main body 1.65 x 2.01 x 1.77 meters, containing the electronics and propulsion subsystems, and a truss-type tower holding the antennas. The tower extends from the earth-facing surface of the body. The spacecraft (Fig. 2) is oriented in space with the 2.01 x 1.77 m side facing north and south. The solar arrays extend from this surface approximately 7.8 m each side of the spacecraft. The antennas are oriented with the large 4 and 6 GHz reflectors on the east and west sides.

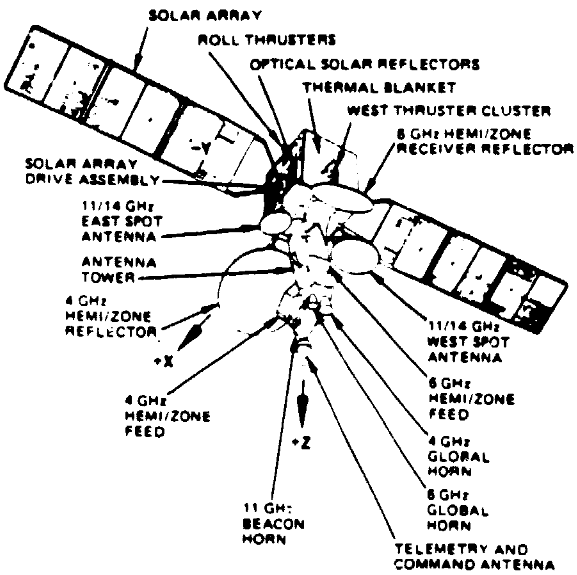

Fig. 2 Spacecraft configuration.

The total spacecraft power requirements for synchronous orbit conditions are presented in Table 1. The resulting power margin is 125.95 W at end of life (EOL) autumnal equinox and 172.68 W at end of life (EOL) summer solstice.

The total spacecraft mass is summarized in Table 2, which indicates a total spacecraft mass margin of 24 kg. The fuel budget summarized in Table 3 illustrates all the individual components which comprise the total fuel budget for the INTELSAT V mission.

INTELSAT V is designed for launch by either the Atlas-Centaur or Space Transport System (STS) launch vehicles. Studies are in progress to determine what design changes are required to permit launch on the Ariane Launch Vehicle.

 This paper is based upon work performed under the sponsorship of the International Telecommunications Satellite Organization (INTELSAT). Any views expressed are not necessarily those of INTELSAT.

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Table 1 INTELSAT V power summary

Load	Synchronous Average Power		
	Autumnal Equinox	Summer Solstice	Eclipse
Communications	782.12	782.12	781.02
Telemetry, command and ranging	43.50	43.50	43.50
Attitude determination and control	49.13	74.13	49.13
Propulsion	0.80	0.80	0.80
Electrical power	9.10	9.10	9.10
Thermal control	109.59	48.59	32.69
I^2 harness losses	10.00	10.00	9.30
Total load (buses 1 and 2)	1004.24	968.24	925.54
Battery charging at 7 years	100.72	29.99	—
Total solar array load	1104.96	998.23	—
Contract load contingency (10%)	123.09	117.09	—
Solar array power availability at 7 years	1354.00	1288.00	—
System power margin at 7 years	125.95	172.68	53.09
Battery DOD for 1.2-hour eclipse (%)	—	—	52.00

Table 2 INTELSAT V summary

Subsystem	Current Baseline Mass (kg)	
	Centaur Launch	STS Launch
Structure/thermal	183.1	183.1
Propulsion	35.3	35.3
Electrical power	141.9	141.9
Communications transponder	174.6	174.6
Communications antenna	58.9	58.9
Telemetry, command, and ranging	28.0	28.0
Controls	72.5	72.5
Electrical integration	40.1	40.1
Mechanical integration	15.4	15.4
Total	749.8	749.8
Apogee motor	922.5	922.5
Propulsion fuel	172.6	185.1
Total spacecraft		
Launch total	1869.3	1897.0
Mass margins	24.4	39.6

Table 3 INTELSAT V fuel budget

Maneuver	Centaur Launch		STS/SSUS Launch	
	Magnitude	Fuel Weight (kg)	Magnitude	Weight (kg)
Transfer orbit				
Spinup	45 r/min	1.5	N/A	—
Active nutation damping	10 min time constant	4.3	10 min time constant	4.3
Reorientation	48°	1.2	140°	3.4
Drift orbit				
Am dispersion correction, including coverage reorientation	65.8 m/s	28.5	92.1 m/s	40.2
Spindown	45 r/min	1.4	45 r/min	1.4
Synchronous orbit				
N-S stationkeeping	347.5 m/s	108.0	347.5 m/s	108.0
E-W stationkeeping	29.0 m/s	11.7	29.0	11.7
Attitude maintenance	7 years	12.3	7 years	12.3
Residuals		2.0		2.0
Total fuel requirements without pressurant		172.6		185.1

Communications Subsystem

The communications subsystem described below provides an rf bandwidth capability of 2137 MHz, which is three times that of its predecessor, INTELSAT IV-A. It accomplishes this by means of extensive frequency reuse of 4 and 6 GHz, accomplished with both spatial and polarization isolation, and by introducing 11/14 GHz operation into the INTELSAT frequency plan. The frequency reuse scheme is accomplished by a multiplicity of antenna coverages, which allows the spacecraft to transmit right (hemi) and left (zone) circularly polarized signals at 4 GHz to many east and west locations at the same frequencies. This provides a 4:1 frequency reuse factor for these locations.

The antenna coverages are shown in Figs. 3, 4, and 5, and a summary of spacecraft communications capabilities may be found in Table 4.

A switching network interconnects the various coverage areas and allocates channels between hemi, zone, and global coverages.

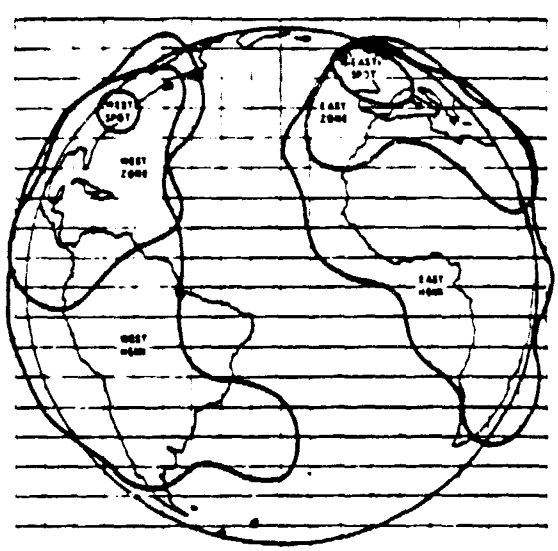

Fig. 3 INTELSAT V Atlantic Ocean coverages.

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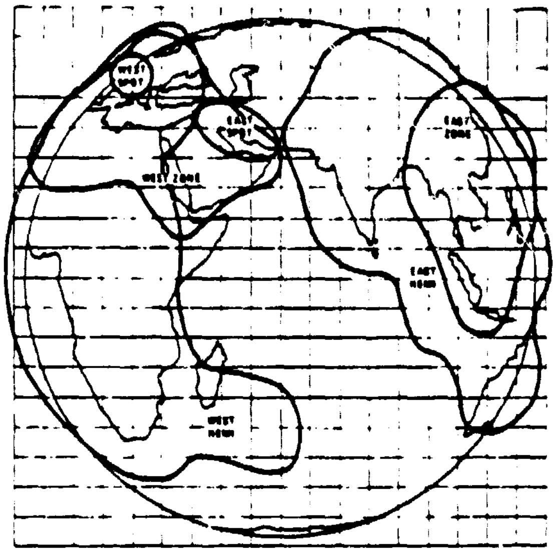

Fig. 4 INTELSAT V Indian Ocean coverages.

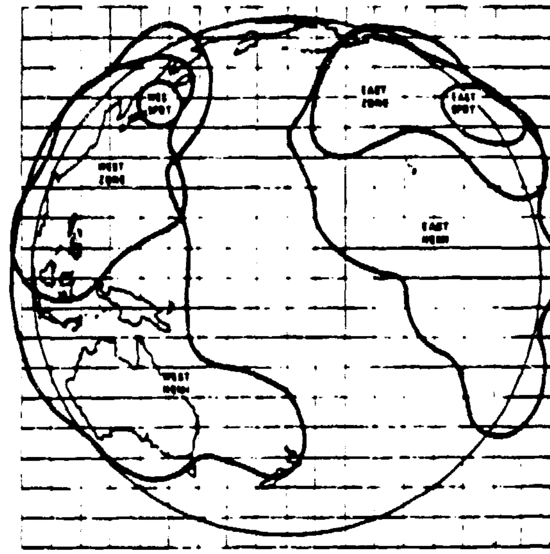

Fig. 5 INTELSAT V Pacific Ocean coverages.

The extremely complex and extensive antenna and multiplexing hardware required to provide the required coverage rely heavily on the use of graphite-fiber-reinforced plastic (GFRP) for antenna feeds, antenna tower structure, waveguide, contiguous output multiplexers, and input channel filters.

Figure 6 is a simplified block diagram that illustrates signal flow, redundancy implementation, and channelization. Twenty-seven independent transponder channels are provided, of which 24 are at least 72 MHz wide. Figure 7 illustrates the transmit frequency plan, including channelization and frequency reuse.

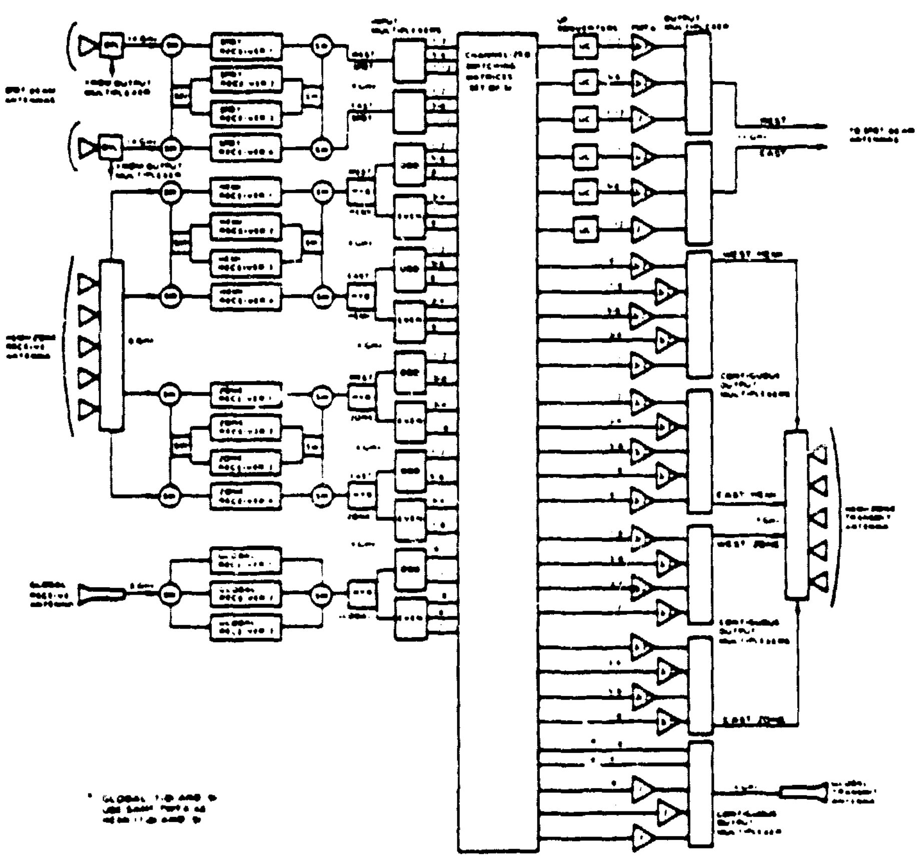

Fig. 6 Communications subsystem simplified block diagram.

Table 4 Communications performance

Parameter	Region and Frequency Band			
	Global 6/4 GHz	Hemi 6/4 GHz	Zone 6/4 GHz	Spot 14/11 GHz
Gain – flux density to saturate each transponder, dBW/m^2, all commandable attenuators set to zero	-76 (-72 for channels 7-8)	-72 (-76 for channel 9)	-72	East -77 West -80.3
G/T – ratio of receive antenna gain to effective noise temperature, dB/K	-18.6	-11.6	-8.6	East 0 West 3.3
EIRP – effective isotropic radiated power, dBW	23.5 (26.5 for channels 7-8)	29 (26 for channel 9)	29	East 41.1 West 44.4
Beam isolation, dB	N/A	27	27	33 (including polarization isolation)
Polarization	Circular	Circular	Circular	Linear
Polarization isolation, dB	32	27	27	See beam isolation

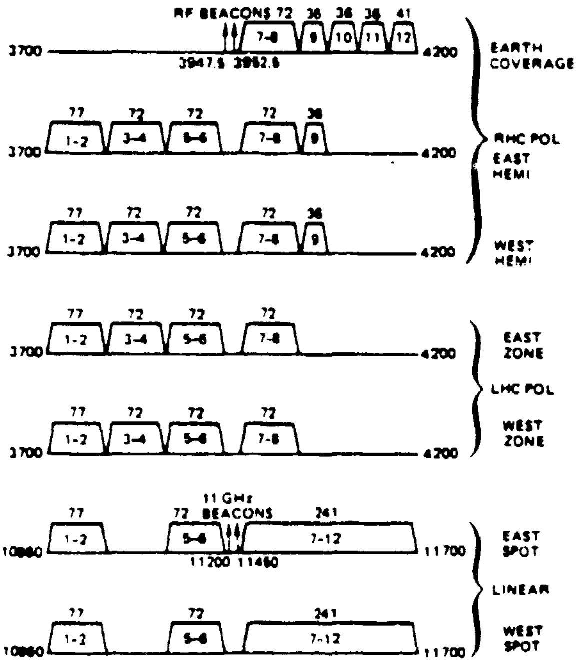

Fig. 7 INTELSAT V transmit frequency plan.

The *hemi/zone transmit* and *receive antennas* consist of large, offset-fed parabolic reflectors (2.44 m and 1.54 m) illuminated by clusters of square feed horns (feed elements). The feed elements are excited with proper amplitude and phase through power division/phasing networks to produce the shaped hemispherical and zone beams. Both the hemispherical coverage and the zone coverage beams are generated simultaneously employing opposite senses (right-hand and left-hand) of circular polarization with low ellipticity ratio. Each antenna geometry (reflector size, focal length) is chosen to produce appropriately shaped beams with a sharp edge rolloff, low sidelobes, and good isolation between the coverage regions.

The east and west hemi beams are shaped to accommodate the appropriate ground station locations in the east and west hemispheres, respectively, as seen from all specified satellite locations in all oceans. A single east hemi pattern and a single west hemi pattern satisfy all these requirements with no switching.

The required zone coverages are also specified by designated ground station locations. In this case, the difference between the Atlantic, Pacific, and Indian Ocean distributions is so great that two pairs of beams are required: one pair (east and west) for Atlantic and Pacific coverage, and a second pair for Indian Ocean coverage. Four coaxial switches (east and west transmit, east and west receive) reconfigure the antenna feeds for the two locations.

The hemi/zone antenna feed consists of a closely packed array of 88 square waveguide feedhorns attached to multiple layer, air-supported stripline power division/phasing networks. The east and west hemispherical beams are formed by a fixed number of feed elements, each element being excited through one of the two excitation ports. The antenna zone beams are similarly formed by clusters of elements; however, the zone clusters utilize oppositely polarized excitation ports. Furthermore, each zone beam utilizes several common feed elements and several other elements that are selected by ground command to provide differently shaped Atlantic/Pacific or Indian Ocean zone beams.

The *feed array elements* are made up of three basic parts: (1) stepped aperture, which provides matched transition between square waveguide and the radiating aperture; (2) septum polarizer, which converts linear signals from each excitation port into circularly polarized signals; and (3) coaxial-to-waveguide adapter, which provides a convenient method of transitioning between a rectangular waveguide and the power division/phasing network. The elements are designed to survive the space environment, launch, and handling during manufacturing and assembly. The elements are constructed from graphite-reinforced-plastic (GFRP) material in order to minimize antenna weight and maintain dimensional stability over a wide temperature range. The inside of each element is lined with a thin copper layer to achieve good electrical conductivity.

An extremely important part of the hemi/zone antenna design is the polarization purity required to achieve the necessary hemi-to-zone isolation. The axial ratio required for achieving a carrier to interference ratio of 27 dB at the worst location in a beam is of the order of 0.5 dB. Extensive development was required to achieve polarization purities of this order from a closely packed array of elements.

The *11/14 GHz spot beam antennas* are designed to provide communications coverage to high traffic areas, using narrow beams that can be steered by command from the ground. The antennas provide essentially constant beamwidths at the downlink (transmit) frequencies of 10.95 to 11.70 GHz and at the uplink (receive) frequencies of 14.0 to 14.5 GHz. The transmit and receive beams are linearly orthogonally polarized.

Each spot beam antenna consists of a nominal 1-meter-diameter offset-fed reflector illuminated by a conical corrugated feedhorn. The reflector is mounted on a support structure through a two-axis gimbal to enable reflector pivoting in two orthogonal planes. Two linear actuators are used to pivot the reflector and thus obtain beam scanning without moving the feed.

The antenna positioner equipment consists of east and west spot beam antenna positioner mechanisms (APM), an earth coverage antenna positioner mechanism, and an antenna positioner electronics (APE). The electronics is a dual redundant unit with each channel being capable of driving any of the five steerable axes (ie, two orthogonal axes for each of the east and west spot APM and one axis for the earth coverage APM). For the east and west spot beam APM, the steering axes are rotated 45° from the spacecraft X and Y axes.

Positioning of any axis is accomplished by selecting the desired axis, selecting the direction of stepping, and generating a series of 250 ms pulses with a 50% duty cycle on the APM step command. The selected actuator will then advance one step per pulse in the desired direction. Telemetry provided by the APE is status information plus the indicated position of the five axes. This position is submultiplexed in the APE, and the five positions plus reference are repeated in telemetry once every 4 seconds.

Each spot beam reflector is a honeycomb sandwich using GFRP faceskins and aluminum honeycomb core. The west spot reflector is parabolic in both the vertical and horizontal planes to produce circular (1.6° diameter) antenna beams. The east spot reflector is parabolic in the vertical plane but distorted (shaped) in the horizontal plane to produce elliptical (1.8° by 3.2°) transmit and receive beams with the minor axis inclined 22.9° clockwise from true north, as seen from the satellite.

The two *earth coverage antennas* (4 GHz transmit and 6 GHz receive) are circularly polarized conical horns. The basic design for the two antennas is identical except that the higher gain transmit antenna is designed to cover a 18° field of view while the receive antenna covers a 2?° field of view. The transmit antenna is mounted on a single-axis gimbal, which enables the antenna beam to be steered up to ±2.0° in pitch to reposition the beam toward the earth's center whenever the spacecraft is pitched in the east-west direction. This provides a global effective isotropic radiated power (EIRP) that is more than 1.5 dB greater than that provided by previous INTELSAT spacecraft. The wider beam receive antenna is fixed on the spacecraft.

Receivers are implemented with all-solid-state components and use microwave integrated circuit technology. The 6 GHz receiver begins with a four-stage bipolar amplifier at 6 GHz, followed by a low-loss balanced mixer. The 14 GHz receiver employs a single-stage 14 GHz tunnel diode amplifier, followed by a low-loss balanced mixer. In both cases, the mixer is followed by a transistor amplifier. The number of stages in the transistor amplifier differs for each of the global, hemi, zone, and spot varieties of receivers. All 6 GHz receivers contain an interstage commandable attenuation that can provide either nominal or extra high gain.

The *input multiplexer* consists of even-and-odd channel filters that are circulator coupled, with even and odd sets hybrid coupled. Each filter is followed by an isolator, a group delay equalizer, and a commandable switched attenuator. Some channels also include an amplitude (tilt) equalizer.

The heart of each multiplexer channel is an eight-pole, pseudo elliptic function filter made of GFRP. It provides the required out-of-band rejection and inband amplitude response. Each filter is assembled from prefabricated pieces, each of which consists of halves of two cylindrical cavities and an iris plate. These units are assembled with metallic slip joints located at low current density points, and bonded.

The INTELSAT V *4 GHz TWTA's* are nearly identical to INTELSAT IV and IV-A TWT designs in terms of vacuum envelope design, cathode loading and gun geometry, degree of overvoltage, and general stress levels. One difference from earlier configurations is the inclusion of an amplitude (slope) equalizer on the input to each tube to insure meeting the allocated 0.2 dB peak-to-peak variation over each channel. This was required because, unlike previous INTELSAT spacecraft, a given tube may be driven from several different sources, and it is therefore not possible to perform a unique end-to-end equalization of a channel. Also, most INTELSAT V channels are at least twice as wide as are those of previous spacecraft in the series, but the same 1 dB peak-to-peak passband flatness requirement has been imposed.

The electronic power conditioner (EPC) for both 4 GHz TWTA's differs from those of previous INTELSAT spacecraft in that it employs a switching regulator to accommodate the unregulated 26.5 to 42.5 volt bus with uniformly high efficiency. The heater supply voltage is dc to minimize spurious modulation of the beam by EPC switching transients.

The *11 GHz TWTA* represents several firsts for an INTELSAT spacecraft: the first 11 GHz TWTA, the first dual-collector TWT, and the first impregnated cathode.

The tube is evolved from a 20 W design developed for another program. Modifications for INTELSAT V included a slightly smaller cathode, lower electrode voltages, and a lower cathode temperature to insure extremely long cathode life.

In addition to displaying the efficient regulation against bus voltage variation described above, the 11 GHz TWTA EPC includes a cathode current regulator that varies anode voltage to hold the cathode current constant should variations in cathode emission occur during the life of the tube.

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A dual-collector TWT has the characteristic that the partitioning of the beam current between the two collectors is a function of the drive level into the tube. Operation of such a tube with large dynamic swings in drive level, such as imposed by time division multiple access (TDMA) traffic, places extreme demands on the collector power supplies. Extensive measures are taken in the EPC to provide adequate energy storage and electronic filtering for TDMA operation.

The heater supply voltage is ac to avoid electrolysis effects known to occur in the heater potting material at the operating temperature required for impregnated cathodes. A spurious cancellation circuit suppresses the heater-coupled EPC switching transients, which would otherwise modulate the beam.

The *4 GHz output multiplexers* are an advanced contiguous design; that is, filters for adjacent channels are collocated on a common waveguide manifold. Consequently single transmit antennas are used rather than duplicate odd and even antennas. The design of the output multiplexer places the 3 dB rejection points of each of the contiguous band channel filters halfway between adjacent channels. The filters are each of the singly terminated design. This design takes advantage of a much higher skirt selectivity than is possible for lower ripple, doubly terminated designs.

The filter in each of the multiplexer channels is a six-pole, dual-mode quasi-elliptic design with two extra couplings: one between the first and fourth resonators and the other between the third and sixth resonators. This design was developed first and then used as the basis for the element design values in the singly terminated version.

The complete multiplexer design requires the use of additional reactive cavities on the manifold to provide appropriate adjacent-channel reactances for those filters that carry the highest and lowest channels being multiplexed.

Controls Subsystem

The controls subsystem provides active stabilization for the spacecraft to keep the antenna beams fixed on earth throughout the mission. Fig. 8 is a simplified block diagram of the controls subsystem. In transfer orbit, the spacecraft is spin stabilized by means of active nutation control electronics, which fires hydrazine thrusters. Attitude determination is derived from earth sensor and sun sensor data, which is processed by the attitude determination and control electronics (ADCE).

For *rate damping and acquisition*, the spacecraft is despun and rate damping is performed about all three axes to less than 0.5°/s. Acquisition is commanded in which the spacecraft performs a series of automatic maneuvers to point the roll axis at the sun and to rotate the spacecraft at 0.5°/s about the roll axis. The solar arrays and reflectors are deployed, and the solar array drive is required to slew both arrays 90° to orientate the arrays normal to the sun line. Six hours after sun acquisition, the ADCS performs earth and yaw acquisition and the spacecraft is finally pointed at the earth centroid. The solar array drive is enabled for normal sun tracking at 15°/h. The momentum wheel is then spun up in preparation for transition from stationkeeping to normal on-orbit control.

The *normal mode* control logic will automatically estab-

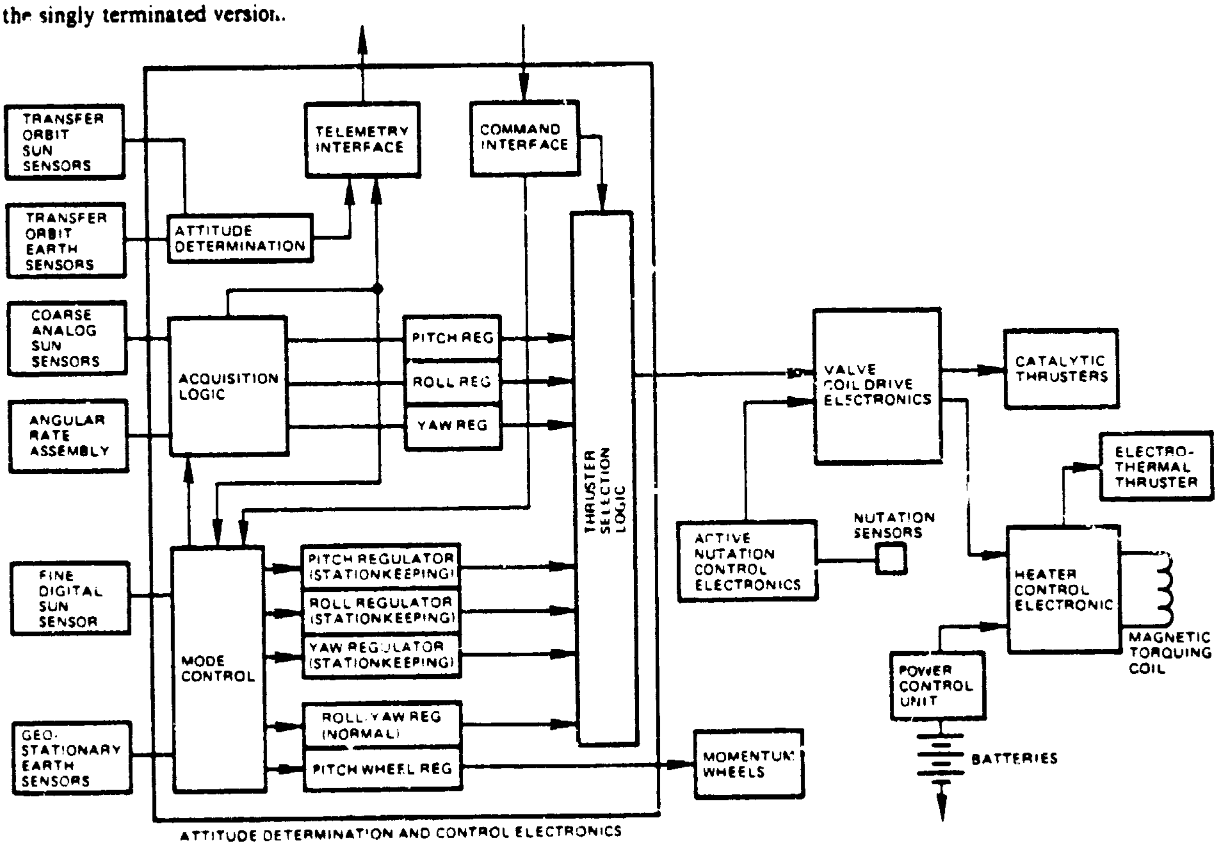

Fig. 8 Controls subsystem block diagram.

lish autonomous pitch control via the geostationary orbit infrared sensor (GEO-IRS) and the flywheel and establish autonomous roll/yaw momentum bias control using GEO-IRS roll error signals to constrain the spacecraft motion to a small angle limit cycle. Small offsets are implemented by introducing bias commands into GEO-IRS output in roll and pitch axes. Due to external disturbance torques, the flywheel will accumulate angular momentum that finally results in increased or decreased wheel speed until a saturation limit is reached. At this point a wheel unload pulse is automatically generated, removing the wheel from saturation.

The *stationkeeping mode* occurs during corrections for north-south or east-west stationkeeping. These corrections are implemented by firing thrusters in pairs, thus inducing disturbance torques due to thrust imbalance and misalignment. In this mode, the flywheel is either operational or commanded to a preset speed.

Pitch roll control is provided by the appropriate thrusters in response to earth sensor error signals. In addition, an active yaw control loop is closed around the fine digital sun sensors (FDSS) and the nominally inactive yaw thrusters. When the electrothermal thrusters are used for north-south control, disturbance torques are much smaller than with catalytic thrusters because of lower thrust. Maneuver time will therefore increase. In this case, the roll and pitch axis thruster control systems maintain earth reference pointing. For yaw control, the yaw thrusters are used in the same direction as the electrothermal thrusters. In the backup scheme, a pair of catalytic thrusters providing the spacecraft velocity increment will be automatically inverse-modulated to provide the control torque about the corresponding axis.

When the pitch thrusters are used for east-west stationkeeping, they provide the spacecraft velocity increment and are off-modulated to control pitch torques. The roll and yaw thrusters maintain the earth reference pointing during the entire maneuver. For the single catalytic thruster operation during east-west stationkeeping, the pitch, roll, and yaw thruster control system maintains earth reference pointing.

The INTELSAT V *automatic nutation control* (ANC) utilizes nutation sensor signals and electronic signal conditioning to provide thruster firing pulses for active control of satellite nutation during the spinning phase of transfer and drift orbit. The ANC is designed to operate in two different modes: large nutation angle and end-game. The large nutation angle mode is utilized to capture large initial tipoff nutation angle, whereas the end-game mode is utilized to control small nutation angle as well as to minimize spin axis precision. Mode switching is automatically selected by determining the frequency of thruster firings of the ANC system during satellite nutation control.

The ANC consists of two channelized sets, each containing a nutation sensor, electronics channel, and axial thruster During large nutation angle operation, both sets fire to efficiently reduce nutation. During end-game mode, one channel (selectable via ground command) maintains the nutation half-cone angle to less than 0.1° while the second channel (backup) maintains the nutation angle to a larger value 3° as a backup redundancy in case of failure to the prime channel.

The ANC electronics also provides the automatic spacecraft spinup function, required when utilizing the Atlas-Centaur launch vehicle. The spinup function of each channel of the ANC electronics is channelized to the two spinup thrusters. At separation from the launch vehicle, the sequencer commands the spinup thrusters to fire for approximately 9 minutes and then automatically enables the active nutation control function.

The *dynamic conditions* experienced by the spacecraft during various mission phases, the transfer orbit, and operational orbit attitude dynamics environment must be considered in the control system design. Particular attention is given to on-orbit disturbance torques.

Among the conclusions reached, the following are of particular significance. The solar torque modeling does not appear to be overly sensitive to either minor variations in spacecraft optical properties or to secondary reflection effects. The use of a body-fixed magnetic torquer coil is adequate to reduce the high solstice roll body torques to manageable magnitude. Among the thruster perturbations, the most significant is the transient effect caused by the relocation of the propellant mass at the beginning of stationkeeping maneuvers.

Table 5 summarizes the key features of the spacecraft solar torque characteristics.

Tabie 5 Maximum values of solar torque components

Torque Component	Magnitude (μNm)	Occurrence
Pitch average	0.81	Solstice EOL
Pitch peak	73.10	Equinox BOL
Roll average	18.50	Solstice BOL
Yaw average	5.55	Solstice BOL
Inertial roll yaw average	1.56	Equinox BOL

Torques are given in body-fixed axes roll, pitch, and yaw as well as in an inertial torque frame that coincides with the nominal orientation of the body axes at midnight ($t = 0$, orbit angle 0°).

The roll body-fixed torque component reaches values of about 1.7^{-6} N·m during the solstice periods. A torque of this magnitude disrupts the normal operation of the on-orbit roll-yaw regulator, causing excessive thruster firing (approximately 200/day) and inefficient propellant utilization.

Accordingly, a *magnetic roll torque compensation* scheme (using a dipole aligned with the spacecraft yaw axis) has been included in the baseline design. The magnetic torquer control equipment consists of two magnetic torquer coils and dual redundant current control circuits. The magnetic torquer is a device used to generate a spacecraft body-fixed torque (about the spacecraft roll axis). This roll torque is necessary to cancel out a solar pressure-induced body-fixed torque. The solar pressure torque is essentially constant over a daily period and varies sinusoidally over a year cycle with peaks occurring at the two solstices. The magnetic torquer utilizes a constant current source to generate a commandable (eight-state) constant magnetic dipole that reacts to the earth's magnetic field (<100 gammas at synchronous orbit altitude) to generate the roll torque. The magnetic torquer is commandable in discrete steps with a resolution error of ±11.4

A · m^2 to a maximum value of ±183 A·m^2. The purpose of this device is to reduce the total number of thruster firings and the average gas consumption. These functions are performed in an open-loop manner by adjusting the magnetic torque (by command) to match the average roll torque.

With magnetic compensation the maximum constant torque translates into a mission average of 2.19 x 10^6 N·m over mission life, and will have an effect on pitch wheel unloading requirements. The periodic terms in pitch have no significant effect.

The overall spacecraft *pointing error* estimate and budget for normal operation and operation during stationkeeping maneuvers, including errors associated with the operation of the 4 and 6 GHz communications links, are the most significant for design purposes. Pointing errors of the 11 to 14 GHz spot beams will be much smaller, primarily because of reduced alignment errors and thermal distortions. The error sources are divided into four categories as shown in Table 6.

Telemetry, Command, and Ranging Subsystem

The telemetry, command, and ranging (TC&R) subsystem consists of two functionally redundant and independent command and telemetry channels. The major elements of the TC&R subsystem are shown in Fig. 9.

The *command* subsystem provides operational ground control for all spacecraft functions through a microwave link consisting of two ring-slot antennas, two command receivers, and two command units. A command transmission consists of a microwave carrier FM-modulated by a sequence of tone bursts at three discrete frequencies, resulting in 1, 0, and execute functions. The command receivers demodulate the microwave carrier and transmit the baseband tones via the spacecraft wire harness to the command unit bit detector. The command unit processes these discrete tones, and formats and executes specified discrete pulse, relay, and proportional command types. The command receivers and command units are fully cross-strapped, providing complete redundancy during all modes of operation.

Table 6 Worst case pointing error

Error Source	Pitch (degrees)		Roll (degrees)		Yaw (degrees)	
	Random	Deterministic and Bias	Random	Deterministic and Bias	Random	Deterministic and Bias
Attitude control						
Earth sensor (CEO–IRS)	±0.020	±0.033	+0.020	+0.037	–	–
Sun sensor (FDSS)	–	–	–	–	0.016	0.14
Electronics effects	+0.030	+0.030	+0.030	±0.030	+0.030	+0.030
Maximum deviation (limit cycle)	±0.070	±0.015	±0.055	+0.015	–	+0.250
Wheel wobble and solar array effects	±0.010	–	±0.10	–	±0.010	–
Subtotal (rss)	±0.079	±0.047	±0.067	±0.050	±0.035	±0.288
Thermal distortion		±0.037		±0.081		
S/C alignments		±0.020		±0.010		±0.043
Subtotal	±0.079	±0.104	±0.067	±0.121	±0.035	±0.331
S/C total (direct)	±0.183		±0.188			±0.366
Orbit worst case	±0.018		±0.018		±0.100	

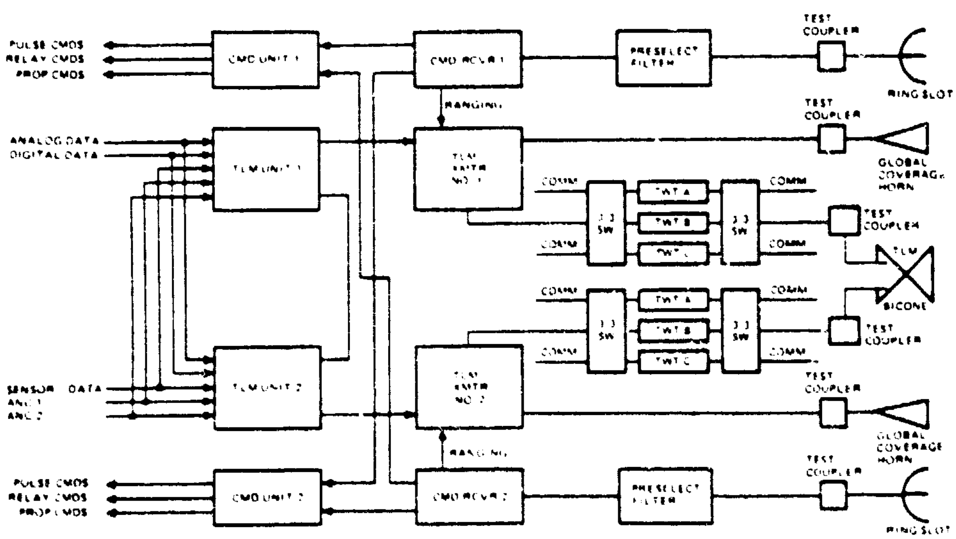

Fig. 9 Telemetry, command, and ranging block diagram.

The *telemetry* subsystem provides two independent and redundant data channels for transmission of diagnostic data received from sensors, transducers, and subsystem status. One of the two telemetry units processes and formats all incoming bilevel digital and analog telemetry for transmission via two phase-modulated telemetry beacon carriers. The telemetry unit has the capability of operating in three selectable modes: PCM, PCM dwell, and FM real time. The telemetry digital bit stream is utilized to biphase modulate a 32 kHz subcarrier, which phase modulates the telemetry transmitter in the PCM and PCM dwell mode operation. The FM real-time mode is used for real-time attitude pulses (sun sensor, earth sensor, and command execute) or nutation sensor signal. The occurrence of a sensor pulse or nutation signal switches the frequency of the IRIG channel 13 subcarrier oscillator (SCO) from its pilot tone to a frequency depending on the sensor pulse or nutation angle. The SCO output phase modulates the telemetry transmitter.

The telemetry transmitter has the capability of two transmission modes: (1) via the directional antenna for normal on-orbit earth coverage, and (2) through one of three selectable TWTA's via a dual toroidal beam antenna for omni coverage during transfer orbit. These outputs are both available whenever power is applied to the transmitter.

Electrical Power Subsystem

The electrical power subsystem (EPS) for the INTELSAT V spacecraft is a dual-bus, direct-energy-transfer system designed to accommodate a continuous spacecraft primary load of approximately 1.3 kW for a 7-year equinox synchronous orbit lifetime. Primary power is provided by two separate sun-oriented planar solar array wings. The power output of each solar array wing is regulated by a separate sequential linear partial shunt regulator. During periods of insufficient solar array power for support of spacecraft loads, power is supplied by two 28-cell nickel-cadmium batteries. Interrelationship of the major EPS elements is illustrated in Fig. 10.

The *solar array* consists of two single-axis sun-oriented wing assemblies. Each assembly consists of a deployment mechanism, three rigid panels, and an orientation mechanism connected to the solar array drive system. The solar array drive assembly (SADA) for the INTELSAT V spacecraft consists of a dual, two-channel solar array drive electronics (SADE) and two solar array drive mechanisms (one for the north solar array and one for the south). The drive provides for the support and positioning of the arrays about the spacecraft pitch axis and for the transfer of power and signals from each array to the spacecraft module.

The SADE is a dual box containing two redundant sides. Each of these sides is capable of controlling both channels (north and south) of solar array drives. The solar array drive has a stepper motor with two independent motor windings for redundancy.

The SADA always provides drive motion at the rate of one step (0.1125°) of each array every 27 seconds. This corresponds to an angular rate of 15°/s for each array. In addition to this stepping rate, a slew augmentation capability is provided to speed up the operation of each or both the north and south arrays at a slew rate consistent with dynamic constraints. The direction and number of slew steps are commandable from the ground.

The total panel area of 18.12 m^2 is covered with 17,568 solar cells. The solar array is electrically interfaced with sequential shunts to achieve the necessary bus voltage regulation and is configured to provide direct battery charge current.

During transfer orbit the array is stowed so that load support and battery charging are accomplished with two outer panels (one per wing). The array is designed to support synchronous orbit operation at end-of-life equinox with an electrical power capacity of 1354 W.

The *battery* configuration consists of two nickel-cadmium batteries connected to the applicable bus through the battery

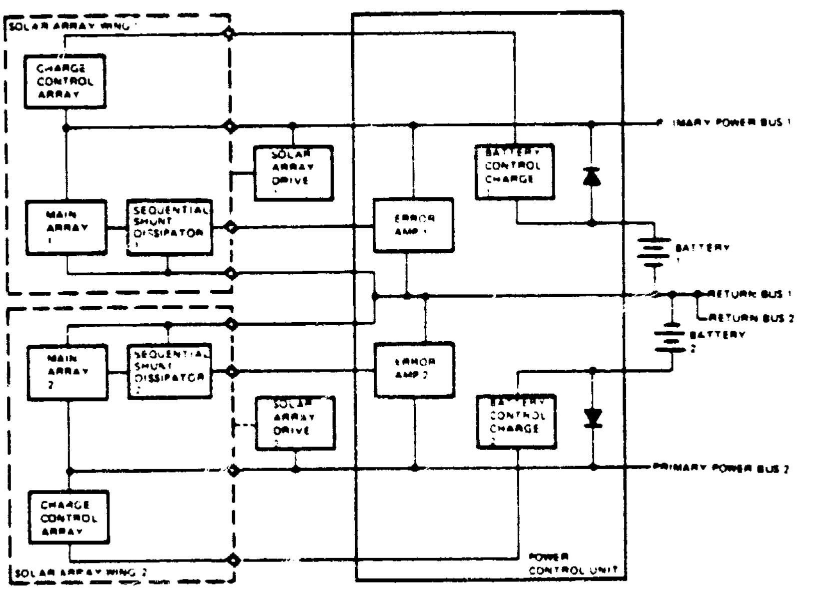

Fig. 10 Electrical power subsystem block diagram.

discharge diodes. The battery charge current is controlled by dedicated solar array sections and battery charge controllers in the power control unit (PCU). The charge current is applied sequentially to each battery on a 50% duty cycle.

Each battery assembly consists of 28 hermetically sealed prismatic cells connected in series. The nominal discharge voltage is 33.6 V with a capacity of 34.0 Ah.

Open-circuit protection is provided for the batteries by diode bypass networks connected across each cell. Temperature sensors are utilized to provide temperature control inputs for battery heaters throughout the spacecraft's mission.

The *power control electronics* (PCE) consists of a PCU and two shunt dissipator assemblies. A key feature of the PCE is the provision of two independent primary buses. The outputs of one solar array wing and one battery are dedicated to each bus, with the capability provided to parallel connect or separate the two buses by command, as required. The output of each solar array wing is independently regulated to 42 ±0.5 V dc by use of a sequential linear partial shunt regulator.

The PCE provides sequential battery charge control and individual battery reconditioning capability by ground command. Single-part failure criticality is eliminated by use of circuit redundancy, and alternate modes of operation are selected by command. All spacecraft electroexplosive devices (EED's) are controlled by the PCE, which employs redundant, fail-safe circuitry for these important functions.

Propulsion Subsystem

The propulsion subsystem works in conjunction with the controls subsystem to maneuver the satellite. It consists of two screen-type surface-tension propellant/pressurant tanks that are manifolded to two redundant sets of thrusters. Two 22.2 N thrusters are used during transfer drift orbit for orientation, active nutation, and orbit velocity correction. Spacecraft spin/despin, east-west stationkeeping, and pitch and yaw maneuvers are performed by 2.67 N thrusters. These thrusters also serve as backup to the 0.3 N electrothermal thrusters, which are designed to perform the north-south stationkeeping function. Roll maneuvers are performed by 0.44 N thrusters. Latching isolation valves separate the tanks into half systems. The plumbing is arranged so that through use of these isolation valves either tank can be used to feed one or both sets of thrusters. A layout of the subsystem is shown in Fig. 11.

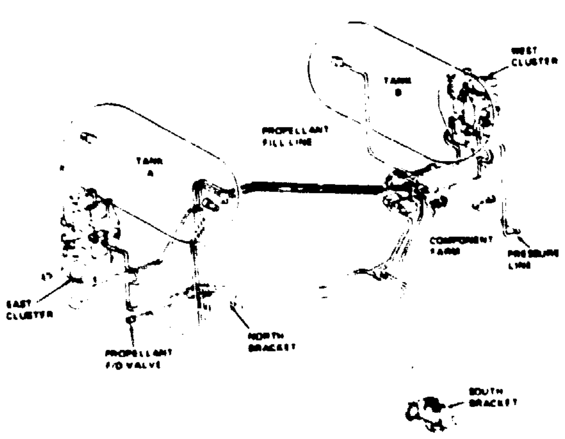

Fig. 11 Thruster layout.

For high reliability, previously space-qualified hardware has been used wherever possible. Propellant tanks and electrothermal thrusters (ETT) were development items chosen for their particular benefits to the satellite design.

Two titanium *propellant tanks* are provided for storing the hydrazine propellant. The internal propellant management device feeds fuel to the thrusters under zero gravity conditions as well as one gravity conditions in all tank positions. Internal volume is 140.7 to 141.7 liters by design and allows loading of greater than 213 kg of hydrazine. Nominally 185 kg fuel is required for a shuttle launch. The excess capacity is designed to provide margin, growth, and additional offload capability to accommodate a variety of transfer orbit, booster apogee motor configurations.

Expulsion efficiency is predicted to be 99% using gas blowdown pressurization. Gas-free propellant delivery is provided under all conditions of operation, including the failure mode operations associated with recovery from flat spin at rates as low as 30 r/min with volumetric loadings as low as 55%. The propellant feed system is of all-welded construction to minimize weight and leakage. The only mechanical joints in the subsystem are the thruster propellant valve seats and the fill-and-drain valve seats. High-strength titanium alloy is used for the tanks. All other components and lines are stainless steel. Diffusion bonded transition joints are used where titanium-to-stainless-steel joints are required.

Electrothermal thrusters (ETT's) were selected for INTELSAT V because they potentially can deliver a mission average specific impulse I_{sp} of 304 seconds by heating hydrazine propellant to 4000°F (2206°C) prior to ejection.

The thruster assembly (Fig. 12) includes a propellant valve, thermal decomposition chamber, vortex heat exchanger, and thermal insulation. The thermal decomposition chamber employs a discrete spray capillary tube injector, a platinum wire mesh thermal bed, and redundant chamber heaters. Attached directly to the decompositon chamber is the high temperature vortex heat exchanger consisting of a vortex flow chamber, exhaust nozzle, high temperature heater element, and electrical feed-through.

Both components are fabricated from refractory metals, and all mechanical joints are made by high temperature brazing or electron-beam welding.

The electrothermal thruster heater control electronics (HCE) switches the power to the electrothermal thruster heaters, and includes interlock logic to insure that the control signals are applied in the correct sequence. Each thruster can

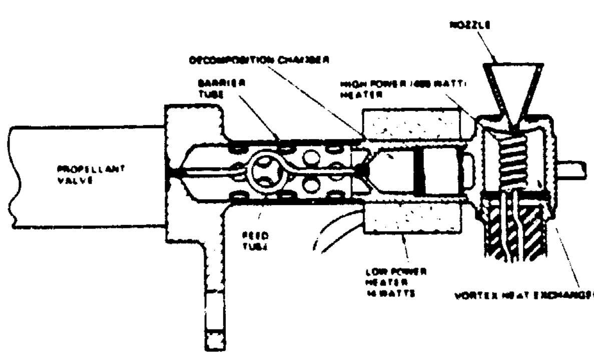

Fig. 12 Electrothermal thruster configuration.

receive power from either selected battery bus. The power bus is protected by fuses at each interface.

In addition, if the fuel control signal is removed before the high power heater is turned off, the heater is shut down automatically.

Weight savings actually achieved by the INTELSAT V spacecraft will depend upon the I_{sp} delivered to the space- craft as well as the length of time the thrusters remain opera- tional (see Fig. 13). For a nominal 7 years of operation at an expected mission average I_{sp} of 285 to 304 seconds, the weight savings is between 16 and 25 kg. In order to offset associated hardware weight (5.5 kg) or bit correction effi- ciency loss due to long burn times (approximately 0.5 kg) and additional attitude control fuel required to offset the expect- ed ETT thrust mismatch (1.6 kg), the ETT's must operate with an I_{sp} above 250 for 7 years.

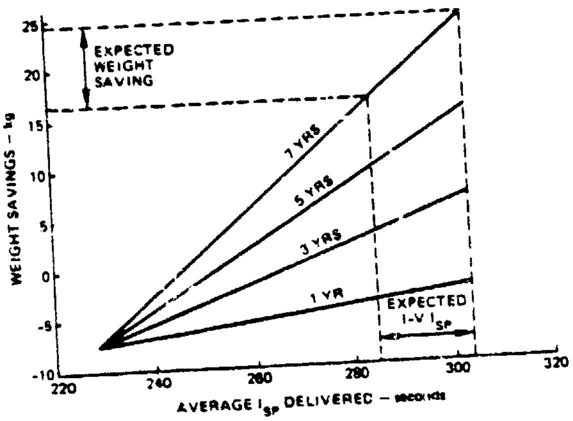

Fig. 13 Weight saving vs ETT performance.

Thermal Control Subsystem

Thermal control of the INTELSAT V spacecraft is ac- complished using conventional passive techniques, including selective location of power-dissipating components, selective use of surface finishes, and regulation of conductive heat paths. The passive design is augmented with heater elements for components having relatively narrow allowable tempera- ture ranges. The design approach provides simple and reli- able temperature control. The thermal subsystem is configu- red to provide flexibility for variation in the spacecraft heat load, including payload growth, through easily accomplished modification of insulation blankets and radiators.

The thermal design for the spacecraft modules and major assemblies in the operational synchronous orbit configuration is presented in Fig. 14. Overall temperature control is achieved by:

a. The thermal energy dissipation of components in the communications and support subsystems modules.
b. The absorption of solar energy by the solar array, antenna module, and main body radiators.
c. The reemission to space of infrared energy by the solar array, antenna modules, and main body radia- tors.

High thermal dissipators, such as the TWTA's, are lo- cated on the north and south panels of the main body so that they may efficiently radiate their energy to space via heat sinks and optical solar reflector radiators. The north and south panels were selected to contain the radiators because these panels are least affected by transient daily and eclipse variation in solar incidence. However, seasonal solar flux variation, which ranges from zero to a maximum solar inci- dence angle of 23.5° above the surface horizontal, must be allowed for on the north and south panels. The solar flux varies slowly enough to be considered steady state at each incident angle (time of year).

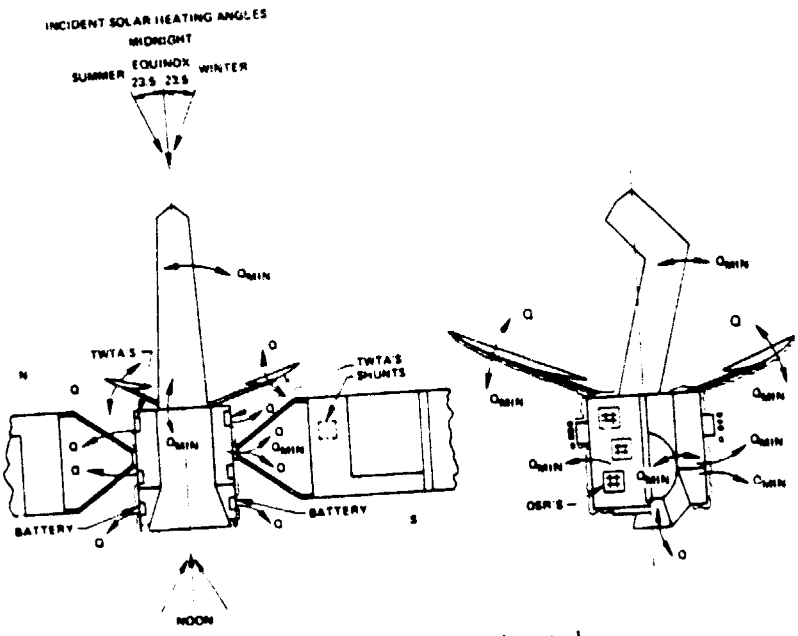

Fig. 14 Synchronous orbit thermal control.

The east and west panels, antenna deck, and aft surfaces are covered with multilayer insulation to minimize the effect of solar heating on equipment temperature control during a diurnal cycle. Thermal control of the tower supporting the various antenna reflectors and horns is achieved by the use of a three-layer thermal shield around the tower. Thermal control of the antenna reflectors, positioners, feed assemblies, and horns is achieved by the use of thermal coatings, insulation, and aperture covers, as necessary.

The thermal control concept indicating heat transfer paths is illustrated in Fig. 14.

Redundant heater elements are used to augment the passive thermal control design to achieve increased reliability, performance margin, and component life. Heater elements are employed to maintain temperatures above minimum allowable levels on the propellant tanks, lines, valves, apogee motor, and batteries. The thermal control subsystem is designed to maintain equipment temperature levels that will ensure satisfactory performance throughout a 7-year mission life.

Structural Configuration

The three main elements of the spacecraft (Fig. 15) are the antenna module, communications module, and support subsystem module. The latter two modules form the main body. Each of these modules is manufactured separately.

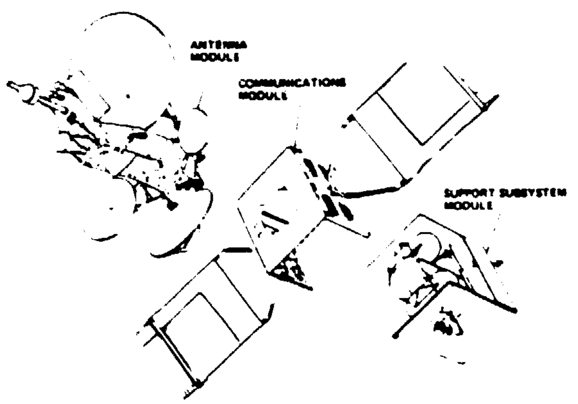

Fig. 15 Spacecraft modular construction.

The *antenna module* layout was selected to produce clear fields of view for communications and to produce as nearly as possible a static mass balance. The large 4 GHz reflector hinge position has been selected to provide approximately 50 mm clearance to the Centaur launch vehicle fairing and the 4 GHz feedbox. The 6 GHz reflector is positioned to minimize beam blockage by the tower and to provide a small offset of the axis center of mass. The east and west spot beam reflectors are located so that the rf beam clears the tower-mounted components while the height above the antenna deck is as low as possible in order to minimize solar array shadowing. The east spot beam reflector is positioned such that no deployment is required. The remaining antennas and associated equipment are mounted on the tower to provide a clear rf field of view for each antenna without obstructing other antennas.

The *communications module* is arranged to provide the shortest possible microwave interconnection per channel. The module consists of the north and south equipment panels and the antenna deck. These panels are arranged in a C-shape and are interconnected with two vertical webs dividing the north and south into two sections each. The two vertical webs serve multiple functions: (1) structural load path for support of the panels, (2) attachment of the solar array drive, and (3) area for mounting the communications transponder equipment. The five major equipment groupings of the transponder mounted here are the receivers, input filters, switch matrices, traveling wave tube amplifiers (TWTA's), and output filters. The receivers are located on the antenna deck to provide isolation from the TWTA temperature extremes. The hemi and global TWTA's are located on the south panel while the zone and spot TWTA's are located on the north panel; both locations are selected for thermal reasons. The input multiplexers are located as close as possible to the receivers and switch matrices to minimize path losses. The output multiplexers are located as close as possible to the traveling wave tubes to maximize total output power.

The *support subsystem module* consists of the structural cylinder, a horizontal deck called the attitude control subsystem (ACS) deck, and north and south equipment panels. The support subsystem module contains the apogee motor, the hydrazine propulsion system, and most of the support subsystem electronics. Momentum wheels are also mounted in this module. The location of the thrusters in two clusters of eight each on the east and west sides facilitates the modular concept. The roll thrusters, two each located on the north and south panels, are mounted 6° west of the anti-earth vector about the pitch axis to provide yaw coupling. The apogee motor is installed through the aft conical opening in the thrust tube, and is mounted to an aluminum ring. The momentum wheels are mounted to brackets from the central cylinder. The mounting bracket minimizes interaction with the equipment panels.

Spacecraft Operations

The INTELSAT V spacecraft mission sequence for the Atlas-Centaur launch is schematically shown in Fig. 16 and discussed below. There are four distinct orbit phases: (1) launch and ascent, (2) transfer orbit, (3) drift orbit, and (4) final equatorial synchronous orbit.

Launch may occur within a period of more than 30 minutes each day as defined by the launch window. The minimum launch time as well as severest spacecraft mission will occur for equinox launches due to eclipse conditions during drift and final orbit.

Upon launch vehicle command, spacecraft separation will occur without ground station coverage 2 minutes after transfer orbit injection; this is followed, after 2 seconds, by spinning thruster firing. Booster attitude, separation mechanism, and spinup thruster pointing errors are designed to maintain spin on yaw axis attitude parallel to orbit normal within 8 to 14°, and angular velocity 40 ±5 r/min corrected to ±1.5 r/min.

Ground station coverage commences 30 to 60 minutes after injection and is continuous except for one 2-hour perigee outage.

A reorientation maneuver to apogee motor fire attitude is performed using 5 lb axial thrusters. These same thrusters

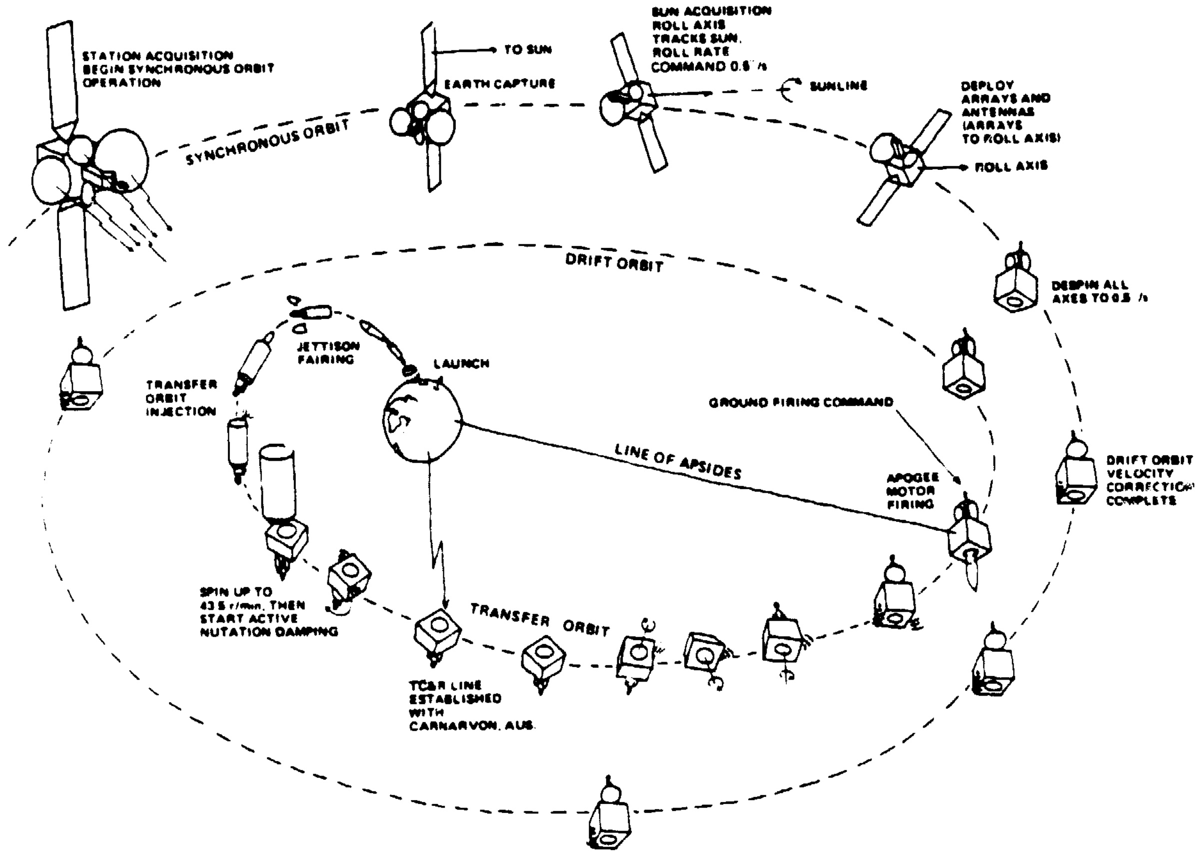

Fig. 16 Atlas-Centaur mission sequence.

are automatically triggered by the active nutation damping systems when a 0.1° nutation amplitude is detected. Nutation pulses are fired in balanced two-pulse groups to avoid random attitude perturbations. Tracking and attitude data accuracies are sufficient to allow apogee motor firing attitude pointing to 0.5° half cone angle 3 σ.

An apogee motor firing velocity vector diagram is shown in Fig. 17. Nominal velocities are given for both the Atlas-Centaur and Shuttle launches. The hydrazine fuel budget and tank capacity have been sized to allow velocity augmentation of the apogee motor if appropriate. This results in a nominal drift orbit perigee 1400 km below synchronous and allows launch vehicle and apogee motor pointing error corrections to be accomplished with the same fuel used to raise drift orbit perigee.

For maintaining full TC&R coverage throughout the drift orbit, a spin axis reorientation to -70° declination and back to drift orbit correction attitude can be performed at the option of ground control. These will be scheduled as close to the apogee motor firing point as possible, so that the reorientation impulse will impart orbit velocity in the direction required. To correct apogee motor dispersion errors and launch vehicle inclination errors and raise drift orbit perigee, both 5 lb thrusters will be fired placing the spacecraft in a nearly circular synchronous orbit.

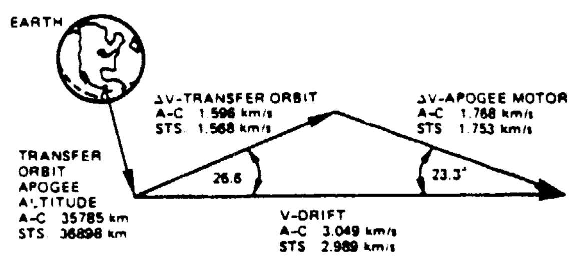

Fig. 17 Apogee motor firing velocity vector diagram.

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APPENDIX D

PROGRAM OF MEDIUM-SCALE BROADCASTING SATELLITE FOR EXPERIMENTAL PURPOSE

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Abstract

The Japanese Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) will be launched in February 1978 from ETR, U.S.A., using a Delta 2914 launch vehicle, and located at 110°E in a synchronous orbit. The BSE is a three-axis stabilized spacecraft having sun-oriented solar array for high power generation and 14 GHz/12 GHz direct conversion mission transponders capable of two channels color TV relay broadcasting. On the orbit, various experiments of TV broadcasting, K-band radio wave propagation and spacecraft control will be conducted. This paper will present the mission objectives, spacecraft and ground systems configurations, and intended experimental items.

I. Introduction

In Japan, more than 6000 terrestrial TV broadcasting stations are in operation at present time using either VHF or UHF bands. However, 70% of these stations are so called "small power stations" which re-broadcast TV signals by receiving waves of the regular "Plan stations". In most cases, their broadcasting soureces are 3 to 4 times relayed signals, and their servicing TV signal qualities are not satisfactory. Besides, 3% of the population, in remote islands or mountain districts, are still left outside of the general service area, and enormous costs would be required for covering these small percentages of population when ordinary terrestrial broadcasting means are applied. Recently, it is a severe problem how to overcome TV signal quality degradations in large cities due to massive buildings' shading or multi-path interference effects. Introduction of TV broadcasting satellite system is a quite effective solution to these problems.

Reflecting these social circumstances, Ministry of posts and Telecommunications (MOPT) has initiated the BSE program in 1972, and has made preliminary designs of the spacecraft. The BSE is a medium-scale spacecraft and is used to acquire technologies necessary for establishing future large-scale operational broadcasting satellite systems capable of individual home TV receptions. In November 1973, results of the preliminary design works were transferred to National Space Development Agency of Japan (NASDA) for further spacecraft development. Making contracts with Toshiba/General Electric industry team, NASDA has completed the basic and detailed designs of the spacecraft in 1975 and is now developing a proto-flight and a flight model.

The BSE will be launched in February 1978 from Eastern Test Range of U.S.A. by using a Delta 2914 launch vehicle, and located at 110°E in a stationary orbit. The launching and stationing of the spacecraft will be carried out by NASDA with support of NASA, and after initial check up of the spacecraft performances on orbit, various mission experiments will be conducted by Radio Research Laboratories (RRL) of MOPT for three years of the spacecraft design life, with close cooperation of Japan Broadcasting Corporation (NHK). The BSE is a three-axis stabilized spacecraft weighing about 350 Kg in orbit, and has large extended solar array panels generating high power of about 1 kilowatts and 14 GHz/12 GHz direct conversion type transponders with 100 watt TWT amplifiers for two channels color TV broadcasting. The 12 GHz broadcasting waves are radiated from the shaped beam parabolic antenna to cover whole Japan territory efficiently. It is expected to be able to receive high quality color TV signals throughout Japan mainland with Simple Receive Equipments (SRE) with 1 to 1.6 meters dish antenna, and in its surrounding remote islands with Receive Only Stations (ROS) with 2.5 to 4.5 meters dish antenna. The frequency channel plan of the BSF is as follows:

	up-link	down-link
channel A	14.25-14.30 GHz	11.95-12.00 GHz
channel B	14.35-14.43 GHz	12.05-12.13 GHz

Two frequency bands of S and K are available for Tracking Telemetry & Command (TT&C) operations, the S-band is used at NASDA's Tracking and Control Station (TACS), and the K-band is used at RRL's Main Transmit and Receive Station (MTRS).

Major items of intended experiment include measurements of the on-board mission equipments characteristics, video and audio signals transmission characteristics, K-band radio wave propagation characteristics, and investigations of the effective service area. The experiments on satellite broadcasting system operations, including spacecraft control, access from multiple transmitting earth stations and others, will also be conducted. Improvement of reception techniques of the broadcasting signals will be another important experimental item. Various kinds of earth terminals such as MTRS, Transportable Transmit and Receive Stations (TTRS), ROSs and SREs will be distributed throughout Japan for the experiments.

II. Spacecraft

Spacecraft Design Configuration

The BSE system parameters are shown in Table 1.

The spacecraft is three axis control type using various attitude sensors and reaction wheels for pointing on-board K-band antenna RF beam to a specified ground point. The antenna is designed to have adequate gain over the Japanese territory and to cause minimum interference over neighboring countries.

The solar cell array is folded during transfer orbit and fully deployed on-orbit. It tracks the sun and provides electrical power to the on-board equipment supplemented by rechargeable batteries during eclipse periods.

Tbble 1 System Parameters

Satellite Location	110° East Longitude
Experimental Coverage	Japanese Territory
Frequency Bands	14.25-14.43 GHz uplink 11.95-12.13 GHz downlink
Number of TV Channels	2
Picture Quality	S/N = 45 dB (TASO Grade 1)
Power Flux Density	Japan Mainlard (-108 dBW/m^2) Remote Territory (-117 dBW/m^2)
System life	3 Years
Booster	Thor-Delta 2914
Command and Control	S Band and K Band from Control Stations in Japan

In the transfer orbit, the spacecraft attitude is spin stabilized and a passive damper is provided to damp nutations. Synchronous orbit injection is accomplished by firing an Apogee Kick Motor (AKM).

The precession maneuver for orienting the spacecraft for AKM burn, despinning the spacecraft after AKM burn, stationing and unloading reaction wheels are provided by a secondary propulsion system using monopropellant hydrazine.

The spacecraft in the orbital configuration is shown in Figure 1.

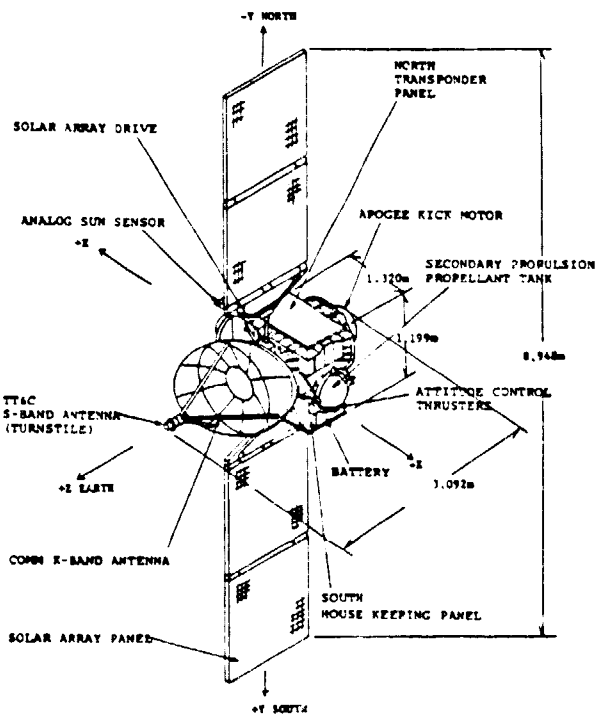


Fig. 1 Spacecraft Orbital Configuration

Earth sensor, monopulse sensor, and antennas are mounted on the earth viewing surface of the isolated by an insulated truss to minimize temperature effects. A S-band telemetry antenna is mounted forward of the K-band feed horns to minimize pattern interference from any other spacecraft element.

The solar cell array which tracks the sun is positioned outboard of the antenna by stand-off yokes. Completely redundant solar cell array drives and power takeoff assemblies are connected via a throughshaft.

The equipment module which is the main structual element supports the following subsystems:

a. Communications Subsystem
b. Tracking, Telemetry and Command Subsystem
c. Attitude Control Subsystem
d. Electrical Power Subsystem
e. Structure Subsystem
f. Thermal Control Subsystem
g. Secondary Propulsion Subsystem
h. Apogee Kick Motor

As shown in Figure 2, modularity and accessibility permitting parallel subsystem assembly and test, are emphasized on the design.

The spacecraft weight distribution and subsystem power requirement are shown in Table 2.

The reliability prediction for subsystems and the overall spacecraft reliablility after 3 years are shown in Table 3.

The key overall spacecraft performance parameters are presented in Table 4, and a functional block diagram of the spacecraft is shown in Figure 3.

Table 2 Spacecraft Weight and Power Summary

	Weight (Kg)	Ave. Power (Watts)
Structure/Mechanical	76.2	-
Thermal Control	21.6	29.5
Electrical Power	73.4	11.3
Attitude Control	26.6	22.4
Secondary Propulsion	47.7	-
Apogee Kick Motor	341.0	-
Tracking Telemetry & Command	11.6	29.5
Antenna	7.0	-
Communication	62.7	626.4
Ballast	2.2	-
Total	670.0	719.1

Table 3 Reliability Prediction

Electrical Power Subsystem	0.994
Attitude Control Subsystem	0.902
Communication Subsystem	0.852
Tracking Telemetry & Command Subsystem	0.968
Thermal Control Subsystem	0.999
Secondary Propulsion Subsystem	0.984
Structure Subsystem	0.999
Apogee Kick Motor Subsystem	0.996
BSE System	0.725

Table 4 Spacecraft Performance Parameters

Antenna Pointing Accuracy	± 0.2° (3 σ)
Orbit Positioning Accuracy	± 0.1°
Solar Array Power	970 watts (worst case BOL)
Orbit Life	3 years (expendable limit)
Reliability	0.725 (3 year mission)
Launch Weight	670.5 Kg

Subsystems Design Features

(1) Communications Subsystem

The Communication Transponder is a K-band single conversion rebroadcast-transponder with provision

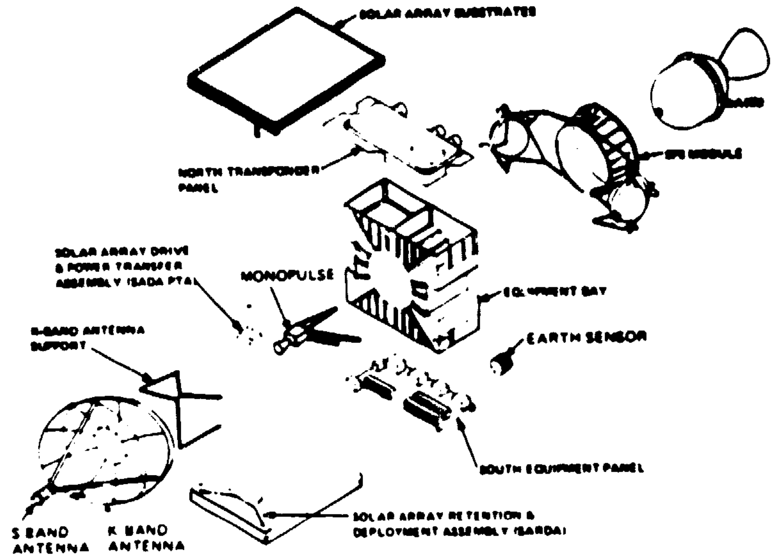


Fig. 2 Exploded View of the Spacecraft

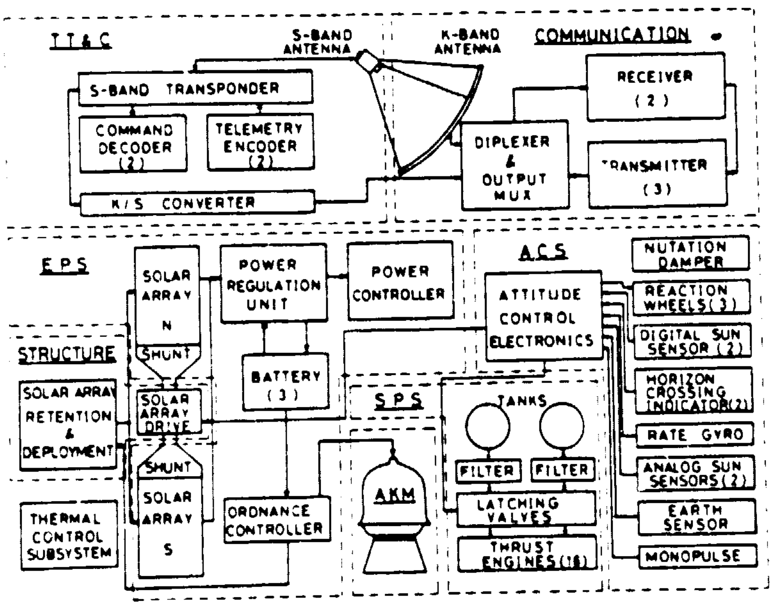


Fig. 3 Functional Block Diagram of the Spacecraft

for frequency conversion of K-band TT&C signals to operate with S-band TT&C equipment.

Transponder block diagram is shown in Figure 4.

Refering to the block diagram, the received signals (TV and TT&C) are routed by the diplexing circulator to the receive multiplexer, and separated. The TT&C signal is downconverted in one of two redundant mixers to 2.3 GHz, and coaxially interconnected to the S-band receiver. The 14 GHz TV signal is routed to one of two redundant receivers by the latched ferrite switches. In the receiver it is amplified by Tunnel Diode Amplifier (TDA), and then downconverted by 2.3 GHz in a wide band mixer. The resultant 12 GHz signal is amplified in another TDA and separated into its respective channel (A and B) components at the input multiplexer.

The input and output switching assemblies operate in conjunction to route the channel A and B (channelized) signals through their respective primary transmitters, or either channel through the redundant transmitter. Within each transmitter the respective channel signals are amplified by Low

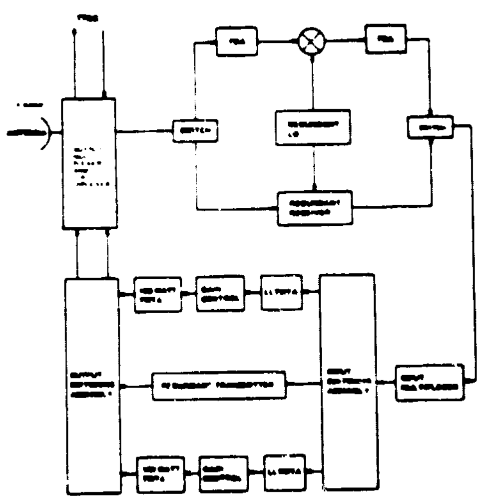


Fig. 4 Transponder Block Diagram

Level TWT (LLTWT),

The level control electronics maintains the 100-watt TWT drive power at a constant level independent of received signal power com, nent gains or frequency.

The 100-watt TWT output signals are routed through the output switching assembly to the output multiplexer where the signals are band limited and combined onto a common waveguide manifold with the TT&C transmit signal. The S-band transmit signal is upconverted in a parametric upconverter to K-band. The combined TV and TT&C transmit signals are then routed through the diplexing circulator to the communication antenna. The transponder performance is summarized in Table 5.

Table 5 Transponder Capability

PFD at Spacecraft	-82 to -96 dBW/m^2
Level Control	Automatic over 16 dB range
TWT Drive Control	64 levels by command
Noise Figure	Less than 8.5 dB
TWT Output Power	100 watts minimum
Frequency Response	±1.0 dB in band
Response Attenuation	-50 dB below peak at 50 MHz outside band

Spacecraft K-band antenna is a center feed shaped beam parabolic antenna which has three feed horns, and the antenna pattern studies have developed a coverage footprint as shown in Figure 5. This multibeam pattern provides for a rapid falloff to the westward of Japan and a wider beam to the eastward.

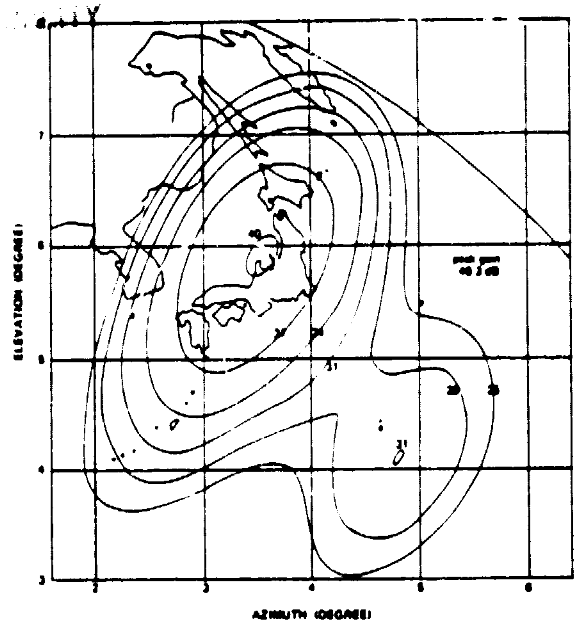


Fig. 5 Ground Coverage Footprint

(2) Tracking/Telemetry and Command Subsystem (TT&C)

The TT&C subsystem block diagram is shown in Figure 6. The TT&C subsystem utilizes a redundant S-band receiver-transmitter combination and a redundant K/S band converter to accept uplink commands, send spscecraft telemetry to earth on the downlink carrier, and process a tone modulated signal for spacecraft ranging information.

All command and ranging signals required during prelaunch, launch and transfer orbit phases will be received at S-band through the S-band antenna, passed through the diplexer to the S-band receiver. Ranging signal will be detected and presented to the S-band transmitter. Spacecraft data will be sampled, encoded and formatted for presentation to the S-band transmitter where it will be summed with ranging tones and transmitted via the diplexer and antenna.

Table 6 summarizes the TT&C subsystem characteristics.

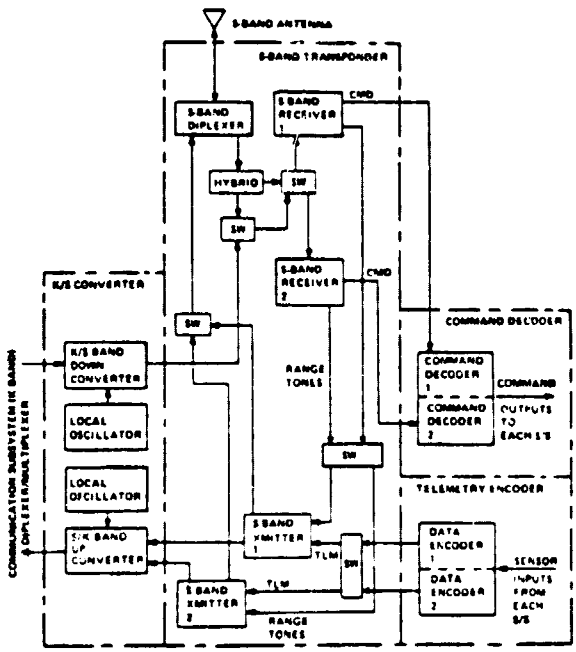


Fig. 6 TT&C Block Diagram

Table 6 TT&C Characteristics

Item	Telemetry	Command	Ranging
Carrier frequency	S Band & K Band	S Band & K Band	S Band & K Band
Modulation	PCM/PSK/PM	PCM/PSK/FM/PM	Tone/PM
Bit Rate	512 BPS	1000 BPS	-
Capability	≈300 Telemetry points	≈200 Commands	

(3) Attitude Control Subsystem (ACS)

The Attitude Control Subsystem (ACS) block diagram is shown in Figure 7. The ACS controls spacecraft attitude, spacecraft linear velocity (with Secondary Propulsion Subsystem) and spacecraft momentum during the period from booster separation through on-orbit pointing, including reacquisition as may be required.

The spacecraft is spin stabilized in the transfer and injection modes. On-orbit control is achieved through a zeromomentum, three-axis stabilization system. A passive earth sensor, a monopulse sensor, and solar array mounted sun sensors are used to derive roll, pitch and yaw error signals. Processing of the sensor signals allows any two of the three sensors to provide sufficient information for three-axis control.

When on-station in synchronous orbit, the ACS sensor complement includes: an earth sensor detecting spacecraft axis pitch and roll errors:

a monopulse sensor detecting roll and pitch errors referenced to the RF beam center: and analog sun sensors form which yaw error is extracted. Normal operation is the utilization of the attitude information from any two of these three sensors.

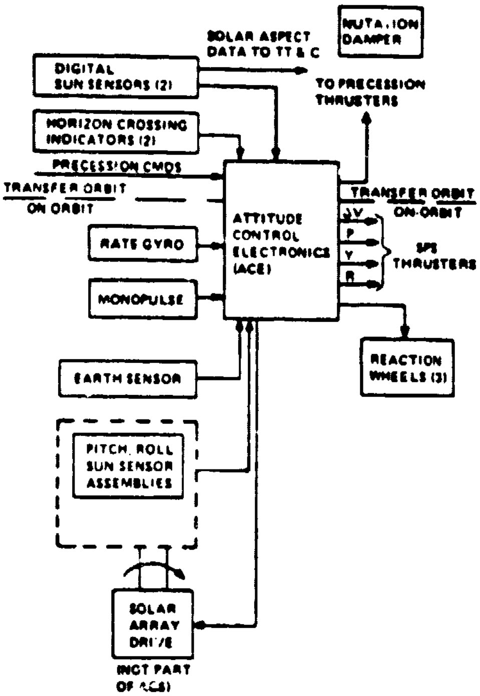


Fig. 7 ACS Block Diagram

(4) Electrical Power Subsystem (EPA)

The Electrical Power Subsystem (EPS) provides the elecrical power for all modes of spacecraft operation from launch through parking and transfer orbits, and for three years in the synchronous orbit. The power subsystem utilizes a solar array for power generation and batteries for energy storage. A solar array consists of four panels, two per spcecraft side, and batteries consist of three 4-Ah sealed nickel-cadmium batteries. The battery provides energy for spacecraft loads during launch, ascent and transfer orbit injection until the folded array assemblies can be illumunated. After the launch vehicle shroud is removed, 50% of the active surface of the array is exposed. The array is restrained in a folded position during launch and throughout the transfer orbit.

After injection into synchronous orbit the array is released, fully extended and oriented to the sunline. During the sunlit portion of the orbit, energy is transferred directly from the solar array to the load, and during periods of array eclipse the batteries are discharged through a boost regulator to provide power required for spacecraft loads. The EPS performance characteristics are shown in Table 8.

Table 8 EPS Performance Characteristics

Solar Array Area	9.58 Meters^2
Minimum Array Power - 3 Years	780 Watts
Maximum User Load - 3 Years	748 Watts
Regulation at EPS Terminals	28 Volts $\pm$ 1%
Maximum Depth of Discharge (including 2 battery condition)	60%

(5) Thermal Control Subsystem (TCS)

The function of the Thermal Control Subsystem (TCS) is to maintain all spacecraft component temperatures and temperature gradients within design limits for all missions. The TCS which has been designed to achieve this objective consists of passive element supplemented by heaters, thermostats, and heat pipes. The passive elements consist of multilayer insulation blankets, thermal control coatings, and insulation standoffs.

The primary heat rejection surface of the spacecraft is the transponder (north) panel. The energy dissipated on the north panel tends to be concentrated in discrete locations on the panel such as below the TWT bodies. In order to distribute this energy uniformly over the panel and prevent "heat spots", heat pipes are used. Because of the large variation in power dissipation on the north panel, there are compensation heaters located on the panel.

The south panel has much less power dissipation than the north panel, and the power dissipation on this panel is more constant than on the north panel. Therefore, no heat pipes are required on the south panel.

There are several components which require special thermal control: These are the batteries, the Secondary Propulsion Subsystem (SPS), the earth sensor, the monopulse sensor, the RF oven, the AKM, and the shunt load panels.

Launch, Insertion and Orbit Stationing

The sequence of major events from launch through orbit stationing is depicted in Figure 8.

The spacecraft will be launched from the United States Eastern Test Range, Florida by Thor-Delta 2914 launch vehicle into 95-degree flight azimuth. The spacecraft will be injected into a nominal 166.7 X 35786.2 Km, 27.20 degree inclination transfer orbit.

The third apogee is selected for nominal orbit injection to allow time for preceise orbit determination and spacecraft attitude adjustment. After attitude stabilization to the earth, orbit velocity adjustments are made to correct injection errors and to optimize the drift to the final orbital station at 110° East Longitude, normally 30 days after synchronous orbit injection.

III. Earth Stations

The constitution of overall BSE experimental system is shown in Figure 9.

Features and characteristics of various earth terminals of the BSE program are described here.

Main Transmit and Receive Station (MTRS)

MTRS is the key station for the BSE program experiments and now under construction at Kashima Branch of RRL which is located about 100 Km north-east of Tokyo. MTRS is used for the 14 GHz/12 GHz TV bradcasting expriments and TT&C operations in the same frequency bands during the mission experiment period. The overall functional block diagram is shown in Figure 10. The antenna is a 13 meters dish near-field Cassegrain type of Az-El mount, and installed on the roof of the three stories main control building symmeterically with the K-band antenna for Experimental Communication Satellite Program.

Roughness of the main reflector surface will be kept within $\pm$ 0.3 mm rms, and four reflectors

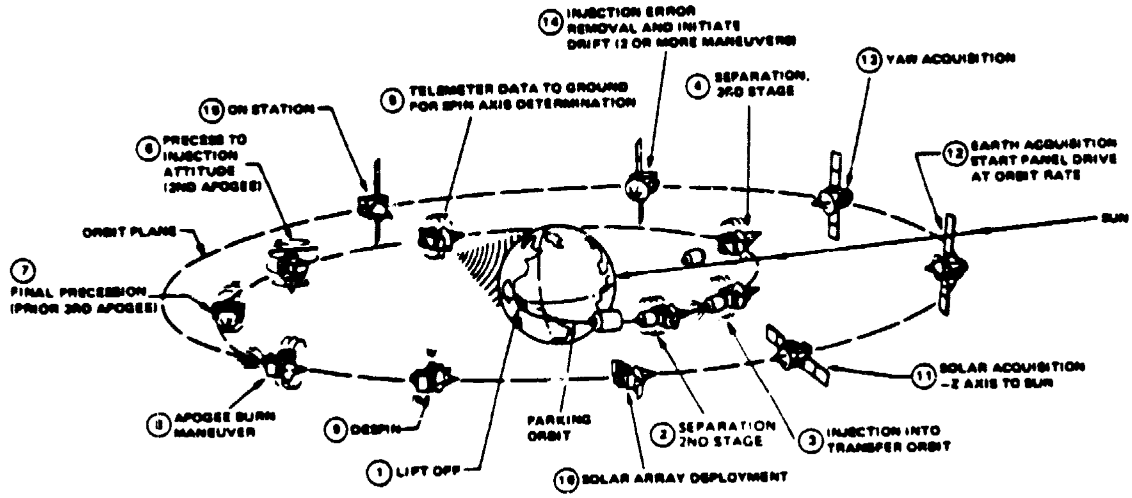
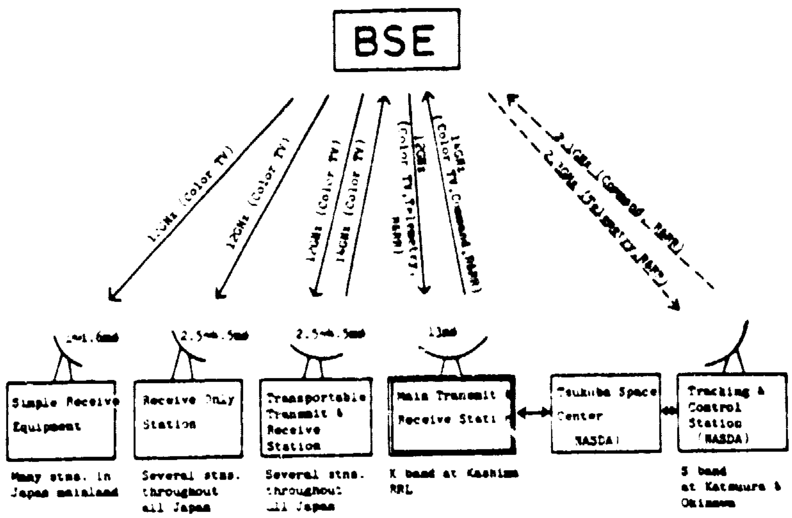


Fig. 8 Launch-to Orbit Stationing Sequence

Fig. 9 BSE Experiment Overall System



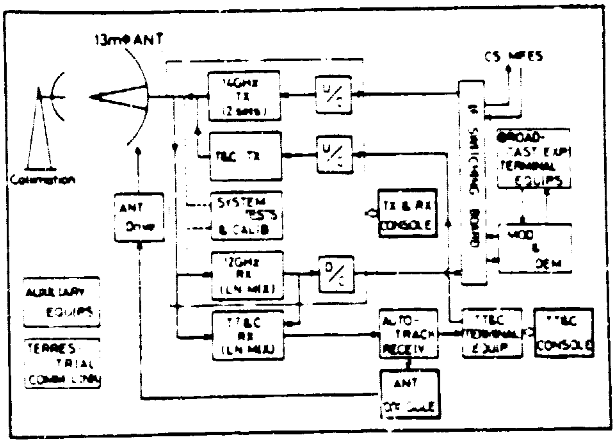


Fig. 10 Functional Block Diagram of the Main Transmit and Receive Station (MTRS)

beam waveguide feeding system is adopted. The primary radiator of corrugated conical horn and duplexing waveguide assembly together with the transmitters and receivers are fixed in the building room separated from the rest of the antenna structure. In this configuration, feeding loss reduction and maintenance simplification are achieved. The feature of the antenna is shown in Figure 11. The antenna is whole-sky steerable, and a higher mode (TM_{01} & TE_{01}) type auto-tracking function is facilitated. The tracking accuracy will be better than 0.01° rms at -125 dBm receiver input level. In the duplexing waveguide assembly, a polarization auto-tracking mechanism is also equipped, and the linear polarization wave will be received with matching accuracy within ± 0.1°. The typical electrical characteristics of this antenna system is as follows:

System G/T	above 32.0 dB°K (12 GHz, 40°El)
Transmit EIRP	78.5 - 91.5 dBW (variable)
Frequency band	14.0 to 14.5 GHz for transmit
	11.7 to 12.2 GHz for receive
Gain with feed loss	62.0 dB at 14.25 GHz
	61.0 dB at 11.95 GHz
Noise temperature with feed loss	below 65°K (12 GHz, 40°El)
Cross-plarization discrimination	expected 30 dB (12 GHz, linear)

There are three sets of 14 GHz transmitters, two of which are for TV signals transmission and the other one is for command/renging signals

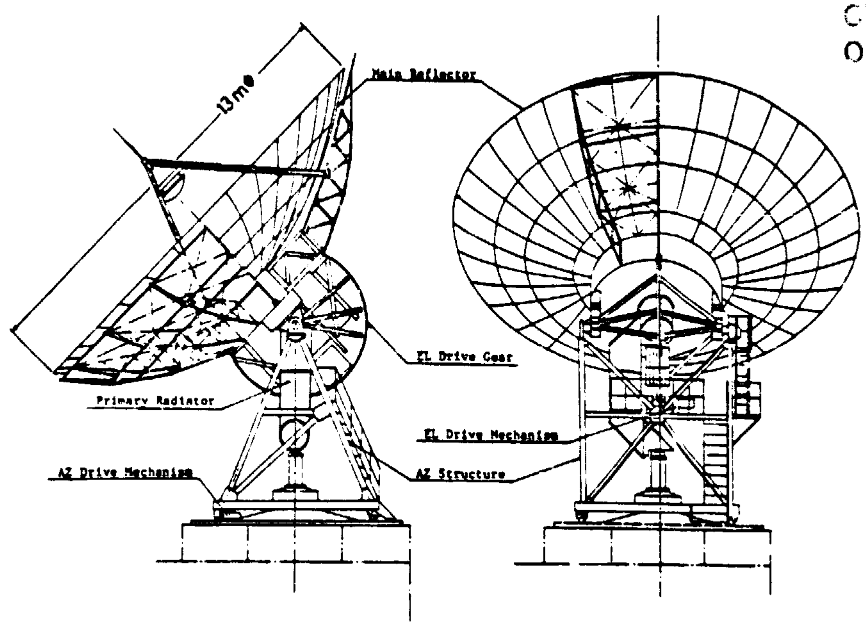


Fig. 11 Feature of the K-band Antenna of the Main Transmit and Receive Earth Station (MTRS)

transmission. They consist of 140 MHz/14 GHz up-converters, 14 GHz high power TWT amplifiers and a transmitter output switching diplexer. Output powers of the TV transmitters can be set at any level from 100 watts to maximum 2 KW by use of the pin diode attenuator in the level control units, and the output power of the command transmitter is set at fixed level of 200 watts.

The received 12 GHz signals both of TV and telemetry/ranging are fed from the antenna subsystem and down-converted to 400 MHz IF signals by low noise mixers of 600°K noise temperature. The mixers are image compressor type and their maximum bandwidth is 180 MHz. The down-converting mixers of the same type for the antenna pointing and polarization angle auto-tracking receivers are also installed. In order to keep phase coherency of these signals, output of the common X-tal oscillator is distributed to each mixer as their local signals after frequency multiplication and amplification by a Gunn diode amplifier.

The 400 MHz IF signals are again downconverted to 140 MHz band 2nd IF signals and fed to modulator/demodurator sections through IF signal switching board.

There are two wide band 140 MHz FM modulation/demodulation equipments, various bandpass filters, average and clamped types AFC amplifiers, dispersal and emphasis circuits as well as various video/audio signals baseband equipments for experimental purposes. The TT&C subsystem consisting of command signal generator/modulator, telemetry signal demodulator/decommutator, ranging equipment, Tosbac-40C computing systems with various peripheral devices and others are installed. Ground communication networks connecting this station and other organizations such as RRL HQ, NASDA's Tsukuba Space Center, NHK and other earth teminals will be established by 1977 fiscal year.

Other Earth Stations

Transportable Transmit and Receive Stations (TTRS) are used for TV signal transmission and reception at many places throughout Japan. They are equipped with one channel TV transmitter of maximum output power of 2 KW 2 TV channels receiver of 910°K in system noise temperature including 1 dB rainfall attenuation effect.

There are two kinds of TTRS, type A and B: the former is intended to be used in many places throughout Japan including the surrounding remote islands, and the latter is limited only in the mainland. The type A has a 4.5 meters diameter antenna which is designed to be easily transported and assembled, and the whole transmitters and receivers are housed in one shelter. It will be installed in any place on the ground or on the roof of existing buildings after transportation. Step track antenna pointing device is provided to follow the satellite motion. In the output high power amplifier, a newly developed air-cooled klystron with 50 MHz bandwidth at 14 GHz band is used.

The type B is fully mobile, and all subsystem, including a power supply generator, are installed in a van. The antenna pointing is manually controlled. The antenna whose diameter ranges from 2.5 to 3 meter, is mounted on the rear end of the van. The functions are almost the same as those of type A except its mobility. Figure 12 shows the feature of the TTRS Type A.

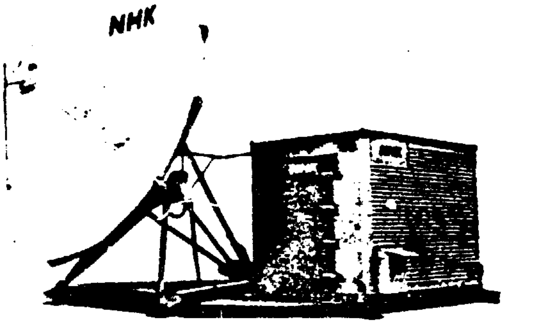


Fig. 12 Feature of the Transportable Transmit and Receive Station (TTRS Type A)

Receive-only stations (ROS) are used for evaluation of community reception of satellite TV signals in the remote islands. Sometimes, ROS will be used at places not preferable for geographical or weather conditions. The diameter of an antenna to be used in the mainland is less than 2.5 meter, and 4.5 meter in the remote islands. The 2.5 meter antenna pointing is maually adjusted, and the 4.5 meter antenna has a program tracking device. The system noise temperature of these receivers is less than 660°K.

Simple Receive Equipments (SRE) have been developed by NHK Technical Researh Laboratories aiming at application to the future individual TV satellite system in K-band. The receiver features 500°K system noise temperature over 180 MHz of bandwidth, using a simplified down-converter as well as a simplified direct FM-AM modulation converter. With this technical breakthrough, low cost, high sensitive 12 GHz receivers suitable for mass production and adaptable to the existing home TV sets have been realized. Figure 13 shows the feature of SER. Link budgets of typical circuits in the BSE system is shown in Table 9.

Fig. 13 Feature of the Simple Receive Equipment (SRE)

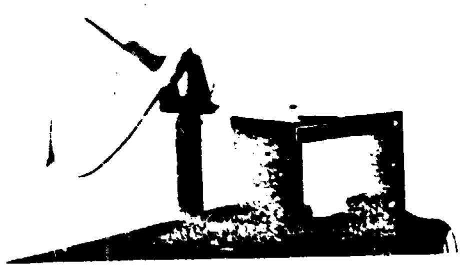


Table 9 Link Budget

Up Link (Kashima to BSE)		
TX power (dBW/ch)		20.0
TX feeder loss (dB)		-3.5
TX antenna gain (dB)		62.0
Free space loss (dB)		-207.2
RX antenna gain (dB)		39.5
RX feeder loss (dB)		-0.5
Noise power (dBW/25 MHz)		-122.6
C/N		32.9
Down Link		
Service area	Mainland	Remote Ils
Antenna of RX	1.6mφ	4.5mφ
TX power (dBW/ch)	20.0	20.0
TX feeder loss (dB)	-1.7	-1.7
TX antenna gain (dB)	37.0	28.0
Free space loss (dB)	-205.8	-205.4
RX antenna gain (dB)	43.5	52.5
Received Carrier (dBW)	-109.7	-109.4
Noise power (dBW/25 MHz)	-126.4	-126.4
C/N	19.4	19.8
Total C/N (dB)	19.2	19.6
Threshold C/N (dB)	9.0	9.0
Rain attenuation (dB) (99.99% of any month)	-7.0	-7.0
Link margin (dB)	3.2	3.6

Experiments

1. Experiments on basic technologies in the broardcasting satellite system

(1) Evaluation of the broardcasting service area; At many places in the Japanese territory and its circumference, field strength of the radio wave from the BSE, carrier to noise power ratio (C/N), TV signal quality and their variations with time will be measured. Effective service area will be evaluated comparing with that preestimated from the design data on antenna radiation pattern, transponder output power, attitude stabilization accuracy, ets. The reception of TV signal will also be conducted on ships.

(2) Experiments on TV transmission; The characteristics of radio signal transmission through the satellite are measured in items of signal level diagram, up-link and down-link path losses and their variations with time, carrier to noise ratio, signal amplitude and phase characteristics with frequency, amplitude lineality, frequency stability and so forth. Turn-around characteristics of video/sound signals are also measured varing modulation parameters.

The transmission parameters pertinent to the color TV broadcasting are as follows.

System	NTSC standard (525 lines, 30 frames/sec)
Sound subcarrier	
Frequency	4.5 MHz
Modulation	FM, Freq. deviation ±25 KHz (0-p)
Modulation	FM, Freq. deviation 12 MHz (p-p)
Sound/video ratio	1/6
Emphasis	CCIR Rec. 405-1

Of interest are advanced methods of TV transmission. These are techniques of multichannel sound multiplexed transmission (FDM type subcarrier system, FDM/TDM combination type subcarrier system, TDM system or independent carrier system), Y/C signal separate transmission, TV signal digital transmission, still pictures broadcasting and others. A distributing technique of time and frequency standard signal accompanied with the TV broadcasting signal will also be evaluated.

(3) Experiments of radio wave propagation; Statistical studies of 14 GHz and 12 GHz radio waves propagation characteristics, especially rainfall attenuation and site diversity effects, will be made by collecting data obtained at various earth terminals and using spacecraft telemetry data. Detailed studies will be made about the effects of scintillation, depolarization/polarization plane angle variation, atmospheric absorption and dispersion in addition to the study of the rainfall attenuation by utilizing rain gauges, radiometers and specially designed weather radar.

(4) Experiments on frequency sharing; Interference between the satellite and terrestrial broadcasting TV signals in 12 GHz band will be investigated by changing distance between, and antenna direction of receiving earth terminals against a terrestrial TV broardcasting station. In this experiment, NHK's experimental station for 12 GHz terrestrial broadcasting will be incorporated.

(5) Measurements of spacecraft equipment characteristics; Characteristics of the on-board K-band antenna will be measured respecting its radiation pattern in 14 GHz and 12 GHz, cross polarization, effects of thermal distortion by the solar radiation and transient responses of the antenna beam pointing during spacecraft position and attitude maneuvering.

The characterictics of the transponders will also be measured by use of test signals related to the experiment item (2). The measurements will be conducted periodically, and performance degradation with time will be investigated making reference to the prelaunch data.

2. Experiments on control and operation of satellite broardcasting system

Spacecraft control techniques such as orbital adjustment, spacecraft attitude maneuvering, etc., will be studied. Computer softwares for these operations are being developed.

Experiments of automatic and manual control of ground transmitter power will be conducted to keep the satellite receive signal level optimum against the up-link rainfall attenuation. Techniques for multiple access to a satellite from multiple transmitting earth stations are also developed. Relating to the exchange of the broadcasting TV signals from multiple stations, switching control signal transmission procedure, carrier on/off timing control technique and double illumination or signal break-off effects will be investigated.

3. Evaluation of received TV signal qualities and improvement of receiving techniques

Evaluation of received TV signal qualities will be made extending over a long period of time at ROSs and SREs which are located at many places of various geographical and weather conditions. Local states of radio wave interferencs or jammings, effects of natural features on the earth or effects of massed buildings, power-transmission lines and towers, overhead railways and other various constructions will be investigated. The reception techniques regarding easiness of equipment installation, maintenance and initial satellite acquisition will be improved. Techniques of re-broadcasting at TTRSs or ROSs will be developed through these experiments.

Acknowledgment

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EXPERIMENT RESULTS OF JAPANESE BSE PROGRAM IN THE FIRST YEAR

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Abstract

The Japanese Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) was launched successfully on April 8, 1978 JST. BSE was stationed on April 26 at the predetermined geostationary orbit position, 110 degrees east longitude. After the initial check of the satellite function, various kinds of satellite broadcasting experiments started on July 20, 1978. The experiments will be conducted for three years in order to obtain the technical data necessary for establishing future operational domestic satellite broadcasting systems. Most parts of experimental items planned in the BSE program have been carried into operation. This paper will present the results of BSE experiments which have been obtained heretofore along with a brief description of future experiment plan.

1. Introduction

The Japanese Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) was launched successfully on April 8, 1978 JST from the Eastern Test Range of USA, using a Delta 2914 launch vehicle. After several precession maneuvers, Apogee Kick Motor (AKM) was fired at the third apogee and put into the drift orbit.

On April 26, BSE was stationed at the predetermined geostationary orbit position, 110 degrees east longitude. The BSE is held within the accuracy of ± 0.1 deg. and ± 0.2 deg. in orbit position and antenna beam pointing respectively.

The BSE is a three-axis stabilized spacecraft weighing about 350 Kgs in orbit.

It has two sets of Ku-band (14/12 GHz) transponders with 100 watt output power, and a uniquely shaped beam paraboloidal antenna for color TV broadcasting.

On July 20, 1978, the Radio Research Laboratories (RRL) of the Ministry of Posts and Telecommunications (MOPT) and the Nippon Hoso Kyokai (NHK: Japan Broadcasting Corporation) started various kinds of satellite broadcasting experiments. The experiments will be conducted for three years in order to obtain the technical data necessary for establishing future operational domestic satellite broadcasting systems. NASDA is responsible for the control and maintenance of the BSE during the experimental period.

The earth terminals which participate in the BSE experiments are Main Transmit and Receive Station (MTRS), two types of Transportable Transmit and Receive Stations (TTRSs, Type A and B), three types of Receive Only Sations (ROSs), and many Simple Receive Equipments (SREs).

Since the beginning of experiments, most parts of experimental items planned in the BSE program have been carried into operation.

Main experimental items of the BSE program are experiments on the evaluation of broadcasting service area, experiments on TV signal transmission, experiments on radio wave propagation, experiments on frequency sharing, experiments on satellite broadcasting signal reception, experiments on control and operation of satellite broadcasting system, and so on.

Details of results of these experimental items will be described in the following sections.

2. Experiments on the evaluation of broadcasting service area

The service area can be evaluated by measuring the field strength and received TV signal quality at many places throughout Japan. The satellite antenna has a suitable radiation pattern for providing high quality color TV broadcasting services to the whole Japan territory. Fig. 1 shows the BSE antenna radiation pattern and locations of the various earth terminals which participate in the BSE experiments, plotted on a map of Japan.

The Main Transmit and Receive Station (MTRS) is located in Kashima, which provides not only TV signal transmission and reception, but also Ku-band TT&C operation for experimental purposes. The receiving stations (ROSs and SREs) usually receive TV signals which are transmitted from MTRS or TTRSs. For TV-reception tests, additional SREs of about thirty are further incorporated.

The measurements of the received carrier level, video signal-to-noise ratio, and TV signal quality assessment have been carried out by MTRS, TTRSs, ROSs and SREs. One example of measurement results is shown in Table 1.

3. Experiments on TV signal transmission

3.1 Satellite transponder characteristics

To measure initial performance and time variation of satellite transponder characteristics, the initial check and periodical checks per every half year have been performed. Measured items are input-output characteristics (linearity, AGC characteristic, etc.), output characteristics (intermodulation, mutual modulation, spurious emission, etc.), amplitude characteristics, delay characteristics, frequency stability, noise characteristics, and so on.

The measurement results of all these characteristics were satisfactory. Fig. 2 shows the variation of satellite output power from July 1978 to March 1979. The output level of satellite was obtained by converting the receiving level at MTRS. Each point gives a monthly average of every day values which are measured in a fixed measurement method at the same time in the morning.

As a whole, level variation of ± 0.5 dB is observed.

3.2 Standard TV signal transmission

(1) Radio frequency transmission characteristics

To clarify the RF transmission characteristics of satellite transmission links, various characteristics have been measured at the main station. They are level diagram of satellite links, transmitting power and its variation in up and down links, C/N and S/N in up, down and overall links, frequency characteristics (amplitude, delay, DG, DP), transponder input-output and frequency stability, spurious and intermodulation characteristics, and so on.

Here several representative characteristics will be described. As level diagrams are the most fundamental characteristics, they have been measured from the initial check period up to the present.

An example of radio frequency link levels between the MTRS and the BSE is shown in Table 2. The results show good correspondence with calculated design values.

At the main station, C/N is usually very high compared with other satellite links. So C/N can be measured over very wide range in the BSE links. Fig. 3 gives measurement results of C/N in up and overall links. C/N in uplink can be estimated from EIRP of the main station, and also from telemetry data of the satellite. Both estimated C/N values coincide within tolerances of 1 to 2 dB which correspond to telemetry quantization errors.

Fig. 4 gives the relation between C/N and S/N. Measured values coincide fairly well with calculated curves, and the improvement effect by emphasis (2.9 dB) is also apparent.

Using LCE (Level Control Electronics) settings as parameters, C/N in up, down, and overall links were measured to get noise figures of transponder with varying EIRP of the main station. Fig. 5 gives noise figures for channel A1 transponder. The noise suppression effect caused by HL-TWT's (100 W TWTA) nonlinearity is apparent.

It is fundamental to examine the frequency characteristics of amplitude, delay, differential gain (DG) and differential phase (DP) to know the satellite links characteristics for transmitting FM television signals.

In the satellite loop-back measurements, characteristics of both the satellite transponder and the earth station are mixedly measured. The characterisics of satellite transponder are obtained by subtracting the characteristics of earth station from the characteristics measured in satellite loop-back.

To transmit FM television signals faithfully, it is necessary to have flat amplitude and delay characteristics in pass-band. Fig. 6 shows measured amplitude and delay characteristics of overall link. Equalizers in the main station are effective in improving overall amplitude and delay characteristics. Fig. 6 gives the measurement results in March 1979, showing little change from the characteristics measured in July of 1978.

Fig. 7 shows DG and DP characteristics of overall link, which were measured at the same period as Fig. 6. It is seen from these measurement results that the BSE links have excellent RF transmission characteristics as television transmission links.

(2) Baseband transmission characteristics

Measurements of baseband transmission characteristics have been performed for many items. For video signals, they include modulation characteristics, amplitude and delay characteristics, waveform distortion, linearity (DG,DP), S/N and subjective assessment of picture quality. For sound signals, they are modulation characteristics, emphasis characteristics, frequency characteristics, distortion, S/N, and subjective assessment of sound quality, and so on The BSE experiments have been conducted under the same parameter setting, assuming FM transmission of conventional NTSC-M color television signal as standard. Since January of 1979, dispersal signal has been added.

It is seen from these measurement results that baseband characteristics are almost determined by those of the main station, and are scarecely influenced by the satellite transponders.

3.3 Advanced TV Broadcasting system

Various kinds of signal transmission experiments have been carried out with the purpose of developing advanced TV Broadcasting technique or new application of satellite broadcasting system. Among them are PCM-TV transmission, ranging system using TV synchronous signal, standard time and frequency dissemination system via satellite, high-definition TV transmission and so on.

(1) High-definition television transmission

A high-definition television system parameter tentatively specified by NHK Technical Research Laboratories is shown in Table 3.

Fig. 8 shows the experimental system for the high-definition TV transmission with the BSE. A unique feature of this system is that the luminance (Y) and chrominance (C) signals are transmitted through the separate radio frequency channels. Necessary RF band widths is 80 MHz and 25 MHz for Y and C signals, respectively. Major advantage obtained by the Y/C separate transmission over the conventional composite color signal transmission is a great improvement, approximately 10 dB, of the signal to noise ratio. In other words, the satellite transmitting power can be decreased to 1/10 of that required for the conventional transmission method.

In November 1978, the first transmission experiment through the BSE was carried out at NHK Technical Research Laboratories for four days. As the signal sources, a color print of landscape scene and a strip from a 70 mm movie were picked up by the return beam Saticon camera and the special telecine equipment, respectively. Quality of the received picture was quite satisfactory so that one can hardly tell the degradation after the satellite transmission except a very slight increase of noise. Table 4 shows the carrier-to-noise ratio (CNR) measured on the Y and C channels. Also an average picture SNR is shown in Table 5. At the second transmission experiment held in March 1979, a high-definition TV reception was successfully demonstrated at the Ministry of Posts and Telecommunications down town in Tokyo.

The channel plan to be applied to the 12 GHz broadcasting satellite system operated in the ITU

Regions 1 and 3 has been decided by the World Administrative Radio Conference held in 1977 (WARC-BS). Since the plan is based on the conventional TV system such as NTSC, PAL or SECAM, it is evident that the high-definition TV described here does not conform with the technical standards specified by the plan. From the technical point of view, however, the experiment still remains to be meaningful because the effectiveness of the Y/C separate transmission method is proved through the actual satellite path, in considering its application to the 22 GHz and higher frequency bands allocated to the broadcasting service.

(2) Preliminary experiment on the dissemination of time and frequency

The dissemination of time and frequency standard by means of TV signals from a broadcasting satellite has a great advantage in the point that one can utilize such a system at any place throughout the country, using a simple receiving system with the same type of calibrating apparatus. But such system suffers from the frequency doppler shift due to the satellite orbital position variation. It is, therefore, necessary to take some preventive measures against this sort of frequency shift in order to disseminate the highly precise frequency standard.

In the doppler shift measurement system. Rb (rubidium) and Cs (cesium) atomic frequency standards were installed respectively at the BSE main station (at Kashima) and the RRL headquarters (at Koganei), about 100 Km apart each other. The two frequency standards are precisely synchronized in frequency to 1×10^{-12}, via TV synchronizing signals in the terrestrial TV signals. At both places the same type frequency synthesizers (HP 5100A) are used to generate reference color subcarriers. At Koganei, a simple receiving equipment with 1 mϕ antenna was used, and received composite video signal was used to "GENLOCK" a sync-generator, of which 3.58 MHz output signal was used to measure the frequency doppler shift averaged over 10 minutes by way of reading the phase comparison record.

The experimental result is shown in Fig. 9. Curve a gives measured doppler values at Koganei, together with calculated ones at Kashima which were estimated from predicted orbital values. Measured values coincide with calculated ones fairly well within the measurement error of 10^{-11} in the phase difference recording, although the doppler shift amounts to $\pm 4 \times 10^{-9}$ which is comparatively large value due to the fact that the measurement period was just before BSE orbital correction maneuvers, and also just at a new moon time meaning much influence of heavenly bodies.

Curves b and c show respectively the values of doppler shift, relative to the value at Kashima, at Wakkanai and Okinawa, the farthermost locations in the country. These two curves show variation amplitudes of $\pm 2 \times 10^{-10}$. This means that it is possible to receive standard frequency with the error within 2×10^{-10}, everywhere in the country if some measures are taken to cancel the doppler shift as received in Tokyo area. That will be realized by the phase (frequency) control of the transmitter by use of the prediction value or the servo control loop.

Further, it can be expected to get precision better than 10^{-11} by the method of averaging over 24 hours or utilizing zero doppler shift time calculated from orbital prediction value.

As for the influence of transmission path, there was little influence on the phase comparison even in the hard rain time. So it is thought that 12 and 14 GHz propagation characteristics do not give any severe influence on the time and frequency dissemination.

(3) Multi-channel still picture broadcasting system

Experiments on the transmission of approximately 50 still picture signals each consisting of a series of still color picture accompanied by digitally coded sound signal were conducted using one television channel exclusively.

The basic transmission parameters of the still picture broadcasting system such as the very low frequency transient characteristics and the pulse code transmission characteristics were measured by the transmission test via satellite.

From these test results it was concluded that the still picture broadcasting system could be realized which is compatible with the satellite broadcasting of standard television system.

(4) Multi-channel sound multiplexed television system

The sound multiplexing system was designed to transmit several sound signals using two sub-carriers 4.5 MHz and 5.0 MHz. The 4.5 MHz sub-carrier which carries main sound signal is compatible with the terrestrial television broadcasting. The 5.05 MHz sub-carrier is capable of transmitting up to four 5 KHz signals.

As a result of transmission test via satellite, the compatibility with the standard transmission system was confirmed and the cross talks between each sound channels and the cross effect from sound channel to video channel were found to have no major problems.

(5) PCM-FM sound transmission

The purpose of the experiment is to provide data to establish sound program broadcasting as a means of broadcasting high quality stereophonic or multi-channel sound programs.

The experiment was conducted with PCM transmission of stereo sound signals of 1.544 M bit/s using four phase PSK modulator.

As a result of experiment, the relation between C/N and the Bit Error Rate was quantatively cleared and the result was very near to that of theoretical value.

(6) Digital TV transmission

To search the possibility of digital TV broadcasting, a series of experiments on the digital transmission of TV signals have been conducted in both MTRS and TTRS of type B.

Measurements were performed to obtain fundamental data such as transmission characteristics of satellite link, Bit Error Rate characteristics for 4- or 8-phase PSK transmission in satellite links, 4-phase PSK transmission of DPCM coded color TV signals.

4. Experiments on radio wave propagation

The frequency band of 12 GHz allocated to satellite broadcasting has been applied to the down-link in this experiment, together with 14 GHz to the up-link. Since these frequencies are more easily affected by rainfall and snow than 4/6 GHz of the C-band, it is necessary to investigate propagation characteristics in various kinds of climate in Japan, in order to know how much percentage of time is guaranteed for the satellite broadcasting.

Here several propagation characteristics obtained at various locations in Japan, cocerning 14 and/or 12 GHz along the satellite-earth path for periods up to about one year will be described.

4.1 Data acquisition and processing

The locations of the stations concerned with the propagation measurements are already shown in Fig. 1. At the MTRS, the K-band beacon level (11.7 GHz) is received for measuring rain attenuation and depolarization. The other stations usually receive the TV signal which is transmitted from the MTRS or TTRSs.

The measured data at the MTRS are processed and edited by an on-line computer. In parallel with the measurement of radio signal from the satellite, several kinds of observations have been conducted in the MTRS, using a network of rain-guages, a rain radar of the C band and others.

Concerning with NHK, the transmission of data measured and temporarily memorized at the TTRS and ROSs is performed daily through telephone lines or via the BSE in-band talk channel, and finally the data are edited on MTs.

One of the most important points of processing is how accurately and efficiently to extract additional attenuation due to rainfall from given data. The received power can be fluctuated with influence of such factors as attitude and orbital position of the satellite and pointing error of a receiving antenna. The computer processing procedure to eliminate the influence of other factors than rain was devised and it oprates fairly well.

4.2 Results

In Fig. 10 is shown an example of comparison between rain attenuations of the up- and down-links on a rainy day at Kashima. The plotted data are scattered a little for small attenuations. The ratio of attenuation of the up- to the down-link in decibel is about 1.4 which is almost equal to the theoretical value. As this relation was kept for other various rain events, it is possible to convert the statistics of the down-links to the ones for the up-links.

Fig. 11 shows cumulative distribution curves of attenuation of the BSE beacon signal (11.7 GHz) as well as the ones from the propagation experiment with the Engineering Test Satellite type II (ETS-II), which was performed during May 1977 to April 1978 using 11.5 GHz. As the frequency in the ETS-II is near the one in the BSE, the statistical curve of the ETS-II can be applicable also for the down-link of the BSE.

Fig. 12 presents cumulative distributions of rainfall rate at the main station. Correlation between the curves in Fig. 11 and those in this figure are not good. Because the distribution of rainfall covers 100 % of the time and that of rain attenuation covers only about 70 % due to various troubles of the system.

These statistics have to be taken at various locations and then receiving system parameters such as antenna size can be determined, required for practical service, when a certain amount of rain attenuation is given for a specified percentage of the time.

Cumulative distributions of rain attenuation and rainfall rate were derived from the data obtained at the ROSs and the TTRS during August to December, 1978. In Fig. 13 are shown the distributions for two typical locations, Owase and Kesennuma where the maximum and minimum rainfalls occurred respectively during the observation. In Table 6 rain attenuation and rainfall rate are given for 1 and 0.1 % of the time at each location, which were read from the above-mentioned distributions, together with the corresponding observed time. The observation of attenuation has been limited due to the cease of transmission on Saturday and Sunday, besides at nighttime in the beginning of the measurements. The rainfall rates in Table 6 are different from the one to be read in Fig. 13, because the rainfall data in the figure are employed only during the observation of attenuation.

In Fig. 14 are plotted points at which attenuation and rainfall rate occurred for the same percentage of time. From the figure, effective path length is about 3 km, which is almost coincided with the one in CCIR Report 564-1 and the result by the ETS-II. Effective path lengths were also derived from the measurements at the ROSs, of which the values for typical locations are given in Table 7. In comparison with the above-mentioned value at Kashima and the ones quoted in the same table from the CCIR Report, the values in the table are considerably shorter for severe rainfall rates. Although this may be ascribed to difference of meteorological conditions between the measuring locations, more data are needed to draw a conclusion.

The analysis of the propagation measurements has revealed preliminary but interesting results on statistics of rain attenuation at various locations of Japan, which would lead to final fruitful results at the end of the experiment for the expected full three years, besides an efficient method for eliminating non-propagation effects from obtained data.

5. Experiment on frequency sharing

In order to lay down basis for sharing criteria between up-links to broadcasting satellite (BS) and between up-links to BS and to communication satellite (CS) using the same frequency band at around 14 GHz, experiment on evaluation of interference criteria was carried out using the BSE.

In this experiment, interferences between the following simulated links have been considered.

[1] BS (FM-TV) → BS (FM-TV)
[2] BS (FM-TV) → CS (FM-TV)
[3] CS (FDM-FM) → BS (FM-TV)
[4] BS (FM-TV) → CS (FDM-FM)

Transmission parameters used for each uplink are shown in Table 8.

The TTRS type B was transported to be used mainly as interfering station at the Kashima Branch of the RRL where the MTRS is located, to eliminate error to be generated by satellite attitude drift.

5.1 Evaluation of intereferncе to the wanted FM-TV signals from the FM-TV and FDM-FM signals (cases [1] ∿ [3] above)

Subjective assessment of the wanted FM-TV signal interfered with FM-TV and FDM-FM signals, by varying an offset angle of unwanted station antenna, was conducted to obtain protection ration required and various margin which might need to compensate the difference between theoretical and actual values.

Tables 9 and 10 contain results obtained from experiment. Viewing condition used for this experiment is so different that viewers stand in front of picture monitor to facilitate them to detect interference to obtain protection ratio for high picture quality, which may be applied for up-link interference evaluation.

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Although additional experiment is required, the following preliminary conclusion could be derived:

- BS/FM-TV → BS/FM-TV: protection ratio = 38 dB
- BS/FM-TV → CS/FM-TV: " " = 31 dB
- CS/FDM-FM → BS/FM-TV: " " = 35∿32dB (60∿972ch)

5.2 Interference from broadcasting satellite service (earth to space) earth station into fixed service satellite

Interference from FM-TV into FDM-FM was measured using the 14 GHz band for up-links, changing various parameters such as the ratio of disired-to-undesired signal power (DUR), TV video signals (color bar or color test chart), energy dispersal (with or without) and frequency deviation. The signal-to-interference noise ratio was proportional to D/U as shown in Table 11 and was not affected by TV video signals and energy dispersal.

The signal-to-noise ratio was also measured, changing the antenna direction angle of BSE earth station. Experimental results agree with the calculated values as shown in Fig. 15.

6. Experiments on satellite broadcasting signal reception

6.1 Received power and its stability

It has been confirmed by the measurements carried out simultaneously at 39 locations all over Japan that received powers were generally coincided with the corresponding predicted ones as shown in Fig. 16. Deviation of the received powers from the prediction were within 1 dB for 75 % of the measurements.

Comparatively long term variations of received power were measured at the ROSs. At the beam edge of the satellite transmitting antenna, where the ROSs situated on the isolated islands, the variation showed a maximum and reached up to about 5 dB, which included pointing error 2 dB inevitable to the simple tracking antenna equipped there.

Quality of received picture has been assessed subjectively, which was almost excellent at each location, using color-bar and specially prepared VTR signals.

From the TV-reception tests, an antenna size has been derived which was required to obtain weighted SN ratio of picture of more than 45 dB for 99 % of the time at each location. The required diameter is about 1 m around the center of the beam of the transmitting antenna, about 1.6 m for the fringe area of the mainland and 2.8 m to 4.5 m for the isolated islands. These meet approximately the initial design specification.

By the TV-reception tests, it has been confirmed that received power was generally coincided with the predicted values and also that excellent quality of picture was obtained at each location all over Japan. Influence of snow, especially fall of wet snow on a receiving antenna causes severe degradation of reception. It is needed keenly to clarify its mechanism and statistics and to develop a method for improvement.

The field tests in the urban and rural areas have also been conducted to investigate the influence of buildings and topography. The influence of high-ways, rapid railways, and airports, etc. on the reception quality of TV signals from the BSE have been investigated.

6.2 Solar noise interference

The solar noise interferences were measured after the autumnal equinox in 1978 and before the vernal equinox in 1979 in many earth terminals.

It is well known that the sun transits in a beam of a ground receiving antenna toward the vernal and autumnal equinoxes, if the antenna points to the geostationary orbit. A harmful interference can be happened to reception of satellite broadcasting at that case. Increase of noise was measured at several locations with antennas of different diameter.

Fig. 17 shows increase of noise power due to the solar noise interference at a receiver, of which noise temperature is about 600 K.

Fig. 18 shows duration time of the possible solar interference per day and number of days of its occurrence. In comparison of these results with the rain attenuation statistics, it is understood that the solar noise interference affects satellite broadcasting service only for much smaller percentage of the time than rain attenuation does, and moreover occurrence time and intensity of the interference can be predicted with practical accuracy. The solar noise interference was realized to affect satellite broadcasting service only for much smaller percentage of time than rain attenuation does.

7. Experiment on control and operation of satellite broadcasting system

7.1 Range measurement of broadcast satellite utilizing television sync-pulse

The range between the ground transmit and receive station and the satellite can be measured using the television sync-pulse.

TV Ranging Equipment was developed to evaluate the accuracy of the system with the BSE and TTRS Type A.

The expected error has -1.0 m mean and 0.56 m standard deviation. This value comes mainly from round-off error and high signal to noise ratio causes only 0.3 m error component.

Fig. 19 shows the change of the range in a short span. The residual fitting with first order function is 0.72 m in this case, and this value is a little greater than expected. The evaluation in a long span is achieved using a high accurate orbit elements, and it was concluded that the error is less than few meters that is enough for orbit determination.

7.2 Automatic television signal quality assessment (VITS measurement)

Transmission characteristics measurement equipment including VITS (Vertical Interval Test Signal) inserter and digital data processor was developed to measure and examine the stability of TV signal transmission.

An example of the received television signal characteristics is shown in Table 12.

7.3 Access to the satellite from the multiple ground stations

Program switching tests were performed via satellite between the MTRS and the TTRS moving around Japan using multiple-access control equipment fitted with propagation time dissolution logic.

As a result of subjective evaluation test, the switching function was found to be smooth and to have no visual problems.

8. Conclusion

The BSE experiments have been conducted favourably since July 1978. Most of experimental items planned in the BSE program have been carried into operation. But there are several experimental items which ought to be conducted hereafter, such as the investigation of scattering phenomena especially in the up-link path of 14 GHz, the regular experiments on standard time and frequency signals dissemination by means of TV signals, the experiments on simultaneous amplification of multiple sound signals for the purpose of sound broadcasting, and so on. They will be conducted in the latter half experimental period. It is expected that all the experiments in the BSE project will be performed with satisfactory results.

The operational broadcasting satellite BS-2 is now under consideration. It is expected to be launched in 1983 fiscal year with an on-orbit spare satellite.

According to the proposal, the BS-2 and its spare satellite will be similar to the present BSE satellite with respect to their scale and functions. The experimental results of the BSE program will be reflected to the system configuration of both space and ground segments.

The experimental results described in this paper are due to the endeavours made by many people who participated in the BSE experiments.

The authers wish to express their sincere thanks to the persons concerned of RRL, NHK, and NASDA. Also particular thanks are due to the staff of MOPT for their guidance in the BSE program.

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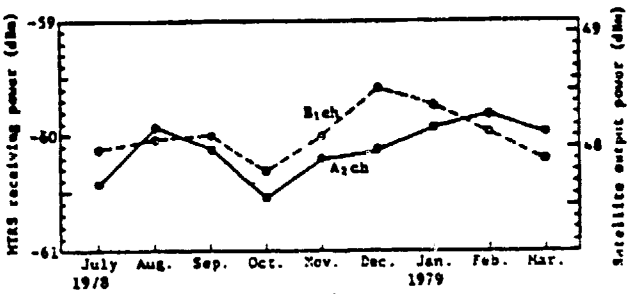


Fig. 2 Variation of satellite output power

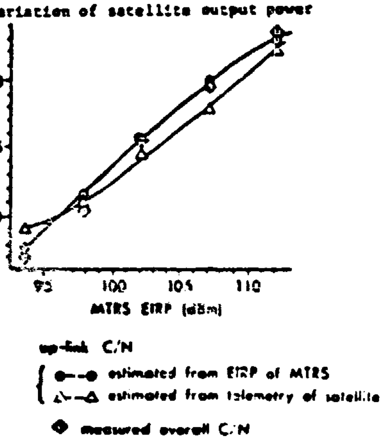


Fig. 3 C/N measurement result

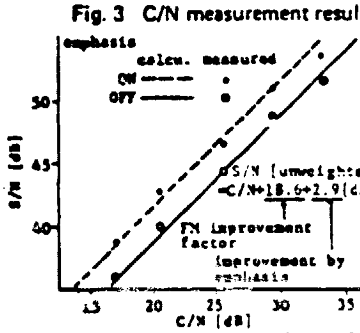


Fig. 4 Relation between C/N and S/N

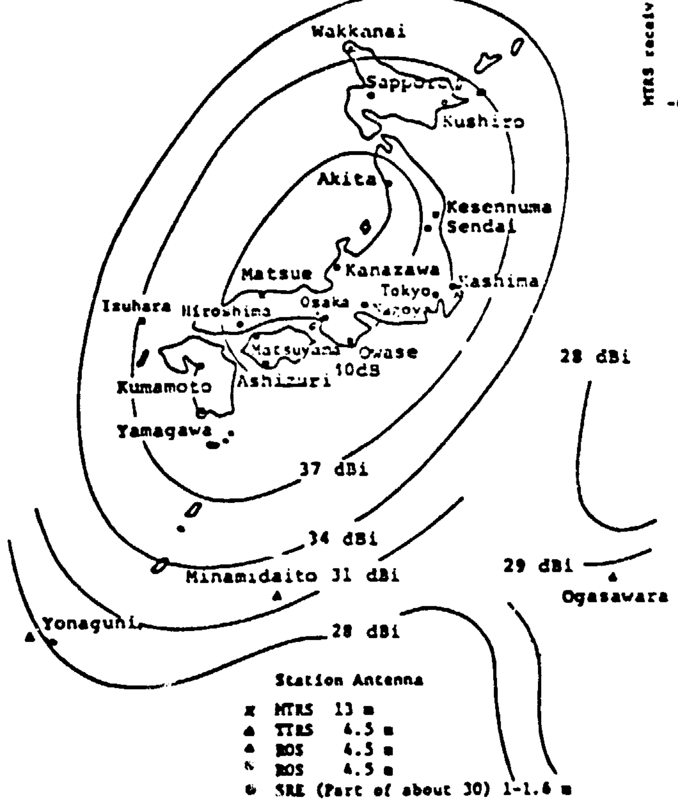


Fig. 1 The BSE antenna radiation pattern and ground station location

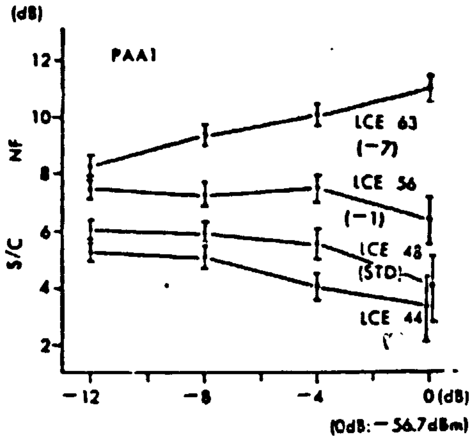


Fig. 5 NF characteristics of transponder

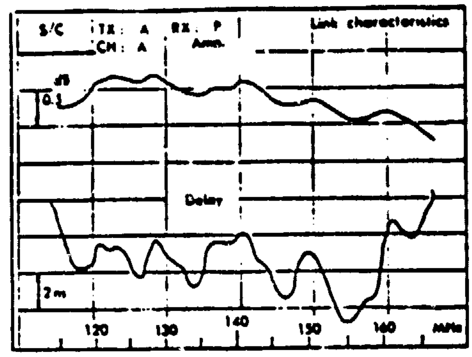


Fig. 6 Amplitude and delay characteristics of link

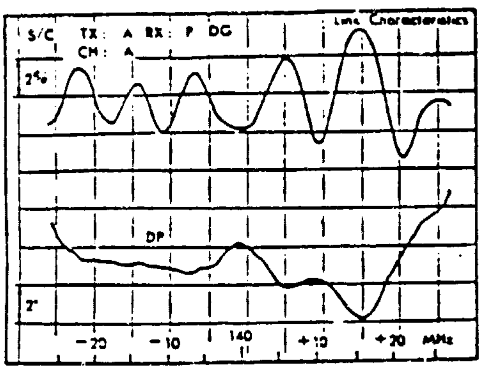


Fig. 7 DG and DP characteristics of link

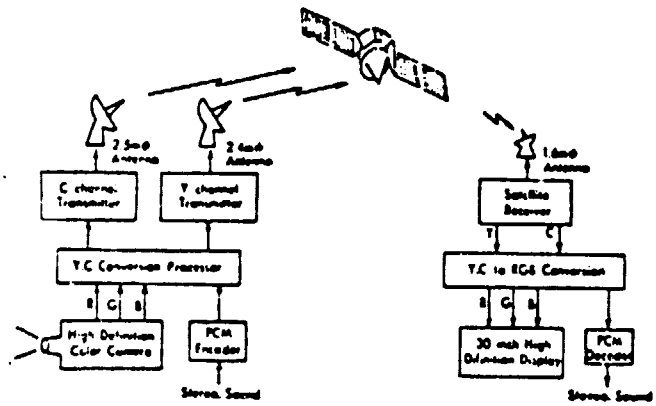
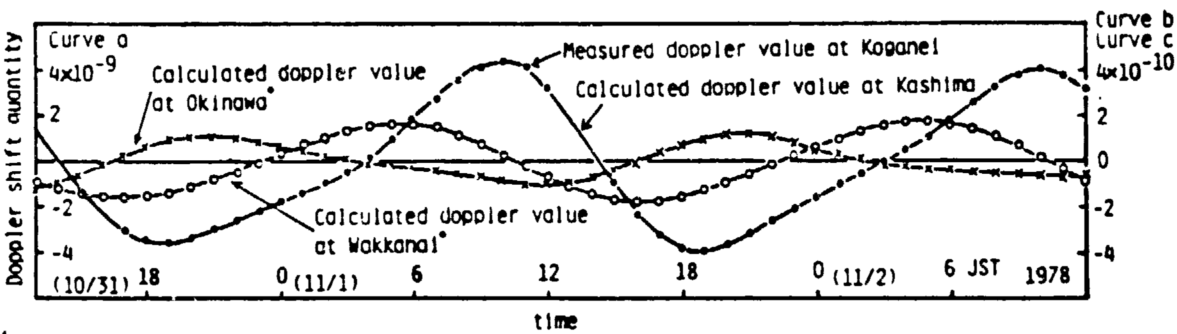


Fig. 8 High-definition TV experiment system with the BSE



•: Calculated freq. shift when compensated at the transmitting side so as to cancel doppler shift at Koganei calculated by orbit determination program

Fig. 9 Doppler frequency by BSE

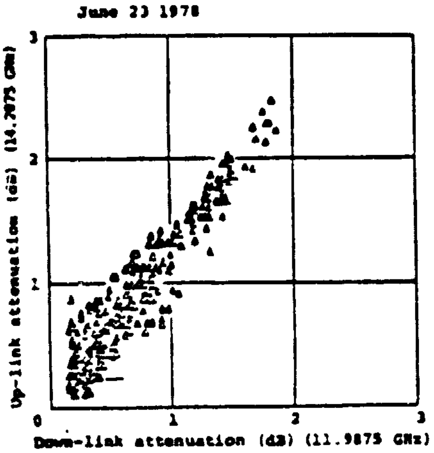


Fig. 10 Relation between measured attenuations of up and down links at Kashima

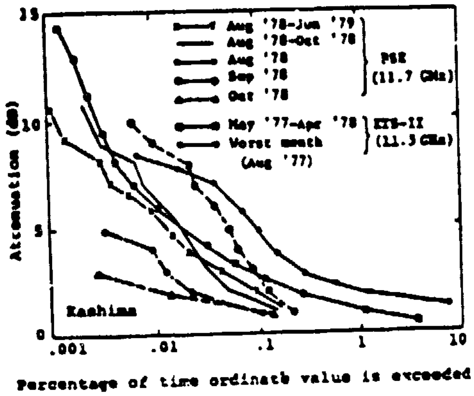


Fig. 11 Measurements of rain attenuation at Kashima

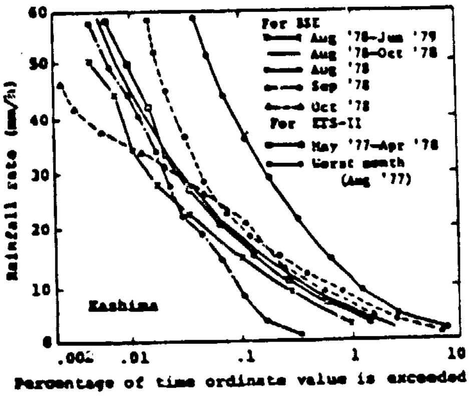


Fig. 12 Measurements of rainfall rate at Kashima

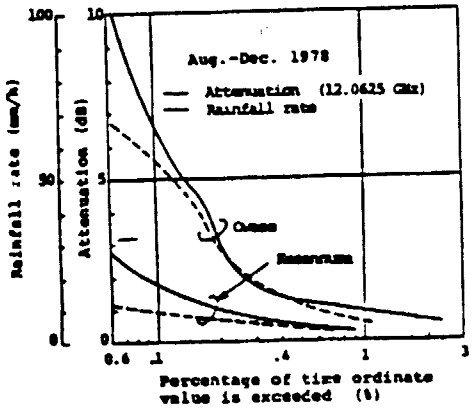


Fig. 13 Measurements of rainfall rate and attenuation at rainy and dry locations

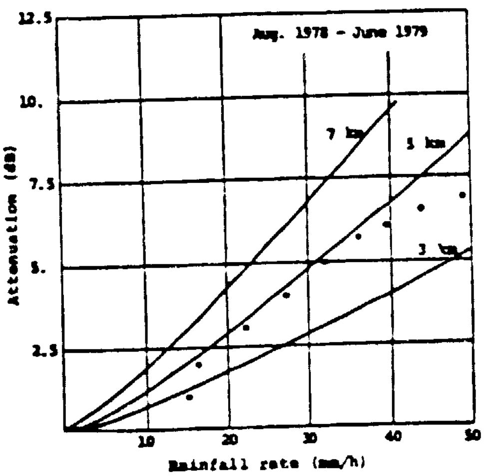


Fig. 14 Effective path length obtained at Kashima

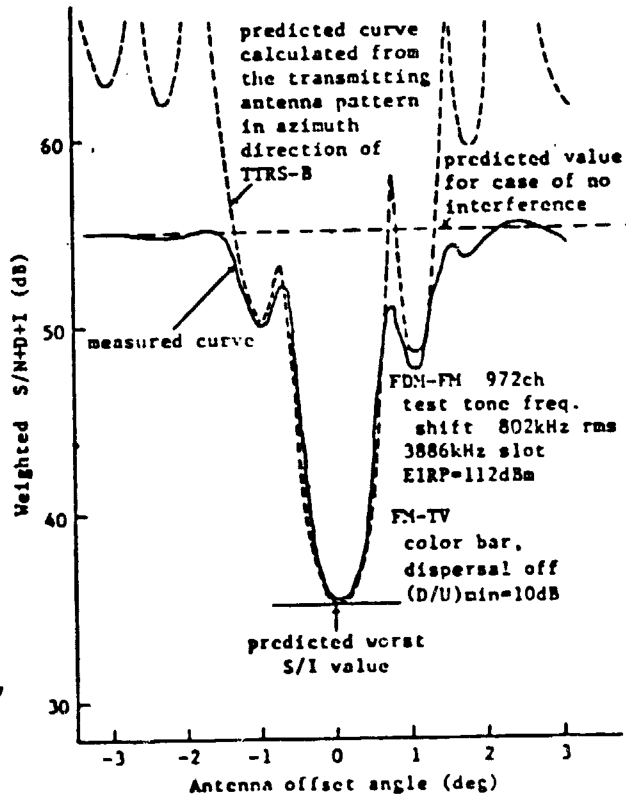


Fig. 15 Weighted S/N measured in changing MTRS antenna direction

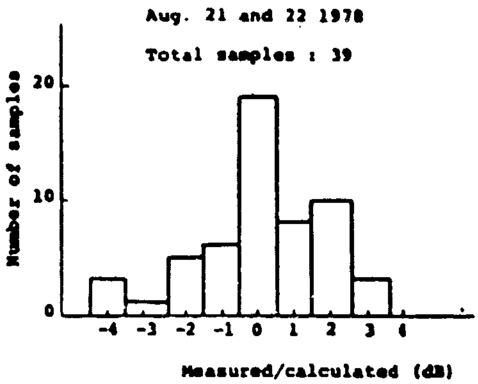


Fig. 16 Deviation of received power from calculated value

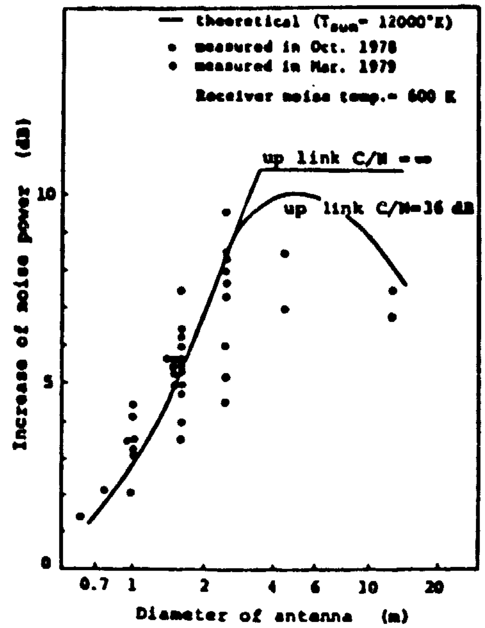
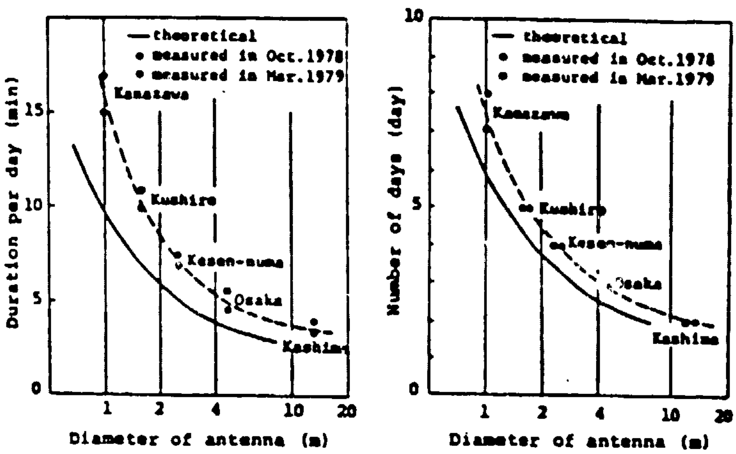


Fig. 17 Increase of noise at receiver input due to solar noise interference



(a) Duration per day (b) Number of days

Fig. 18 Duration and occurrance of solar noise interference

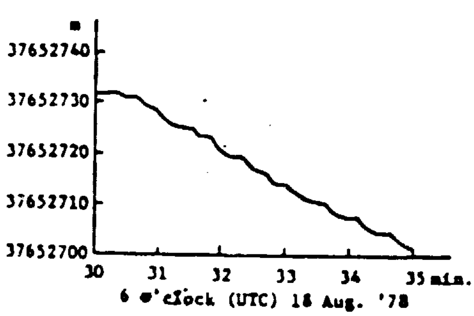


Fig. 19 Range change in a short span

Table 1 Measurements of Received Television Signal Characteristics

Location	Station	Antenna Diameter	Received Carrier Level		Weighted S/N
			Calculated	Measured	
Kashima	NTRS	13 m	-59.9 dBm	-59.8 dBm ~ -60.2	58 dB
Osaka	TTRS A-type	4.5	-66.7	-63 ~ -64.5	50
Tokyo	TTRS B-type	2.5	-74.0	-73 ~ -74	54
Wakkanai	ROS	2.5	-75.9	-77.5 ~ -81.2	47
Kesennuma	ROS	2.5	-72.8	-72.8 ~ -74.4	48
Owase	ROS	2.5	-71.2	-72.4 ~ -74	50
Matsue	ROS	2.5	-70.8	-72 ~ -73	49
Ashizuri	ROS	2.5	-70.6	-68.7 ~ -71.3	54
Izuhara	ROS	2.5	-73.1	-73.4 ~ -76.2	49
Ogasawara	ROS	4.5	-75.3	-78.8 ~ -81.6	48
Yonakuni	ROS	4.5	-79.1	-77.5 ~ -79.5	48
Minami Daito	ROS	4.5	-74.2	-73.5 ~ -74	51
Hachijo	ROS	1.6	-80.7	-81 ~ -83.3	48

Table 2 BSE link budget

Up-link (MTRS to BSE)				
MTRS, E.I.R.P.	(dBm/ch)		112.2	
Free space loss	(dB)		-207.4	
Rx. antenna gain	(dB)		38.1	
Noise power	(dBm/25 MHz)		-92.9	
Up-link C/N	(dB)		35.8	
Down-link Service area		MTRS	Mainland	Remote islands
Antenna of Rx.	(m)	13.0	1.6	4.5
Tx. power	(dBm/ch)		50.0	
Tx. feeder loss	(dB)		-1.7	
Tx. antenna gain	(dB)	37.6	37.0	28.0
Free space loss	(dB)	-205.9	-205.8	-205.4
Rx antenna gain	(dB)	61.9	43.0	53.5
Rcved carrier power	(dBm)	-58.1	-77.5	-75.6
Noise power	(dBm/25 MHz)	-96.4	-97.3	-96.6
Down-link C/N	(dB)	38.3	19.8	21.0
Total C/N	(dB)	33.9	19.7	20.9
TV signal quality				
FM improvement factor	(dB)		18.6	
Emphasis improvement factor	(dB)		2.9	
Unweighted S/N	(dB)	55.4	41.2	42.4

Table 3 Provisional standard of high-definition TV

Number of scanning lines	1125
Aspect ratio	3 : 5
Line interlace	2 : 1
Field repetition frequency	60 Hz
Video frequency bandwidth	
Luminance (Y) signal	20 MHz
Chrominance (C) signal	0.5 MHz*

* Line sequential

Table 4 Carrier-to-noise ratio for Y and C channels

Date, (Nov. 1978) Time (hours)	8th 15:40	9th 10:00	13th 15:40	15th 15:40	Mean
CNR (dB)					
Y ch.	16.7	–	16.4	16.8	16.6
C ch.	21.7	21.2	23.2	22.7	22.2

Table 5 Picture signal-to-noise ratio for Y and C channels

	Y ch.	C ch.	Remarks
CNR (dB)	16.6	22.2	mean
SNR (dB)	40.6	49.2	unweighted

Table 6 Measurements of attenuation and rainfall rate at RCSs and TTRS (12.0625 GHz, August to December 1978)

Item / Location	Attenuation exceeded for given % (db)		Rainfall rate for given % (mm/h)		Observation Time (1000 min)	
	1	0.1	1	0.1	Attenuation	Rainfall
Ogasawara	/1)	1.1	3	19	29	82
Minamidatio	0.8	2.3	6	15	37	98 2)
Yonaguni	2.3	5.5	6	39	34	59
Kosennuma	0.3	1.7	4	12	38	160
Owase	0.8	6.5	13	52	41	164
Matsue	1.2	3.0	7	15	40	162
Ashizuri	1.2	3.3	6	28	39	162
Izuhara	/1)	/1)	7	20	32	161
Osaka	1.6	3.9	5	12	34	165

Note 1) No significant data due to trouble of equipment.
2) Observation time becomes shorter due to failure of rainguage.

Table 7 Effective path length obtained at rainy and dry locations

Location	Effective path length for given rainfall rate (km)		
	10 mm/h	25 mm/h	50 mm/h
Owase	4.3	3.2	2.6
: rainy	(5.3)	(4.7)	(3.8)
Ashizuri	5.0	2.9	2.6
: rainy	(5.1)	(4.5)	(3.7)
Kosennuma	6.8	/	/
: dry	(6.3)		

Note The values in ( ) are derived from Fig. 2 of CCIR Rep. 564-1 (Tokyo area)

Table 8 Transmission parameters of up-link signal

BS/FM-TV	video signal deviation emphasis energy dispersal	12MHz CCIR Rec 405-1 600kHz
CS/FM-TV	video signal deviation emphasis energy dispersal	21.5MHz CCIR Rec. 405-1 1MHz
CS/FDM-FM	noise-loaded with the following test-tone deviation 972ch ; 802kHz/ch 60ch ; 270kHz/ch	

Table 9 Protection ratio required for interference from FM-TV signal

wanted	unwanted	antenna offset method	laboratories test
BS/FM-TV	BS/FM-TV	35dB	37.8dB
BS/FM-TV	CS/FM-TV	29.3dB	31dB

(test picture : color bar)

Table 10 Protection ratio required for interference from FDM-FM signal

wanted	unwanted	antenna offset method*		laboratory test	
		60ch	972ch	60ch	972ch
CS/FDM-FM	BS/FM-TV	26.4dB	23.9dB	35.5dB	32.4dB

(test picture : color bar)
* : values were limited by signal-to-noise ratio of received signal

Table 11 Interference from FM-TV into FDM-FM in the same frequency channel

capacity	S/I*	d/U**	test condition
972ch	43dB 50dB 60dB	17.5dB 24.5dB 34.5dB	with the parameters for the Intelsat 972-channel carrier FM-TV (color bars) without energy dispersal
60ch	43dB 50dB 60dB	8.5dB 16.0dB 26.5dB	test-tone deviation 270kHz rms emphasis off FM-TV (color bars) without energy dispersal

* : signal-to-interference noise ratio in the worst channel due to interference from an analogue FM-TV transmission
** : the ratio of wanted-to-unwanted signal power at the satellite input

Table 12 Example of VITS automatic measurement

```
08/31        15:14

LEVEL(IRE)   PICTURE          SYNC             BURST
               99              42               40

FREQ.(MHZ)     0.50    1.00    2.00    3.00    3.50    4.20
    (DB)     - 0.2   - 0.3     0.1     0.5     0.6   - 3.7

DISTORTION   LUM.BAR(%)   2T/BAR RATIO(%)   2T OVERSHOOT(%)
               0.1             1.3            - 3.4

C/L          C/L GAIN(DB)  L-C DELAY(NS)    STREAKING(%)
               1.0             43             - 1.0

S/N          S/N (DB)         DG(%)            DP(DEG)
               49              1.4              2.0
```

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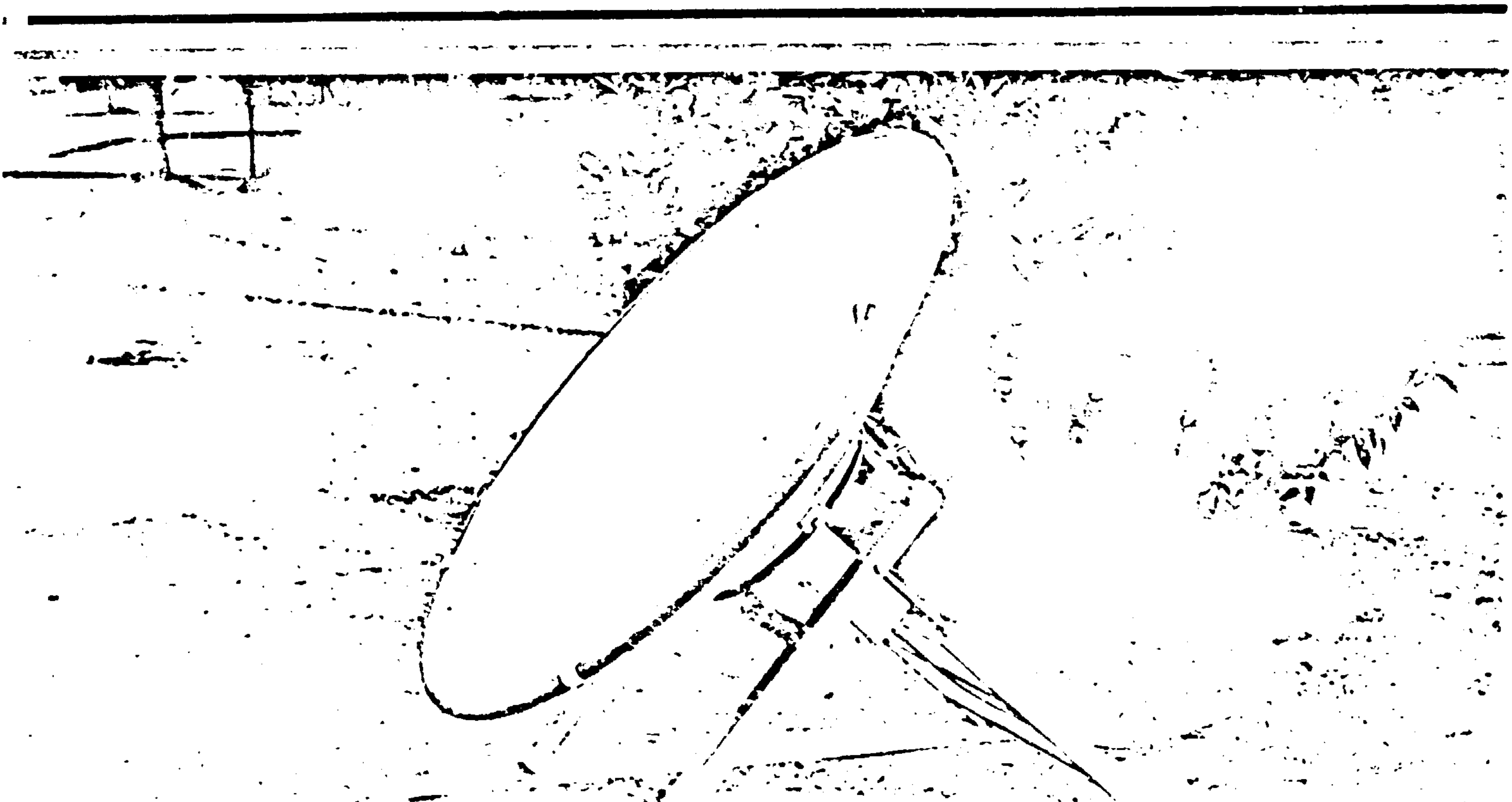
APPENDIX E

NEC

Satellite Television Receiver For 12GHz Broadcast Satellite

Model 790

Applications:
Direct Reception
Community Reception or CATV
Re-Broadcasting
Experimental Use For Receiving

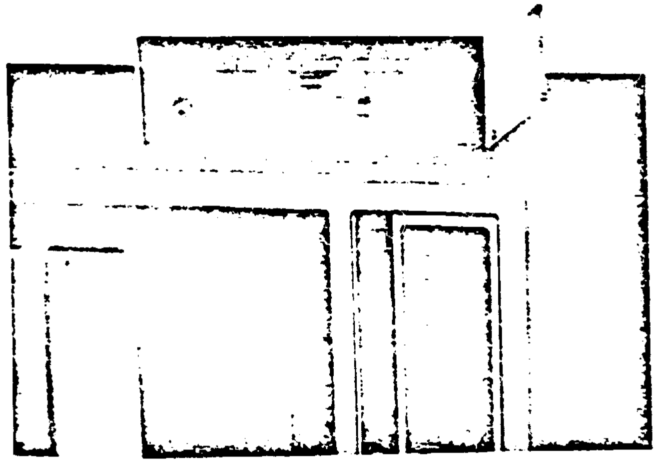


Nippon Electric Co.,Ltd.

MODEL 790 Satellite Television Receiver

FEATURES

- o LOW NOISE: 500K (= 4.3 dB NF)
- o 5-CHANNEL SELECTION
- o BASEBAND AND NORMAL VHF TV CHANNEL OUTPUTS
- o LOW POWER CONSUMPTION: 11 WATT AC
- o COMPACT ANTENNA AND TERMINAL EQUIPMENT
- o SIMPLE INSTALLATION
- o MAINTENANCE FREE
- o LOW COST

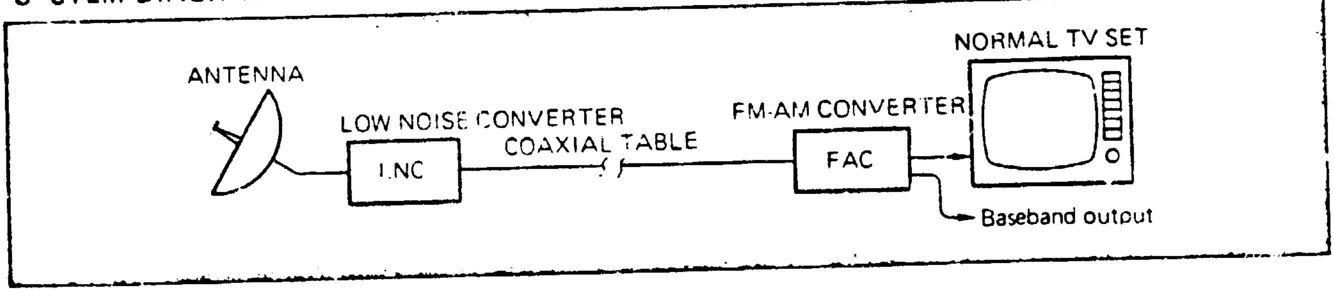


GENERAL

NEC, as a pioneer in space-age communications has long predicted direct satellite reception for broadcast applications. The genesis of this concept occurred in 1973 as NEC and NHK (Japan Broadcasting Corporation) began joint development of such a receiver. By 1975 NEC had supplied single channel receivers for NHK for field testing of the CTS (Communication Technology Satellite). The results were excellent and well publicized.

NEC now proudly introduces the second generation of direct receiver . . . the Model 790. This new, five channel model, has been installed and extensively tested by NHK on the Japanese BSE Satellite (Medium-scale Broadcast Satellite for Experimental Purposes). A 4 GHz version of this product has been developed as a system for Domsat use.

SYSTEM DIAGRAM



LINK DESIGN

An example of link calculation is given for the BSE. As mentioned in Tables, when the satellite EIRP is 55 dBW, the Video S/N becomes 48 dB and threshold margin is 7 dB.

TRANSMISSION PARAMETERS OF JAPANESE BSE

ITEM	PARAMETERS
Satellite EIRP	55 dBW
Polarization	Linear
Video parameters	
Television standard	CCIR system M
Top baseband frequency	4.2 MHz
Modulation	FM
Deviation	12 MHz p-p
Modulation polarity	Sync. negative
Energy dispersal	600 kHz p-p
Pre-emphasis	CCIR Rec. 405
Sound parameters	
Transmission system	Sound subcarrier onto video baseband
Modulation	FM
Top baseband frequency	13 kHz
Sound subcarrier frequency	4.5 MHz
Deviation of RF carrier by subcarrier	±1 MHz Peak
Deviation of subcarrier by sound	±25 kHz Peak
Pre-emphasis	75μsec.

LINK CALCULATION

ITEM		PARAMETERS	
		VIDEO	SOUND
Satellite EIRP	dBW	55.0	–
Path loss (at 12 GHz)	dB	–205.8	–
Ground station G/T	dB/K	13.5	–
Down-link C/T	dBW/K	–137.3	–
Boltzmann's constant	dBW/K/Hz	228.6	–
Bandwidth (27 MHz)	dB Hz	–74.3	–
C/N	dB	17.0	22.2
FM improvement	dB	18.9	19.3
Weighting factor including emphasis	dB	12.8	11.6
S/N	dB	48.7	53.3
Threshold margin	dB	7.0	–

LINK CALCULATION FOR 625 LINE SYSTEMS (OPTION)

CCIR TELEVISION SYSTEM		B, G, H		I		D, K	
Top video frequency		5 MHz		5.5 MHz		6 MHz	
Sound subcarrier frequency		5.5 MHz		6 MHz		6.5 MHz	
ITEM		VIDEO	SOUND	VIDEO	SOUND	VIDEO	SOUND
Satellite EIRP	dBW	55.0	–	55.0	–	55.0	–
Path loss (at 12 GHz)	dB	–205.8	–	–205.8	–	–205.8	–
Ground station G/T	dB/K	13.5	–	13.5	–	13.5	–
Down-link C/T	dBW/K	–137.3	–	–137.3	–	–137.3	–
Boltzmann's constant	dBW/K/Hz	228.6	–	228.6	–	228.6	–
Bandwidth (27 MHz)	dB Hz	74.3	–	74.3	–	74.3	–
C/N	dB	17.0	20.5	17.0	19.7	17.0	19.0
FM improvement	dB	16.6	25.[illegible]	15.4	25.3	14.2	25.3
Weighting factor including emphasis	dB	16.3	[illegible]	12.9	9.2	18.1	9.2
S/N	dB	49.9	55.0	45.3	54.2	49.3	53.5
Threshold margin	dB	7.0	–	7.0	–	7.0	–

(Note Above link calculation for 625 line systems is made on the assumption of the same specifications as those of Japanese BSE value.)

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TYPICAL PERFORMANCE

General performance	
Frequency range	11.950–12.130 GHz, other frequency optional
Tuning	5 channel, push-button select
Antenna size	1.2 m, other sizes available
Outputs	Baseband (Video, sound) & AM (VHF TV CH)
Antenna characteristics	
Gain	41 dB at 12.0 GHz
Polarization	Linear, circular available
Adjustment	Azimuth: ±5° Elevation: 20°–55°
Wind survival	40 m/sec
Base	0.61 x 1.25 m
Weight	38 kg approx.
Receiver characteristics	
Noise temperature	500 K typical (≈4.3 dB NF)
Standard input level	−110 dBW
Baseband output	Video: 1 V p-p/75Ω Sound: 0 dBm/600Ω
VHF output	Vision carrier: 80–85 dBμV/75Ω Sound carrier: 14–10 dB down to vision carrier
Power consumption	11W approx. AC 50–60 Hz
Operating temperature	LNC: −20°–+40°C FAC: 0°–+40°C
Weight (approx.) & Dimension	LNC: 1.3 kg, 49(H) x 92(W) x 289(D) mm FAC: 3.1 kg, 70(H) x 230(W) x 186(D) mm IF cable: 2.0 kg, 30m long

RECEIVER CONFIGULATION

Receiver consists of

o Antenna	1
o Low noise converter	1
o FM–AM converter	1
o IF cable (30m long)	1
o Output cables for video	1
Sound	1
VHF	1
o Instruction manual	1

The information, drawings, or any other data included herein are subject to change without notice.

Cat. No. HTD-E-4144

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O. Hellman
July 78 DEC R/D

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UDC 621.397.62.029.6:629.783

12 GHz TV Receiver for Direct Reception from Broadcasting Satellites

By Hiroshi YOSHIDA*, Hiroshi WATANABE*, Katsuaki TOMODA† and Yasushi KUROKAWA†

ABSTRACT This report deals with the performance of a TV receiver for direct reception of VHF signal output from a broadcasting satellite which will be launched from Japan in March 1978. For probable mass production in the future, the design of this TV receiver is simple, compact, stable and lightweight. With a 1.2 meter diameter antenna typical receiver G/T is 13.5 dB and NF is 4.0 dB. It features in a circuit which eliminates the energy dispersal signal in a 600 $kHz_{p\text{-}p}$ deviation. Its power consumption is as low as 11 W AC.

1. INTRODUCTION

Active studies are now being conducted worldwide on satellite broadcasting. In 1977, the technical standards for satellite broadcasting were adopted by WARC-BS of the ITU Radio Conference. A Medium-scale Broadcasting Satellite for Experimental Purposes (BSE) was scheduled to be launched in March 1978 from Japan [1]. With full cooperation of Technical Research Laboratories, Japan Broadcasting Corporation (NHK), the writers have been working on the development and realization of a direct receiver since 1973 [2]. TV receivers for direct reception from a broadcasting satellite, developed and delivered to NHK, have been quite successfully operated in field tests on a Communication Technology Satellite (CTS) [3].

The writers wish to report on the 5-channel receiver, which has been particularly developed for Japan's BSE. This receiver is designed for direct TV reception from a broadcasting satellite, with consideration given to simplified circuits and mass production. When compared with conventional microwave equipment, its features are simple configuration and low price.

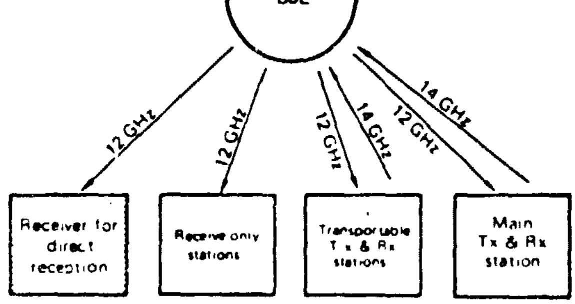
A brief exposition will be made in this report on the BSE, which is to be used with this receiver, its experimental system and various transmission parameters. Then the system and operation of this receiver will be detailed, together with typical performance characteristics, as well as measured value distributions for some of the characteristics.

2. BSE SYSTEM

BSE was scheduled to be launched into geosynchronous orbit at 110°E longitude. Its purposes are to test TV signal transmission characteristics and run experiments on satellite broadcasting system control, thereby finding better ways to meet various broadcasting demands.

Of BSE earth station facilities, several stations are related to TV signal transmission, besides the receiver for direct reception. They include the main transmission reception station, transportable transmission/reception stations and receive-only stations. A system diagram is shown in Fig. 1.

The radiation pattern from a spacecraft transmitting antenna has already been made public, as shown in Fig. 2 [1]. Since the output power from the TWT loaded on the spacecraft is determined as 20 dBW, satellite EIRP is estimated as over 55 dBW throughout the Japanese mainland, covered by the inside zone



*Broadcast Equipment Division

of the 37 dBi contour.

The expected signal-to-noise ratio (S/N) of this TV receiver is shown in Table I; while the video weighted S/N could be 48.4 $dB_{p\text{-}p}$/rms, if as much as 13.5 dB receiver's G/T can be attained. Modulation parameters are assumed to be those listed in Table II.

3. RECEIVER SYSTEM

This receiver is composed of an antenna, a low-noise frequency converter (LNC), and an FM-to-AM converter (FAC), connected by an IF cable. Unit dimensions are shown in Table III. Receiver structure is compact and simple, compared with satellite communication equipment. This receiver is designed for direct TV signal reception at anyone's home from a satellite. Its antenna and LNC are shown in Fig. 4, and an FAC mounted on a TV set is shown in Fig. 5.

This receiver employs the double heterodyne system. The 12 GHz signal, received by the antenna, is shifted down by LNC to the 1st IF in the UHF band, and transmitted to FAC via the IF cable. The UHF signal, which is related to the required channel through the 1st IF channels, is again converted by the FAC mixer into 130 MHz 2nd IF. Then it is FM-demodulated and its output is remodulated into an AM signal.

The frequency allocations for both the 12 GHz band and 1st IF (UHF band) are shown in Fig. 6, in which the 1st LNC local frequency is selected as 11.66 GHz. The FAC output, as mentioned above, consists of the VHF-AM signal, baseband video and sound signals and AGC voltage output.

The VHF-AM signal is derived from the baseband signal by remodulation. This signal can be connected from the FAC directly to the antenna terminals on ordinary TV sets. Therefore, satellite broadcasts can be received by a simple TV set.

Baseband outputs can be measured to obtain data on output characteristics vs satellite broadcast data, simply by connecting the outputs to video or sound monitor equipment or to test equipment.

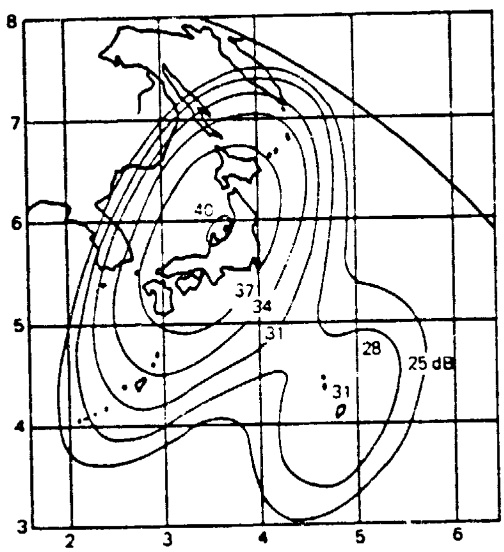


Fig. 2 BSE 12 GHz antenna gain.

Table I BSE link calculation.

Satellite EIRP	55 dBW
Path loss	−205.8 dB
Ground receiver G/T	13.5 dB/K
C/T	−137.3 dBW/K
Boltzmann's constant	228.6 dBW/Hz/K
Bandwidth (27 MHz)	[illegible] dBHz
C/N	17.0 dB
FM improvement	18.9 dB

Table II Modulation parameter.

Modulation	
Video	FM
Sound	FM-FM
Energy dispersal	triangular waveform
SHF deviation	
Video	12 MHz $_{p\text{-}p}$
Sound subcarrier	2 MHz $_{p\text{-}p}$
Energy dispersal	600 kHz $_{p\text{-}p}$
Sound subcarrier deviation	50 kHz $_{p\text{-}p}$
Emphasis	
Video	CCIR Rec. 405
Sound	75 μsec
Baseband frequency range	
Video	60 Hz ~ 4.2 MHz

The AGC voltage output represents the SHF input level. Consideration is given to its setting for probable antenna direction adjustment upon installation of the receiver and for measuring satellite wave intensity after the installation.

4. UNIT DESCRIPTION

4.1 Antenna

The antenna that receives the satellite waves consists of a parabolic antenna and its support bay to secure the antenna on the ground. The diameter of this parabolic antenna is set at 1.2 meters in order to ensure about 13 dB receiver G/T. Its horn is designed for maximum gain. Its gain at 12 GHz is 41.2 dBi and 58 K noise temperature. Antenna patterns are shown in

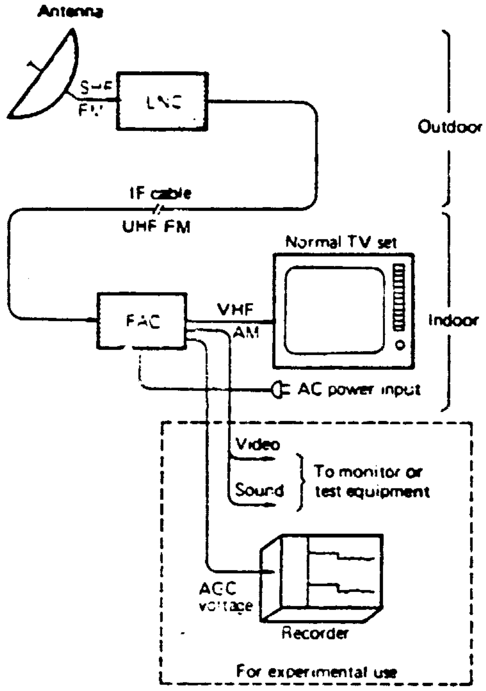


Fig. 3 Satellite receiver system diagram.

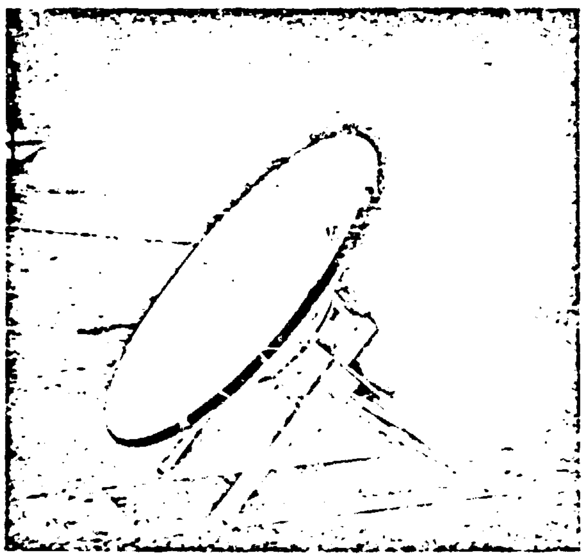


Table III Typical receiver performance characteristics.

Video output characteristics	
Output level	1 V_{p-p}/75Ω
Gain/frequency response	±0.5 dB
DG	2% (APL 50%)
DP	1° (APL 50%)
Sound output characteristics	
Output level	0 dBm/600Ω
Gain/frequency response	±1 dB
Harmonic distortion	1%
VHF output characteristics	
Carrier frequency stability	±100 kHz
Output level	83 dBμV/75Ω
Frequency response	±1 dB
920 kHz IM product	−50 dB
DG	4% (APL 50%)
DP	2° (APL 50%)
Sound carrier level respect to video carrier level	−11 dB
Operating temperature range	
LNC	−20 ~ +40°C
FAC	0 ~ +40°C
Dimensions	
LNC	49(H) X 92(W) X 289(D) mm
FAC	70(H) X 230(W) X 186(D) mm
Weight	
LNC	1.3 kg
FAC	3.1 kg
AC power consumption	10.7 W/AC 100 V,

Fig. 7.

The bay that supports the antenna must be equipped with both coarse setting and fine adjustment mechanisms, since the elevation and azimuth of the satellite will vary, considering the latitude and longitude to the point where the receiving antenna is installed.

Antenna elevation setting is changed by either closing or opening the pantograph legs supporting the antenna, as shown in Fig. 8. Support leg positions are chosen along holes P bored in the sides of the support base. Hole separations represent 10° elevation steps.

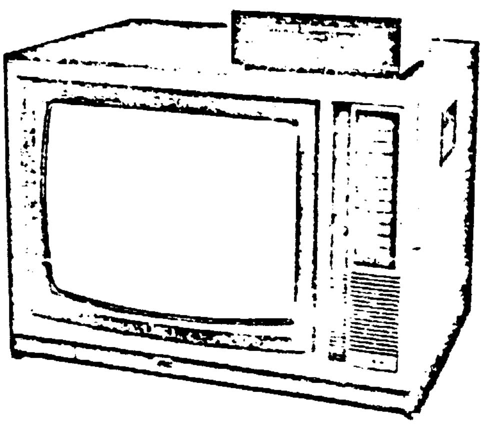


Fig. 5 FAC on TV set.

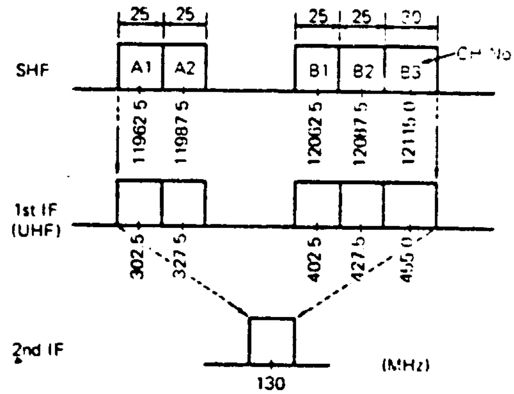
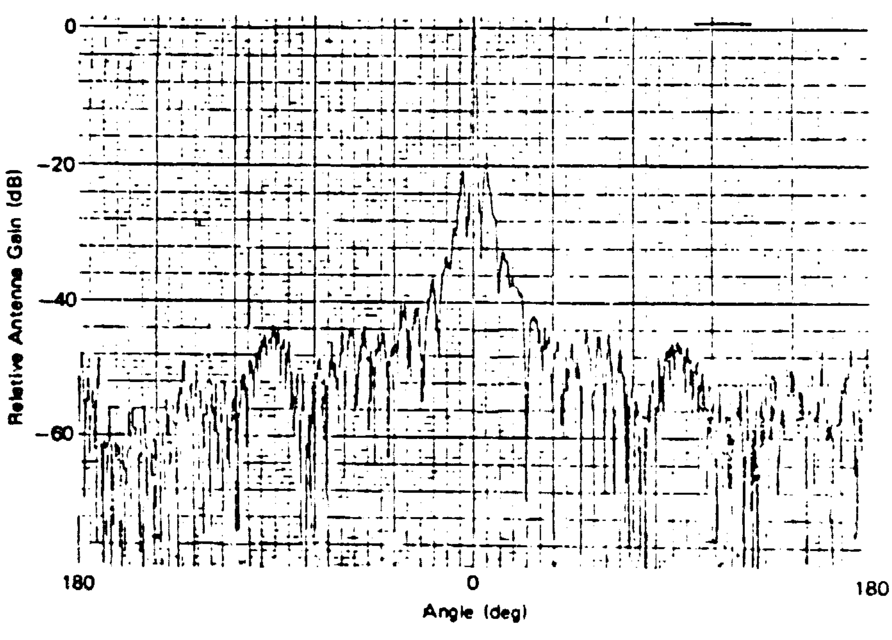


Fig. 6 Input SHF, 1st IF and 2nd IF frequency allocations.



Desired elevation for the installation location is determined. Antenna support bracket leg positions are scissored open or closed to the desired configuration. Then the support bracket legs are bolted into place. Following this coarse alignment, fine adjustment is made in the antenna alignment within a ±5° range using a fine adjust screw.

The azimuth is designed to be adjustable with the fine adjust screw within ±5° range after the antenna bay is secured at the precalculated azimuth. Both the antenna and its bay are designed to withstand wind velocity of up to 40 m/sec.

4.2 LNC

As shown in Fig. 9, LNC is composed of a 1st mixer (MIX 1), which shifts SHF input down to the 1st IF signal in the UHF band, an IF amplifier (IFA) to amplify the above UHF signal to a sufficiently strong level, and a 1st local oscillator (LO 1), which supplies the local power to MIX 1. Figure 10 shows the LNC appearance.

For its main purpose of a low-priced and stable receiver, this receiver does not use any parametric amplifier or FET amplifier, yet it is capable of low noise performance by optimization of noise figures for the aforementioned mixer. MIX 1 is an image-shorted circuit employing a GaAs Schottky-barrier diode LSS11 (NEC) with high cutoff frequency. It is made with a planar circuit mounted in waveguide (PCMW) [4] [5]. It is thus effective in achieving as low conversion loss as 3 dB or lower.

The IFA noise figure also seriously affects the total noise figure of LNC. Employing the low-noise bipolar transistor V219 (NEC) enables obtaining a noise figure of about 1.5 dB and a gain of about 50 dB within the 290 MHz to 480 MHz frequency range. LO 1 uses the 4 GHz transistor oscillator and a chain of varactor diode tripler, aiming at easy adjustment and stability. The 11.66 GHz local power can be produced by LO 1.

The 4 GHz oscillator employs a dielectric resonator in its feedback loop. This oscillator and the multiplier are both composed of stripline circuits.

The average LNC performance attained by the above configurations indicates about 4.0 dB noise figure and about 47 dB gain. Noise figure frequency characteristics examples are shown in Fig. 11. The cutoff frequency of the Schottky-barrier diode, used in the above examples, is 635 GHz. Figure 12 shows linearity characteristics for the LNC input versus output power. From Fig. 12, it is apparent that the two-tone intermodulation product ratio is a satisfactory value of −73 dB considering the fundamental output at a standard −110 dBW input level point. *C/N* by channel intermodulation is calculated as 67 dB, even if 5 channels are simultaneously applied to LNC. Therefore, satisfactory linearity can be ensured.

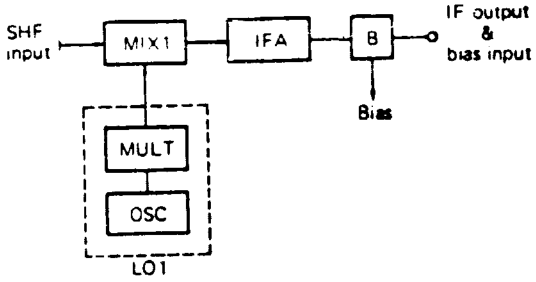


Fig. 9 LNC block diagram.

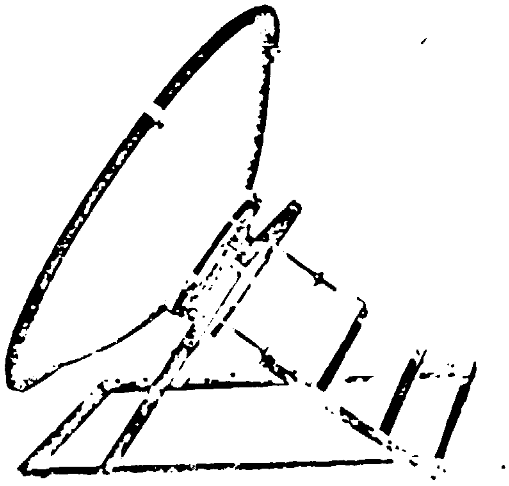


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Fig. 10 LNC

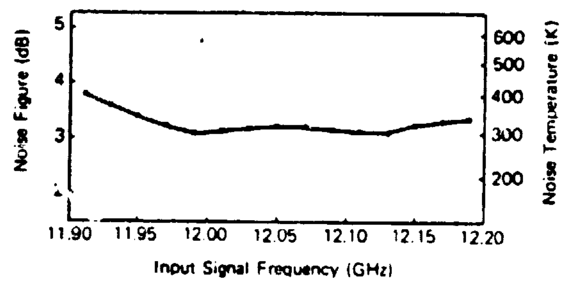


Fig. 11 Noise figure characteristics.

4.3 FAC

A block diagram of this FAC is shown in Fig. 13. The channel selection for this direct receiver is achieved by FAC under the control over the 2nd local oscillating frequency in the varactor tuning. Any channel can be selected out of 5 channels within the 1st IF band (290 MHz to 470 MHz) by presetting the tuning voltage. The 2nd IF is 130 MHz. A bandpass filter (BPF 1) is inserted before the MIX 2 so as to bring the image rejection of the 2nd conversion performance to 20 dB or more and the IF rejection to 30 dB or more. S/N deterioration, caused by noises infiltrating from the MIX 2 image band, can thereby be suppressed below 0.05 dB.

BPF 2 is a filter, which determines the receiving bandwidth of each channel. The 3 dB bandwidth is set to 27 MHz. The cutoff characteristics hold attenuation at over 25 dB at ±29.7 MHz to eliminate interference from adjacent channels. Both BPF 1 and BPF 2 are the 2-pole 3-section Tchebychev filters.

AGC is a forward AGC using a bipolar transistor. Its output variation is limited to less than ±0.1 dB, within the standard input range ±10 dB. It is thus capable of supplying signals to the limiter in the next section at an optimum input level. The limiter is a serial limiter using a silicon Schottky-barrier diode. It is capable of AM suppression over 25 dB against input level fluctuation within ±10 dB, in conjunction with the AGC in the previous section.

The FM-discriminator is a Travis type. Its S-curve characteristics are 70 MHz in peak-to-peak value. DG and DP for this discriminator proper are 1% and 1° or less, respectively. The

circuit has been developed to compensate for distortions for the vertical synchronization period. Figure 14 shows a block diagram of this video clamping circuit. The high-pass filter (HPF) of RC attenuates the

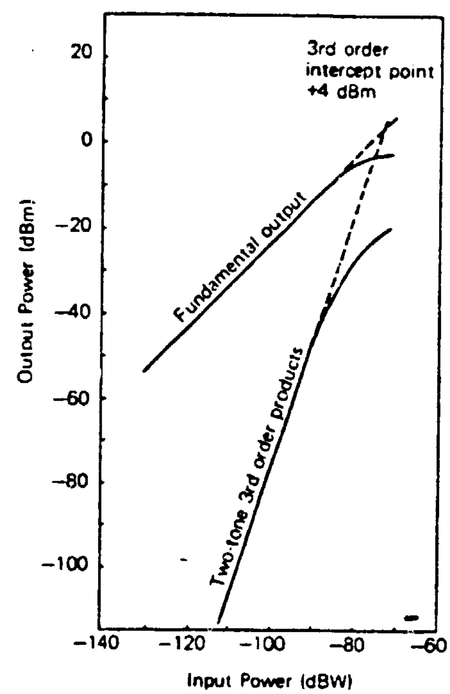
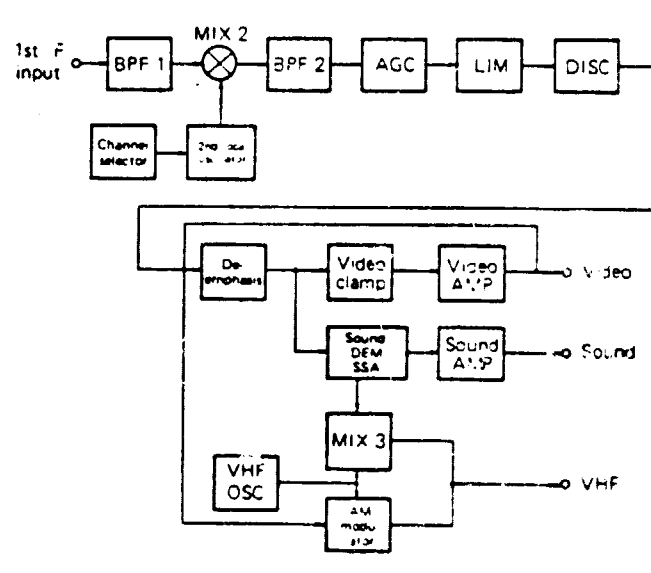


Fig. 12 LNC output power vs input power.



fundamental component of the 30 Hz triangular wave to approximately 20 dB. The clamping circuit is an ordinary diode clamping circuit that is given high-pass characteristics. This clamping circuit is enable to attenuate the 30 Hz fundamental components to 35 dB in all, in conjunction with the previous HPF.

As the vertical synchronizing signal is also differentiated by the said high-pass characteristics, and thereby produces certain distortion, such a vertical synchronizing signal is separated by the synchronizing separator circuit, and then applied to the above clamping circuit to compensate for the distortion in the vertical synchronization. AFE at the next section is an amplitude-frequency equalizer composed of *RC*, and compensates for the distortion in the field blanking interval. This eliminating circuit is effective to suppress the triangular waveform signal for energy dispersal by approximately 40 dB. Figure 15 shows video signal waveforms before and after the eliminating circuit for triangular waves, that are equivalent to deviation at 600 kHz $_{p\text{-}p}$ value.

The amplitude modulation circuit, sound subcarrier amplifier (SSA) and sound demodulator, as shown in Fig. 13, are all composed of integrated circuits to provide simpler circuits. The bandpass filters and notch filters employed in these circuits for sound subcarrier are ceramic filters, thereby obviating any further adjustment. Obtained DG and DP values for the amplitude modulation circuit can be as much as 2% and 3°, respectively.

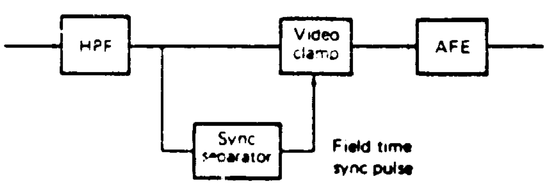


Fig. 14 Video clamping circuit block diagram.

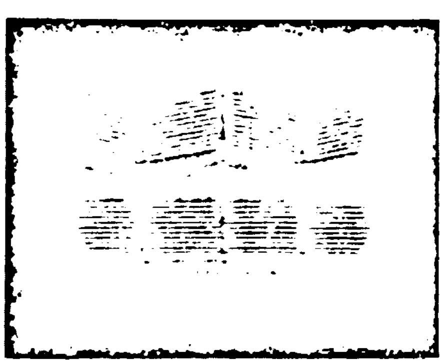


Fig. 15 Video signal waveforms of input (upper) and

Adding to the above FAC configuration, the following three requirements were taken into consideration in the design of this block:

(1) Low noise.
(2) Low price.
(3) Low power consumption.

For the low noise value, particular attention has been paid to the level diagram, cutoff characteristics of BPF 1 and BPF 2, AM rejection by the limiter and balance in FM-discriminator, etc. As a result, the residual value of the video signal-to-unweighted noise ratio (unweighted *S/N*) is found to be more than 60 dB, while a value approximating the ideal value can likewise be obtained for the input SHF carrier level versus *S/N*. Figure 18 shows these characteristics. For low price, the most component circuits of this receiver are already in use, and are quite instrumental in reduction in parts prices, in conjunction with the simple adjustment-free circuits made of integrated circuits and ceramic filters.

Low power consumption can be manifested by FAC, including LNC, which consumes about 4 W DC power in all and about 11 W AC power. It can be expected to reduce the AC power consumption to 5 W or so by means of switching regulators. It may also be feasible in the future to use solar batteries, if available at cheaper prices, in the head-end of the unattended cable system, by joint operation with DC battery.

5. PERFORMANCE

5.1 Noise Figure Distribution

The noise figure for 5 receiving channels has been measured for an LNC unit. Results are shown in Fig. 16, together with the noise figure data distributions observed in 13 LNC units for a total of 65 channels. It is apparent, from this figure, that the average noise figure is 3.978 dB (=435 K), and the standard deviation is 0.375 dB. Thus, the noise figure values for approximately 84% of all test channels are better than the sum of 3.978 + 0.375 = 4.353 dB (= 505 K).

5.2 Local Frequency Stability

ambient temperature of the 1st LO is quite substantial, and frequency characteristics vs temperature changes should be regarded seriously. Distribution in the said characteristics is shown in Fig. 17. The temperature change coefficient is counted in a +0.32 to +4.7 ppm/°C range.

5.3 Signal-To-Noise Ratio (S/N)

Figure 18 shows unweighted S/N performance for video and sound signals together with the SHF input carrier power (C) or an input equivalent carrier-to-noise temperature ratio (C/T), where C denotes $T = 560$ K, or the value in fine weather.

Point B of the above figure is the same point when C/T is equal to -137.3 dB, as shown in Table I. Point C is equivalent to the point where the C/T deterioration is 1.2 dB in the rain for 1% of the time. Point D to the point when the C/T deterioration is 2.6 dB in the rain for 0.1% of the time, and point E to the point when the C/T deterioration is 8.3 dB in the rain for 0.01% of time [5].

Point A is equivalent to the point where the C/T increment amounts to 4.7 dB, assuming the same power flux density of -103 dBW/m^2 as the 3rd region of the WARC-BS technical standards is given. From pictures relevant to each point, it can be understood that this receiver can be properly operated for 99.99% of time.

All other baseband characteristics are integrated into Table III. These values that can be well accepted, not only for direct TV reception from a satellite, but also for community reception and rebroadcasting purposes.

6. CONCLUSION

The present study on the TV receiver, which has been developed particularly for BSE operation, has

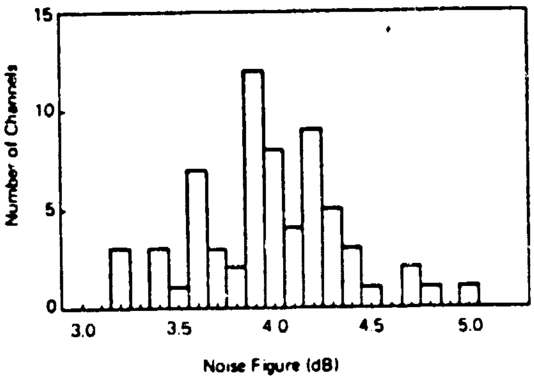


Fig. 16 Noise figure distribution.

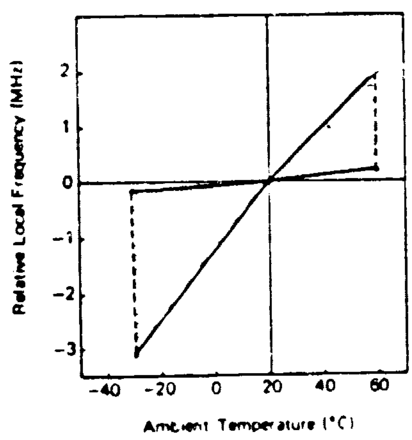


Fig. 17 Local frequency deviation range by ambient

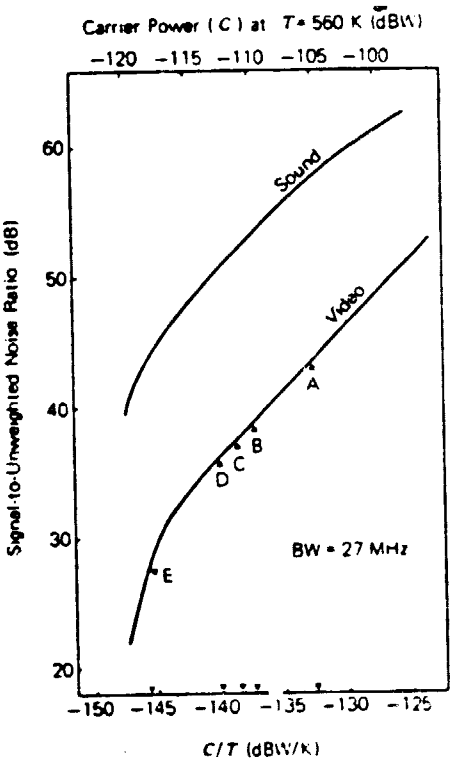


Fig 18 Video and sound signal-to-unweighted noise

shown performance sufficiently suitable for practical operations, despite its simplified structure. Findings include:

(1) Noise figure distribution for this receiver shows 84% of the samples are approximately 4.4 dB or less. Further, this receiver is capable of receiving BSE over the Japanese mainland with a 99.99% reliability.

(2) A new circuit has been developed, which can eliminate the 600 $kHz_{p\text{-}p}$ energy dispersal signals, according to the requirement of the 1977 WARC-BS technical standards.

(3) Solar batteries can likewise be employed in this receiver, for its DC power consumption is only about 4 W.

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14/12 GHz-Band Mobile-Type Earth Station for Japanese Broadcasting Satellite Communication System

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and Noriyuki YAMASHITA‡

ABSTRACT Japanese experimental medium-scale broadcasting satellite was launched on April 8, 1978. The broadcasting satellite communication system is expected to operate in the 14/12 GHz frequency band and be capable of simultaneous transmission of two color television channels. NEC has supplied NHK with a mobile-type earth station accessing to the Japanese broadcasting satellite. This report describes function and performance of earth station system and subsystems, designed for using higher carrier frequencies, and station construction for mobile use.

1. INTRODUCTION

The Japanese medium-scale broadcasting satellite was launched in April 1978. The experimental system is intended for conducting various experiments on the transmission of television signals using the 14/12 GHz bands. Meanwhile, various earth terminal facilities have been prepared ready for use. The Radio Research Laboratory (RRL) of the Japanese Ministry of Posts and Telecommunications (MPT) has provided the main earth station equipment having tracking and control capabilities. Japanese Broadcasting Corporation (NHK) has prepared a mobile-type earth station, a transportable earth station, and simple receive-only terminals.

2. BROADCASTING SATELLITE COMMUNICATION SYSTEM OUTLINE

The broadcasting satellite communication system will be used to conduct transmission tests on television signals and sound by using a satellite communication system. It is desired to establish operating techniques for the broadcasting satellite communication system as a step toward future launching of large-scale broadcast satellites which will allow these TV signals to be received separately by simplified receiving equipment, thus to cope with domestic broadcast demands and contribute to education and the reduction of fringe areas where reception is poor. The broadcasting satellite communication system consists of an experimental medium-scale broadcasting satellite to stay on a geostationary orbit (above the equator) at longitude 110°E and associated earth station facilities. Figure 1 shows the configuration of the entire broadcasting satellite communication system.

This system employs the 14 GHz band for the up link and the 12 GHz band for the down link. The satellite proper is a 3-axis control type, incorporating two working TWT systems and one stand-by TWT system, each using a high-efficiency 100 W TWT. It is designed to allow simultaneous transmission of two television channels. In 1971, the WARC-ST determined frequency assignment to broadcast satellites. The frequency allocation granted to the broadcasting satellite communication system by the WARC-ST is shown in Fig. 2. In this frequency allocation, telemetry/command signals are allocated in the lower portion of the 500 MHz bandwidth and five television channels (A_1, A_2, B_1, B_2 and B_3) and four orderwire channels are allocated in the upper 180 MHz bandwidth portion. For signal transmission, the main carrier will be frequency-modulated with a baseband signal containing TV video. 4.5 MHz sound subcarrier and the orderwire signal will be frequency-modulated with a voice frequency signal. The station reported herein is transportable earth station Type B, shown in Fig. 1, which allows transmission and reception of TV signals and orderwire signals by means of a 2.5 mϕ or 3.0 mϕ antenna.

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†Microwave and Satellite Communications Division
‡Satellite Communications Systems Division

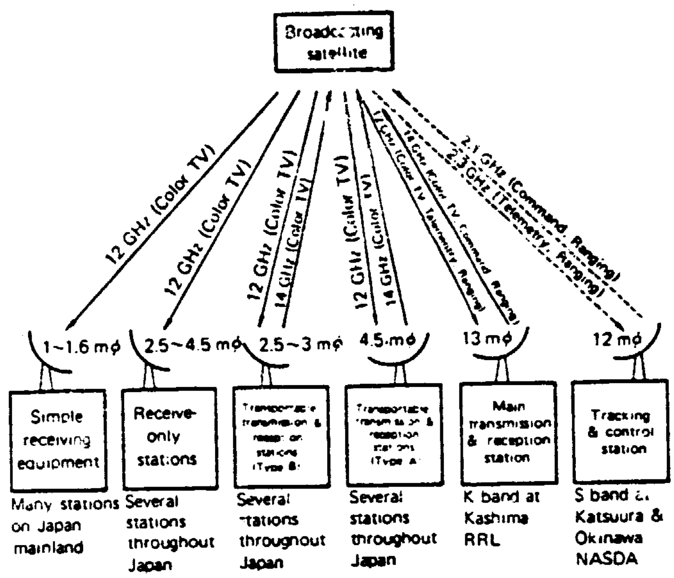


Fig. 1 Broadcasting satellite communication system configuration.

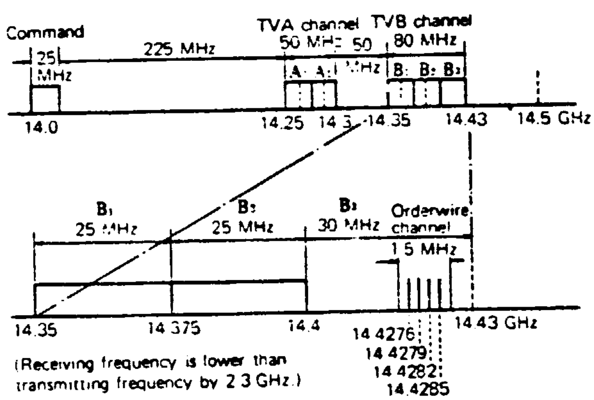


Fig. 2 Transmit carrier frequency arrangement for broadcast satellite communication system.

3. BROADCASTING SATELLITE MOBILE-TYPE EARTH STATION SYSTEM CONFIGURATION AND PERFORMANCE [1]

The broadcasting satellite mobile-type earth station is designed to incorporate all the equipment necessary for constructing a satellite communication earth station on a vehicle. That is, it incorporates the antenna, communications equipment, test equipment, monitoring equipment and power supply equipment. As shown in the system configuration of the mobile-type earth station in Fig. 3, the 14/12 GHz bands are employed to allow simultaneous transmission of one TV channel (CH B_1) and two orderwire channels, as well as reception of two TV channels (CH A_1 and B_1) and three orderwire channels – all at one time.

The appearance of the broadcasting satellite mobile-type earth station is shown in Photo 1. The antenna and receiving low-noise frequency converter are mounted at the rear of the vehicle. All other equipments are accommodated in the van. The following consideration is given to this mobile-type system.

(1) All functions necessary for an earth station are mounted on one vehicle with due consideration for mobility and operation ease.

(2) Since RF frequencies in use are high and the antenna beam width is very narrow, the vehicle strength and stability are increased so as to minimize the pointing error.

(3) The electron tubes of the power amplifiers and associated waveguides need not be dismounted when driving the vehicle from point to point.

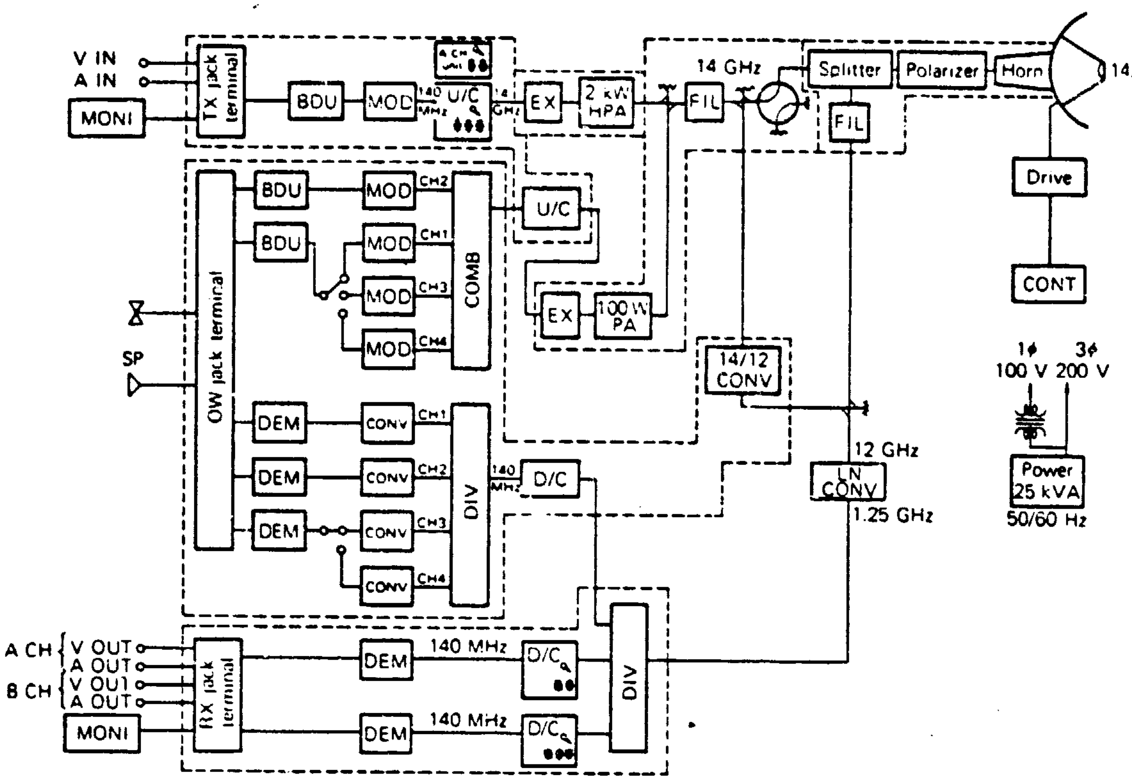
(4) The antenna can be assembled and stowed in a short time.

(5) The antenna is designed to reduce radiation side lobe level.

(6) Each equipment is designed to be compact, lightweight and shockproof, and for low-power consumption.

(7) Human engineering concept is adopted to ensure operation ease and personnel safety.

Transmission during rain is described by the link budget in Table I. An overall system carrier-to-thermal-noise ratio (C/N) of 19.6 dB is obtained for the Japanese mainland by this mobile station. To obtain the e.i.r.p. (effective isotropically radiated power) of 79 dBW, with as small an antenna as 2.5 mϕ, a newly-developed 2 kW klystron tube high-power amplifier was used. This earth station e.i.r.p. overcomes the 3 dB rain attenuation and keeps the total receiving signal-to-noise ratio of 45 dB for receive-only earth station having 4.5 mϕ antenna at any place in Japan. The 12 GHz low-noise down converter of a 4.5 dB noise figure is used on the front end of the receiver because of the small diameter antenna. To achieve such a low-noise figure, a recently-developed planar circuit



2 kW HPA:	2 kW high-power amplifier	DEM:	Demodulator
100 W PA:	100 W power amplifier	D/C:	Down converter
EX:	Exciter	COMB:	Combiner
U/C:	Up converter	DIV:	Divider
FIL:	Filter	CONV:	Converter
MOD:	Modulator	LN CONV:	Low-noise converter
BDU:	Baseband distribution unit	OW:	Orderwire

Fig. 3 Mobile-type earth station block diagram.

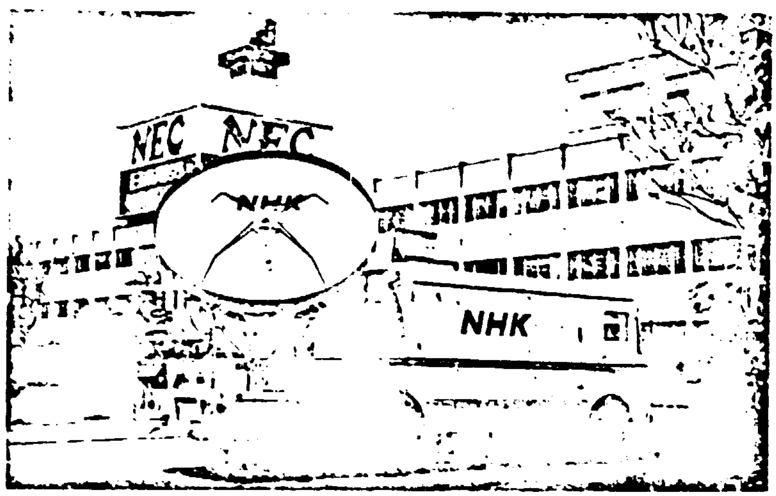


Photo 1 Broadcasting satellite mobile-type earth station.

mixer, mounted in a waveguide [2] [3] [4], is employed.

The TV video signal in the transmit system is frequency-modulated at 140 MHz into a 14 GHz-band signal, which is amplified by a 2 kW klystron tube power amplifier to be fed to the antenna. The orderwire signal is amplified by a 100 W TWT and combined with the TV signal at a 10 dB coupling. In the receiving system, the 12 GHz receiving signal from the antenna is converted to a 1.25 GHz signal by a receiving low-noise frequency converter. After being branched, the TV signal is frequency-modulated at 140 MHz and the orderwire signal at 10.7 MHz.

The antenna is a cassegrain type, which can be mounted on a vehicle, in either 2.5 mϕ or 3 mϕ antenna form. The antenna is designed giving particular consideration to the low level side lobe characteristic. When the vehicle is driven from point to point, the antenna is kept vertical on the vehicle. Such main reflector portions that extend over the width of the vehicle are divided into 2 or 3 pieces so they can be stowed separately.

After adjusting the antenna to point the satellite roughly at the site, orientation adjustment can be effected manually while monitoring the receiving signal level in the vehicle. A translator for use in loopback test and test equipment for monitoring TV video signals are mounted to ensure operation and maintenance ease. To furnish power for operating this system, a compact 25 kVA capacity engine generator is used. Continuous operation over long periods of time, is assured, since the generator uses diesel fuel which is also used by the vehicle. The major overall performance of this system is given in Table II.

4. EACH SUBSYSTEM

4.1 Antenna

The antenna for the mobile-type earth station is

Photo 2 Receiving low-noise frequency converter (LNC) installed behind antenna.

Table I Calculated link budget (TV-video channel).

(1) Up Link (14 GHz)		
Mobile Station		
Transmit power	33	dBW (2 kW)
Feeder loss	3	dB
Antenna gain	49	dB (2.5 mϕ)
EIRP (on axis)	79	dBW
Path loss	207.5	dB
Rain loss	3	dB
Satellite pointing loss	1.2	dB
Total loss	211.7	dB
Satellite		
Antenna gain	38	dB
Feeder loss	0.5	dB
Noise temperature	33.3	dBK (2120 K)
G/T	4.2	dB/K
C/T	−128.5	dBW/K
k	−228.6	dBW/K·Hz
B	73.6	dB/Hz (23 MHz)
Up link C/N	26.5	dB
(2) Down Link (12 GHz)		
Satellite		
Transmit power	20	dBW (100 W)
Feeder loss	1.5	dB
Antenna gain	37	dB
EIRP (on axis)	55.5	dBW
Path loss	205.8	dB
Rain loss	1	dB
Satellite pointing loss	1	dB
Total loss	207.8	dB
Mobile Station		
Antenna gain	47.5	dB (2.5 mϕ)
Noise temperature	29.6	dBK (910 K)*
G/T	17.9	dB/K
C/T	−134.4	dBW/K
k	−228.6	dBW/K·Hz
B	73.6	dBHz (23 MHz)
Down link C/N	20.6	dB
System C/N	19.6	dB
Threshold margin	9.6	dB
FM gain	18.3	dB
Weighting factor	12.8	dB
Total S/N	50.7	dB

* This value includes the noise temperature increment with 1 dB rain loss.

designed to achieve compromise performance in gain, noise temperature and side lobe characteristics, with as small a diameter as 2 ~ 3 mϕ. In particular, the side lobe peak value of the antenna was designed to meet the standard pattern ($32-25\log\theta$) recommended by CCIR for interference calculation. It has been considered rather difficult for such a small-diameter antenna to meet the CCIR standard pattern.

Mechanically, due consideration was given to the equipment, shockproof and lightweight features due to the necessity for being mounted on a vehicle. In consideration of these design requirements, a compact high-efficiency cassegrain antenna, with a shaped reflector, is adopted so as to obtain a uniform aperture illumination distribution and low level side lobes.

A corrugated horn, with corrugations on the inside surface of the conical horn, is used as the primary radiator. By making the depth of the corrugations $\lambda/4 \sim \lambda/2$, EH_{11} mode is produced and maintained. By radiating an ideal Gaussian beam having a low level side lobe and by being symmetrical with respect to its axis to the subreflector, efficiency degradation and generation of undesired side lobes due to spill-over power are controlled.

For improving the side lobe characteristics, a shield plate furnished with a radio wave absorber is employed around the periphery of the main reflector, so as to control spill-over power. In addition, a subreflector support was selected experimentally to minimize radio wave dispersion scattering. A wave absorber is used on its surface to reduce unwanted dispersion scattering.

The main reflector is divided into three portions. It is made of FRP, as in the case of the subreflector. The reflector face is coated with metal spray. The reflector surface accuracy is maintained sufficient for use at 14/12 GHz.

The feed section of this antenna is composed of a polarizer [5] used for rotating the polarization plane and an orthomode transducer for branching the transmit and receive signals. The broadcasting satellite polarization system is a linear polarization, where transmit signal and receive signal polarizations are parallel to each other. In order to combine and separate those transmit and receive signals in an antenna feed, a diplexing filter has been conventionally used. However, the design of the diplexing filter introduces difficulty in obtaining a new filter which can handle high power up to 2 kW. Therefore, in the antenna feed design to solve the above defects, a specific polarizer using a $0/\pi$ phase shifter, which has been newly developed to withstand up to 2 kW power and which reduces the loss in the antenna feed section, is employed in this system. The polarizer is a rotary type, which provides a relative phase difference of 0° in the 14 GHz band and 180° in the 12 GHz band. As shown in the Fig. 4, when the transmitting and receiving linearly polarized waves, which are orthogonal to each other, are applied to the orthomode transducer, the 12 GHz wave causes polarization rotation and the 14 GHz wave causes no rotation of

Table II Major overall performance.

Operating frequency ranges	
Transmission:	14.25 ~ 14.43 GHz
Reception:	11.95 ~ 12.13 GHz
Effective radiation	
TV:	more than 79 dBW
Orderwire:	more than 54 dBW
Transmission capacity	
Transmission:	1 TV channel + 2 orderwire channels
Reception:	2 TV channels + 3 orderwire channels
Receiving system noise temperature:	
below 640 K (Attenuation by precipitation: 1 dB)	
Antenna characteristics (2.5 mϕ)	
Gain (Transmission/reception):	50.0/48.9 dB
Noise temperature (Elevation: 40°):	below 40 K
Side lobe characteristics:	as per $32-25\log\theta$
Movable range:	
AZ;	−45° ~ +45°
EL;	−5° ~ 50°
Video characteristics (Earth station RF loopback)	
Frequency range:	60 Hz ~ 4.18 MHz
Low-frequency line frequency distortion:	1%
$2T\sin^2$ wave response:	Rating factor $K<1$
Signal-to-noise ratio:	more than 65 dB
Differential gain and differential phase.	
DG;	1.2%
DP;	1.3°
Audio characteristics	
Frequency range:	50 Hz ~ 13 kHz
Signal-to-noise ratio:	more than 58 dB
Orderwire characteristics	
Frequency range:	300 Hz ~ 3.4 kHz
Signal-to-noise ratio:	more than 56 dB

polarization plane, allowing transmission and reception of parallel-linearly polarized waves. Axial rotation of the feed section enables easy adjustment of its polarization plane to that of the broadcasting satellites. An example of test data obtained from the wide-angle side lobe measurement of the 3 mϕ cassegrain antenna thus designed is shown in Fig. 5. These data sufficiently meet the required performance specifications. A measured antenna noise temperature, as shown in Fig. 6, exhibits an excellent characteristics in spite of the use of a radio wave absorber.

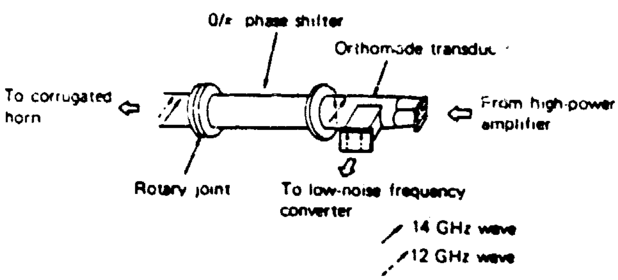


Fig. 4 Polarization rotation at 0/π phase shifter.

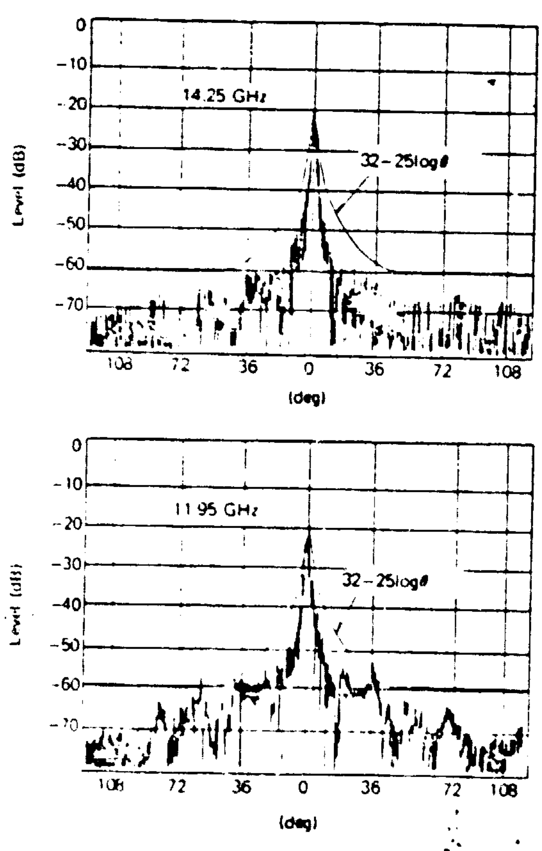


Fig. 5 Antenna radiation pattern (3 mϕ).

4.2 Receiving Low-Noise Frequency Converter

This equipment is designed to be connected directly to the 12 GHz output of the antenna feeder and is housed in a waterproofed cabinet case. The receiving 12 GHz band signal is converted by this equipment to the 1.25 GHz first IF signal having a bandwidth of 180 MHz. This equipment is designed to minimize noise figure with a simple circuit configuration. For this purpose, the RF section is constructed by a microwave planar circuit [2] [3] [4]. A low-noise GaAs FET (2SK-85), manufactured by NEC, is employed for preamplification of the 1.25 GHz band, obtaining an excellent overall noise figure of less than 4.5 dB, as shown in Fig. 7.

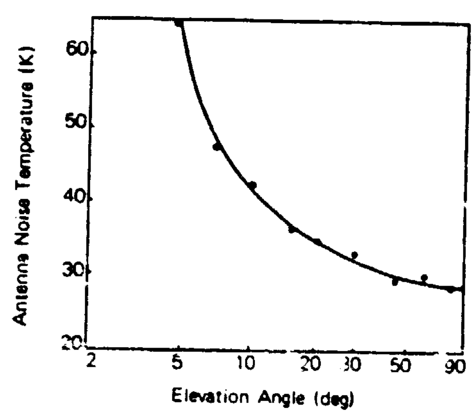


Fig. 6 Antenna noise temperature.

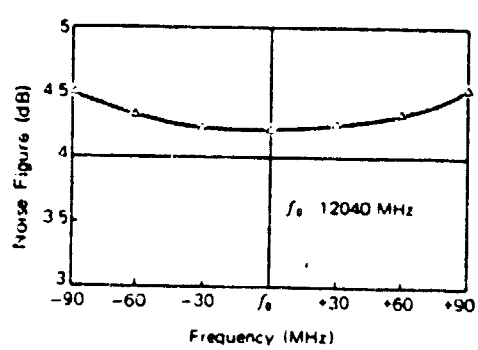


Fig. 7 Noise figure characteristic of LNC.

4.3 High-Power Amplifier

This is a high-power amplifier in the 14 GHz-band television signal. It uses a 2 kW klystron tube. This equipment, designed for use on a vehicle, has compact, lightweight circuits whose power consumption is low, involving, particularly, less rush current upon switching on the high voltage power supply.

A negative-resistance Gunn amplifier is employed in the exciter stage. All circuits, except for the klystron tube, are solid state, assuring high reliability. The 2 kW klystron tube LD-4198 [6] has been newly developed through joint research with NHK's Technical Research Laboratories. This klystron tube features compactness, high gain, high efficiency, forced air cooling and a long service life. The tuning range of the klystron tube is 14.0 ~ 14.5 GHz. A 3-channel preset tuner with a 50 MHz tuning bandwidth (1 dB bandwidth) is provided by using five cavities. An external view of the 2 kW klystron tube is shown in Photo 4.

A 100 W TWT is used for orderwire signals power amplification. A 10 dB directional coupler is employed for combining the orderwire signal with the TV signal. Photo 3 shows an external view of the power amplifier. The power amplifier seen on the right is a 2 kW klystron tube power amplifier. That on the left is a 100 W power amplifier with an associated output waveguide circuit. These two power amplifiers are accommodated in separate cabinets, each measuring 700 mm wide, 750 mm deep and 1650 mm high.

The 100 W TWT power amplifier bay incorporates an output microwave circuit, which comprises a harmonic filter, a waveguide switch, a 2 kW dummy load and an automatic power control circuit which stabilizes the TV signal carrier output power. These power amplifiers are designed to assure easy transportation and operation for use on a vehicle. Consideration is also given to shockproof property, requiring no coupling disconnection in the waveguide system when the vehicle is moved from place to place.

4.4 TV Transmitter and Receiver

This equipment incorporates modulation, demodulation and frequency conversion functions for one TV transmit channel and two TV receive channels in a bay. In the TV transmit modulator, the TV video signal is, after pre-emphasis (as per CCIR 405-1), passed through a low-pass filter and combined with the 4.5 MHz sound subcarrier, then frequency-modulated by the 140 MHz band modulator.

The FM modulator conducts reactance modulation by a variable capacitance diode and employs two kinds of digital counter type AFCs for frequency stabilization. The AFC system in use incorporates, in addition to a conventional average type AFC circuit, a keyed AFC circuit for simplified receiving stations using FM-AM converters. Either of these two AFC circuits can be selected.

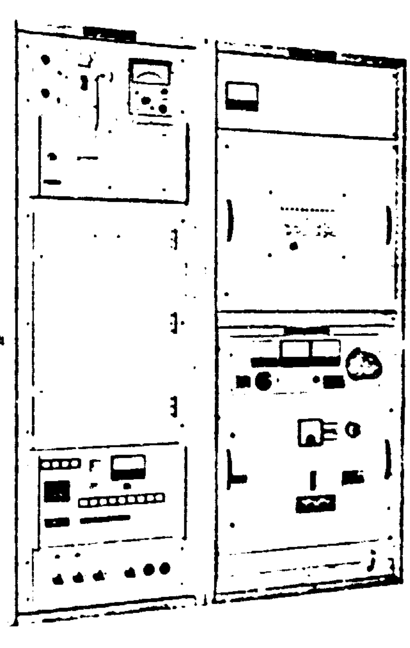


Photo 3 14 GHz band 2 kW and 100 W power amplifiers.

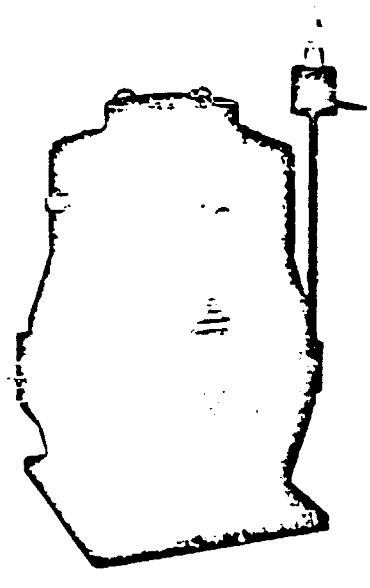


Photo 4 2 kW klystron tube.

stability is maintained with jacks. The jacks are hydraulically-operated and can be operatei singly.

(3) An engine generator (3ϕ, 200 V, 25 kVA) is included for use at locations where commercial power is not available. Continual operation foı ten hours is allowed at 35°C at 1000 meters altitude. The diesel engine in use was made by the manufacturer of the vehicle engine and assures ease of maintenance.

(4) An 8400 kcal/h cooling capability airconditioner is used to maintain equipment operation, including the large heat dissipation high-power transmitter at optimum temperature. The interior temperature is kept below 27°C, even at an outdoor temperature of 35°C, which is the average high temperature in Japan.

(5) Careful consideration is given to measures against pollution, such as noise and exhaust gas froni the engine generator and to operation safety by providing an ITV for monitoring the road at the rear of the vehicle while it is being driven.

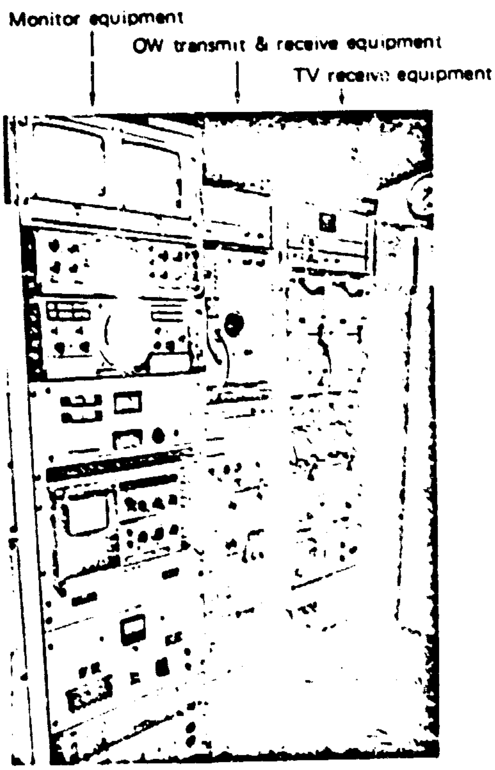


Photo 5 Monitor, OW transmit & receive equipment, and TV receive equipment installed in vehicle.

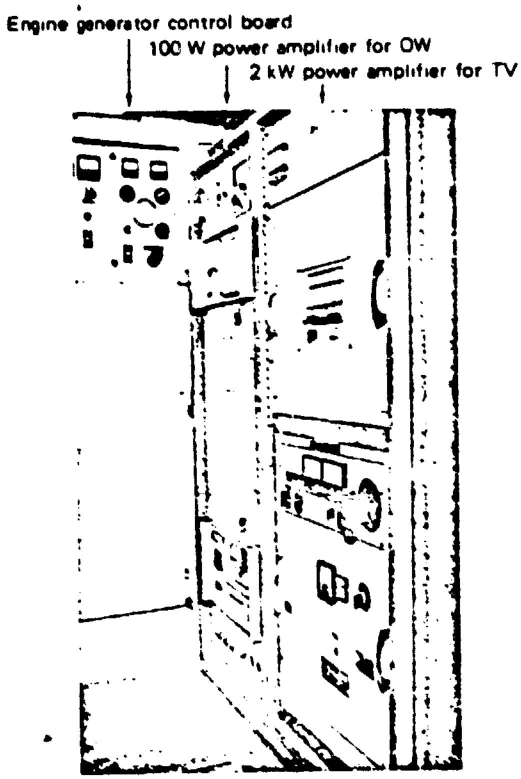
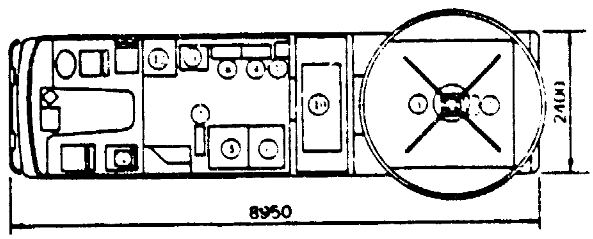


Photo 6 14 GHz-band power amplifier installed in vehicle.



① Antenna
② Dehydrator
③ Low-noise receiver frequency-converter
④ TV receiver
⑤ 2 kW power amplifier
⑥ 100 W power amplifier
⑦ TV transmitter
⑧ Orderwire equipment
⑨ Monitor
⑩ Engine generator
⑪ Power distribution board
⑫ Airconditioner

Fig. 8 Equipment layout.

In the keyed AFC, the frequency of the IF signal corresponding to the backporch portion of the video signal is counted down and phase-compared with a reference frequency by the crystal oscillator to produce a voltage in proportion to the frequency difference. The voltage is fed back into the modulator to maintain a frequency corresponding to the backporch portion at a constant 137.6 MHz.

In the average AFC, the average of the modulator output frequency is controlled to a frequency of 140 MHz.

The IF signal is converted to a 14 GHz-band signal by a frequency converter, which is fed to the high-power amplifier.

In the TV receive demodulator, the 1.25 GHz receive input signal from the low-noise frequency converter is branched, obtaining 140 MHz signals in the respective channels (channels A and B), which are then FM demodulated. In the TV sound subcarrier transmission system used for satellite transmission, 6.2 or 6.8 MHz is generally employed as the subcarrier frequency. In this broadcasting satellite communication system, however, the subcarrier frequency is made 4.5 MHz in consideration of future individual reception. Since the frequency difference between the maximum video signal frequency (4.18 MHz) and subcarrier frequency is very narrow, severe performance is required for the filter used for separating and combining these two frequencies. This low-pass filter for TV signal use also conducts delay equalization in 11 stages, meeting the required characteristics specifications.

4.5 Orderwire Transmit and Receive Equipment

In this broadcasting satellite communication system, a 1.5 MHz band is provided in the channel B_1 high frequency range for orderwire transmission. Four orderwire frequencies are assigned at intervals of 300 kHz in the 1.5 MHz band. This equipment incorporates orderwire transmit/receive functions for two transmit channels and three receive channels in a bay. Various operating modes can be selected by depressing pushbuttons. Orderwire signal is frequency-modulated by a 140 MHz-band modulator with high frequency stability into a 14 GHz-band signal. The receive signal is frequency-converted to a 10.7 MHz signal and then FM demodulated. Since the orderwire carrier frequency drift is more than 100 kHz due to the frequency uncertainty of the local oscillator in the satellite transponder, Doppler shift and the frequency uncertainty of the receive local oscillator, use of an ordinary FM demodulator will require adoption of an AFC circuit for meeting the less than 50 kHz specification requirement in equivalent noise bandwidth. Accordingly, a PLD (phase lock modulator) having frequency tracking capability is adopted. The PLD equivalent noise bandwidth is approximately 30 kHz.

4.6 Test Equipment

A 14/12 test translator and a monitor are employed as the mobile-type earth terminal test equipment. The 14/12 GHz test translator picks up a portion of the 14 GHz-band high-power amplifier output by a directional coupler. This output is frequency-converted to a 12 GHz-band signal to be fed to the receiving low-noise frequency converter. By this translator, the transmit signal is looped back to the receive side to allow various performance measurements. The monitor consists of a video distribution amplifier, video/sound switcher for monitoring, various types of measuring instruments for video and sound, and a spectrum analyzer. The switcher for monitoring allows selection of transmit signal, receive signal, or loopback signal, whichever is desired to be measured. The monitor is furnished with an antenna control panel used for manual control of the antenna position and indication of azimuth/elevation of the antenna. Photo 5 shows equipment installed in the vehicle.

4.7 Vehicle

Features of the vehicle designed to mount the earth terminal are as follows. Photo 6 shows the engine generator and high-power amplifiers installed and Fig. 8 shows the interior layout in the vehicle.

(1) To allow movement to desired locations throughout Japan, the vehicle is designed to be compact and have advanced traveling performance. For this purpose, a 2-axis chassis having a 4.7 meter wheel base is used.

However, since the standard engine with this class of chassis is somewhat small for the net weight, a high-power engine is used to provide a margin in power per unit weight. In order to increase the traveling performances, the weight balance of the vehicle is improved and a method of mounting the antenna was devised so that its center of gravity could be lowered. The equipment layout allows systematic signal transfer between equipment.

Vehicle specifications are given in Table III.

(2) The chassis is reinforced to allow operation even under a wind velocity of 25 meter/sec with the antenna beam angle deflection being within ±0.25°. During equipment operation, vehicle

Table III Major vehicle specifications

Vehicle:	
	BD40 (modified) manufactured by Isuzu
Total engine displacement:	
	12.023 liters
Vehicle dimensions:	
	8.95 m(L) × 2.46 m(W) × 3.35 m(H)
Interior dimensions:	
	4.00 m(L) × [illegible] m(W) × 1.90 m(H)
Passenger capacity:	
	4 persons
Vehicle gross weight:	
	13960 kg
Front wheel loading ratio in loaded condition:	
	35.6%
Maximum stable inclination:	
	Right; 30°20'
	Left; 30°20'
Maximum speed:	
	110 km/h
Maximum gradeability:	
	$\sin\theta = 0.304$
Minimum turning radius:	
	8 meters
Maximum engine horse power:	
	260 PS/2500 rpm

5. CONCLUSION

After being supplied to NHK in March 1977, this system has been used for many experiments. After the launching of the Japanese experimental medium-scale broadcasting satellite, this system will be used for varieties of experiments, putting the broadcasting satellite into practical use.

ACKNOWLEDGMENT

The authors wish to express their sincere gratitude to those concerned in the NHK Headquarters of Technical Administration & Construction, and the Technical Research Laboratories for their continued co-operation and guidance.

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APPENDIX F

GROUND TERMINALS FOR MEDIUM-SCALE BROADCASTING SATELLITE FOR EXPERIMENTAL PURPOSE.

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MITSUBISHI ELECTRIC CORPORATION

1. INTRODUCTION

Japan's first experimental broadcasting satellite was launched into its stationary orbit above the equator at long. 110°E. in April 1978. For carrying on satellite broadcasting service, it was assigned the frequency bands of 12GHz (down-link) and 14GHz (up-link). Now using these bands, full-fledged experiments are currently conducted to assure the feasibility of color TV transmission system by the Medium-scale Broadcasting Satellite for Experimental Purpose.

The earth station terminals of the experimental satellite broadcasting system comprise the following:

(1) Main Station (Kashima Branch of Radio Research Laboratory of the Ministry of Post and Telecommunications).

(2) Transportable Type-A Station (Transportable type).

(3) Transportable Type-B Station (Mobile type).

(4) Various types of TV receive-only stations.

(5) Direct-to-home type Receivers.

The numerous R&D efforts have been made on these terminals to enable them to be the most suitable ones for the experiment objectives, and they have already been installed in various sites in Japan.

Most of newly developed techniques established through the above R&D efforts ... introduce new concepts in the RF circuits of ... terminal equipments on the 14/12GHz band, ... the low-noise converter to be achieved by ... of a planner circuit mounted in the waveguide, ... transmitter, the antenna, and the direct-to-home receiver for the FM TV signals.

This paper gives the construction and performances of the transportable Type-A earth station terminal, the mobile TV receive-only earth station terminal, and direct-to-home receivers that were researched and developed by Mitsubishi Electric Corporation (MELCO) under the supervision of Japan Broadcasting Corporation (NHK), and manufactured by MELCO for being integrated in the total system. It gives also the summary of the experimental satellite broadcasting system.

2. SUMMARY OF EXPERIMENTAL SATELLITE BROADCASTING SYSTEM

The experimental satellite broadcasting system uses the 14/12GHz band whose transmission parameters are shown in Table 1. The medium-scale broadcasting satellite and various experimental ground terminals comprising the system are shown in Figure 1.

The experiment objectives are to confirm (1) the fundamental performances when televising the TV programs via the satellite from the various type transmit earth station terminals set up in various points of the mainland of Japan (including remote islands) and (2) the technical aspect of whether it is possible to compose a ... network yielding the receive video quality conforming to the CCIR broadcasting quality standards by direct-to-home receiver with inservice time availability of 99% upward.

In other words, these objectives call for the following:

(1) Establishment of techniques on FM system required for enabling the majority of the TV auditors receiving the TV signals from the satellite to judge the picture quality rated as TASO 1 (Excellent) on setting up a network to secure the rated S/N ratio of 45dB with the above time availability.

(2) Research on operational scheme.

(3) Development of new techniques for the ground terminals.

(4) Collection of propagation data for the 14/12GHz band covering the entire mainland of Japan.

The link frequency spectra of the broadcasting satellite network are shown in Figure 2. As can be seen from these spectra, two transponders are used to form A-Channel and B-Channel. And each of these channels are divided into five subchannels, A1, A2, B1, B2, and B3, which are allocated according to the experiment objectives. The ground terminals are designed on the basis of having A and B Channels together cover 180MHz band.

Table 1. Transmission Parameters of Broadcasting Satellite System

1. Television Signal		
Video Frequency	:	60Hz~4.18MHz
Frequency Deviation	:	12MHzp-p
Emphasis	:	CCIR Rec. 405-1(525/60)
Modulation Polarity	:	Positive
Energy Dispersal	:	600kHzp-p (Symmetry triangular with waveform synchronizing the field blanking interval)
Transmit AFC	:	DC average/keyed AFC
2. TV Sound Signal		
Sound Frequency	:	50Hz~15kHz
Subcarrier Frequency	:	4.5MHz
Subcarrier Frequency Deviation	:	±25kHz
Subcarriers RF Frequency Deviation	:	±1MHz
Emphasis	:	75us
3. RF Allocated Bandwidth		
TV Channel	:	23MHz
4. Orderwire (OW) Signal		
Voice Frequency	:	0.3~3.4kHz
Test Tone Frequency Deviation	:	±6.8kHz
Occupied Bandwidth	:	20kHz

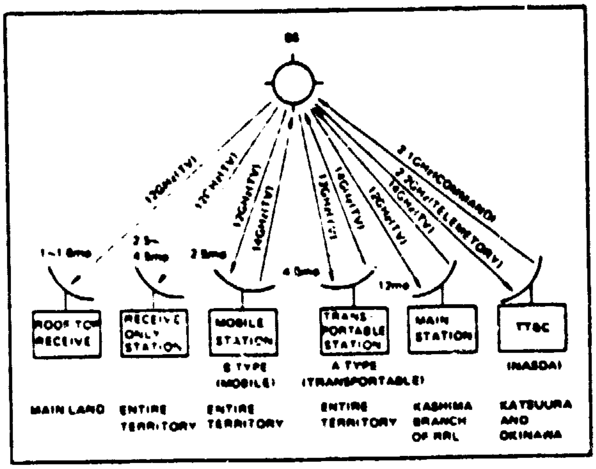

Figure 1. System Block Diagram of Satellite Broadcasting System.

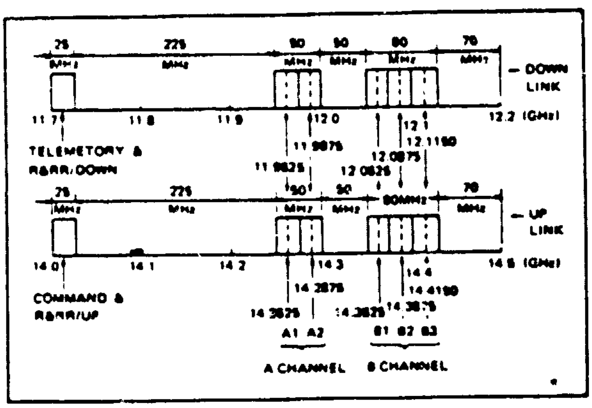

Figure 2. Link Frequency Spectra of Broadcasting Satellite Network.

Table 2. Typical Link Parameters of Broadcasting Satellite Link

Up-Link

1. Type of Stations		Transportable-A Station (Mainland)	Transportable-B Station (Remote Islands)
Antenna Dia	:	4.5mϕ	4.5mϕ
EIRP (99.9%)	:	81dBw/84dBw	81dBw/84dBw
2. Up-Link/Satellite Receive			
Path Loss	:	207.3dB	206.9dB
Rain Loss (99.9%)	:	0dB/3dB	0dB/3dB
Satellite Receive Antenna Gain	:	37.0dB	30.0dB
Pointing Error	:	1.0dB	3.0dB
Feeder Loss	:	0.5dB	0.5dB
System Noise Temperature	:	32.6dBK	32.6dBK
Up-Link CNR	:	31.5dB	22.9dB

Down-Link

1. Type of Stations		Transportable-A Station (Mainland)	Receive Only Station (Entire Territory)	Receive Only Station (Remote Island)
Antenna Dia	:	4.5mϕ	1.6mϕ	4.5mϕ
System Noise Temperature	:	910K	660K	660K
Earth Station G/T	:	22.9dB/K	14.8dB/K	24.3dB/K
2. Satellite Transmit/Down Link				
Satellite EIRP	:	55.5dBw	55.5dBw	46.5dBw
Pointing Error	:	1.0dB	1.0dB	1.0dB
Path Loss	:	205.8dB	205.8dB	205.4dB
Rain Loss (99.9%)	:	1dB/7dB	1dB/7dB	1dB/7dB
Receive Antenna Tracking Error	:	–	0.5dB	2.0dB
Down-Link CNR	:	25.5dB/ 18.5dB	16.9dB/ 9.9dB	16.3dB/ 9.3dB
Receiving Level	:	–69.6dBm/ –76.6dBm	–79.3dBm/ –86.3dBm	–80.4dBm/ –87.4dBm

Overall Link

Total CNR				
(Transmit from Mainland)	:	24.5dB/ 18.3dB	16.7dB/ 9.9dB	16.2dB/ 9.3dB
Transmit from Remote Island)	:	23.6dB/ 17.2dB	15.9dB/ 9.7dB	15.4dB/ 9.1dB

The design of the satellite link calls for the parameters yielding the weighted S/N ratio of 45dB based on a station in the mainland of Japan having an antenna of 1.6m diameter and a receiver of 600K system noise temperature. The performance requirements for these small stations including direct-to-home receivers are relaxed as much as possible, fundamentally the same concept as for the ordinary TV broadcasting service network to make them economy.

The fixed group delay characteristics including those of the satellite transponder are to be all equalized at the transmit station. Table 2 shows a typical link parameters of the Broadcasting Satellite Link.

3. TRANSPORTABLE TYPE-A STATION (TRANSPORTABLE ON KNOCKDOWN BASIS)

The fundamental requirements of the transportable Type-A earth station terminal (hereinafter called the Type-A station) are as follows.

(1) Any one subchannel of its five subchannels of A1, A2, B1, B2, and B3 be selectable and usable for transmission of telecasts.

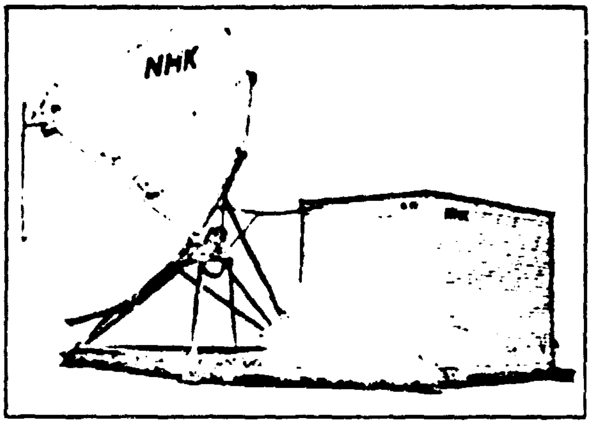

Figure 3. External View of Transportable-A Earth Station.

(2) Any one subchannel in each of A and B channels be usable simultaneously for reception of telecasts.

(3) Transmission to or reception from the main station (Kashima Branch) or a transportable station of audio and data transmission signals be possible via the FM orderwire circuit (OW) in the B3 subchannel.

(4) The station be of small size and light weight, enabling its setting up in a short time and ease of withdrawal (removal) and transportation. And upon once being set up, it be usable for a stable operation over a long period.

Figure 3 shows an external view of the Type-A station, which was developed and designed to meet the above requirements; and Figure 4, its overall block diagram. As can be seen in the figures, the station can be roughly divided into two main components, i.e., the 4.5 m dia antenna and the equipment shelter. All of the transmit and receive equipments (excluding the low-noise converter) and the antenna control equipment can be accommodated in this shelter.

The high-power amplifier (HPA) employs a 5-cavity klystron of 2kW saturated output power, and covers the 180MHz band spread over two channels by means of a 3-stop preset tuning mechanism. Its external view is shown in Figure 5. When transporting the shelter, the only things that need to be done are to remove the klystron and the traveling-wave tube of the OW-HPA.

The antenna is of a cassegrain type, and is supported by an X-Y type mounting. For yielding transportability over the entire mainland of Japan, it was designed to enable it to be set up easily and pointed at the satellite without precise adjustments. And it possesses the function of automatically tracking the satellite in ±5° steps by means of the step-tracking system.

When carrying on high-power transmission with this type of small-diameter antenna, the wide-angle side-lobe characteristics of the antenna become extremely important from the standpoint of causing interference to other terrestrial networks, preventing effective utilization of the satellite orbit, etc. So good performance

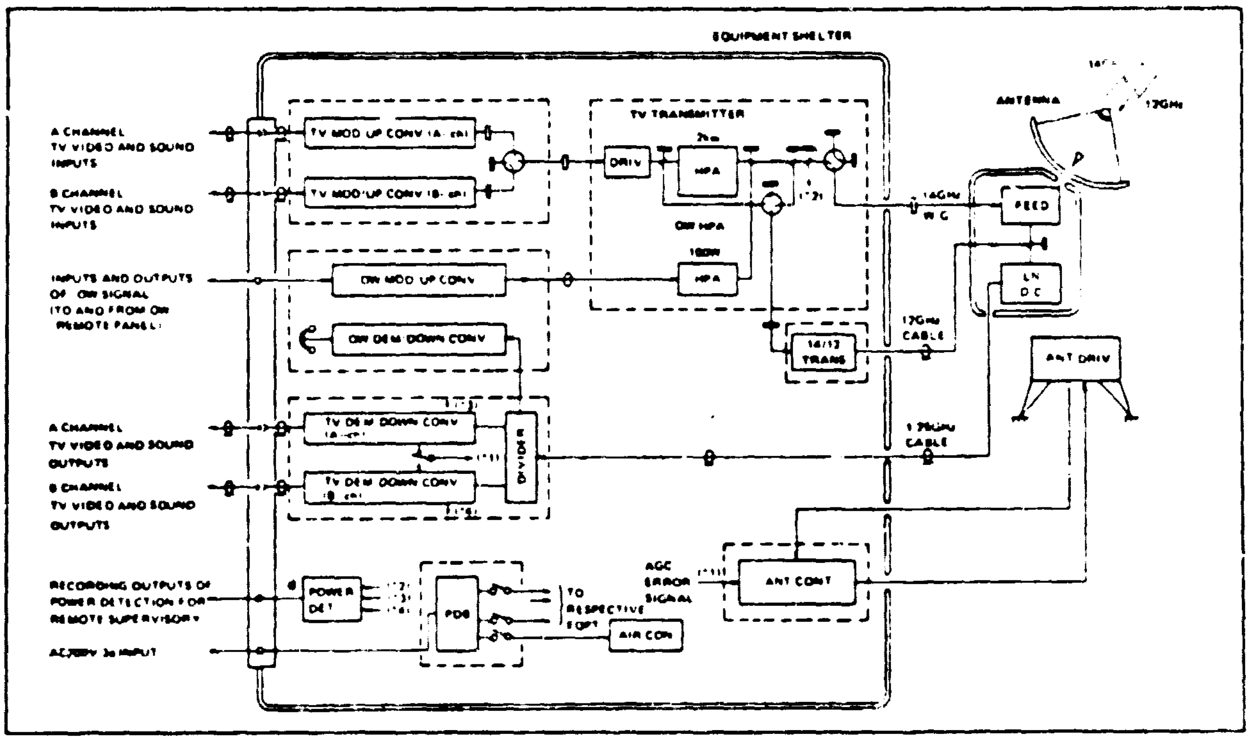

Figure 4. Overal Block Diagram of Transportable-A Earth Station.

characteristics were obtained by taking various countermeasures such as the adoption of a corrugated horn, optimization of the diameter ratio between the main reflector and subreflector, reduction of unnecessary scattering by use of a shaped reflector and a specially shaped tripod of subreflector. These characteristics were reported in CCIR(SG-4) of May 1976.

The front end of the receiving subsystem adopts the low-noise converter that consists of a planner circuit mounted in the waveguide, converts the receive signal into that of the 1.25GHz band, amplifies it, and distributes it to the respective receiving channels. By use of this converter, the receiving performance with the system noise temperature below the specified limit and the 180MHz wideband characteristics are simultaneously obtained.

The modem for the TV signal has an IF frequency in the 140MHz band, which is converted to a 14GHz signal by the up-converter of the transmit system. For demodulation TV signal the 1.25GHz receive signal is converted to a 140MHz signal by the down-converter of the receive subsystem.

The OW modem also has an IF frequency in the 140MHz band, and performs the FM modulation and demodulation of the FM-SCPC signals for four channels each of transmit and receive. The demodulator has a ±150kHz pull-in range and adopts the PLL type threshold extension demodulator, and aims to improve threshold characteristics.

The overall performance of the Type-A station equipped with the above equipments is given in Table 3.

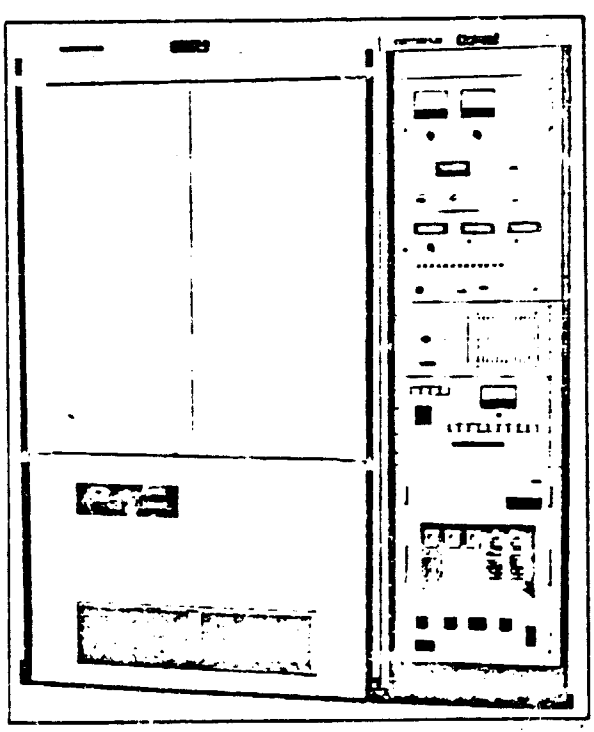

Figure 5. 2kW Klystron High Power Amplifier (HPA).

Table 3. Performance of Transportable-A Earth Station.

1. Frequency Range		
Transmit	:	14GHz, one of TV channel in A_1, A_2 or B_1, B_2, and B_3 OW ch 1~4
Receive	:	12GHz, one of TV channel in A_1 or A_2, and one in B_1 or B_2 or B_3 OW ch 1~4
2. Transmit EIRP		
TV Transmit	:	81dBw (+3~−10dB Variable)
OW Transmit	:	56dBw/ch (0~−10dB Variable)
3. System Noise Temperature	:	Less than 910K (at 1dB rain drop attenuation)
4. Transmit Stability		
EIRP	:	Less than 0.5dB/day
Frequency	:	Better than 1×10^{-6}
5. Overall Loop Performance		
(1) TV Video		
Baseband-to-Baseband Gain/Frequency Response	:	Within ±0.5dB/60Hz~4.18MHz
Baseband-to-Baseband Group Delay Response	:	Within ±30ns/3.58MHz
SNR	:	(Periodic Noise) More than 50dB (p-p/p-p) (Random) More than 60dB (p-p/rms)
DG, DP	:	Less than 3%, less than 2°
Waveform Distortion	:	(Line Time) within ±1% (Field Time) within ±1% (2T $\sin^2$ Response) K≦1
(2) TV Sound		
Baseband-to-Baseband Gain/Frequency Response	:	Within ±0.5dB/50Hz~13kHz
SNR	:	Better than 60dB
Cross Talk SNR	:	Better than 55dB (rms/rms)
Distortion	:	Less than 1%
(3) Orderwire		
Baseband-to-Baseband Gain/Frequency Response	:	Within ±1dB/300Hz~3.4kHz
SNR	:	Better than 45dB
Distortion	:	Less than 5%
6. Antenna		
Gain	:	(Transmit) better than $(54.0+20\log f(\mathrm{GHz})/14.25)$ dB (Receive) better than $(52.5+20\log f(\mathrm{GHz})/11.95)$ dB
Sidelobe	:	(1st Sidelobe) lower than −14dB (1°~48°) lower than $(32-25\log\theta)$dBi (48°~180°) lower than −10dBi
Noise Temperature	:	Lower than 70K (El:40°)
Polarization	:	Linear
Tracking	:	Step tracking, accuracy: Better than ±0.05°

4. TRANSPORTABLE TV RECEIVE-ONLY STATION

The transportable TV receive-only earth station terminal (hereinafter called the TV receive-only C station, or TVRO) was designed and developed mainly to be hauled to various areas of the mainland of Japan, and be used to augment the data obtained by various kinds of TV receive-only stations, measure their transmission characteristics, and perform receive video quality evaluation. A great stress was placed on its receive flux density measuring function especially in view of its great mobility and the role of data collection at various places.

The TV receive-only C station consists of a 1.6m dia antenna of a 4 section precast type, a low-noise converter, and a receiver in-door unit that is installable on a maintenance jeep available at each NHK station. The entire assembly of equipments can be loaded on one jeep, hauled to any desired place, and immediately applied to various kinds of measurements.

The external view of the TV receive-only C station is shown in Figure 6; and its overall block diagram, in Figure 7.

The antenna subsystem is of a 4-section precast type, and features a front-feed type parabola antenna mounted on a tripod support structure. It has the mechanism for easily adjusting the AZ and EL angles of the antenna by hand, and the repeatability of the antenna's gain performance upon assembling of the subsystem is within 0.5dB.

The low-noise converter is of the type having a planner circuit in the waveguide, the same as that of the Type-A station. And its IF frequency band is 290 to 470MHz, and its performance characteristics are as shown in Figure 8 and Table 4.

The receiver in-door unit consists of a channel divider, an FM demodulator, and a pilot signal receiver. It is capable of simultaneously receiving on one subchannel each of the A and B Channels (total of two subchannels) and of measuring the pilot signal's receive flux density.

The TV receive-only C station has the function of sending and repeating the receive signal from the satellite to the IF stage of the existing TV broadcasting translator. So in addition to the above equipments, it incorporates a VSB-AM modulator, a TV noise-loading test set, a waveform monitor, a color video monitor, a recorder, etc. The performance of the TV receive-only C station as constituted by these equipments is shown in Table 5.

5. DIRECT-TO-HOME RECEIVER

The direct-to-home receiver was researched and designed to serve as a model for receiving TV programs by either a common receive terminal or a home TV receiver. It can be divided mainly into the following two elements.

(1) The antenna of about 1m diameter to whose rear is attached the Outdoor Unit (low-noise converter).

(2) The Indoor Unit to be used in combination with a conventional TV set.

Figures 9 and 10 show the external views of the indoor and outdoor units respectively.

The outdoor unit converts the 12GHz band signal from the satellite to a 400MHz signal. Then, of the five subchannels A1, A2, B1, B2, and B3 formed in the indoor unit, the desired subchannel is selected by pushing of the selector buttons. Then, the signal of the selected subchannel is demodulated by the FM demodulator built in the indoor unit and output as video and audio signals. And at the same time, it has the function of extracting the signals converted to the usual terrestrial broadcasting VHF frequencies of the No.1 or No.2 channel upon their passing through the built-in VSB-AM modulator.

Accordingly, if the output is to be directly fed to a home TV set, it would constitute a direct reception of a satellite broadcasting program, and the equipment would be a very simplified one compared with that for reception via a common receive terminal.

It should be added here that preceding the NHK's satellite broadcasting experiments, MELCO's direct-to-home receiver was used in the U.S.A. and Canada in the CTS receiving experiments. And that the clearness of video obtained therefrom was the object of attention in various countries.

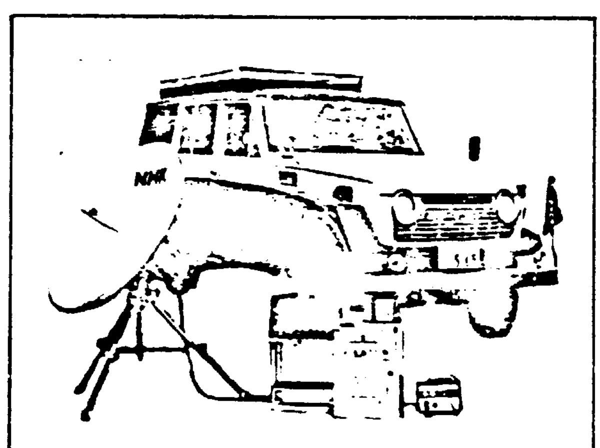

Figure 6. External View of TV Receive Only-C Station.

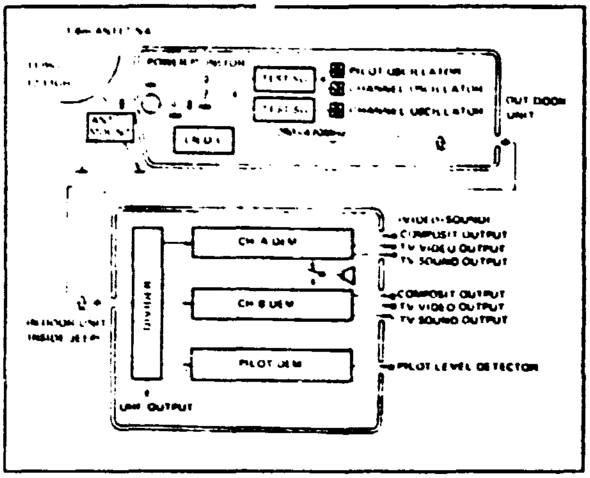

Figure 7. Block Diagram of TV Receive Only-C Station.

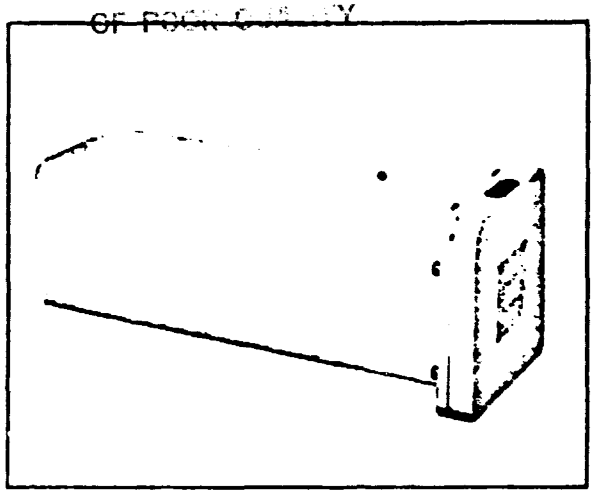

Figure 10. External View of Out-Door Unit.

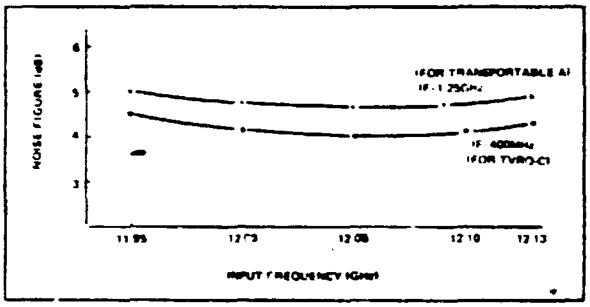

Figure 8. Noise Figure of Low Noise Down Converter.

Table 4. Performance of Low Noise Down-Converter

	For Transportable-A	For TV Receive Only and Direct-to-Home Receiver
Input Frequency	11.95～12.13GHz	11.95～12.13GHz
IF Frequency	1.16～1.34GHz	290～470MHz
Local Oscillator	10.79GHz	11.66GHz
Noise Figure	Less than 5.0dB	Less than 4.5dB
Converter Gain	More than 40dB	More than 50dB
Frequency Stability of Local Oscillator	Within $\pm1\times10^{-8}$ (Multiplier with Xtal OSC)	Within $\pm2.6\times10^{-5}$ (TVRO) Within $\pm4.2\times10^{-5}$ (Direct-to-Home Receiver) (Stabilized Gunn OSC)
Environmental Conditions	$-20°$～$+40°$C 100%	$-20°$～$+40°$C 45～90%

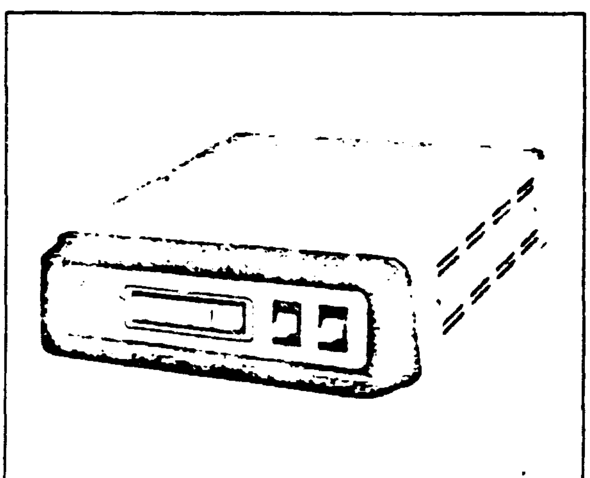

Figure 9. External View of In-Door Unit.

Table 5. Performance of Transportable TV Receive Only Station

Item	Performance
Antenna	
Frequency Range	11.95～12.13GHz
Gain	Better than 43dB
Sidelobes	$10.5+25\log\phi/\phi_0$ or $10\log G_0$ (ϕ_0: 3dB beam angle, G_0: gain at beam center)
Noise Temperature	Less than 50K (EL 40°)
Receiver	
Input Frequency	11.95～12.13GHz
Level Range	-85～-65dBm
Noise Figure	Less than 4.5dB
Output Level	TV video 1Vp-p/75Ω unbalanced, positive polarity TV sound 0dBm/600Ω balanced
IF Center Frequency	27MHz/ch
SNR	TV video: better than 31dBp-p/rms (unweighted) TV sound: better than 50dB rms/rms

Table 6. Performance of Direct-to-Home Receiver

Item	Performance
Frequency Range	11.95~12.13GHz
1st IF Frequency	290~470MHz
2nd IF Frequency	130MHz
1st LO Stability	Within ±4.2x10^{-5} (±500kHz)/−20°~+40°C
Modulation	FM (TV video) FM-FM (TV sound)
Noise Figure	Lower than 4.5dB
Receiving Bandwidth	27MHz/ch
Threshold Level	−85dBm
AGC Characteristics	Within 1dBp-p over input range −90 to −60dBm
TV video Output Level	1Vp-p/75Ω unbalanced, positive polarity
TV sound Output Level	0dBm/600Ω balanced
VHF AM Output	More than 80dBμV, 91.25MHz or 97.25MHz
Power Supply	AC 100V
Power Consumption	40VA
Dimensions and Weights	Out-Door Unit: 98(W)x98(H)x 240(D)(mm) 1.5kg In-Door Unit 280(W)x85(H)x 240(D)(mm) 3.9kg

6. CONCLUSION

The satellite broadcasting system by Medium-scale Broadcasting Satellite for Experimental Purpose and related ground terminals have been presented.

The full-fledged experiment using these terminals was commenced in July 1978. The data obtained therefrom will no doubt contribute to establish essential technical standards to be applied to and to reflect in the hardware of the next generation satellite broadcasting system using the 14/12GHz band and to bring up practical operation technique; i.e., the multiaccess.

And with introduction of new semiconductors, whose performance is being improved by leaps and bounds, smaller size and lower cost equipment with better performance for practical use will be developed.

The authors express their appreciation to the engineering staffs in the NHK's Technical Research Laboratories and Headquarters of Technical Administration & Construction and also thank those within MELCO for all the advice extended to them in the development of the system and devices.