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REPORT NO. GDC-DCF70-002
CONTRACT NAS 8-21036

TELEVISION BROADCAST SATELLITE STUDY

VOLUME II • TECHNICAL REPORT

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Convair Aerospace Division

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REPORT NO. GDC-DCF70-002

TELEVISION BROADCAST SATELLITE STUDY

TVBS SYSTEM

TECHNICAL REPORT

VOLUME II

CONTRACT NAS 8-21036

31 December 1970

Prepared for
E. C. Hamilton, COR
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

Prepared by
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San Diego, California

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FOREWORD

This report was prepared by the San Diego operation of the Convair Aerospace Division of General Dynamics under Contract NAS8-21036, Television Broadcast Satellite Study, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Astrionics Laboratory of the George C. Marshall Space Flight Center.

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INTRODUCTION

The Television Broadcast Satellite Study was performed by the Convair Aerospace Division of General Dynamics Corporation for the Astrionics Laboratory of the NASA - George C. Marshall Space Flight Center under contract number NAS 8-21036. This study was initiated in December 1968 with completion originally scheduled for 17 November 1969 but later rescheduled, at NASA's request, to 31 December 1970.

In this study the Convair Aerospace Division was supported by the Aerospace Group of Hughes Aircraft Company as subcontractor.

1.1 SCOPE AND GUIDELINES

Specifications and guidelines under which this study was conducted were:

- LAUNCH VEHICLE

  Saturn V/Apollo System
  - Command/Service Module
  - LEM laboratory
  - Spent S-IVB stage
  - LEM Adapter

- SPACECRAFT
  - Unmanned
  - Man-assisted during the initial 15-45 days
  - Minimum 2-year life

- ORBIT AND COVERAGE
  - Synchronous equatorial
  - 0.5M to 10M sq. mi. area within 3db beamwidth of the antenna pattern
  - Single and multiple beams

- TRANSMISSION
  - Television, monochrome and color
  - ERP: 40 to 80 dbw
  - FM and AM/VSB
  - Frequencies: 470 to 890 MHz
    2 to 3 GHz
    8.3 to 8.5 GHz
    11.7 to 12.7 GHz

- RECEIVING SYSTEMS
  - Direct to conventional home receivers
  - Direct to modified home receiving systems
  - To specialized equipment for necessary broadcasts.

Whinin these guidelines the immediate study goals were, as shown in Table 1-1. A three-phase program was outlined to define and select the three best concepts for detailed analysis.

Table 1-1. TVBS Study Goals

PHASE I & II
ASCERTAIN REAL TVBS USER REQUIREMENTS
DEVELOP OPTIMIZATION SYNTHESIS PROGRAM
• OPTIMUM-COST TOTAL SYSTEM
• SENSITIVITIES OF OPTIMUM SYSTEMS
DEVELOP SATURN V CLASS TVBS CONFIGURATIONS
DETERMINE CRITICAL TECHNOLOGY
SELECT BEST USER/SYSTEM APPLICATION
PHASE III
REFINE 3 BEST SPACECRAFT & GROUND SYSTEMS PERFORMANCE, COST, OPERATIONAL SCHEDULE

1.2 STUDY APPROACH

The overall study approach is illustrated in Figure 1-1. The major tasks are:

1. Computer Analysis. The TV Broadcast Satellite system synthesis/optimization computer program is a flexible, comprehensive design tool for the analysis of cost and technology requirements over a broad range of user requirements and system configurations. The program uses a total system approach in which the ground uplink, spacecraft, launch vehicle and ground downlink systems are simultaneously synthesized to determine minimum total-system cost designs. In addition, the selection of feasible configurations, the sensitivities of the selected configurations to pertinent system parameters — e.g. design parameters and weight and volume constraints -- and subsystem models can be determined.

2. User Analysis. Convair's user analysis was based primarily upon personal contacts with potential users of television broadcast techniques. More than thirty such contacts were made with key representatives in the seven major categories being considered. These contacts were supplemented by more than a hundred other contacts -- both personal and by correspondence. As a result, ten users and their technical requirements were analyzed and the results compiled for comparative evaluation.

3. Communication System Analysis. FM and AM/VSB TV communication subsystems were analyzed in detail. Data for the analysis was derived, primarily, from related NASA-funded studies of high-power amplifying devices, and low-cost ground receivers. Additional technical and cost data was developed during the study to support areas such as telemetry and control, uplink transmission systems, multiple sound channels per video channel, transmitter efficiency, and reliability. Computer analyzed antenna patterns were plotted for each area of coverage to illustrate

FOLDOUT FRAME 1

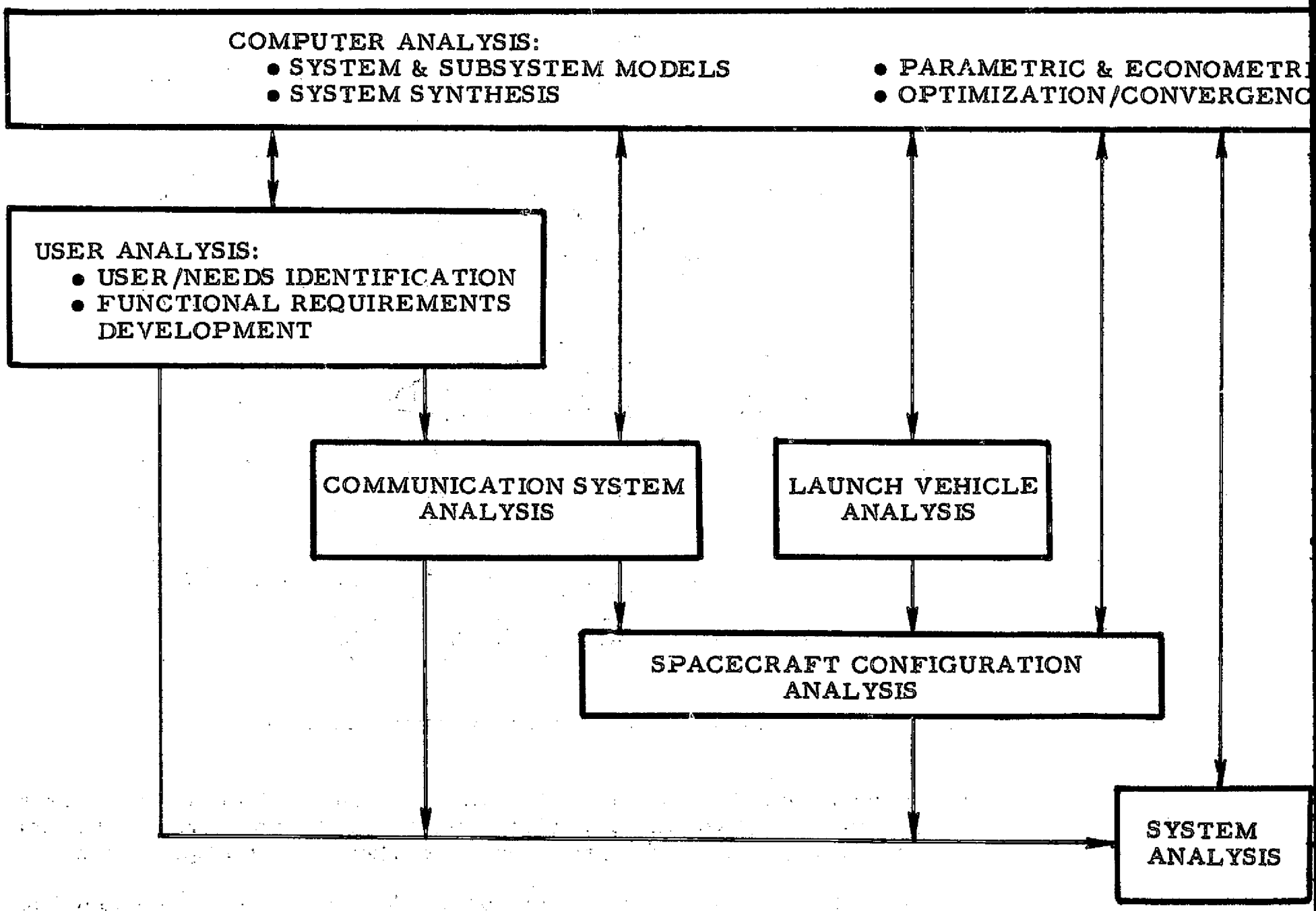
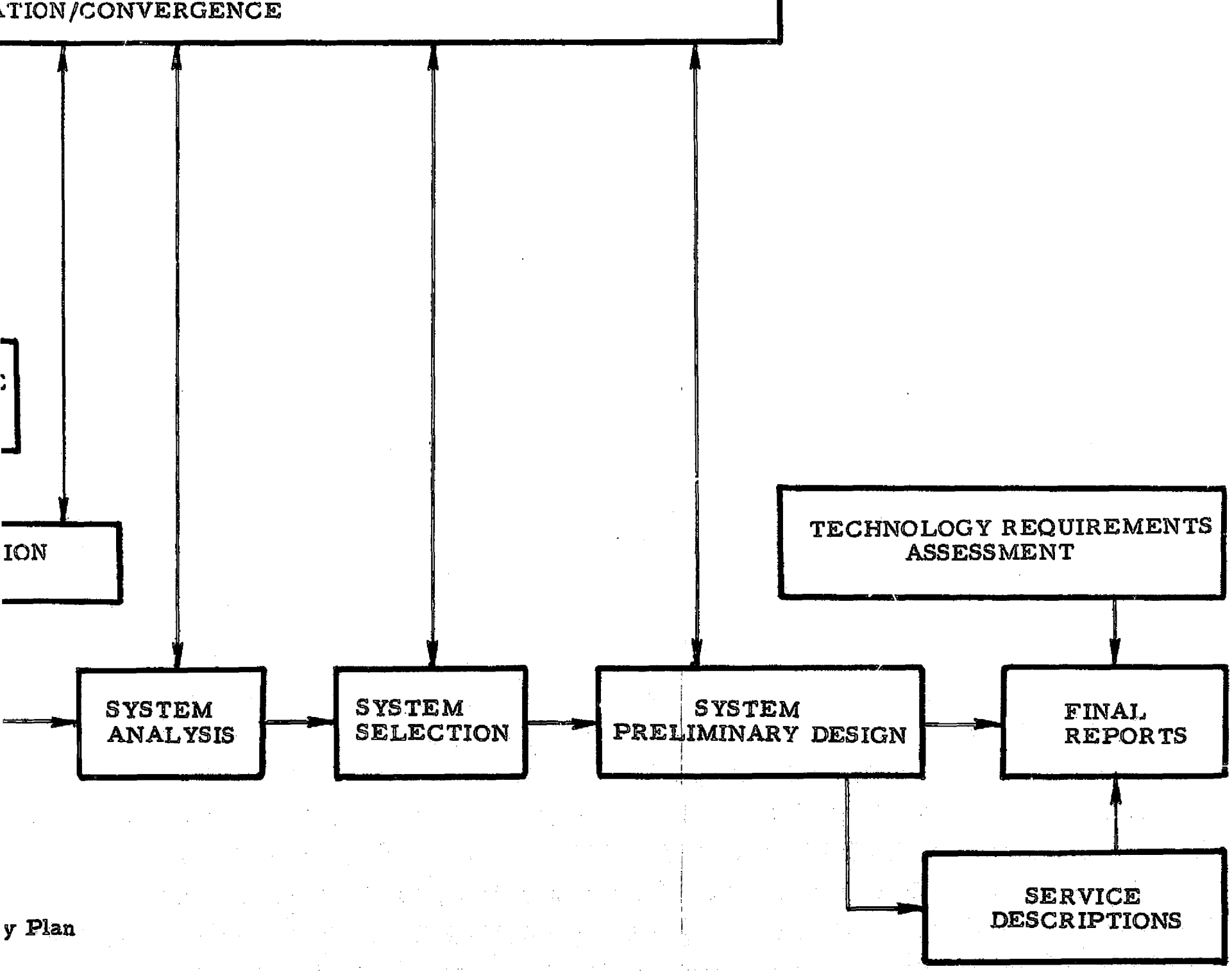


Figure 1-1. Television Broadcast Satellite Study - Overall Study Plan

FOLDOUT FRAME 2



y Plan

probable interference. (Figure 1-2.) An optimization, using overlays of these projections, can be used to select an "optimum" position for the satellite. Sidelobe effects will preclude co-channel usage from the eastern to the western time zones in the U.S.

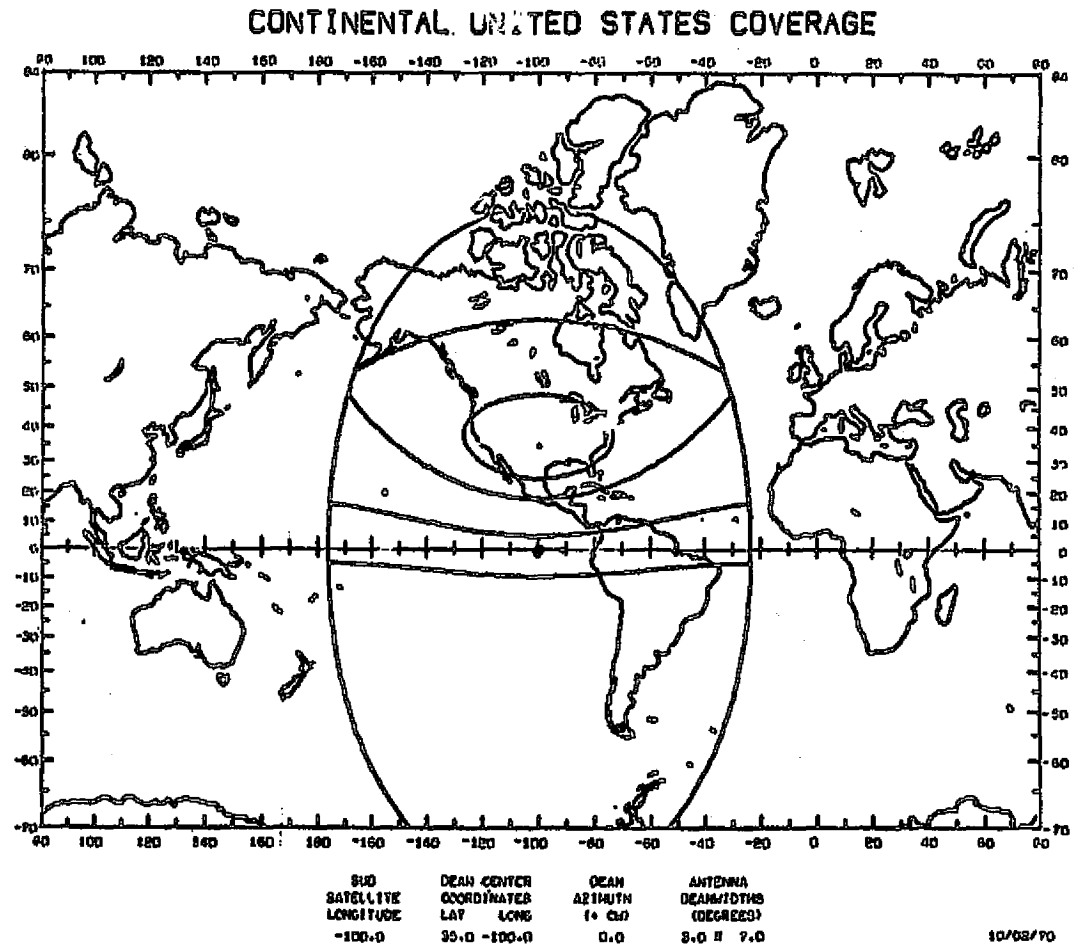


Figure 1-2. Typical Antenna Coverage Plot

4. Launch Vehicle Analysis. The Saturn V launch vehicle (Table 1-2) is capable of delivering up to 60,000 lb. to synchronous orbit. This permits a wide range of approaches to be taken to user requirements:

   a. Multiple short-lived satellites can be orbited to fulfill a long life requirement.

   b. Large redundancies can also be considered for long-life systems.

   c. Multiple satellites for multiple users can be launched simultaneously.

   Affecting these advantages is the large commitment in cost and payload in the event of a launch failure. If schedule is not critical this issue can be resolved by an appropriate insurance as in the Intelsat series.

Table 1-2. Effect Of Saturn V On TVBS

GOOD
EXCESS PAYLOAD & VOLUME
STATE-OF-ART SYSTEMS
INCREASED REDUNDANCY
REDUCED DEVELOPMENT TIME
COST EFFECTIVE (2:1 COMPARED TO TITAN)
MULTIPLE USERS ACCOMMODATED
PHYSICAL INTERFERENCE REDUCED
RESUPPLY, REPAIR, MAINTENANCE, FEASIBILITY
BAD
HIGH INITIAL COST
LARGE LOSS WITH FAILURE
RF INTERFERENCE

5. Spacecraft Configuration Analysis. A series of spacecraft was configured to take full advantage of the various Saturn V payload options. The range from 2,000 lb. to 42,000 lb. in weight and include various provisions for rigid or deployable solar arrays and antennas. Unmanned versions are included as well as manned versions using the Multiple Docking Adapter (MDA) or the Basic Subsystem Module (BSM). The smaller spacecraft were also constrained to be compatible with the payload capabilities of smaller launch vehicle as single payloads. On Saturn V they were arranged on a multiple payload dispensing system.

6. System Analysis. In this task the user requirements are combined with the spacecraft configurations and a communication system is derived for each mission. Sensitivities to variations in the missions are also derived to provide further insight into each concept.

7. System Selection. Systems are selected primarily on the basis of minimum total system cost. Since there are many combinations of users and spacecraft this is done in two steps. First, it is accomplished on the mission level where the primary and secondary spacecraft concept candidates were identified. In the second step these candidates are combined with each other and the frequency of occurence of the spacecraft concept was the determining factor. This resulted in the identification of 3 concepts to be recommended for more detailed study.

8. Documentation. This task includes the detailed study reports as well as a review of technology requirements and service descriptions for each of the selected missions.

These topics are discussed in detail in the remaining chapters of this report.

2

SYSTEM ANALYSIS

2.1 USER ANALYSIS

The process of user analysis results in input data for the communication system synthesis program. The steps which were accomplished during the study were:

1. Identification of potential users by the discussion of requirements and plans of groups who are currently using telecommunications.
2. Distribution of User questionaires to interested potential users.
3. Use of questionnaires and previous user analysis studies to establish candidate user systems.
4. Processing of the requirements for each candidate system to generate a set of synthesis program input parameters for each system.

2.1.1 Potential Users -- Groups that have significant communications usage are listed in Table 2-1. People in these organizations were contacted and their particular communication needs were discussed. Those that had operations which could be extrapolated to include satellite television relay capability were provided with user questionnaires. A list of some of the personnel of these organizations contacted is provided in Table 2-2.

2.1.2 Users' Telecommunications Requirements -- A user questionnaire form was generated to aid in assembling and standardizing user requirements. These forms were completed for the Armed Forces Radio and Television Service, Educational Television Operations, and for a Parochial school system television service by interested users. Additional user requirements were derived from discussions with user organizations. The forms have been structured in such a way as to derive the requirements of the user objectively, without any reference to satellite systems. In other words, this format in no way makes the user slant his requirements toward any preference of transmission system; instead, it leaves him entirely objective in delineating his requirements for the application he has or

Table 2-1. Potential User Agencies

CONTACT	INTEREST
U.S. Government Agencies:	
NASA/HQ	Space Communications & Broadcast
NASA/HQ	Space Communications Research
FCC	Frequency Allocations Research
USIA	Overseas Broadcast
D.O.S.	International Communications Management
U.S. Mission to UN	International Communications
DOD/Education	ETV World-Wide, Including High Seas
DOD/ASN	Radio & TV, State-Side & Foreign
Office Economic Opportunity	ETV Nationwide, Rural Health Information
U.S. Office of Education	ETV Nationwide
HEW/NIH	Biomedical Communications, Nationwide; Medicenters, Continuing Education
State Government Agencies:	
California TV Advisory Committee	Total State Communications System
Illinois Telecommunications Commission	Total State Communications System
Indiana Higher Education Telecommunications System	Educational Communications Applications
Michigan State University	Instructional Media
Academic Institutions:	
Ventura County Junior Colleges	ITV & ETV on Regional Basis
University of Akron	ITV Teaching & Research
Stanford University	ETV Studies & Ground Receiving Systems
West Virginia University	ETV Studies Including Two Satellites
University of Minnesota	ETV, Including International Aspects
Purdue University	ITV on a Intra- & Interuniversity Basis
Stanford University/ICR	Communications Research
Nonprofit Organizations:	
Education Commission of the States (ECS)	39 States Plus 2 Territories
San Diego Area Instructional TV Authority	ITV on Regional Basis
Diocese of Brooklyn	ETV for Parochial School Systems
National Catholic Education Association	ITV in the Nationwide Catholic School System
Appalachia Education Lab	ITV on Regional Basis
National Education Association	ETV, ITV on Regional, Rural, or National Basis
Rural Supplementary Education Center	ITV & ETV on Rural Area Basis
EDUCOM	ETV, Interconnection
Electronic Industries Association	Technical
Joint Council for Educational Telecommunications	Education Applications
National Association of Educational Broadcasters	Program Distribution
National Educational Television	Program Distribution
Channel 15/San Diego	ETV/ITV
Corporation for Public Broadcasting	ETV Broadcast Nationwide & Regional
International Agencies:	
United Nations	Worldwide ETV & ETV, ITV for Developing Nations
Swedish Mission to the United Nations	Regional European TVBS System
Radio Nederland	Commercial TV & Communication Linking Caribbean, Madagaskar & Holland
Industrial Firms:	
COMSAT Corporation	Technical & Revenue Communication System
National CATV Association	CATV for Local Coverages Throughout the World
Kessler Associates	ETV, ITV, Technical Feasibility

Table 2-2. Users Contacted

No.	Name	Affiliation
1.	Gerard Appy	National Educational Television New York City
2.	Julius Barnethan	American Broadcasting System
3.	Dr. Jordon Baruch President	EDUCOM
4.	Dr. Cliff Block	Dept. Of State/AID
5.	J. Broger Director	Armed Forces Radio & Television Services
6.	John T. Caldwell Manager Of Operations	Ed. Foundation/WGBH
7.	Ben Carmichael	Appalachia Educational Laboratory
8.	L. Madison Coombs	Bureau of Indian Affairs/Education
9.	Bernarr Cooper Chief, Mass Communications	State University of New York
10.	Col. L. Cruciana	Armed Forces Radio & Television Services
11.	Frank W. Cyr Director	Rural Supplementary Education Center
12.	Dr. Ruth Davis Associate Director/NLM	National Institute Health/ Health Education Welfare
13.	Mr. R. DuMont Director	AMA - Radio, TV and Motion Picture Department
14.	Rev. Walter C. Flaherty Director	Boston Catholic TV Center
15.	Wm. F. Fore Executive Director	National Council of Churches
16.	Col. Fradenberg	DOD/Office of Assistant Secretary for Education
17.	A. Fredette Coordinator of Instructional Communications	Albany Medical College

Table 2-2. Users Contacted (Cont'd)

No.	Name	Affiliation
18.	W. Harley	National Education Association & NAEB
19.	Rev. Healy Director	Diocese of New York Communications Center
20.	Thomas P. Hoving Chairman	National Citizens Communication for Public TV
21.	William J. Kirkley Captain, USCG	U.S. Mission to U.N.
22.	Claire List	Ford Foundation
23.	Norman Locke Director ITV	Boston University School of Education
24.	Len Marks	United States Information Agency
25.	Charles Marquis	National Association of Educational Broadcasters
26.	Rev. J. Meyers	National Catholic Education Association
27.	John Morrison Director of Programming	Eastern Ed. Network (EEN)
28.	Tom Nelson	Department of State
29.	Tom Nesbitt	Department of State
30.	Frank W. Norwood Executive Secretary	Joint Council on Education Telecommunications
31.	Monsignor J. O'Keefe	Diocese of New York Committee on Education
32.	Dick Oldham Chief Engineer	Ed. Foundation/WGBH
33.	Peter Perry	U.N. Information Center
34.	Rev. J. Pindar	National Catholic Office for Radio and Television
35.	Dr. Dave Pollen Deputy Assoc. Commissioner	Bureau of Research, HEW

Table 2-2. Users Contacted (Cont'd)

No.	Name	Affiliation
36.	Dr. Donald G. Potter Director	Audio-Visual Center University of Nevada
37.	John Powell	Office of Economic Opportunity
38.	Don Quayle	Corp. for Public Broadcasting
39.	Ray Reid Television Coordinator	General Services Office Of State of California
40.	Mr. C. E. Reilly Executive Director	National Catholic Office for Radio and TV
41.	Marvin Robinson	U.N. Secretariat
42.	George Sitts Chief Engineer	Diocese of Brooklyn TV Center
43.	Hugh Smith Commissioner	Commission Nevada Educational Communications
44.	Lt. Col. Souville	Armed Forces Radio & Television Services
45.	R. Stanley	Health Education Welfare
46.	Herbert S. Steffens Director, Project West	Nevada State Dept. Education
47.	Dr. John Sullivan Executive Secretary	National Education Association
48.	Robert Swenson	Comsat Corporation
49.	Sidney Tickton Executive Director	President's Council on Instructional Technology
50.	Zane Thornton Network Engineer	National Institute of Health/ National Library of Medicine
51.	H. Valentino Staff	Armed Forces Radio & Television Services
52.	Dr. Harold E. Wigren President	Joint Council on Education Communications
53.	John Witherspoon	NET, San Diego

visualizes for the future. Sheets A through D are designed strictly to solicit requirement specifications from the user -- which he may otherwise forget if he has no comprehensive guideline to follow. We intend to make the user confident that he is not being constrained to using a satellite system. Sheets E through G are work sheets for Convair to develop systems requirements and comparative cost data.

The completed user's telecommunications requirements forms are shown in Tables 2-3 to 2-6.

2.1.3 Candidate User Systems -- Eleven user systems were defined, from the accumulated user requirements, with the eight most viable shown in Table 2-7.

These systems were judged in terms of user interest, present operational level, current funding, organization, and viability. Four areas of interest that appear most promising are discussed in the following paragraphs.

2.1.3.1 Armed Forces Network -- This use has the objective of providing entertainment programs to overseas military personnel, combining domestic interest with foreign coverage. In fact, it requires global coverage. AFN caters to 3.5 million servicemen and their families in overseas and remote locations:

Southeast Asia	Greenland
Korea, Okinawa, Tainan, Japan	Europe
Kwajalein and Guam	Mid-East
Panama, Puerto Rico, Cuba	Austrilia
Alaska	

They have the identical distribution problem that ETV has at home; they spread a large amount of money each year mailing video tapes between coverage areas. Figure 2-1 shows the Armed Forces Network. Table 2-8 lists the Armed Forces Network television outlets.

Table 2-3. AFRTS Questionnaire

A. USERS' TELECOMMUNICATIONS REQUIREMENTS

USER IDENTIFICATION -

1. ORGANIZATION/AFFILIATION NAME: Armed Forces Radio/Television

2. ADDRESS: Deputy for R/TV 1117 N. 19th Street Arlington, Virginia 22209

3. TELEPHONE: 202 OX 4 8744/OX 4 8059

4. RESPONDER'S NAME: Col Cruciana / Ltc Souville POSITION: DRTV/DRTV-OPS

5. DESCRIPTION OF PRESENT FACILITIES:

281 Radio Ground Stations

a. NO. OF STATIONS: 71 TV " " COVERAGE: Worldwide 99.9% 5° 75° n.l.

b. NO. OF CHANNELS: TV 23 (A-V) VHF & UHF VOICE: FM 20 87.8-107.0 AM 65 540-1600 kl DATA 51TT/38 voice

c. QUALITY: TV/B&W B COLOR none VOICE B DATA B - low restoration

d. INVESTMENT IN FACILITIES: $ 23.5 mil

e. OPERATING BUDGET: /Yr.

f. ANTICIPATED GROWTH: 1970 1980

ADDITIONAL BUDGET: not available

No. OF CHANNELS: 3 (Thailand)

STATIONS/COVERAGE: Australia

Table 2-3. AFRTS Questionnaire (Contd)

B. Coverage Consideration

No. of Areas (Global-Geographic)	Size of each Area: Time Zone Rel to Gmt	Lat&Lon	Geo Loc	Total Outlets (Key-Aff-Retrans) R	TV	Originating Stations K-Key A-Aff-I-Ind R	TV	BrdCst hrs R	wky TV	Audience Size (Mil-Dep-US Civ)
North America (Alaska&NW Terr.)	-9 to -10	55-70N 135-165W	Alaska	71	7	1k, 4A	7 I	168	94	71,200
North Atlantic	-4 to -3	45-77N 45-75W	Canada	5	2	4 I	2 I	120	93	6,100
			Green-land	6	3	2 I	3 I	168	50	1,250
Mid - Atlantic - North	-1	60-75N 15-30W	Iceland	3	1	1 K	1 I(C)	168	62	3,200
Mid - Atlantic	-1	30-45N 15-30W	Azores	1	1	1 I	1 I(C)	168	63	1,700
Caribbeam	-5 to -4	8-25N 60-90W	Cuba(GTMO)	2	1	1 K	1 I (C)	168	65	10,000
			Puerto Rico	4	2	1 K	2 I	168	68	130,000
			Canal Zone	2	2	1 K	1 K (C)	168	60	13,000
South Atlantic	-1	10 S 15W	Ascention	1	0	1 I	0	168	n/a	50
Northern Europe	0 to +1	45-60N 15E-15W	England	1	0	1 I	0	126	n/a	4,000
			Germany	49	8	1 K	4 I	168	60	300,000
			Belgium	2	0	Fr Ger K	0	168	n/a	2,200
			Netherlands	3	0	Fr Ger K	0	168	n/a	2,400

Table 2-3. AFRTS Questionnaire (Cont'd)

Mediterranean	0 to + 1	30-45N	Morocco	1	0	1 I	0	168	n/a	2,000
		15W-15E	Spain	7	0	1 K 2 A	0	125	n/a	11,200
			Libya	1	1	1 I	1 I (C)	133	n/a	4,000
			Italy	10	0	1 K 2 A	0	125	n/a	7,500
			Greece	2	2	1 K 1 A	1 K (C)	158		3,500
Middle East & East Africa	+2 to +3	5-40N	Turkey	21	1	6 I	1 I (C)	168	75	10,200
		30-60E	Ethiopia	2	1	1 I	1 I (C)	168	74	2,000
			Iran	1	1	1 I	1 I (C)	124	62	1,000
			E. Pakistan	1	1	1 I	1 I (C)	138	65	2,000
South East Asia	+7 to +8	5-30N	Thailand	21	5	1 K 5 A	4 I A	168	55	47,500
		105-135E	Vietnam	9	8	1 K 6A	1 K(C)6IA	168	55	515,000
			Taiwan	6	0	1 K 2A	0	166	n/a	8,500
			Philippines	10	3	1 K 4A	1 K 2A	168	98	27,000
Far East Asia	+9 to +10	27-45N	Korea	21	15	1 K 7A	1 K (C)	168	70	55,000
		120-150E	Okinawa	2	1	1 K	1 I(C)	168	92	40,000
			Japan	8	3	1 K 5 A	3 I	168	70	84,200
Pacific Islands	+10 to -11	5-30N								
		165W-150E	Guam	3	0	1 K 1A	0	168	n/a	41,000
			Eniwetok	1	0	1K	0	126	n/a	20
			Johnson I	1	1	1I	1 I (C)	124	46	600
			Kwakalein	1	0	1 I	0	123	n/a	65
			Midway	1	0	1 I	1 I (C)	168	n/a	5500
Australia (planned)	+8	20S-120E	N. W. Cape	1	1	1 I	1 I (C)			

Ships at Sea (closed circuit)
TV Rec. by distribution of materials in SEA area (Vietnam)

Table 2-3. AFRTS Questionnaire (Contd)

Number of Channels		Grade of Service	Bandwith	Data Rate	Usage (Hr./Day)			
1-Way	2-Way	A=MRB			Transmit	Receive	Real Time	Record
TELEVISION: (*Include BW, Color, etc.)								
11	8	B Color	6 Mhz	*	2 hr/day Avg.	8 hr/day Avg.	1600-2400 hrs.	N/A
RADIO/AUDIO:								
17	8 weekly as required	A	9 K hz			24	0001-2400 hrs.	
DATA(Facsimile, Teletype, Computer Stream, Etc.):								
34 TT 38 Fax	9 TT 13 Fax	A	3 khz	60 & 120 wpm	2 hr/day 1 hr/day	24 4	0001/2400 12 - 1600 hrs	1200-1600
OTHER (Specify):								
News Voice 34		B	3khz Voice TT Multiplex			24	0001-2400 hrs.	

Table 2-3. AFRTS Questionnaire (Contd)

SATELLITE COMMUNICATIONS SYSTEM REQUIREMENTS -

Number of TV Channels		Number of Voice Program Channels Radio		Number of Data Channels	ERP/Channel			Total ERP	Band-width	S/N	Number of Beams	Antenna Diameter For Each Beam
1-Way	2-Way	1-Way	2-Way	TT-V-Fax	TV	Voice	Data					
11	8	17	8	43-TT/ voice 51 Fax						-60dbm FM/AM Radio Prog	18	

Table 2-4. Parochial School Questionnaire

USERS' TELECOMMUNICATIONS REQUIREMENTS

A. USER IDENTIFICATION -

1. ORGANIZATION/AFFILIATION NAME: Catholic Schools of Brooklyn Diocesan Television Center
2. ADDRESS: 500 19th Street Brooklyn, N.Y. 11215
3. TELEPHONE: (212) 499 - 9705
4. RESPONDER'S NAME: George Sitts POSITION: Chief Engineer
5. DESCRIPTION OF PRESENT FACILITIES:
   - a. NO. OF STATIONS: 4 COVERAGE: Brooklyn & Queens, New York
   - b. NO. OF CHANNELS: TV 4 VOICE _____ DATA _____
   - c. QUALITY: TV/B&W X COLOR _____ VOICE _____ DATA _____
   - d. INVESTMENT IN FACILITIES: $ 2.5 million
   - e. OPERATING BUDGET: $ 200,000 /YR.
   - f. ANTICIPATED GROWTH:

	1970	1980
ADDITIONAL BUDGET:	20%	100 %
NO. OF CHANNELS:	~~XXXX~~ 4	12
STATIONS/COVERAGE:	4	12

   - g. OPERATING FREQUENCY: VHF _____ UHF _____ ITFS X OTHER _____

Table 2-4. Parochial School Questionnaire (Contd)

B. COVERAGE CONSIDERATIONS -

No. of Areas	Size of Each Area (Time Zone, Sq. Mi., etc.)	Geographical Location of Each Area	Potential Audience To Be Served	
			Type (Pre-School, H. S., Adult etc.)	Number
1 (Interdiocesan Network)	Eastern 6,000 sq. miles	Metropolitan, New York	K - 12 Adult	4 million

Table 2-4. Parochial School Questionnaire (Contd)

C. **STATION CONSIDERATIONS** -

Number of Stations (STA)	Site Size For Class B Area Coverage	* Hours Receive Per Day	* Hours Transmit Per Day	Station Cost Limits	Number of Audience Terminals (AT)	Average Distance (STA-to-AT)
1-WAY (Receive only - For-Redistribution) Stations:						
10		9 9AM-4PM 7AM-9PM	9 9AM-4PM 7PM-9PM	$100,000	10,000	6 miles
2-WAY (Transmit-And-Receive) Stations:						
3		9 9AM-4PM 7AM-9PM	9 9AM-4PM 7PM-9PM	$450,000	3,000	6 miles

* Include local clock times

Table 2-4. Parochial School Questionnaire (Contd)

D. INFORMATION CONSIDERATIONS -

Number of Channels		Grade of Service	Bandwidth	Data Rate	Usage (Hr./Day)			
1-Way	2-Way				Transmit	Receive	Real Time	Record
TELEVISION: (* Include BW, Color, etc.)								
	12		BW *	6 M H z		9	9	9AM- 4PM 7PM- 9PM
RADIO/AUDIO:								
DATA (Facsimile, Teletype, Computer Stream, Etc.):								
		400	1.5 K H z	1.5 K H z		10	10	9AM- 4PM 7PM- 9PM

Table 2-5. ETV Operations Questionnaire

A. USER IDENTIFICATION -

1. ~~XXXXXXXXXXXX~~AFFILIATION NAME: Educational TV Operations

2. ADDRESS: _____

3. TELEPHONE: _____

4. RESPONDER'S NAME: J. Witherspoon POSITION: _____

5. DESCRIPTION OF PRESENT FACILITIES: (1969)

   a. NO. OF STATIONS: 160 COVERAGE: 70-75% of U.S. Population

   b. NO. OF CHANNELS: TV 160 VOICE _____ DATA _____

   c. QUALITY: TV/B&W 160 COLOR * VOICE _____ DATA _____

   d. INVESTMENT IN FACILITIES: $ 120 Million

   e. OPERATING BUDGET: $ 46 Million /YR.

   f. ANTICIPATED GROWTH:

	~~XXXX~~ 1975	1980
Annual Operating ~~XXXXXXXXX~~ BUDGET:	109 Million	162 million
NO. OF ~~XXXXXXX~~ Stations	240	380 (includes second stations in 43 cities)
U. S. Population in ~~XXXXXXXXXXXXXX~~ Coverage Area	85%	95%

   g. OPERATING FREQUENCY: VHF _____ UHF _____ ITFS _____ OTHER _____

*25% capable of studio color production
 70% capable of color transmission

**Extrapolated from Carnegie Commission Report (1967 dollars)

Table 2-5. ETV Operations Questionnaire (Contd)

B. COVERAGE CONSIDERATIONS - (As of 1975)

No. of Areas	Size of Each Area (Time Zone, Sq. Mi., etc.)	Geographical Location of Each Area	Potential Audience To Be Served	
			Type (Pre-School, H.S., Adult etc.)	Number
225	Station Coverage Areas, Average Radius 60 Miles	All parts of U.S., including Hawaii and Alaska. Primary Concentration on Continental Coasts.	Grades K-8 Grades 9-12 Adult	31.5 Million 14 Million 133 Million

*School audiences are 85% (projected ETV penetration) of school populations projected to Autumn 1974 by U.S. Office of Education.

Table 2-5. ETV Operations Questionnaire (Contd)

GENERAL DYNAMICS
Convair Division

C. STATION CONSIDERATIONS - (As of 1975)

	Number of Stations (STA)	Site Size For Class B Area Coverage	Hours Receive Per Day *	Hours Transmit Per Day ** *	Station Cost Limits	Number of Audience Terminals (AT)	Average Distance (STA-to-AT)	Average Distance (AT-to-AT)
1.	1-WAY (Receive only - For-Redistribution) Stations:							
	175	50 Mile Radius	Average 9, but some as many as 18; between 0800 and 2300.	--	Average Annual Operating Cost $375,000	Total 15 Million TV Households	12 Miles	Within Coverage Areas Nearly One per residence
2.	2-WAY (Transmit-And-Receive) Stations:							
	65 (Based Approx. on Carnegie Commission Rationale)	65 Mile Radius	9 - Various Times between 0800 and 2300	Average 2, but some as many as 18; between 0800 and 2300	Average Annual Operating Cost $650,000	Total 30 Million TV Households	15 Miles	Within Coverage Areas Nearly One per residence

* Include local clock times

** "Transmit" is interpreted to mean "electronically transmit program material for use on other stations." It does not necessarily presuppose transmission via satellite.

Table 2-6. Idealized ETV System Questionnaire

A. USER IDENTIFICATION -

1. ORGANIZATION/AFFILIATION NAME: Idealized 1975 ETV System

2. ADDRESS: _____

3. TELEPHONE: _____

4. RESPONDER'S NAME: J. Witherspoon POSITION: _____

5. DESCRIPTION OF PRESENT FACILITIES:
Originating Communities

a. NO. OF ~~XXXXXXX~~: 225 COVERAGE: 95% of U. S. Population

b. NO. OF CHANNELS: TV See Notes VOICE _____ DATA _____

c. QUALITY: TV/B&W 30% COLOR 70% VOICE _____ DATA _____

d. INVESTMENT IN FACILITIES: $ 350 Million

e. OPERATING BUDGET: $ 125 Million /YR.

f. ANTICIPATED GROWTH:

	1970	1980
Annual Operating ~~ADDITIONAL~~ BUDGET:	_____	$160 Million
Additional NO. OF CHANNELS:	_____	50 originating communities 100 Local ITV Services
STATIONS/COVERAGE:	_____	95% (Note that increase is in amount of service, not number of users)

g. OPERATING FREQUENCY: VHF _____ UHF _____ ITFS _____ OTHER _____

_____

_____

Table 2-6. Idealized ETV System Questionnaire (Contd)

B. COVERAGE CONSIDERATIONS -

	No. of Areas	Size of Each Area (Time Zone, Sq. Mi., etc.)	Geographical Location of Each Area	Potential Audience To Be Served *	
				Type (Pre-School, H.S., Adult etc.)	Number
National Service	1 service area divided by time zones	4 - Conlus U.S. Time Zones 1 - Alaska 1 - Hawaii	U.S. Time Zones plus Alaska and Hawaii	Total for all Services: Grades K - 8	34.5 Million
State Services	50	State	States of U. S. including Alaska and Hawaii	9 - 12	15.6 Million
Local Service	225	Metropolitan Areas, Population 50,000 or more (first 225 standard A.R.B. Markets)	All U. S. States	Total out-of-school service potential	209 Million

* Based on 95% potential. Population and Educational Enrollments projected to 1974-75.

Table 2-6. Idealized ETV System Questionnaire (Contd)

C. STATION CONSIDERATIONS - GROUND-BASED TRANSMITTERS, 1975

Number of Stations (STA)	Site Size For Class B Area Coverage	* Hours Receive Per Day	** * Hours Transmit Per Day	Station Cost Limits	Number of Audience Terminals (AT)	Average Distance (STA-to-AT)	Average Distance (AT-to-AT)
1-WAY (Receive only - For-Redistribution) Stations:							
150 Special TV Services	50 Mile Radius	Average 9, some up to 13; between 0800-2300	--	Average Annual Operating Cost $375,000	12 Million TV households and 30% of U.S. Schools	12 Miles	Within Coverage Areas Nearly One per residence
225 Conventional TV Broadcast	Average 15	Average 8; between 0800-1600	--	Average Annual additional cost $50,000	85% of U.S. Schools	5 Miles	Within Coverage Areas 2 Miles
2-WAY (Transmit-And-Receive) Stations: ** These are probably stations serving large metropolitan areas which also act as control stations for state, regional, or national distribution.							
75	65 Mile Radius	9 - Various between 0800 and 2300	Average 2; but some as many as 18; between 0800-2300	Average annual operating cost $650,000	Direct reception by 30 million TV households and 50% of U.S. schools	15 Miles	Within coverage areas, nearly one per residence

* Include local clock times

** "Transmit" is interpreted to mean "electronically transmit program material for use on other stations." This transmission may or may not be via satellite.

Local ITV service facilities in 225 largest U.S. metropolitan areas. Of these, 165 have one channel in this special ITV facility and 60 have 3 channels.

Table 2-6. Idealized ETV System Questionnaire (Contd)

F. GROUND STATION COST COMPARISON -- (Given essentially a satellite-to-home capability)

DIRECT TO USER RECEIVER (from satellite)	Local TV Station REBROADCAST	CATV	CCTV
Least expensive for national or regional service; not possible for local origination or local scheduling	Lease expensive for locally based ETV/ITV service; has limitations of channel capacity for ITV.	Potentially offers a middle ground of satellite-based national service plus local origination plus large channel capacity. Politically uncertain at present.	Not an economical alternative except within institutions or in difficult terrain conditions ITFS-a flexible local ITV service. Probably not as good as cable eventually.

G. SATELLITE AND GROUND AIDS COST EVALUATION --

SATELLITE-DIRECT TO USER RECEIVER	SATELLITE-TO GROUND STATION FOR REBROADCAST	SATELLITE-TO GROUND STATION FOR CATV DISTRIBUTION	EXPANSION OF EXISTING DISTRIBUTION NETWORKS (W/O SATELLITE)

Table 2-7. Tentative User Systems

NAME	COVERAGE	AUDIENCE	UPLINK	DUTY CYCLE
1. U.S. National Ed. TV/ Program Distribution	Full U.S. 4 Time Zones 2 Ch./Zone	To Ground Stations for Rebroadcast. 50 ETV Receivers Per Zone	One N.Y.C. Origin	100%
2. U.S. National ETV/ Operational System	Full U.S. 4 Time Zones + Hawaii & Alaska 2 Ch./Area (12 total)	Direct-to-Home Assume 80% of total U.S. Receivers	a. One uplink in in each area on one channel -Time-shared for local programming b. N.Y.C. Origin for second channel	6:00 A.M. to 9:00 & 5:00 P.M. to Midnight
3. U.S. National ITV/ Operational System	Full U.S. 4 Time Zones + Hawaii + Alaska + U.S. Pacific Terr. + Virgin Is. 4 Ch/Area	Public Elementary & Secondary Schools (~ 300,000) Assume 80% Coverage (~ 240,000 receivers)	Two Originating Stations in each time zone + one each in Hawaii and Alaska	All Channels 8:00 A.M. to 4:00 P.M. 1 Ch/Area - 100% for program pre-viewing
4. U.S. Parochial School System	Full U.S. 4 Time Zone + Hawaii + Alaska + U.S. Pacific Terr. + Virgin Is., etc. 2 Ch/Area	Parochial School/System ITFS Interface 14,000 Schools	One Originating Station - N.Y.C.	100%

Table 2-7. Tentative User Systems (Contd)

NAME	COVERAGE	AUDIENCE	UPLINK	DUTY CYCLE
5. U.S. Armed Forces Radio & TV Services	Global Coverage (Specifically excluding U.S.) 3 Satellites 3 Beams/Sat. 5 Ch/Beam 10^6 Sq. Mi./Beam	$10x10^6$ People (Military Personnel plus dependents & on-base staff) Assume: Uniform distribution 5 people/receiver	Two Originating Stations 1. Washington 2. Los Angeles	3 Channels -100% 2 Channels 5:00 - 8:00 A.M. 5:00 P.M. Midnight
6. National ETV/ ITV System for Mexico	Mexico 800,000 Sq. Mi. 2 Beams (Ea. 400,000 Sq. Mi.) 4 Ch/Beam	45.7×10^6 People 60/Sq. Mi. 20,000 Schools	One Originating Station - Mexico City	1 Channel - 100% 1 Channel - 50% (6:00 A.M. to 6:00 P.M.
7. U.S. Biomedical Communications Network	Full U.S. + Alaska + Hawaii + U.S. Pacific Terr. + Virgin Is., Etc. 3 Ch/Area (Note: May need an additional channel for talk-back from multiple stations)	20 Medicenters Per State and Area - 1,040 total	Five Originating Ground Stations -1 Per Time Zone	2 Channels - 100% 1 Channel - On demand assume 20%
8. National ETC System for India	India 1.3 M Sq. Mi. 1 Time Zone 1 Beam 1 Video Ch. 15 Audio Ch.	511×10^6 People 568,000 Villages 1 RCVR/Village	One Originating Station Delhi	100%

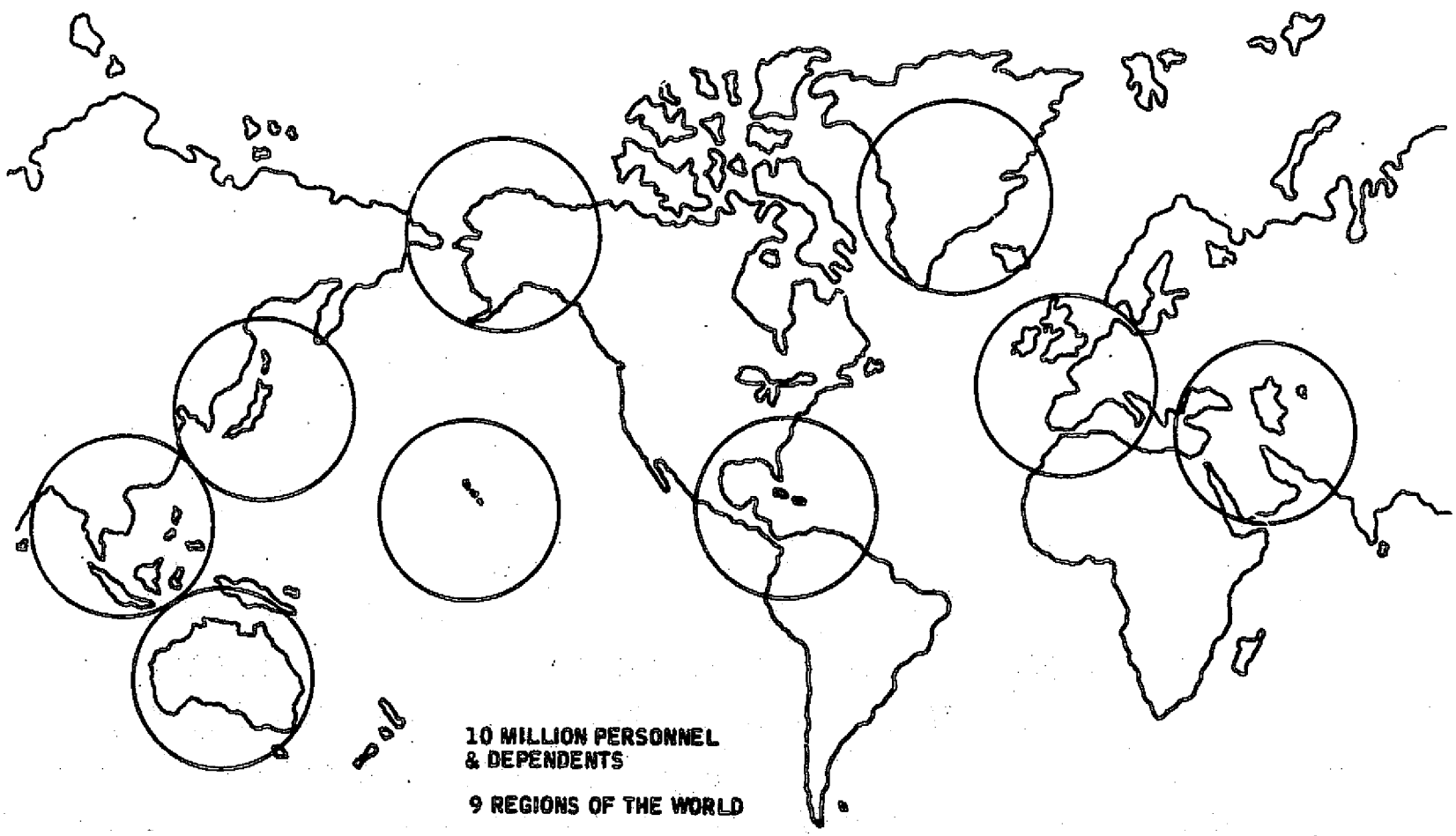


Figure 2-1. Potential User: DOD-Armed Services Network

Table 2-8. AFRTS Outlets

ARMED FORCES RADIO AND TELEVISION OUTLETS

March 1969

	RADIO	TELEVISION	TOTAL
ARMY	93	27	120
NAVY	78	18	96
AIR FORCE	163	37	200
INTERIOR	7	-	7
TOTAL	341	82	423

LEGEND:

*	Studio Station
R	Relay
ADS	Audio Distribution System
CCR	Carrier Current
CPB	Controlled Pattern Broadcast

A	Army
N	Navy
AF	Air Force
I	Dept of Interior

Prepared by: DRTV

*Radio includes 57 Ships
TV includes 12 Ships

Table 2-8. AFRTS Outlets (Contd)

U.S. NAVY SHIPS

TELEVISION

USS AMERICA (CVA-66)	
USS ARLINGTON (AGMR-2)	
USS CONSTELLATION (CVA-64)	
USS CORAL SEA (CVA-43)	
USS HANCOCK (CVA-19)	
USS HORNET (CVS-12)	
USS INTREPID (CVS-11)	
USS NEW JERSEY (BB-62)	
USS RANGER (CVA-61)	
USS REPOSE (AH-16)	
USS SANCTUARY (AH-17)	
USS TICONDEROGA (CVA-63)	

Table 2-8. AFRTS Outlets (Contd)

AREA/OUTLET	Channel	Power	Agency
ALASKA			
Adak	8	120	N
Galena	8	120	AF
Fort Greely	8	71	A
King Salmon	8	120	AF
Kodiak	8	120	N
Northeast Cape	11	200	AF
Shemya	13	100	AF
CANADA			
Goose Bay	8	500	AF
Saglek Bay		CCTV	AF
GREENLAND			
Sondrestrom	8	120	AF
Thule	8	100	AF
Camp Tuto	13R	100	AF
CARIBBEAN			
CANAL ZONE			
Fort Clayton	8	500	A
Fort Davis	10R	500	A
CUBA			
Guantanamo Bay	8	100	N
PUERTO RICO			
Ramey	21	100	AF
Roosevelt Roads	8	10	N
EUROPE			
GERMANY			
Berlin (Dahlem)	25	500	AF
Berlin (Tempelhof)	12-R	1	AF
Helmstedt	11R	CCTV	AF
Ramstein	26	1kw	AF
Spangdahlem	22	1kw	AF
Wiesbaden	15R	1kw	AF
Rhein Main (G.G.)	23R	5	AF
Rhein Main	26R	5	AF
GREECE			
Iraklion, Crete	8	200	AF
Iraklion	6R	25	AF
AZORES			
Lajes	8	100	AF
ICELAND			
Keflavik	8	250	N
MIDDLE EAST/ AFRICA			
TURKEY			
Adana	3	CCTV	AF
PAKISTAN			
Peshawar	3	CCTV	AF
IRAN			
Tehran	8	500	AF
ETHIOPIA			
Asmara	2	50	A
LIBYA			
Tripoli	12	4kw	AF

Table 2-8. AFRTS Outlets (Contd)

AREA/OUTLET	Channel	Power	Agency
PACIFIC			
Johnston Atoll	7	120	AF
Midway Island	4	100	N
FAR EAST			
JAPAN			
Chitose	73	1kw	AF
Misawa	73	600	AF
Wakkanai	11	CCTV	AF
KOREA			
Hwaaksan	12R	500	A
Kunsan	2R	120	A
Kwang-chon	5R	10W	A
Pajuri	6R	500	A
Pusan	2R	120	A
Seoul	2	5kw	A
Taegu	12R	500	A
Taejon	12R	50	A
Camp Ames	2TVT	1	A
Camp Casey	2TVT	1	A
Camp Casey	2TVT	1	A
Camp Kaiser	2TVT	1	A
Camp Mcgovern	2TVT	1	A
Camp St. Barbara	2TVT	1	A
Blue Lancer Valley	2TVT	1	A
PHILIPPINE ISLANDS			
Clark AB	8	80	AF
San Miguel	34R	10	AF
Subic Bay	34R	10	AF
RYUKYU ISLANDS			
Okinawa	8	440kw	AF
SOUTHEAST ASIA			
VIETNAM			
Saigon	11	240	A
*Da Nang	11	40kw	A
*Nha Trang	11	40kw	A
*Pleiku	11	40kw	A
*Qui Nhon	11	40kw	A
Phan Rang	78	1kw TVT	A
*Tuy Hoa	11	40kw	A
Quang Tri	11	40kw	A
THAILAND			
*U Tapao	74	CPB	AF
Sattahip	80	CPB	AF
Camp Vayama	80	CPB	AF
*Nakhon Phanom	74	CPB	AF

*Van Stations

2.1.3.2 U.S. ETV Systems

It is projected that in 1975 the basic national network service will continue to be National Educational Television, NET will provide perhaps five hours daily of basic service (now approximately two hours). NET will continue to emphasize public affairs, however, and will require the capability to gain access to station interconnection at any time during the 24 hour day. Its basic service will continue to be concentrated in the hours after 1800 local time, but an interconnected daytime program is already tentatively scheduled for 1969-70.

The agency primarily responsible for interconnection is the Corporation for Public Broadcasting. The Corporation, while continuing to support NET, will also foster diversity in national programming. It seems likely that a second national interconnection will be developed, perhaps to accommodate lengthy topical programs (Congressional hearings, U.N. proceeding, etc.) that would be local-option alternates to NET programming, provide programming to a larger market having more than one ETV station, etc. The same system might act as a distribution agency for instructional and "service" programming.

The NET system and, to a lesser extent, the second national system, will require time zone delays within the interconnection system.

States are very important programming units. This is true at the level of instruction, since the states have primary responsibility for education; and it is also true at the level of public affairs, because of the states' importance in the political process. Stations within a state will require interconnection. In smaller states, like Nebraska, one dominant station will feed the system. California, on the other hand, will require transmission capability from four stations.

In addition to the above terrestrial system growth model, an idealized system is considered for the same time period which would exploit the economic benefits of satellite systems. The idealized system consists of the following:

1. The capacity for every TV-equipped home and school in the U.S. to receive two national channels of educational television. Experience

indicates that set penetration levels off at about 95% of U.S. households.

2. The capacity for communities of reasonable size to originate (or at least control the schedule of educational TV transmissions. This implies some local origination by conventional broadcast, ITFS systems, cable, etc. For present purposes, the first 225 metropolitan areas of the American Research Bureau are used; these have populations in excess of 50,000. The first 60 of these 225 areas are projected to have a local service totalling four channels; the remainder have two local channels.
3. The capacity for each state to have two channels available for ITV or public TV use. This implies the capacity to receive in every TV-equipped home and school in the state.

The idealized system translates into:

1. A satellite system that provides national and state interconnection service, plus direct-to-home service at least in some areas.
2. 75 principal ground broadcast stations serving major metropolitan areas and acting as control stations for state, regional, or national distribution. How many of these provide direct up-link to the satellite system remains to be seen.
3. 150 broadcast stations in addition to the above, providing local ETV service in secondary cities. Basic local ITV service is of course a part of their responsibility also.
4. 225 ITV service facilities, probably transmitting by ITFS system (the 2500 MHz Instructional Television Fixed Service systems) or on cable systems (usually CATV) as these develop. These provide needed ITV channel capacity to 225 areas. The assumption is made that in the various elements of the ETV/ITV system, production facilities are duplicated as little as possible. Most of these 225 ITV systems are not projected to have production capacity independent of the broadcast service in the area.

The following channel requirements can be derived from the above.

1. Two national satellite program services with delays for time zones including Alaska and Hawaii: total 12 channels.
2. Two channels for state programs in each state.
3. 75 major areas with stations that serve local production/distribution requirements and also act as control stations for state, regional, or national services.
4. 150 secondary stations acting as in "3" except for control functions.
5. 225 ITV service facilities, 165, transmitting one channel and 60 transmitting three channels in addition to the base channels in "3" and "4" above.

2.1.3.3 Parochial School System Television

The Catholic school system exists at every level of education. There are pre-schools, elementary and high schools, junior and senior colleges, universities and seminaries. There are institutions serving atypical and handicapped children, and activities in adult education. All told there are about 14,000 schools in the system. The schools are located in 147 diocese, however, over half of the students are enrolled in the schools of the 20 largest. These metropolitan school systems are aggresively expanding into the promising field of instructional TV. Fourteen diocese now have their own ITV stations. The size and type of service offered is illustrated by the following examples.

2.1.3.3.1 ITFS/Arch diocese of San Francisco —

This system, currently in operation, has central studios and transmitter located at St. Patrick's Seminary. A four channel system provides eight hours of instruction per day. Equipment investment includes:

1.	Transmission System	$180,000
2.	Studio Equipment	$150,000
3.	Installation	$150,000
4.	Receiving System (at each school)	$ 1,500

A total of 140 schools are included in the system 20 of which are being served initially by a system representing a capital investment of approximately $700,000.

Estimated operating costs for alternative programming are:

1.	100% Leased Programming	$160,000
2.	50%-50% Leased and Produced Programming	$240,000
3.	100% Produced Programming	$385,000

The third option is a goal for the system, with emphasis on high quality programs. Experience in New York, Brooklyn and Milwaukee shows that a series has an average life of three years, and offers considerable savings when it can be used beyond the three year average.

This system is being implemented for the specific purpose of reducing the cost of parochial education at the diocesan level. It is expected that the system, with revenue from the parish schools, will be self supporting. Savings will accrue to the using schools, ranging from $2,000 per year for a small elementary school to $20,000 per year for a large high school.

The system, which began operation in 1970, serves the peninsula side of the bay, from Gilroy in the south to San Anselmo in the north. Growth in use of the system is expected to reach 60% of the schools in the diocese by 1974.

2.1.3.3.2 ITFS/Arch diocese of Boston —

The Archdiocese of Boston recently completed phase one of an extensive ITFS system (instructional television fixed service). The first two of four transmitters are now in operation and are reaching some 100,000 students in over 100 schools. The system is replacing a single channel UHF facility which reached 340 schools. The new system will eventually reach 400 receiving sites in a large area surrounding Boston.

An advantage of the 2500 mHz system is that it provides privacy not afforded by the UHF telecasts which could be received on standard home

sets. This allows greater diversity in programming for the two million people within the archdiocese.

Programs originating in the districts' studios are transmitted in an omni-directional pattern from antenna atop the 831-ft. Prudential Center building in downtown Boston. Two or three repeater stations will be added for increased coverage. Signals are received at various locations by parabolic antennas, converted to VHF and delivered to receivers by coax cable.

When the system is complete, it will reach an estimated 172,000 students and 6000 teachers.

2.1.3.3.3 Diocesan Television Center, Brooklyn

The Brooklyn educational television system is the oldest and one of the largest and most active parochial systems. It was the first of the Catholic educational television systems to use the 4-channel ITFS capabilities. Details of the system are given in Table 2-4.

The Brooklyn system serves a large, multilingual cosmopolitan area. The television system provides a means of getting more nearly uniform teaching methods and cirriculum in the area schools, many of which are in "language" parishes where other languages are normally spoken.

The system is also used to exchange administrative information within the area, using both TV and teletype channels.

2.1.3.4 Biomedical Information Transfer Network -- The following categories of information transfer have been identified:

1. Distribution of Library Information -- This service is specifically for the medical community. The libraries would be located at a few regional centers as well as the National Library of Medicine. Types of circuits required would be teletype, telephone and television channels for remote viewing. The primary destinations for the library data would be hospitals. Other receiving points would be medical schools and clinics.
2. Specialized Information Requests -- This service is also specifically for the medical community whereby inquiries can be directed to centrally located data banks. The requests and responses are by means of digital data links.
3. Public Health Information Dissemination -- This service is primarily for the medically uniformed segment of the public. Information is conveyed by commercial quality television. Use would be made of existing educational TV broadcast stations eventually augmented and possible superseded by a medical TV network covering the CONUS.
4. Record Transmission and Inventory Control -- This service pertains to the transfer of information about patient's records and transfer of information necessary to maintain inventory control of vital medical supplies such as blood banks and banks for organ transplants. Digital data links are required initially in metropolitan and regional areas with the ultimate use of a national network.
5. Remote Area Medical and Diagnostic Services -- This service would extend the service of a remote area by transmitting visual information via one-way or two-way TV and diagnostic monitoring data via telemetry from a remote site to a central location. Initially on a sectional basis within states, this service could extend to regional and national areas.
6. Dial Access Systems -- Selectable tape recorded 4-6 minute lectures on current medical problems available by dial telephone by doctors in a state or regional area.

7. Telelecture system for doctor education that uses 2-way radio for lecture followed by Q & A period. A variation uses radio for transmission only with questions from audience received via telephone.

Table 2-11 summarizes operating and proposed medical service communications requirements and facilities. This table shows the types of services provided, the communications media used and the geographic coverage areas. All of the operating or planned programs operate either within a metropolitan area, a state or a region. The proposed Biomedical Communications Network would provide national television coverage.

The following communications functions are associated with the listed medical services:

1. Broadcast television.
2. Two-way television.
3. Two-way telephone voice transmission.
4. Two-way radio voice transmission.
5. Two-way voice via radio and telephone.
6. Telemetry data transmission.
7. Command and control.

Distribution of data and information to network stations include:

1. Mailing of video tapes.
2. Switched telephone.
3. Leased voice grade.
4. Leased TELPAK.
5. Private microwave.
6. C.C.T.T. (Closed Circuit Television Transmission).

There appears to be two primary classes of service that are provided to the medical community through the medium of communications techniques. One of these is the dissemination of information by television broadcast,

FOLDOUT FRAME |

Table 2-11. Medical Servi

DESCRIPTION OF SERVICE	ORIGINATOR	RECIPIENT	CHANNEL DESCRIPT TYPE	GRADE	ONE-WAY	TWO WAY
Medical Education TV (METV)	BCN; Wash, D.C.	Medically uninformed public	Television	Commercial	X	
Calif. Med. TV Network(CMTV)	UCLA (KCET)	Urban & Rural Communities	Television	Commercial		
Amer. Ass'n of Med. TV Broadcasters	Univ. of Utah College of Medicine	Medical Schools Medical Societies	Television	Commercial	X	
Remote Electronic Browsing	Nat'l Library of Medicine (BCN)	Hospitals Med. Schools	Television Frame Addressed	Color CCIR	X	
Telediagnosis	Mass. Gen. Hospital Boston, Mass.	Remote at Logan Airport	Television	Color CCIR		X
			Audio	20Hz-15KHz		X
			Telemetry			X
			Command			X
New Mexico's Rural Diagnostic Service	Physician		Television	Color CCIR		X
			Telemetry		X	
			Voice			X
			Command		X	
Dial Access Systems	Univ. of Wisc.	Physicians	Telephone	Dial-Up		X
	Univ. of Missouri	Physicians	Telephone	Voice		
Louisiana Hospital TV Network	Medical Schools	Hospitals	CCTV			
Telelecture Systems	Univ. of Wisc.	Rural Physicians	FM Radio	Voice		X
			Telephone			
	Albany Med. Coll.	Hospitals	FM Radio	Voice		X
	Univ. of No. Car. School of Medicine	Physicians	FM Radio	Voice		X
			Telephone			
	Ohio State Univ. College of Med.	Hospitals	FM Radio	Voice		X
	U.C. School of Med San Francisco, Ca.	Physicians	FM Radio	Voice		X
	Univ. of Wash. School of Medicine	Physicians	2-Way Radio	Voice		X
Transmission of EKG	Medical College of Georgia	3 other Medical Institutions	Telephone	Voice		
			TV		X	
EKG Hot Line	Univ. of Wash. School of Medicine	Physicians	Telephone	Voice		
Two-Way Telephone Communication Network (Education Programs, Conferences, Poison Information, EKG, Blood Bank, Medical Data)	Univ. of N.Y. School of Medicine Buffalo, N.Y.	Hospitals	Telephone	Voice		X

Table 2-11. Medical Services Communications Systems

FOLDOUT FRAME 2

CHANNEL DESCRIPTION								TERRESTRIAL LINKS		
TYPE	GRADE	ONE-WAY	TWO-WAY	TRANSMIT	RECEIVE	REAL TIME	RECORD	NO. & LOCATION OF TERMINALS	TYPE LINK	COMMO CARRIE
Television	Commercial	X		X		X	X	--	--	--
Television	Commercial									
Television	Commercial	X		X			X	Distrib. of Tapes to broadcast stns.		
Television	Color CCIR	X				X				
Frame Addressed Television	Color CCIR		X			X		One each	Microwave	
Audio	20Hz-15KHz		X			X				
Telemetry			X		X					
Command			X	X						
Television	Color CCIR		X					One at Origin	Microwave	
Telemetry		X			X			Several Remote		
Voice			X							
Command		X		X						
Telephone	Dial-Up		X				X		Telephone Line	X
Telephone	Voice						X		Telephone Line	X
CCTV										
FM Radio	Voice		X		X				Telephone	X
Telephone										
FM Radio	Voice		X						Radio Broadcast	
FM Radio	Voice		X						Telephone	X
Telephone									Radio Broadcast	
FM Radio	Voice		X						Radio Broadcast	
FM Radio	Voice		X						Radio Broadcast	
2-Way Radio	Voice		X						30 Radio Broadcast Stas.	
Telephone	Voice								TV Broadcast	
TV		X				X	X		Leased Lines	X
Telephone	Voice								Leased Lines	X
Telephone	Voice		X						Leased Lines	X

FOLDOUT FRAME 3

TERRESTRIAL LINKS							
RE-CORD	NO. & LOCATION OF TERMINALS	TYPE LINK	COMMON CARRIER	PRIVATE	COVERAGE AREA	OPER-ATING	PRO-POSED
X	--	--	--	--			X
					Southwestern U.S.A.		X
X	Distrib. of Tapes to broadcast stns.				Mtn. States & Adjacent Canada Area		
					Nation Wide		
	One each	Microwave		X	--	X	
	One at Origin Several Remote	Microwave			Remote Area of New Mexico		X
X		Telephone Line	X		Wisc., Minn., N.Dak	X	
X		Telephone Line	X		State of Missouri	X	
					State Wide	X	
		Telephone	X		State Wide	X	
		Radio Broadcast			New England, 1/3 N.Y. 1/3 N.J., N.Y.C.	X	
		Telephone	X				
		Radio Broadcast			State Wide	X	
		Radio Broadcast			State Wide	X	
		Radio Broadcast			San Francisco Bay Area	X	
		30 Radio Broadcast Stas. TV Broadcast			Wash. State; S. E. Alaska		X
X		Leased Lines	X		Intra-State		X
		Leased Lines	X		Wash. State; SE Alaska		
		Leased Lines	X		Western N.Y.	X	

lectures received via telephone or radio, interconnection of libraries, interrogation of data banks and question answering services. The other primary class of service to the medical community through the medium of communications techniques pertains to those functions directly related to diagnosis. Included in this classification are services such as tele-diagnosis, EKG Hot Line, and consulation services (e.g., University of Utah College of Medicine Inter-mountain Regional Medical Program). These two classes of service are of principle value in making it possible for medical personnel to more efficiently utilize their time. This is made possible by making available means of updating knowledge and education without the necessity of spending time traveling from hospital or clinic to a class room, and secondly allowing the physician to remain at his hospital or clinic and concurrently to diagnose and give treatment to a patient at a remote location with no delay in service delivered due to distance separating originator and recipient.

After reviewing the services that are in operation or planned for future and noting what the BCN proposes to implement, it appears that the BCN would provide a nationwide network for what is being done in more limited areas such as metropolitan, state or region with the exception of a service similar to telediagnosis or the remote diagnosis of a patient via television, audio and telemetry. There are rural and remote areas in many regions of thw CONUS and Alaska where a remote diagnostic service would provide a real need and be adaptable to implementation by a satellite link.

Table 2-12 tabulates presently provided and planned service to the medical community according to the type of service, area served and approximately the number being served. Only included were those services that required inter-state or intra-state communications.

It may be noted that the table lists three types of service that are directly related to providing continuing education to over 100,000 physicans; namely, "Dial Access," "Telelecture," and "Medical Educational Television." Apparently because of its widespread and expanding use the telelecture technique, utilizing 2-way radio or 1-way radio and telephone and pre-distributed visual aids, provides a satisfactory and economical service. Medical educational TV finds a substantial audience (including the proposed

Table 2-12. Medical Services to Physicians

TYPE OF SERVICE	ESTIMATED PHYSICIANS SERVED	PERCENT OF U. S. TOTAL	AREA OF COVERAGE
DIAL ACCESS	19,000	5.9	WISC., MINN., N. DAK., MO.
TELELECTURE	107,800	33.5	WISC., NEW ENGLAND, 1/3 N.Y., 1/3 N.J., N.Y.C., N. CAR., OHIO, SAN FRANCISCO BAY AREA, WASH. STATE., S.E.ALASKA
MEDICAL-EDUCATION TELEVISION	34,000	10.8	LOUISIANA UTAH & ADJOINING STATES S.E. ALASKA *SOUTHWESTERN U.S. *N. CAR. DUKE UNIV. & ADJOINING HOSPITALS
EKG TRANSMISSION	12,500	3.9	GEORGIA, WESTERN N.Y., WASH. STATE, S.E.ALASKA
CONSULTING AND ANSWERING SERVICE	11,800	3.7	WESTERN N.Y., ALABAMA, UTAH & ADJACENT STATES
* PLANNED			

California Medical TV Network) with an estimated audience of 33,500 physicians. Telelecture and METV are not necessarily mutually exclusive in that certain educational functions such as surgery demonstrations would require television. On the other hand, lectures using slide illustrations could use either medium. Cost would in that case be the chief factor in determining the choice of system to use. A national network such as BCN to be viable must receive sufficient support from a medical community that might prefer to operate regional systems with services originating in medical schools located centrally in each region.

2.1.4 Computer Program Inputs

The user requirements are reduced in the last step of user analysis to a set of discrete inputs for the communi cation synthesis program. Figure 2-2 shows an input sheet used to summarize the user requirements and subsystem options.

At the time that the data shown in the figure was generated (April 1969), the computer program was being used for initial runs of TVBS examples. The data illustrated a typical set of user requirements and subsystem options. In practice, many of the alternate combinations suggested by the data are not routinely run by the synthesis program. For example, the system is selected to be UHF or S-band for both the uplink and for the downlink. The variation in satellite lifetime shown in the data yielded less significant results than other possible options, and runs are usually made for 5 or 10 year satellite life. The concept options corresponding to satellite configurations A through H (refer to Section 2.2 for configuration descriptions), are generally restricted to use of B and C only, and the subsystem types are automatically selected to best fit the concept used. In practice also, the option of use of color and monochrome has not been used, further reducing the number of possibly less productive optimization runs.

System configurations resulting from the computer optimization program are described in Sections of Chapter 4, preliminary design information in Chapter 5, and service descriptions are included in Volume III.

DESCRIPTION OF RUN: NATIONAL ETV SYSTEM FOR INDIA

	RUN NO.	4/18-01		
USER REQUIREMENTS	COVERAGE MAJOR AXIS(miles)	1700		
	COVERAGE MINOR AXIS (miles)	1400		
	BEAM CENTER LATITUDE	22° N		
	BEAM CENTER RELATIVE LONGITUDE	0°		
	RECEIVER ENVIRONMENT	Rural		
	NUMBER OF RECEIVERS/BEAM	5.7×10^5		
	TASO GRADE	1		
	NO. OF UPLINK FACILITIES	1		
	NO. OF VIDEO CHANNELS/FACILITY	1		
	NO. OF AUDIO CHANNELS/VIDEO	15		
	NO. OF DOWNLINK BEAMS	1		
	NO. OF CHANNELS/DOWNLINK BEAM	1		
	UPLINK FREQUENCY (GHz)	UHF, S-Band		
	UPLINK MODULATION	FM		
	UPLINK MODULATION INDEX	3		
	DOWNLINK FREQUENCY (GHz)	UHF, S-Band		
	DOWNLINK MODULATION	FM		
	DOWNLINK MODULATION INDEX	3		
	BASEBAND BANDWIDTH (MHz)	Video = 4.2		
	TOTAL SYSTEM LIFETIME (YRS)	10		
	SPACECRAFT LIFETIME (YRS)	2, 4, 6, 8, 10		
	DUTY CYCLE (HRS/DAY)	24		
SUBSYSTEM OPTIONS	CONCEPT	*		
	COLOR OR MONOCHROME	*		
	POWER SOURCE TYPE	*		
	BATTERY TYPE	*		
	TRANSMITTER TYPE	*		
	RECEIVER/TRANSLATOR TYPE	*		
	THERMAL CONTROL TYPE	*		
	ATTITUDE CONTROL TYPE	*		
	STATIONKEEPING TYPE	*		

NOTE: An astersik (*) denotes a run through all subsystem options.

Figure 2-2. TVBS Computer Program Input Sheet

2.2 SPACECRAFT CONFIGURATIONS

A graded series of configuration concepts have been generated to provide reasonable weight, volume, and geometry constraints for the computer synthesis runs. These concepts range in size from relatively small, multiple satellite configurations to large, manned versions. The weights for the seven current concepts are shown in Figure 2-3. A summary of general characteristics of the satellites is given in Table 2-13.

Concepts A, B, C and H are completely unmanned satellites. The first three are relatively small satellites which are carried in groups of 3, 7, or 13 on a satellite dispenser for the Saturn V launch. The dispenser is placed in a nominal, near stationary orbit by the launch vehicle. The dispenser kick stage motor is then fired to acquire the proper orbital position for the satellites. The satellites are then separated from the dispenser, one at a time, and automatically deploy their antennas and solar arrays.

This type of concept has some unique potential advantages for the broadcast mission. Although the versions shown assume approximately identical satellites for a given launch, in the real case each satellite could be significantly different to satisfy several users with diverse requirements. It may also be economically attractive to use one or two satellites for TV broadcast and the remainder for completely different missions such as earth resource investigation, or navigation control. This approach could be especially desirable for an early experimental program.

Each satellite is also designed also for individual launch on a smaller booster such as TIIIC, TIIID-Centaur, or SIB-Centaur. Thus, prototype vehicles could be demonstrated by low cost launches and replacement of a single operational satellite is feasible in the event of a premature failure.

Configuration H concept is a large unmanned satellite designed for single launch only. The satellite size ranges covered by Concepts A, B, C, and H include antenna diameters up to 100 feet, and prime power up to about 180 kilowatts. Up to six antenna beams can be produced by a single satellite, either through the use of separate, high frequency antennas or, with larger diameter antennas, a multiple feed on a single reflector.

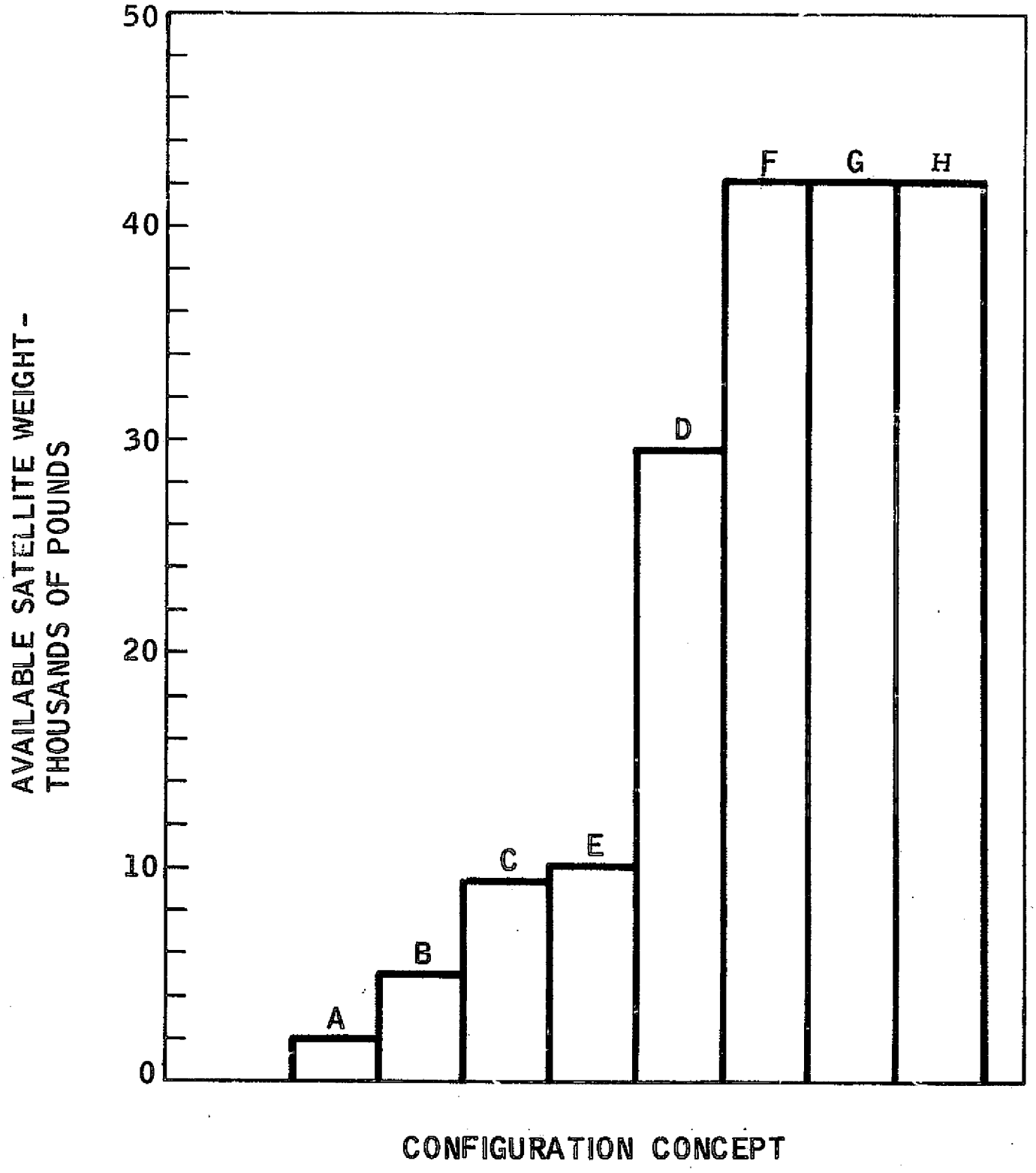


Figure 2-3. Concept Size Steps

Table 2-13. Concept Summary

CONCEPT CODE	ALLOWABLE WEIGHT	ALLOWABLE VOLUME	ANTENNA TYPE	POWER TYPE	MANNED PROVISIONS	BOOSTER TYPE	COMMENTS
A	2,000 lb	98 cf	PETA or Rigid	Solar Cell	None	S-V or T IIIC	Multiple satellite version, 13 per S-V launch. 1 per T IIIC launch.
B	5,200	262	Phased Array, PETA, or Rigid Dish	Solar Cell	None	S-V or T III D/ Centaur	Multiple satellite version, 7 per S-V Launch, 1 per T IIID-Centaur.
C	9,000	310	PETA	Solar Cell	None	S-V or S-IB/ Centaur	Multiple satellite version, 3 per S-V Launch, 1 per S-IB-Centaur
D	29,300	6,000	Rigid Dish Array	Solar Cell	BSM Module	S-V	BSM provides a shirt-sleeve environment for extended manned operation.
E	10,000	4,500	PETA	Solar Cell or Reactor	Dock	S-V with CSM	Dock provided, all operations by EVA or remote control.
F	42,000	6,000	PETA	Solar Cell	Pressurized Feed Module	S-V	MDA Module provides shirtsleeve environment for short periods (14 days).
G	42,000	6,000	Phased Array Dipoles	Solar Cell or Reactor	Optional Dock	S-V	Optional manned support with solar cell power only.
H	42,000	6,000	PETA	Solar Cell Array	None	S-V	Large unmanned configuration for Trade studies with manned versions.

The remaining four configurations are large satellites designed to serve multiple areas. Manning provisions vary from shirt-sleeve environment for extended operations (Configuration D) to provision only for optional support (Configuration G). The succeeding sections provide a more detailed description of the concepts and give the constraints which are input to the synthesis program for each version. Table 2-14 provides nomenclature.

2.2.1 CONCEPT A -- The packaged dispenser and 13 satellites of this version are shown in Figure 2-4. The typical satellite features are shown in Figure 2-5. As shown in this latter figure, each satellite is limited to a 5-foot diameter by 5-foot long cylindrical volume. The practical limit in solar array size for this version, the smallest satellite considered, is about 2 kilowatts. The individual satellites are limited to 2000 pounds to allow launch by a Titan IIIC. Although the use of rigid dish antennas operating at higher frequencies is probably the most desirable for this concept, the PETA antenna can be used to provide antennas up to 15 feet in diameter.

Figure 2-6 defines the geometrical parameters which must be related for input to the synthesis program. Table 2-15 presents the geometrical, volume, and weight constraints in tabular form.

2.2.2 CONCEPT B -- The packaged dispenser and 7 satellites of this configuration are shown in Figure 2-7. A possible satellite configuration with a solt array antenna and roll-up solar arrays is shown in Figure 2-8. Any one satellite could be launched by a TIIID/Centaur. The individual package volume is limited to an 8-inch diameter cylinder of 90-inch length. Both phases array and parabolic antennas can be considered. Data on the phased arrays is not currently available for input to the synthesis program. Therefore, the initial runs will consider only parabolic antennas. Solid dishes to 6.67-feet diameter and PETA reflectors to 30-feet diameter are feasible.

Figure 2-6 defines both Concept B and Concept A geometry relationships. The constraints on weight, volume and geometry for Concept B are given in Table 2-16.

Table 2-14. Nomenclature

ℓ_{EM}	=	Length of Equipment Module
D_{EM}	=	Diameter of Equipment Module
P_{PRIME}	=	Power Source Output in Watts
N	=	Satellite Life in Years
A	=	Area of Solar Array in Square Feet
ℓ_F	=	Length of Feed in Feet
ℓ_A	=	Height of Stowed Antenna in Feet
D_A	=	Diameter of Deployed Antenna in Feet
W_S	=	Weight of Spacecraft Less Stationkeeping
P_{DIS}	=	Power Dissipated by Thermal Control Subsystem in Watts
P_{XMTR}	=	RF Power Radiated by Transmitter in Watts
V_{EM}	=	Volume of Equipment Module in Cubic Feet
P_{DIST}	=	Power Generated by Transmitter to be Dissipated in Watts
P_{DISS}	=	Power Generated by Other Subsystems to be Dissipated in Watts
η	=	Transmitter Efficiency
V_{RD}	=	Volume of Radiator
V_{SA}	=	Volume of Stowed Solar Array
D_U	=	Diameter of the Uplink Antenna
V_F	=	Volume of Feed
V_U	=	Volume of Uplink Antenna
ℓ_U	=	Height of Stowed Uplink Antenna
V_{PP}	=	Volume of Prime Power System

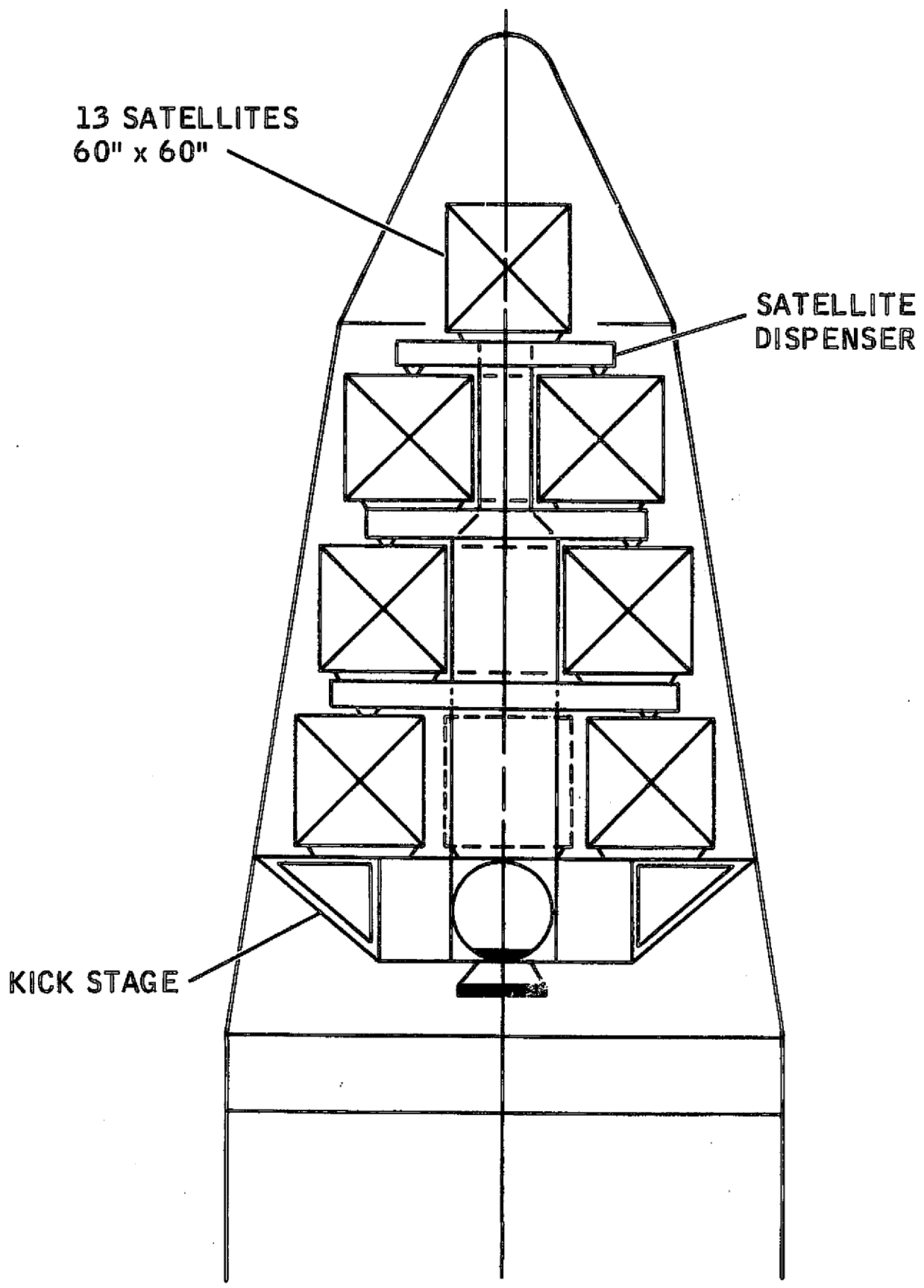


Figure 2-4. Concept A Packaging

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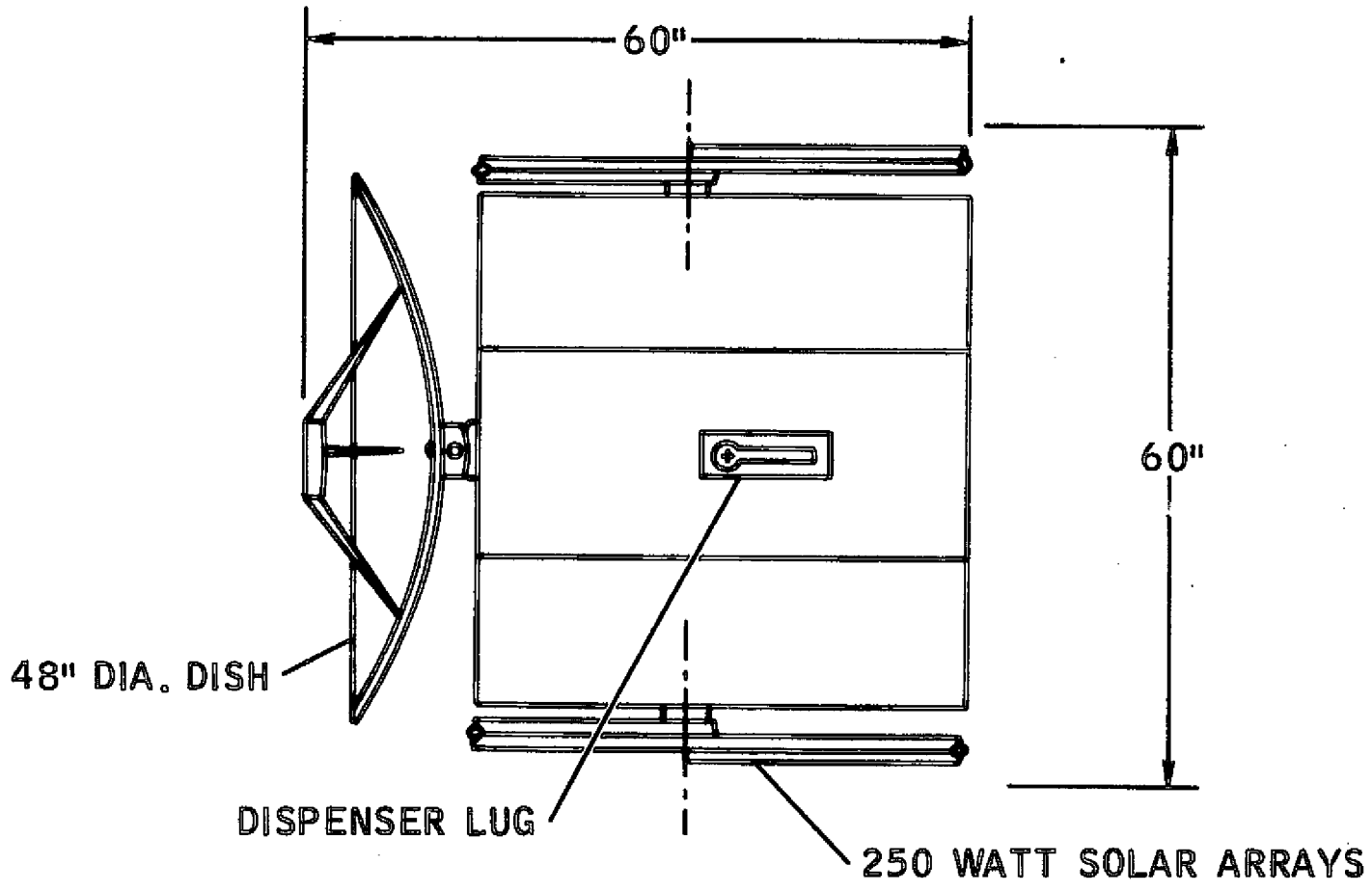


Figure 2-5. Concept A Individual Satellite (Packaged)

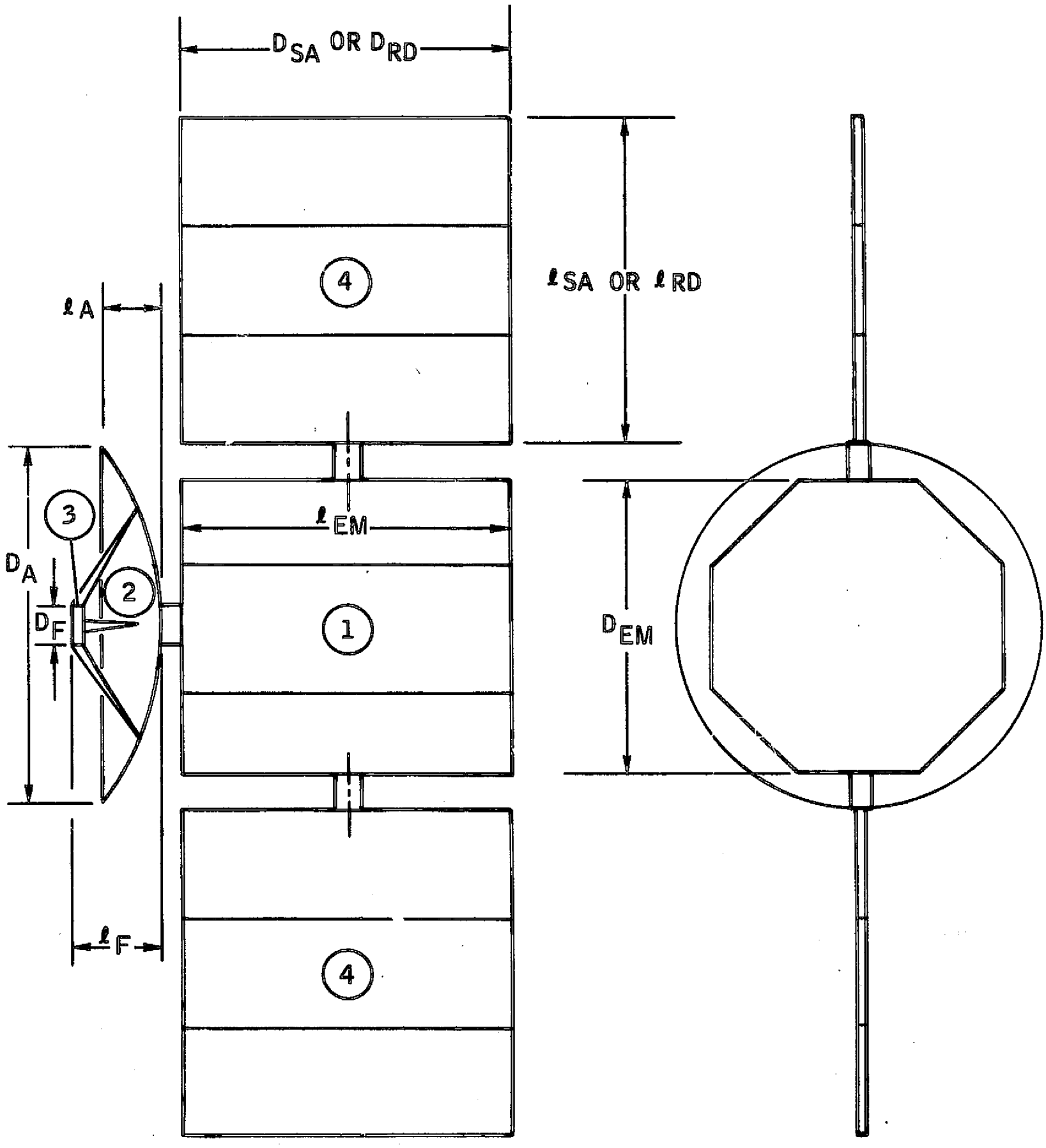


Figure 2-6. Concept A Geometrical Parameters

Table 2-15. Geometry, Weight, and Volume Constraints — Concept A

1. Antenna: Rigid Dish for $D_A \leq 5$

   PETA for $5 < D_A \leq 15$

2. Feed: Cassegrain, Rigid or Hinged

3. Packaged Length:

   a. $\ell_{EM} + \ell_F + 0.5 \leq 5$ for $D_A \leq 5$

   b. $\ell_{EM} + \ell_A + 0.5\,\ell_F \leq 5$ for $5 < D_A \leq 15$

4. Feed Length: $\ell_F = (.2 D_A + .25)$

5. PETA Package Length: $\ell_A = .12\, D_A$

6. Module Diameter = 4.0

7. Module Available Volume:

$$V_{EM} = .83\, \ell_{EM}\, D_{EM}^2 = 13.3\, \ell_{EM}$$

8. Total Volume:

   a. $V_{EM} + V_{RD} + V_{SA} + 19.65\,(\ell_F + .05) \leq 98$; $D_A \leq 5$

   b. $V_{EM} + V_{RD} + V_{SA} + 19.65\,(\ell_F + \ell_A) \leq 98$; $5 < D_A \leq 15$

9. Total Weight ≤ 2000

NOTE: See Table 2-14 for nomenclature.

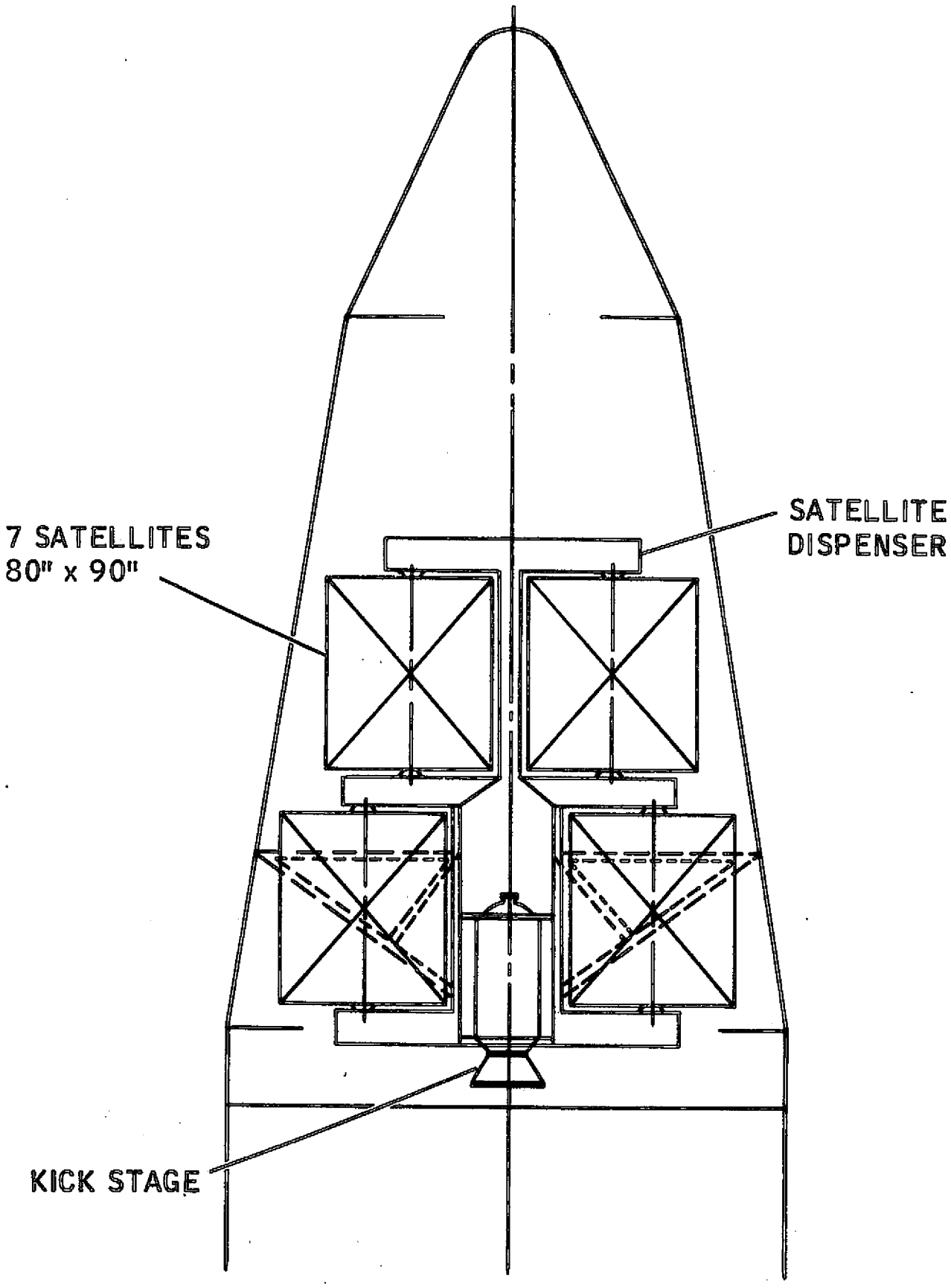


Figure 2-7. Concept B Packaging

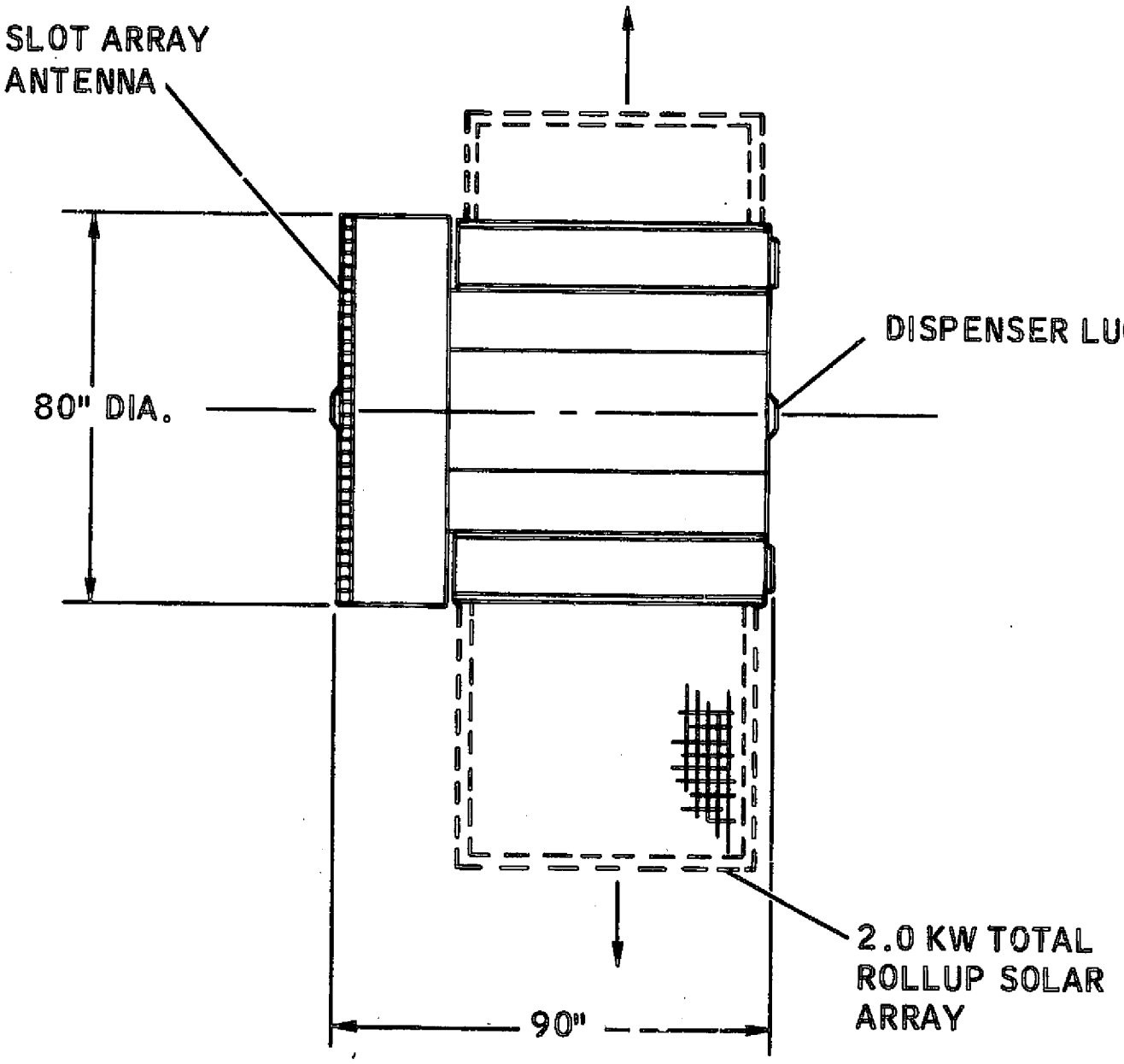


Figure 2-8. Concept B Individual Satellite

Table 2-16. Geometry, Weight and Volume Constraints — Concept B

1. Antenna: Rigid Dish for $D_A \leq 6.67$
   PETA for $6.67 < D_A \leq 30.0$

2. Feed: Cassegrain, Rigid or Hinged

3. Packaged Length:

   a. $\ell_{EM} + \ell_F + 0.5 \leq 7.5$ for $D_A \leq 6.67$

   b. $\ell_{EM} + \ell_A + 0.5\ \ell_F \leq 7.5$ for $6.67 < D_A \leq 30$

4. Feed Length: $\ell_F = (.2 D_A + .25)$

5. PETA Package Length: $\ell_A = .12 D_A$

6. Module Diameter = 5.67

7. Module Available Volume:

   $V_{EM} = 25.3\ \ell_{EM}$

8. Total Volume:

   a. $V_{EM} + V_{RD} + V_{SA} + 34.9\ (\ell_F + 0.5) \leq 262$; $D_A \leq 6.67$

   b. $V_{EM} + V_{RD} + V_{SA} + 34.9\ (\ell_F + \ell_A) \leq 262$; $6.67 < D_A \leq 30$

9. Total Weight $\leq 5,200$

2.2.3 CONCEPT C – This version packages 3 satellites in the S-V volume as shown in Figure 2-9. The individual satellite configuration for a 25-foot diameter PETA antenna and a relative large solar array is shown in Figure 2-10. Only the PETA antenna and solar power will be considered for this concept. The available width envelope of the Saturn V booster with three satellites aboard limits antenna diameter to 56-feet. Similar constraints limit solar array maximum power to about 12 KW. The individual satellites could be launched by an S-IB/Centaur booster configuration.

Figure 2-11 defines the geometry relationships for Concept C required for the parametric analyses. A list of constraints for this configuration is given in Table 2-17.

2.2.4 CONCEPT D – This configuration, shown packaged in Figure 2-12, is a fully manned, single satellite intended to serve multiple areas. Figure 2-13 indicates the orbital configuration with solar arrays, radiator arrasy, and antennas deployed. The Basic Subsystem Module (BSM) is used to house all equipment for both the experiments and life support systems. BSM has been studied extensively by Convair for the Manned Spacecraft Center and is intended to provide a shirt-sleeve environment for up to 12 men for extended periods. The BSM module was chosen for this concept because detailed weights, volumes, and life support system definition for extended manned operation are available. Rigid dish antennas with fixed feed booms have been used in a multiple dish array.

This concept could be used as a large, manned, comprehensive communications laboratory to study the technical and operational aspects of TV, voice, relay, and surveillance communications from geostationary orbit. Table 2-18 gives the weight, volume, and configuration constraints for this concept.

2.2.5 CONCEPT E – This version is manned and is packaged with the CSM in a single Saturn V so that only one launch is required. A large feed module containing a dock and provisions for short-term manned support is provided. The feed module houses all equipment for the satellite. A seventy-foot PETA reflector with up to 3000 SF of solar cells mounted off the reflector

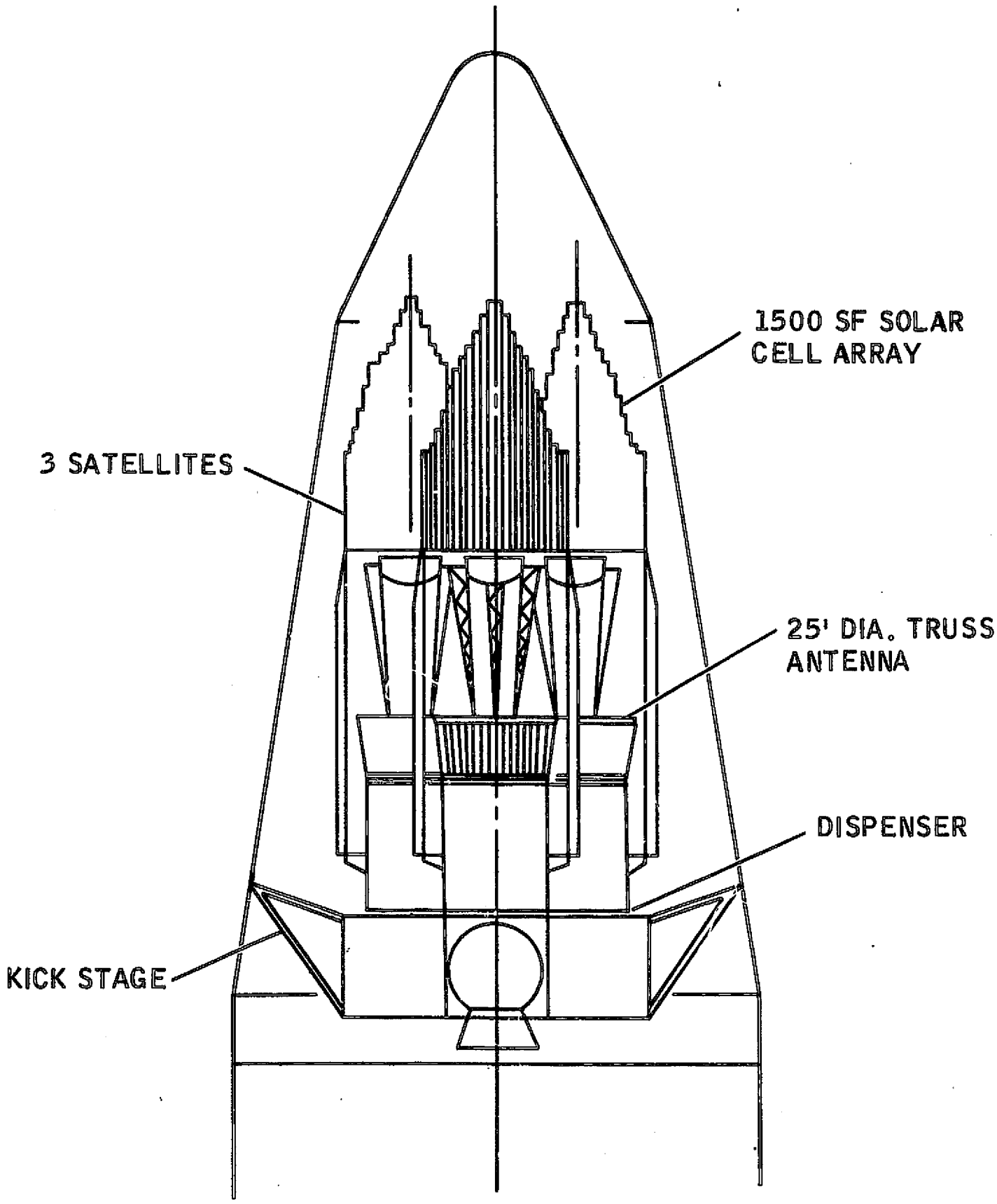


Figure 2-9. Concept C Packaging

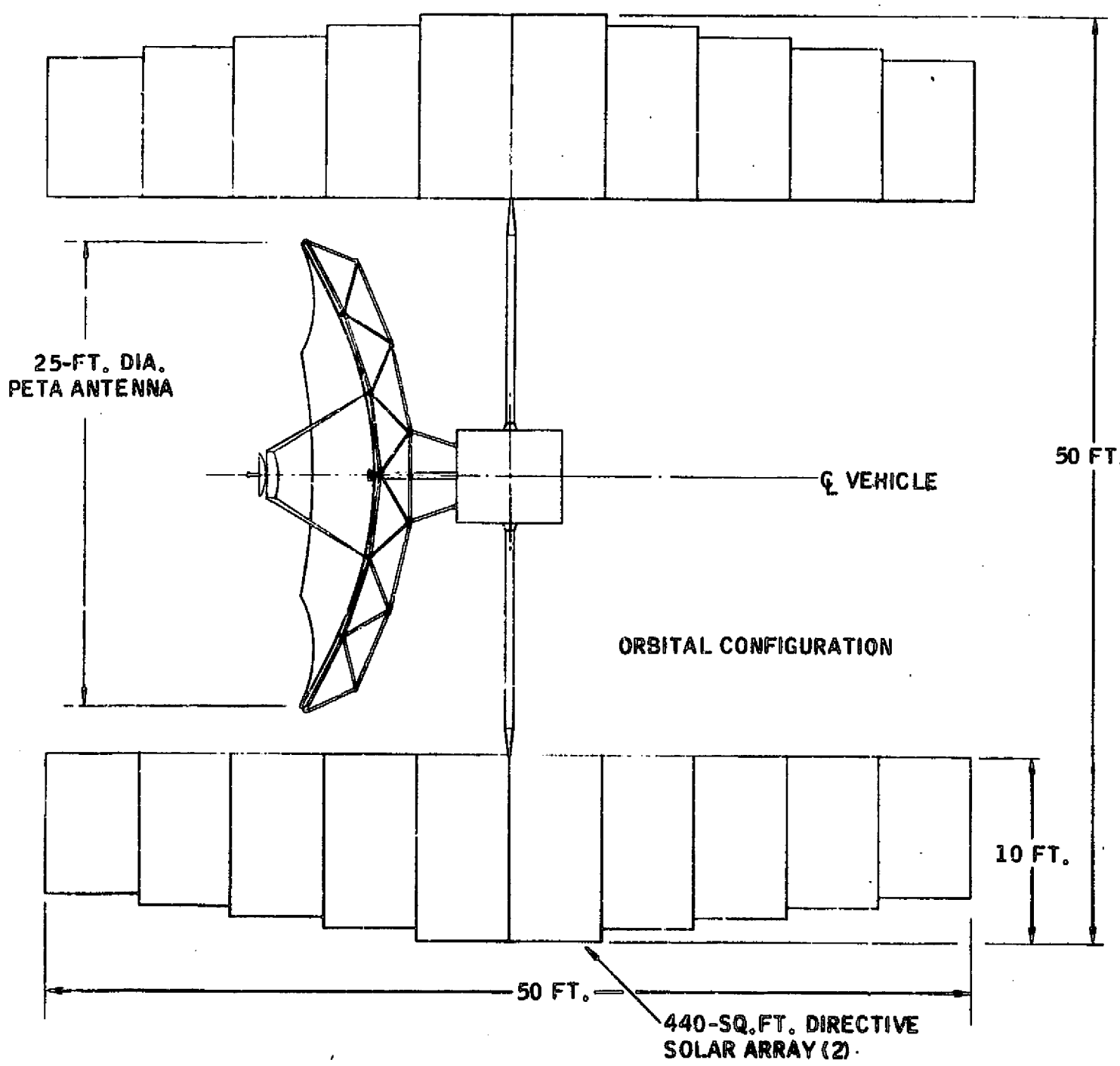


Figure 2-10. Concept C Satellite

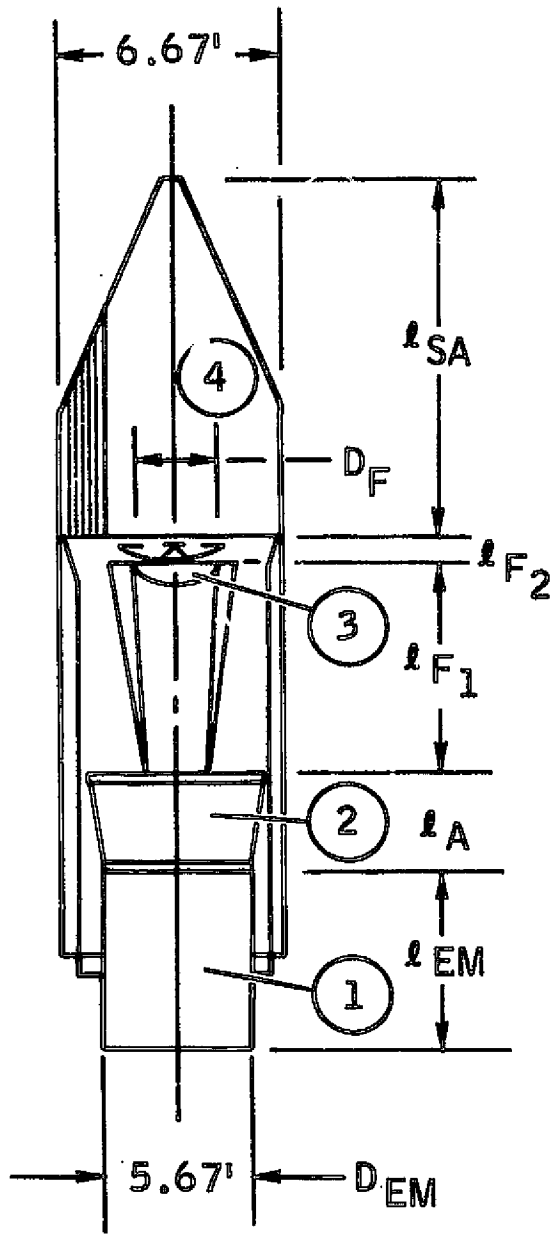


Figure 2-11. Concept C Configuration Geometry

Table 2-17. Geometry, Weight and Volume Constraints — Concept C

1. Antenna: PETA only $D_A \leq 56$

2. Feed: Fixed Cassegrain for $D_A \leq 25$

   Folding Cassegrain for $D_A > 25$

3. Uplink Antenna: Rigid Dish With Cassegrain Feed, $D_U \leq 5.67$

4. Package Length:

$$\ell_{EM} + \ell_A + \ell_F + \ell_{SA} \leq 26$$

5. Feed Length:

$$\ell_F = (.2\, D_A + 0.5) + (.2\, D_U + .25) \quad \text{for} \quad D_A \leq 25$$

$$\ell_F = (.10\, D_A + 0.5) + (.2\, D_U + .25) \quad \text{for} \quad 25 < D_A < 56$$

6. PETA Package Length = $0.11\, D_A$

7. Module Diameter = 5.67

8. Module Available Volume:

$$V_{EM} = 25.3\, \ell_{EM}$$

9. Maximum Solar Array Volume:

$$V_{SA} = 170$$

10. Total Volume:

a. $V_{EM} + V_A + V_{SA} + V_{RD} + V_F + V_U \leq 810$

b. $V_F = .786\,(.2\, D_A + 0.5)\,(.10\, D_A + 1.0)^2$ for $D_A \leq 25$

c. $V_F = .786\,(.10\, D_A + 0.5)\,(.10\, D_A + 1.0)^2$ for $25 \quad D_A \leq 56$

d. $V_U = .786\,(.2\, D_U + .25)\, D_U^2$

11. Total Weight $\leq 9{,}000$

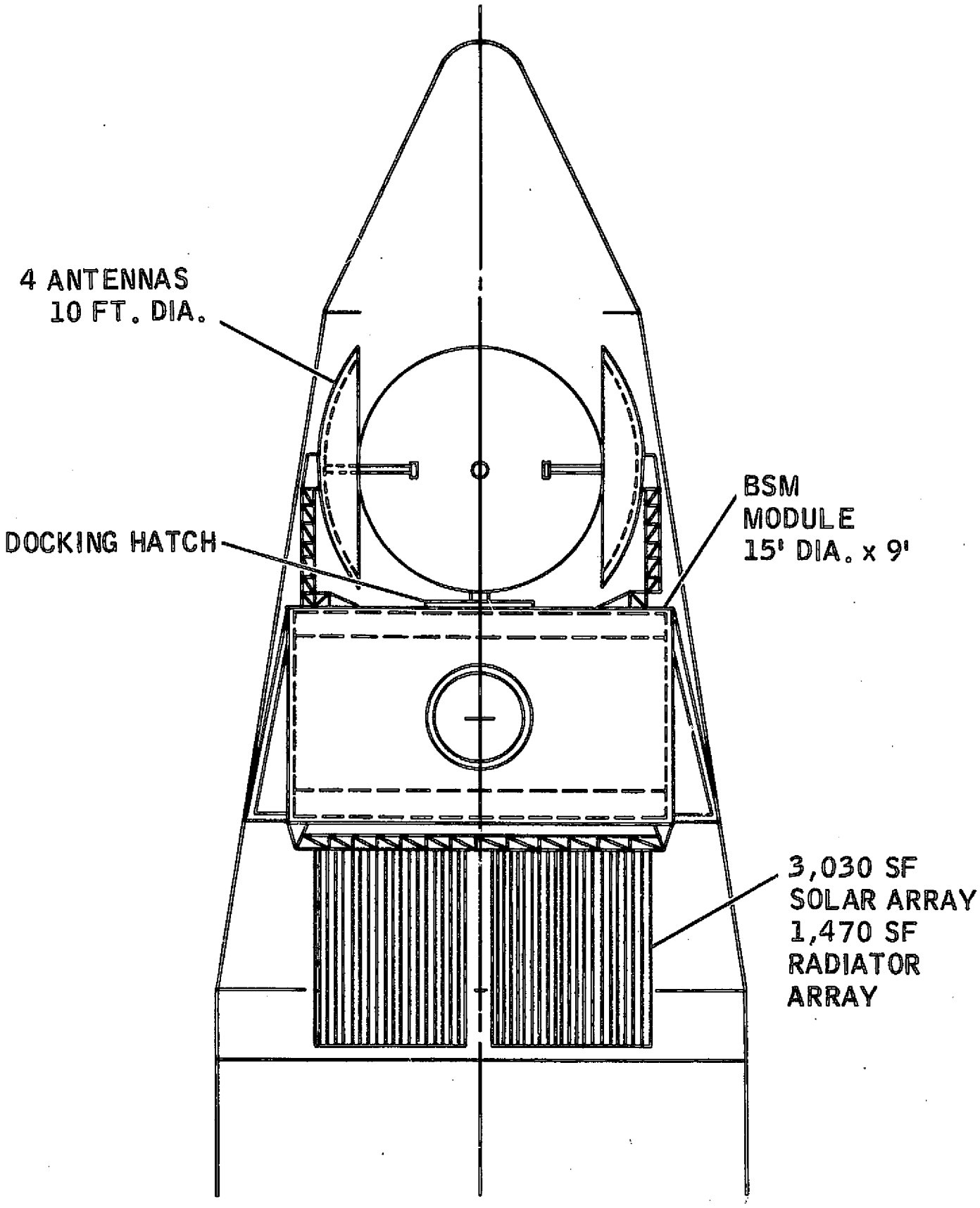


Figure 2-12. Concept D Packaging

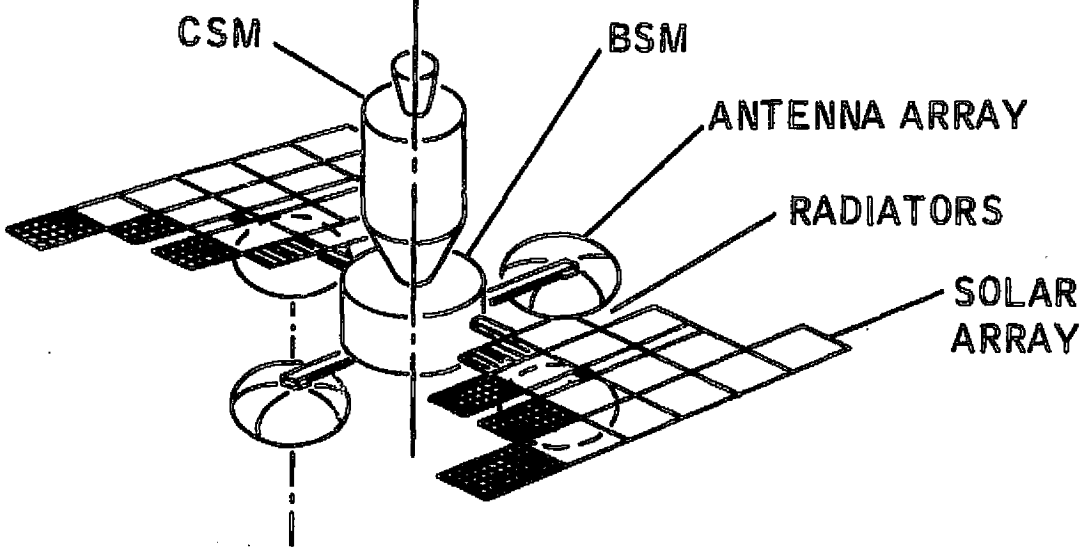


Figure 2-13. Concept D Satellite Deployed and CSM Docked

Table 2-18. Weight, Volume, and Geometry Constraints for Concept D

1. Antenna: Rigid Dish Array $D_A \leq 15$

2. Radiator: Active Boiler/Condenser System with Deployed Radiator/Condenser Units

3. BSM Volume = 1600

4. Total Available Volume = 6,000

5. Total Spacecraft Volume:

$$V_{SA} + V_{RD} + \Sigma V_A + \Sigma V_F + .786\,(.2D_U + .25)\,D_U^2 \leq 4400$$

6. Fixed BSM Weights:

BSM Structure	3650
Equip Racks	2050
Atmosphere Supply	5775
Water & Waste Management	708
Crew Systems	500
Total	12,683

7. Available Payload (with 20% Contingency) = 42,000

8. Available Experiment Weight = 42,000 - 12,683 = 29,317

edge is used. Expandable feed support booms, similar in concept to the PETA reflector, allow the very compact package required for this version.

Multiple beams can be obtained from this satellite by multiple feed arrangements. The configuration is best suited to users requiring high power broadcast to relatively small coverage areas.

Figure 2-14 indicates the packaged and deployed configuration for this concept. Table 2-19 lists concept constraints required for the synthesis program.

2.2.6 CONCEPT F -- This version is designed to satisfy a large variety of user requirements in one satellite. As shown in Figure 2-15, a large (100-foot diameter) PETA structure is shaped by mechanical adjustment of the truss and mesh supports to provide six different apertures, each up to 33-feet in diameter. By varying aperture size and transmission frequency, ground coverage per beam can be varied from 0.5 to 10 x 10^6 square miles. Six feeds are edge mounted on the feed-equipment module to provide separation of each primary beam. The feeds are located at the aperture edge, minimizing RF blockage. Deployment and operation of the satellite is automatic; adjustment of the individual feeds for fine pointing, however, is a desirable astronaut task which can be accomplished from within the feed module. The NASA-MSFC Multiple Docking Adapter (MDA) has been used in the concept shown as the feed module since the necessary CSM and astronaut interface has already been designed into this unit.

The packaging arrangement for this concept is shown in Figure 2-16. Constraint inputs to the synthesis program are listed in Table 2-20.

2.2.7 CONCEPT G -- This configuration, shown in Figure 2-17, uses a phases array antenna only and is intended to aid in establishing the feasibility of this type antenna. The array is a series of dipole elements each having a receiver, transmitter, and amplifier unit. The array is space-fed from a feed array mounted on the equipment module to the backside dipoles. The relatively low power signal is then amplified and transmitted through the front-side dipoles. This arrangement eliminates the long runs of high power RF lines normally associated with phased arrays.

FOLDOUT FRAME 1

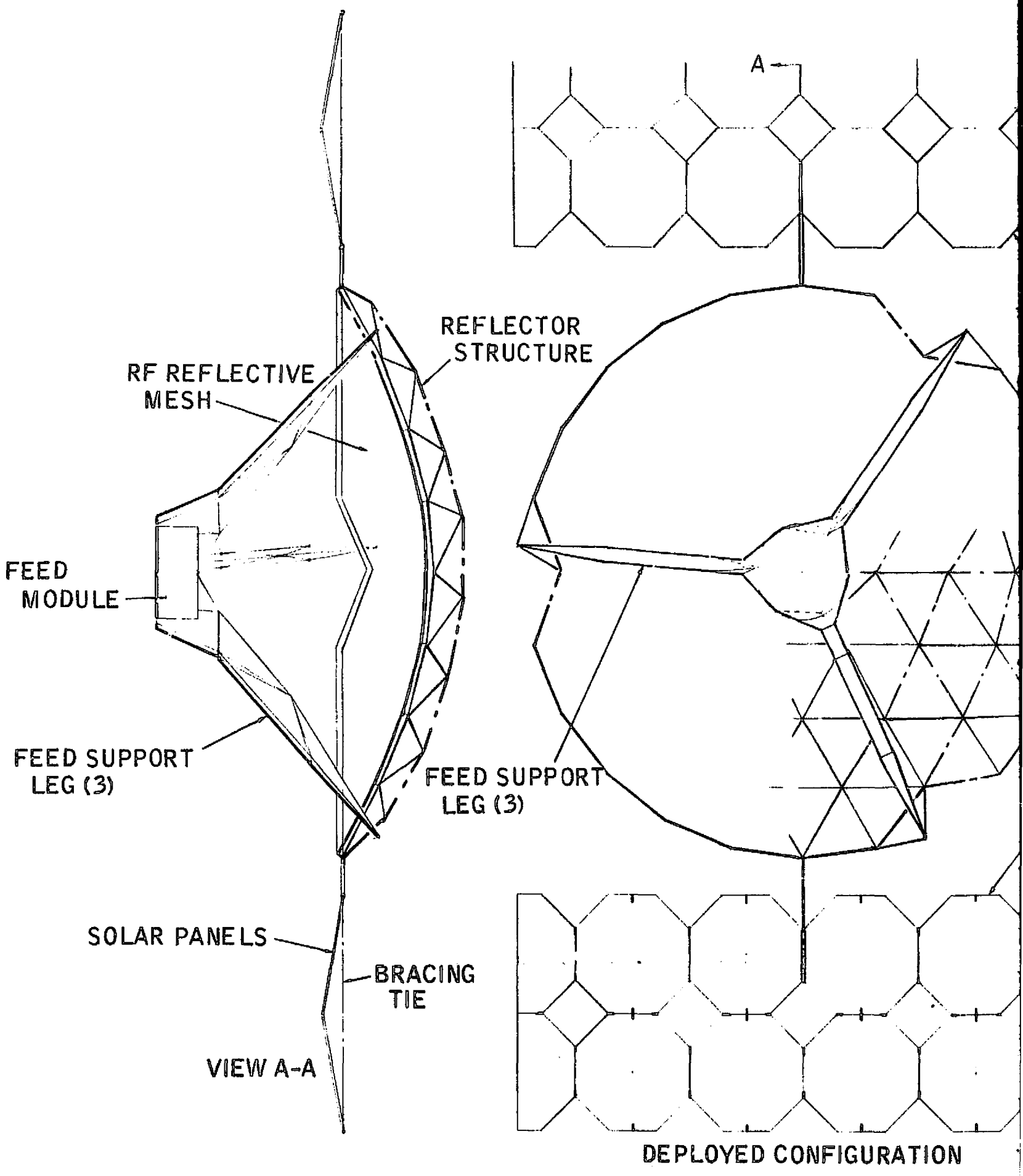
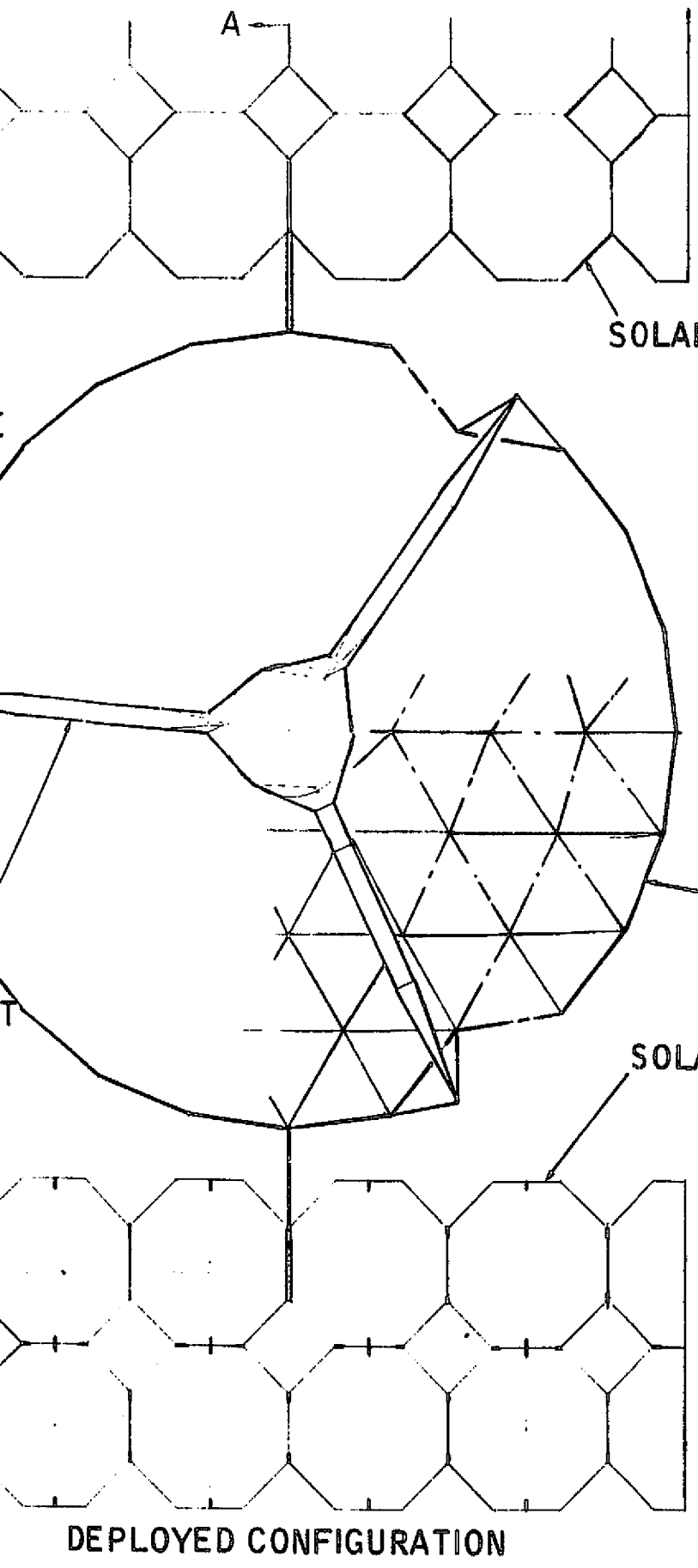
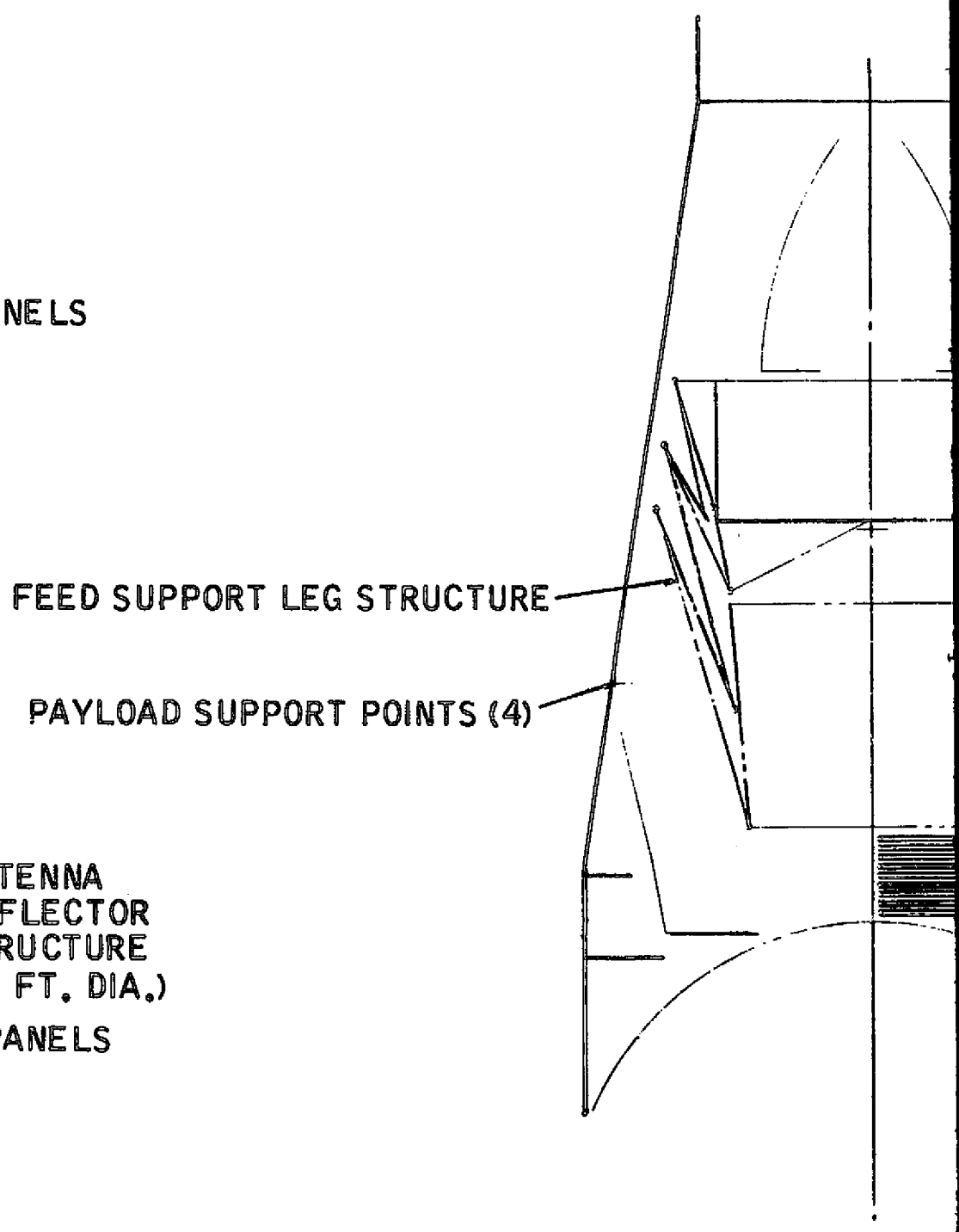


Figure 2-14. TVBS Concept E Arrangement

FOLDOUT FRAME 2



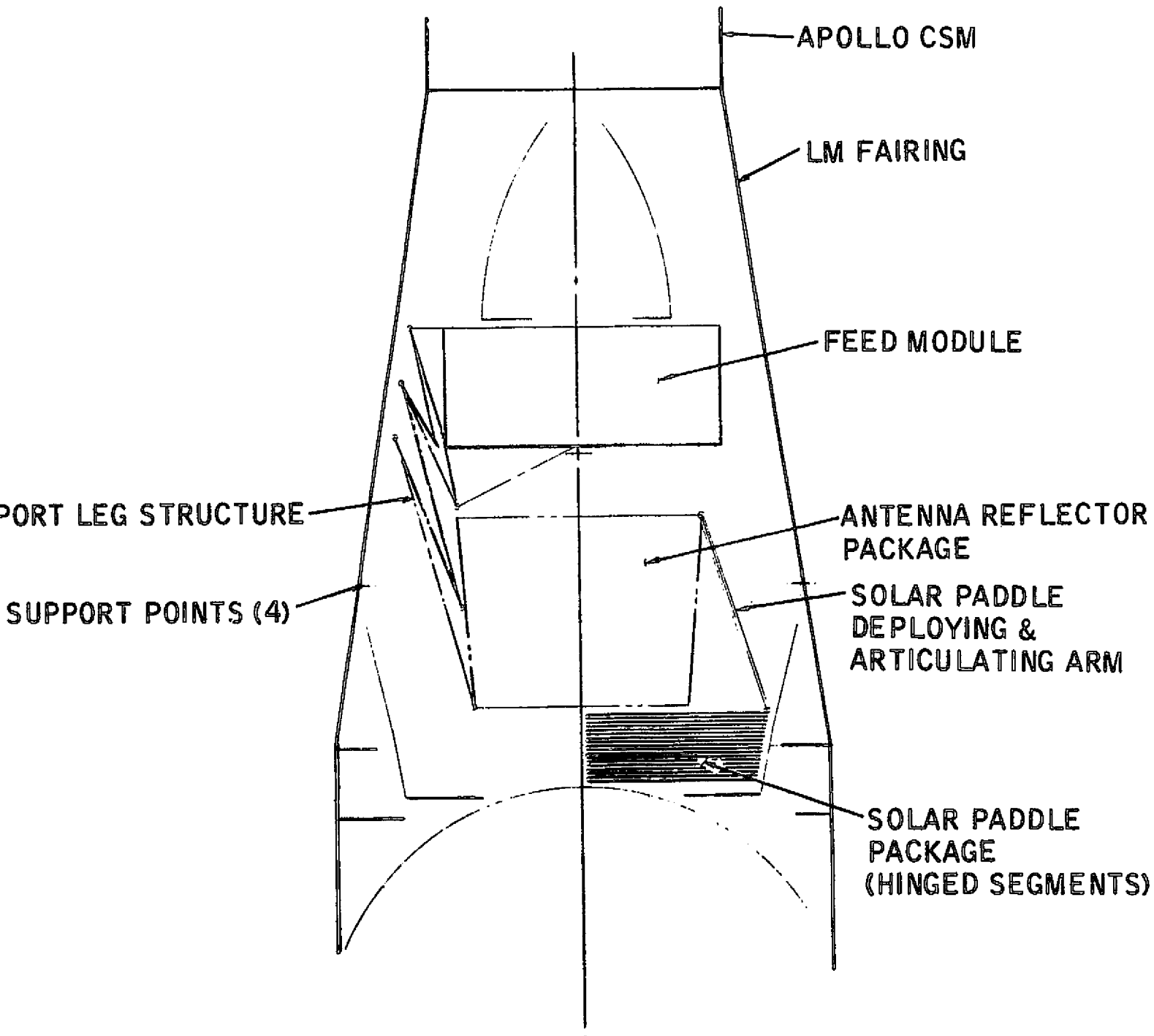
DEPLOYED CONFIGURATION



BOOST CONFIGUR

ept E Arrangement

FOLDOUT FRAME 3



BOOST CONFIGURATION

Table 2-19. Weight, Volume, and Geometry Constraints for Concept E

1. Antenna: PETA $D_A \leq 90$

2. Feed Supports: Expandable

3. Uplink Antenna: Rigid Dish, Cassegrain Feed

4. Packaged Length:

$$*\ell_{EM} + \ell_F + \ell_A + \ell_U \leq 20$$

5. Uplink Antenna Length:

$$\ell_U = (.2\, D_U + .25)$$

6. Total Spacecraft Volume:

$$V_{EM} + V_A + V_{RD} + V_{SA} + V_U + V_F \leq 4,500$$

7. Equipment Module Diameter = $0.10\ D_A$

8. Uplink Antenna Volume = $.786\ D_U^2\ (.2 D_U + .25)$

9. Fixed Satellite Weights:

Docking Cone	300
Crew Systems	500
Emergency Atmosphere	2400
Total	3200

10. Available Weight = 9800 - 3200 = 6600

*In this concept, the equipment module is the feed module.

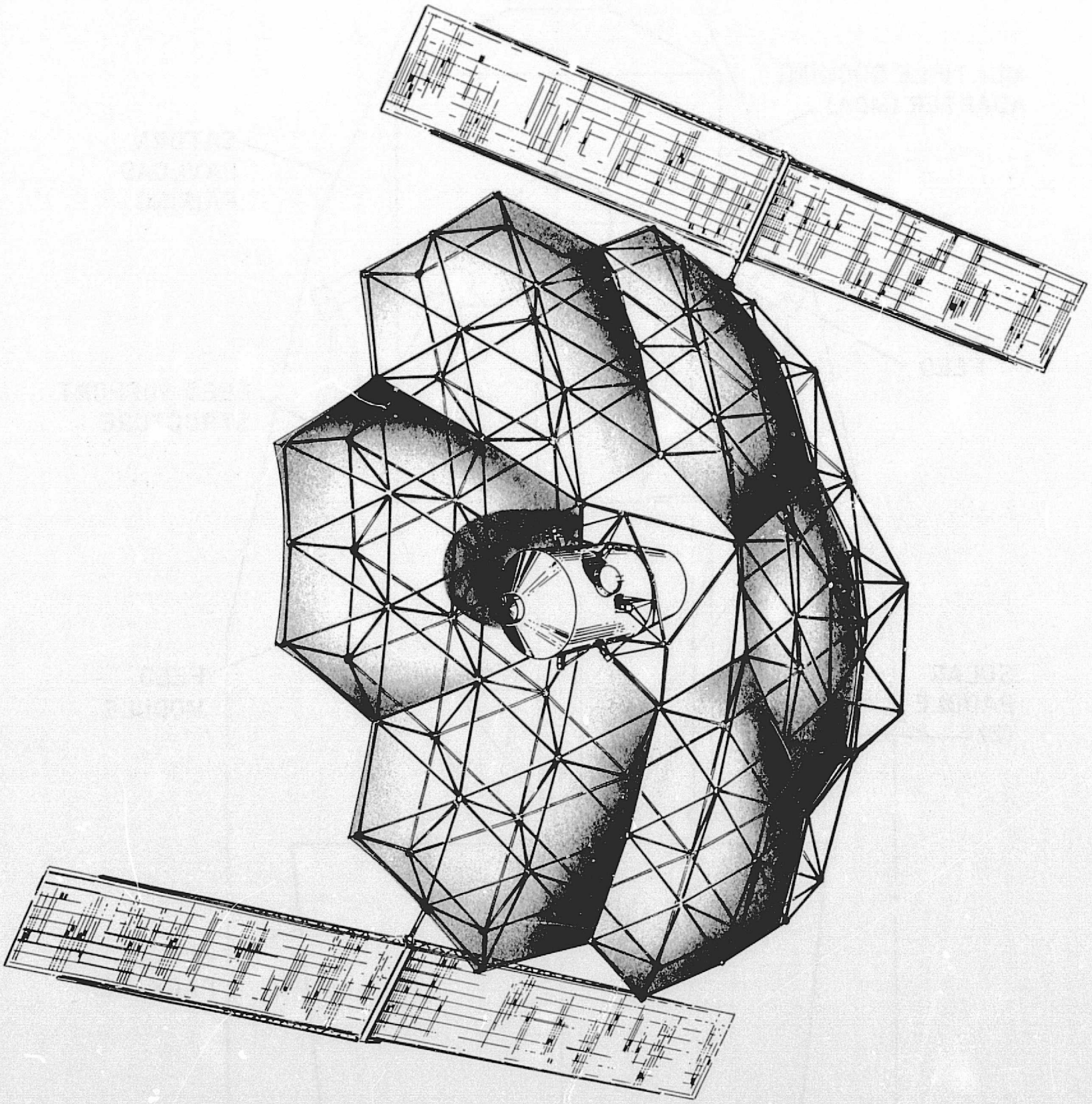


Figure 2-15. TVBS Concept F Arrangement

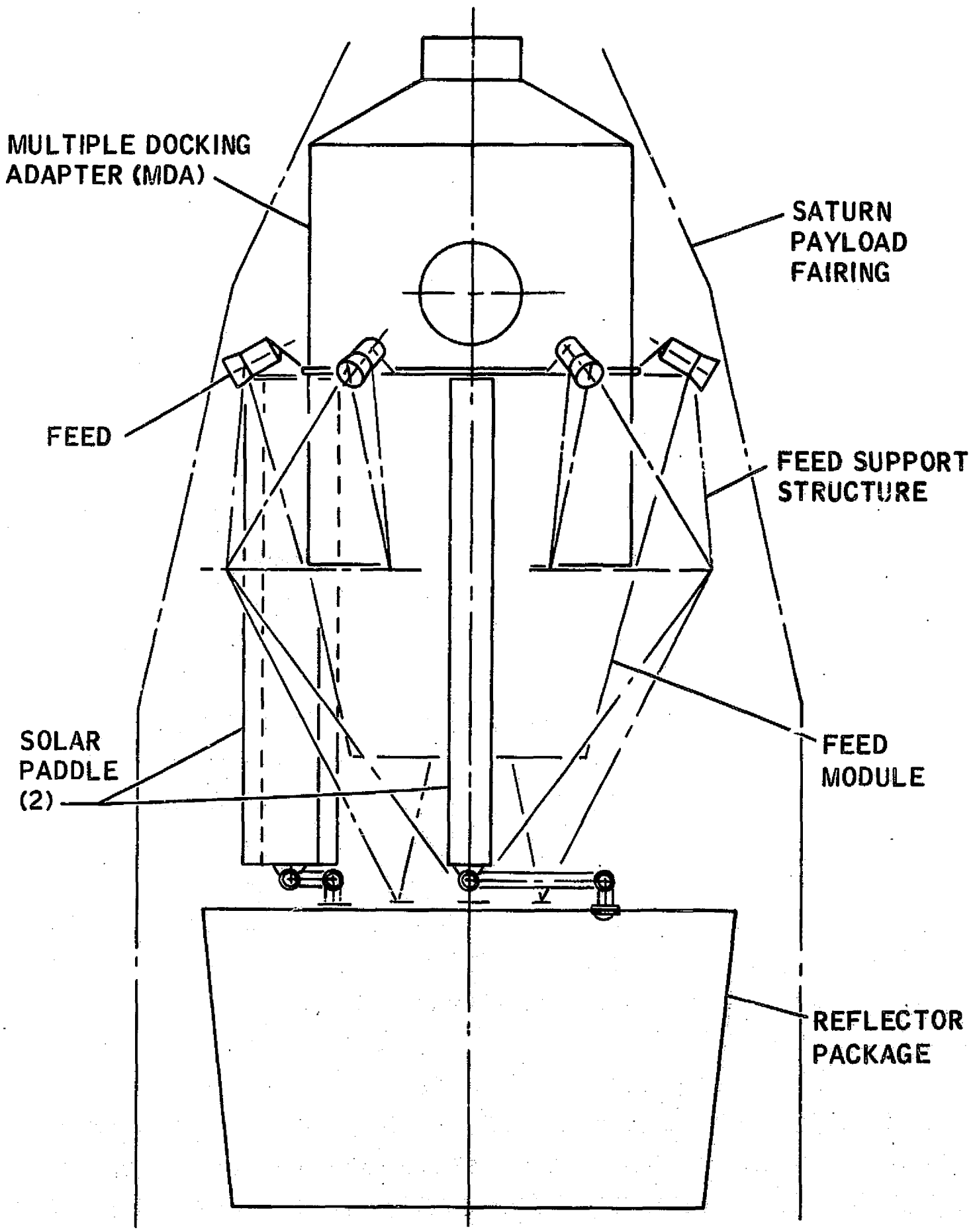


Figure 2-16. Concept F Packaging

Table 2-20. Weight, Volume, and Geometry Constraints for Concept F

1. Reflector: PETA $D_{Total} \leq 100$

2. Antenna Beams: 6 Beams

   $D_A \leq 33$

   $D_{Total} = 2.00\, D_{A(Max)} + 34$

3. Uplink Antenna: Rigid Dish, Cassgrain Feed

4. Packaged Length — Not Critical

5. Packaged Volume:

Fixed Volumes —		
MDA		1300
Feed Booms		170
a. Total Fixed		1470
b. Total Fairing Volume		6000
c. Available Volume		4530
d. $*V_{Reflector} + V_U + V_{SA} + V_{RD}$	$\leq$	4530
e. $V_U = .786\, D_U^2\, (.2\, D_U + .25)$		

6. Fixed Weights:

MDA		8000
Feed Booms		850
Total Fixed	=	8850

7. Available Weight = 42,000 - 8850 = 33,150

*Use D_{Total} to compute $V_{Reflector}$

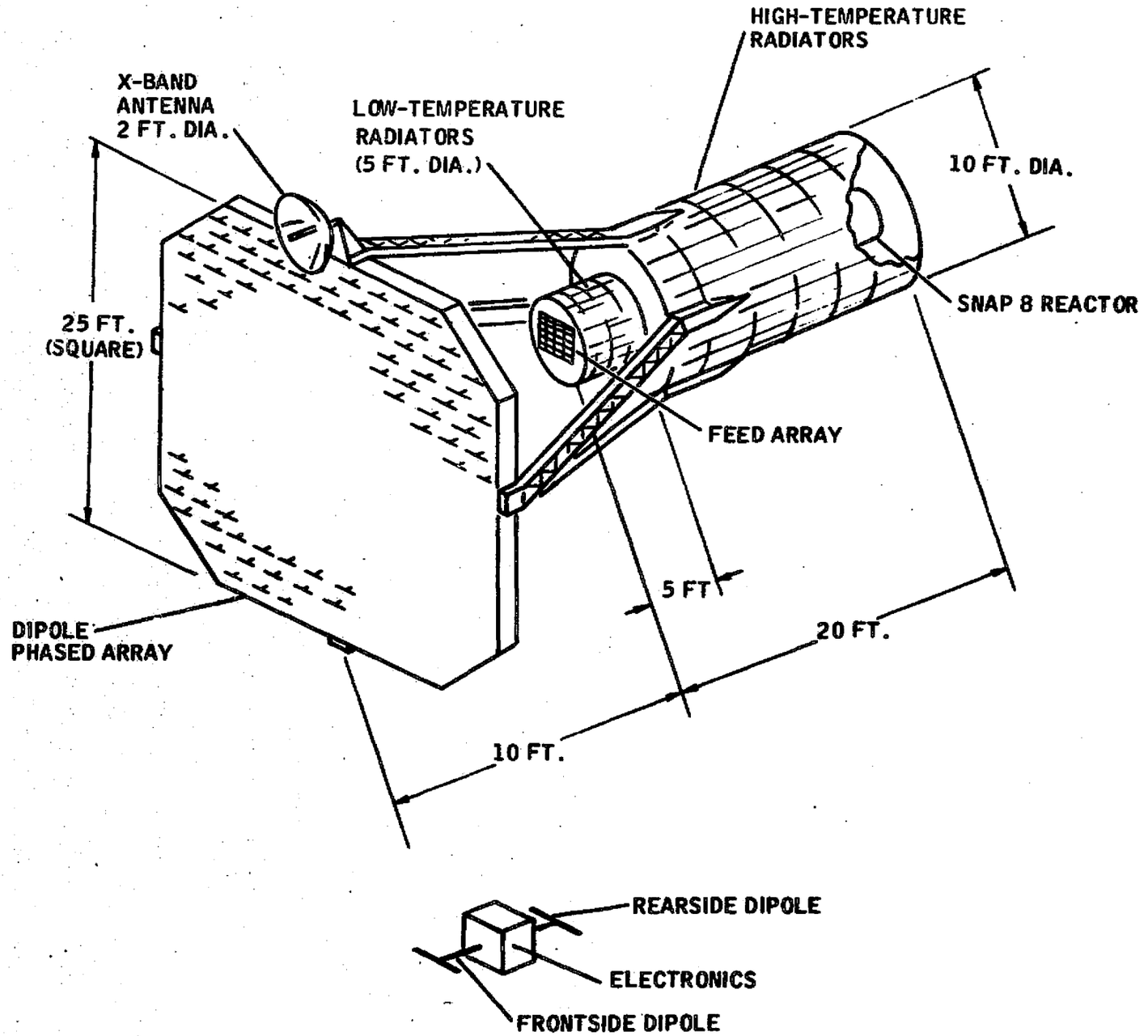


Figure 2-17. Concept G Satellite

The concept sketch indicates the use of an optional nuclear power source. There are advantages to the nuclear power cycle for TVBS applications which warrant their consideration, including continuous power generation, reduction in power conditioning for ion propulsion units and, most important, the elimination of large flexible solar array structures. It is not considered feasible to man an operating nuclear powered satellite, however, because of the very heavy shielding which would be required. Therefore, only unmanned versions using nuclear power will be considered.

The constraints necessary for input to the synthesis program are given in Table 2-21. Several differences in these constraints will be noted from the concepts previously considered. Separate radiators, for example, are not required for the amplifier stage, since the stage is well distributed on the array already. In the case of the nuclear power source, however, large heat outputs must be radiated away from the reactor because of the inefficiency of the converter turbine. Another major configuration difference is the lack of a basic length or width constraint since compact structures are used.

2.2.8 CONCEPT H – Geometry constraints for this concept are given in Table 2-22. The configuration is very similar to Concept E described in the Second Monthly Report in that it employs a single large reflector with a large solar array. The major difference is that the new concept is totally unmanned and uses a cassegrain feed system capable of up to 6-beam generation. Concept H was added to the program inventory to allow trades between large manned and unmanned satellites and to eliminate the volume constraints of the other unmanned version (Concept C).

Table 2-21. Concept G Constraints

1. Antenna: Double Dipole Array

2. Uplink Antenna: Rigid Dish, Cassegrain Feed

3. Power Source: Solar Array or Nuclear

4. Available Volume = 6000

$$V_{EM} + V_A + V_U + V_{PP} \leq 6000$$

5. Available Weight = 42,000

Table 2-22. Geometry, Weight and Volume Contraints - Concept H

1. Antenna: PETA only $D_A \leq 100$
2. Feed: Fixed Cassegrain for $D_A \leq 25$

   Folding Cassegrain for $D_A > 25$
3. Uplink Antenna: Rigid dish with cassegrain feed, $D_U \leq 10$
4. Packaged Length:

   $$\ell_{EM} + \ell_A + \ell_F \leq 35$$
5. Feed Length:

   $$\ell_F = (.2\ D_A + 0.5) + (.2\ D_U + .25) \text{ for } D_A \leq 25$$

   $$\ell_F = (.1\ D_A + 0.5) + (.2\ D_U + .25) \text{ for } D_A > 25$$
6. PETA Packaged Length = $\ell_A = .11\ D_A$
7. Module Diameter = 10.0
8. Module Available Volume = $V_{EM} = 78.5\ \ell_{EM}$
9. Maximum Solar Array Volume:

   $$V_{SA} = 2000 \text{ CF}$$
10. Total Volume

    a. $V_{EM} + V_{SA} + V_A + V_{RD} + V_F + V_U \leq 6000$

    b. $V_F = .786\ (.2\ D_A + 0.5)\ (.10\ D_A + 1.0)^2$ for $D_A \leq 25$

    c. $V_F = .786\ (.10\ D_A + 0.5)\ (.10\ D_A + 1.0)^2$ for $D_A > 25$

    d. $V_U = .786\ (.2\ D_U + .25)\ \bar{D}_U^{\ 2}$
11. Total Weight 42,000
12. Maximum Number of Beams = 6

2.3 PARAMETRIC AND ECONOMIC ANALYSIS

The modeling of a television broadcast satellite system requires an extensive set of parametric data and the means of combining this data into a feasible system. During the course of the study, many sources were utilized to compile this set of data; e.g. previous studies, previous experience and vendor surveys. This section will present the parametric data and the techniques used to apply the data to the various user requirements.

2.3.1 GROUND UPLINK SYSTEM. The ground uplink system is composed of the necessary equipment to transmit the television signal through the satellite for distribution. Included in this system are the building, transmitters, antenna, recording and playback equipment and a telemetry/command subsystem as well as miscellaneous hardware such as a standby power source and test equipment. Personnel to staff the facility are included; however, the cost of originating programming, studios, and related items are not.

2.3.1.1 Ground Uplink Economic Model. The model for applying the cost terms is listed in Table 2-23. For each element specified as a curve, the parametric data was plotted and a curve fit was performed to input to the computer program.

2.3.1.2 Facilities Subsystem. The facilities subsystem includes the buildings which house the equipment, airconditioning, lighting, etc. The model assumes an initial cost of $45,000 for one television channel and an increment of $7,000 for each additional channel as shown in Figure 2-18.

The non-recurring cost for architecture and engineering is set at 10 per cent of the unit recurring cost with annual maintenance of 2 per cent of the recurring.

2.3.1.3 Recording and Playback Equipment. The recording and playback equipment consists of a video tape recorder and a slide/film chain for each channel. The tape recorder is a quadruplex scanning system priced at $70,000 each for color and $20,000 for monochrome. While there are recorders available at a much lower cost,

Table 2-23. Ground Uplink System Economic Model

I.	GROUND UPLINK SYSTEM	VALUE
A.	Unit Recurring Cost	
	1. Facilities	Curve
	2. Recording & Playback Equipment	Curve
	3. Transmitter Subsystem	Curve
	4. Antenna Subsystem	Curve
	5. Telemetry & Command Equipment	Thruput
	6. Standby Power Subsystem	Curve
	7. Test Equipment	Thruput
	8. Ground Uplink Unit Recurring Cost	Σ IA1 thru IA7
B.	Non-recurring Cost (Research & Development)	
	1. Facilities Architecture & Engineering	10% x IA1
	2. Recording & Playback	0% x IA2
	3. Transmitter Subsystem	0% x IA3
	4. Antenna Subsystem	0% x IA4
	5. Telemetry & Command Equipment	Thruput
	6. System Design, Integration & Management	1. x Σ IA3 thru IA6
	7. Ground Uplink Non-recurring Cost	Σ IB1 thru IB6
C.	Acquisition Cost	
	1. Hardware Unit Recurring Cost	IA8
	2. Installation, Activation, & Checkout	20% x ΣIA2 thru IA6
	3. Ground Uplink Acquisition Cost	IC1 + IC2
	4. Total System Ground Uplink Acquisition	N_u x IC3
D.	Operations Cost	
	1. Facility Maintenance	2% x IA1
	2. Recording & Playback Maintenance	15% x IA2
	3. Recording & Playback Personnel	Curve
	4. Transmitter Subsystem Maintenance	15% x IA3
	5. Antenna Subsystem Maintenance	8% x IA4
	6. Telemetry & Command Maintenance	15% x IA5
	7. Telemetry & Command Personnel	Curve
	8. Standby Power Maintenance	5% x IA6
	9. Systems Operation Management	50% x (ID3 + ID7)
	10. Ground Uplink System Annual Operating Cost	N_u x Σ(ID1 thru ID9)
	11. Ground Uplink Total Operating Cost	N_L x ID10

N_u = Number of uplink stations
N_L = System Lifetime in years

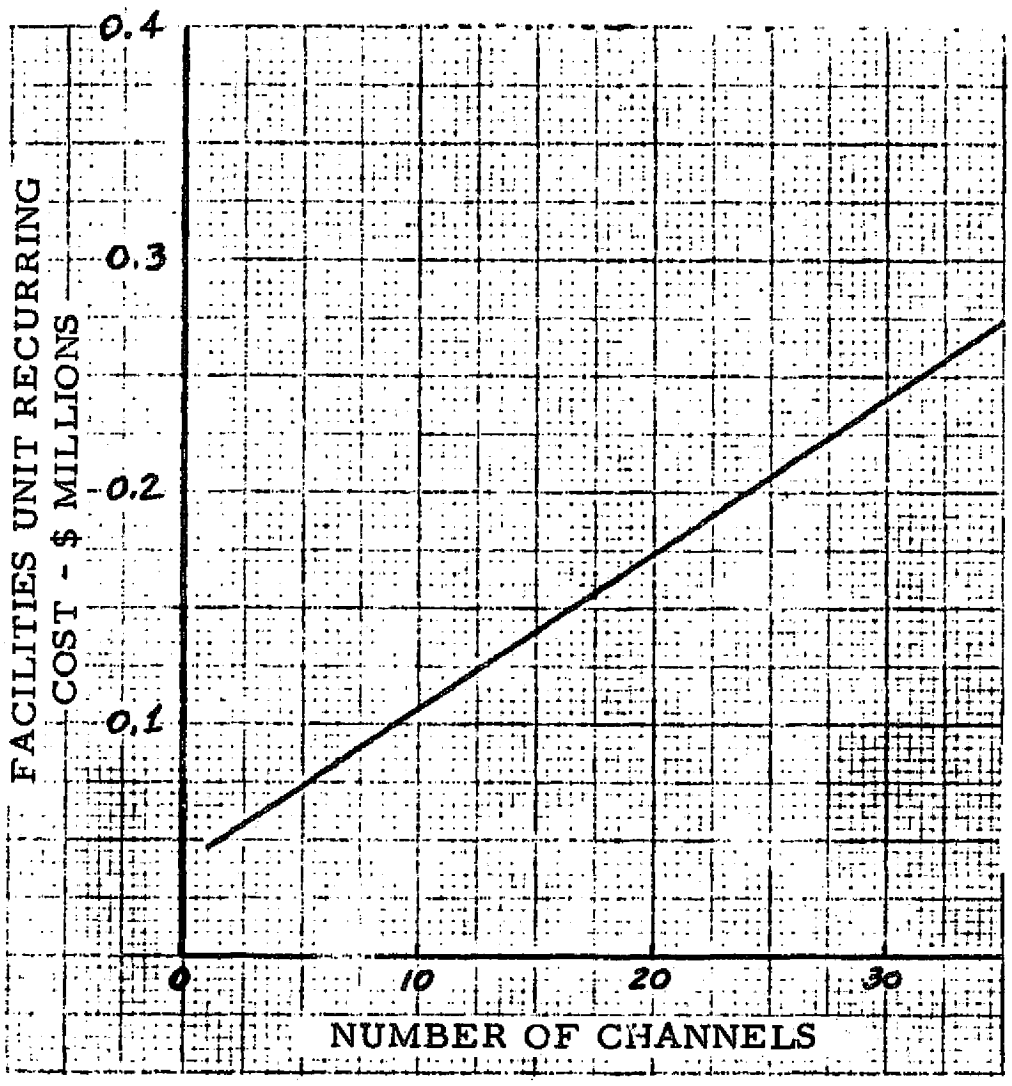


Figure 2-18. Facilities Unit Recurring Cost

they produce only tapes that may be replayed on a recorder of the same type and manufacture. This reduces the available sources for programming material. Slide/film chains cost on the order of $20,000 for monochrome and $50,000 for color. The resulting unit recurring cost for this subsystem is then $120,000 per channel for color and $40,000 per channel for monochrome.

Since the equipment is available, there is no associated R&D cost. Maintenance, however, will run on the order of 15 per cent of the recurring cost. Operating personnel cost is shown in Figure 2-19. The costs assume $20,000 annually for one shift and one channel with second and third shift rates reflecting increases of 10 and 20 per cent respectively. The cost increases such that 8 channels requires 4 times the personnel as for one channel.

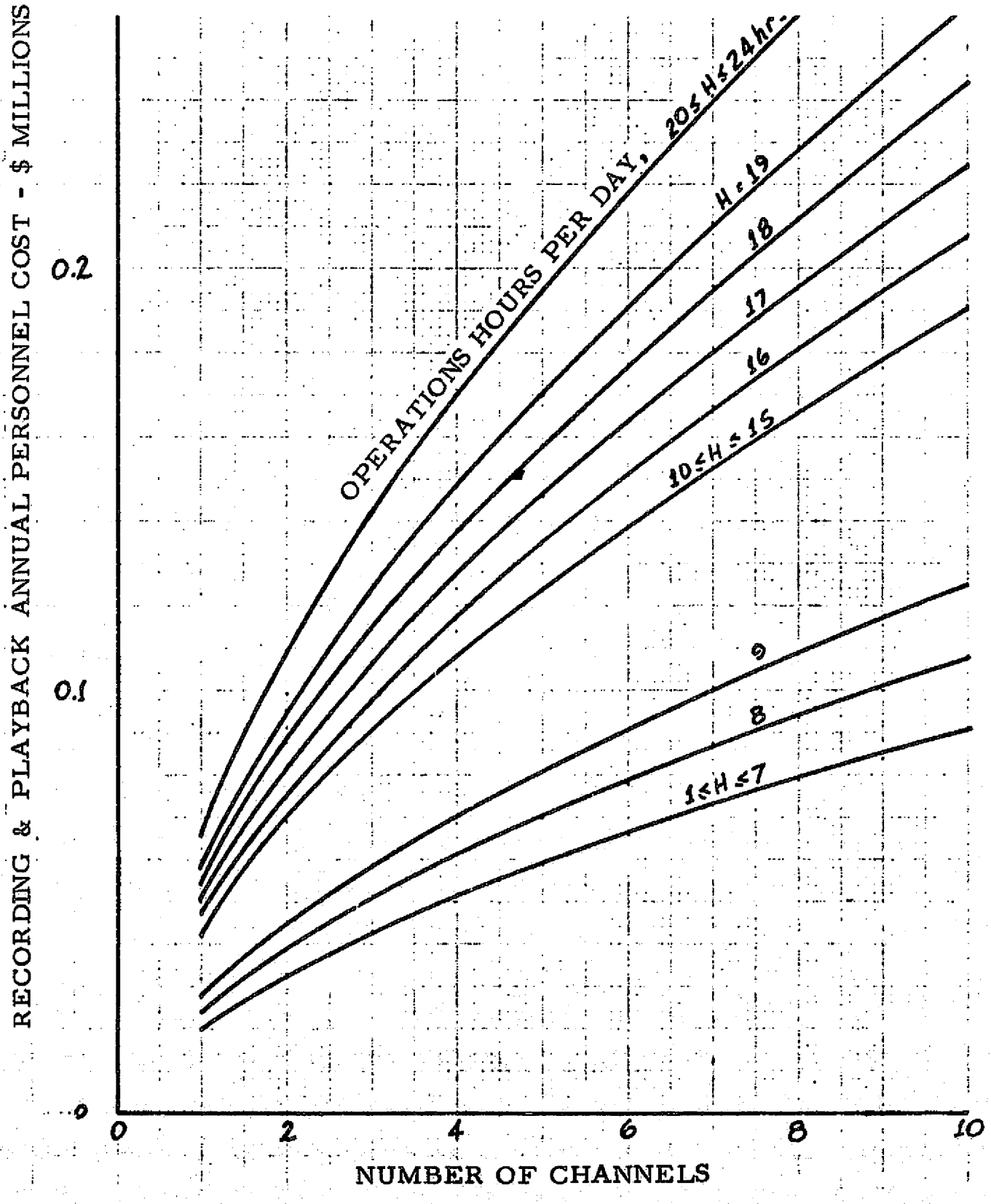


Figure 2-19. Recording & Playback Personnel Costs

2.3.1.4 Transmitter Subsystem. To provide a basis for cost estimates for the uplink transmitting equipment, cost data were collected based on experience with the earth station at Itaborai, Brazil, and various other ground terminals.

Table 2-24 gives the initial and annual operating costs for the uplink transmitter. The initial transmitter cost includes power amplifier, power supply, and power conditioning equipment, display and control equipment (allows for monitoring transmitter r-f outputs only, i.e., excluding baseband) heat exchanger, and exciter. The power tubes are either traveling wave tubes (TWT) or klystrons as indicated in the table. TWT transmitters are capable of much larger instantaneous bandwidths than klystron transmitters, but TWTs are about one half as efficient as klystrons. The annual operating cost includes tube replacement based on continuous operation, 4,000-hour tube life, and an electric power rate of 10¢ per kilowatt-hour (this rate will be less for a U. S. station using commercial utilities). Other operating and maintenance costs are not included since they are highly dependent upon the nature of the labor used, the location of the ground station, and any peculiar logistics problems that might be encountered. The maintenance cost for the transmitter is 15 per cent of the recurring. These transmitters are available items with no R&D cost.

2.3.1.5 Antenna Subsystem. The cost data presented for the uplink antennas in Table 2-25 assumes average soil conditions and reasonable wind specifications (i.e., survival in 120-mph winds). All antennas are limited to approximately $\pm 5°$ motion on both axes. The antenna cost includes feed, drive motors, and mechanisms, but does not include servo electronics.

The annual maintenance is assessed at 8 per cent per year of the unit cost.

2.3.1.6 Telemetry and Command Subsystem. One of the ground uplink stations will have the required equipment to receive telemetry and transmit commands to the satellites in the system.

The antenna is semi-fixed, equatorial mount, push-button control over ± 10 degrees Az-El (no tracking capability). Station is limited purpose, intended only for TV Broadcast Satellite Housekeeping. It is not intended to be a flexible multipurpose

Table 2-24. Transmitter Subsystem Costs

a. TUBE TYPE AND POWER OUT (1)	INITIAL COST	ANNUAL OPERATING COST
5-KW TWT or (2) 10-KW Klystron	$100K	$100K
1-KW TWT or Klystron	50K	45K
300-W TWT	31K	22K
20-W TWT	7K	5K

b. ANCILLIARY EQUIPMENT	INITIAL COST
1. Transmitter Display and Control Equipment Baseband, including monitoring, patching and display of audio, synch and color video.	$ 20K
2. Transmission line — 100' at $10/foot Includes labor, materials, and all fittings.	1K
3. Synch Generator Includes four-output distribution system.	5K
4. FM Modulators	5K
5. Up-Converters (double conversion)	15K

(1) Costs include heat exchangers, power supply, power amplifier, exciter, RF display and control equipment.

(2) Because of a 2:1 ratio of efficiencies, these transmitters have identical initial and operating costs.

Table 2-25. Antenna Unit Recurring Cost

DIAMETER (FT)	INSTALLED COST ($)
8	10K
10	15K
18	40K
25	55K
30	70K
42	120K
60	400K
85	800K
98	875K

station). Real time T & C capability (as is needed for spinner type spacecraft) is not called for, nor is it provided. Preprogrammed computer control for uplink or downlink data (as needed for multiple-mission, multiple-satellite capability) is not called for, nor is it provided. The cost elements are given in Table 2-26.

2.3.1.7 Standby Power. Standby power is provided for operation during power failures due to either generating equipment failure or disaster. The unit recurring cost is based on $33K for one channel and $42K for 10 channels (see Figure 2-20). These correspond to 30 kilowatt and 60 kilowatt precise, no-book generators. The maintenance cost runs at 5 per cent per year.

2.3.1.8 Test Equipment. The test equipment cost is a constant cost of $200K. This covers the acquisition as well as all maintenance and calibration of the test equipment.

Table 2-26. Telemetry and Command Subsystem Costs

	UNIT RECURRING	NON-RECURRING
Antenna, crossed-yagi type, similar to TACO D-1365A, including site work and cables to building, at a U.S. location (supervised by manufacturer of antenna).	$ 45K	$ 15K
Command Transmitter, similar to Collins 242-C and Exciter 242-F, with self-contained Power Supplies	47K	0
Telemetry Recovery and Display, including telemetry receivers (2), in polarization diversity, similar to DEI/Nems-Clark/Vitro, including tracking filters, diversity combiner, discriminator; PCM signal conditioner, data simulator and comparator, tape and graphic recorders, displays, TTY readout.	150K	180K
TOTAL	$242K	$195K
Annual Maintenance	$36K/Year	
Annual Personnel (3 shifts)	$66K/Year	

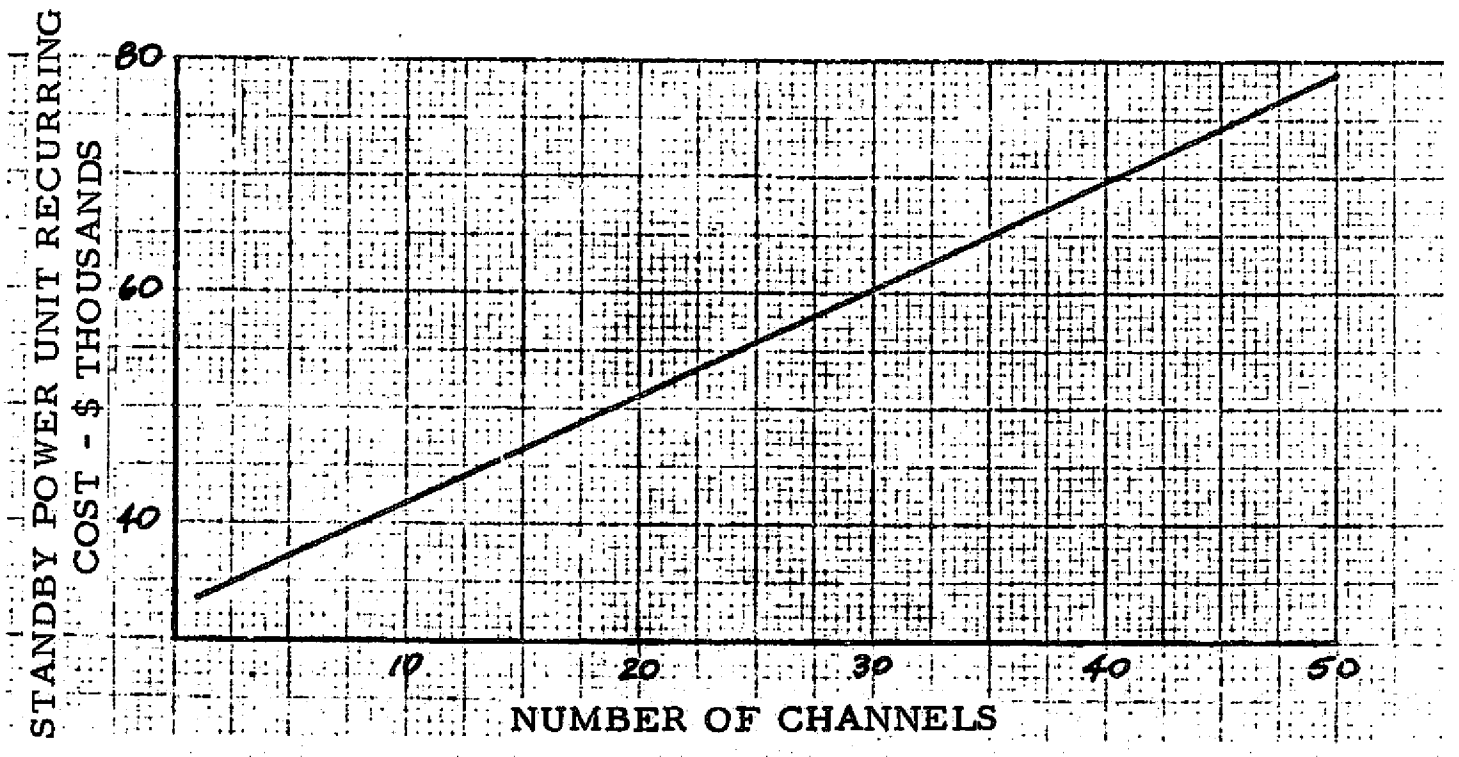


Figure 2-20. Standby Power Recurring Cost

2.3.2 SATELLITE SYSTEM. The satellite system consists of a geostationary satellite system composed of one or more satellites as required to fulfill the system lifetime and coverage requirements. Each satellite is composed of all necessary subsystems to perform the task of relaying wideband television signals from the source stations to the required destination stations. The various parametric data for each subsystem are presented in the following paragraphs.

2.3.2.1 Satellite Economic Model. Each subsystem cost element is shown in Table 2-27. The parametric data for each of these subsystems are given in the following sections.

Table 2-27. Satellite System Economic Model

II. SATELLITE SYSTEM		VALUE
A.	Unit Recurring Cost	
1.	Structure	Curve
2.	Electrical Power Subsystem	
	a. Power Source (Prime)	Curve
	b. Batteries	Curve
	c. Power Conditioning	Curve
	d. Power Distribution	Curve
	e. L/C Filter (AM only)	Curve
3.	Attitude Control Subsystem	Thruput
4.	Stationkeeping	Curve
5.	Thermal Control Subsystem	Curve
6.	Life Support Subsystem	Thruput
7.	Telemetry & Command	Thruput
8.	Uplink Receiver Subsystem	Curve
9.	Downlink Transmitter Subsystem	
	a. Transmitter	Curve
	b. Multichannel Multiplexer	Curve
10.	Antenna Subsystem	Curve
11.	Spacecraft Unit Hardware	ΣIIA1 thru IIA10
12.	Integration, Assembly & Checkout	7.5% x IIA11
13.	Total Spacecraft Unit Hardware	IIA11 + IIA12

Table 2-27. Satellite System Economic Model (Cont'd)

SATELLITE SYSTEM (CONTINUED)		VALUE
B.	Non-recurring Cost (Research & Development)	
	1. Structure	Curve
	2. Electrical Power Subsystem	
	a. Power Source (Prime)	Curve
	b. Batteries	Curve
	c. Power Conditioning	Curve
	d. Power Distribution	Curve
	e. L/C Filter (AM only)	Curve
	3. Attitude Control Subsystem	Curve
	4. Stationkeeping	Curve
	5. Thermal Control Subsystem	Curve
	6. Life Support Subsystem	Thruput
	7. Telemetry and Command	Thruput
	8. Uplink Receiver Subsystem	Curve
	9. Downlink Transmitter Subsystem	
	a. Transmitter	Curve
	b. Multichannel Multiplexer	Curve
	10. Antenna Subsystem	Curve
	11. Spacecraft Subsystems Total	ΣIIB1 thru IIB10
	12. Prototype	N_{pt} x IIA11
	13. Subsystem Design, Integration & Mgmt	50% x IIB11
	14. Center Support & Development	5% x (IIB11 + IIB13)
	15. GSE Design, Development & Testing	50% x IIA13
	16. GSE Hardware	Thruput
	17. Facilities and S/C Test Equipment	Thruput
	18. Total Spacecraft Non-recurring Cost	ΣIIB1 thru IIB18
C.	Acquisition Cost	
	1. Hardware Unit Recurring Cost	IIA13
	2. Center Support Per Unit	5% x IIC1
	3. Launch Operations, Support & Spares	10% x IIC1
	4. Unit Spacecraft Acquisition Cost	ΣIIC1 thru IIC3
	5. Total Spacecraft Acquisition Cost	$(N_s + N_{pt})$ x IIC4
D.	Operations Cost	
	1. Satellite Hardware Replacement Cost	IIC5
	2. Total Hardware Replacement Cost	Nr x IID1

N_{pt} = Number of prototype satellites

N_s = Number of satellites

N_r = Number of reserve satellites

2.3.2.2 Structure Subsystem. The structure subsystem is divided into 3 types -- conventional with a thickness of 3 inches, the Multiple Docking Adapter (MDA), and the Basic Subsystem Module (BSM). Concept D utilizes the BSM while concept F is built around the MDA. The characteristics of these two types are as follows:

		MDA	BSM
WEIGHT	LB	3780	2500
DIAMETER (OUTSIDE)	FT	10.5	15.0
VOLUME (TOTAL)	FT^3	1300	1600
RADIATOR AREA	FT^3	301	313
UNIT RECURRING COST	$M	1.63	1.72
NON-RECURRING COST	$M	7.0	7.0

The cost estimating relationships for conventional structure are illustrated in Figure 2-21. The weight of the structure is given by $W_{STRUCT} = \pi D_{EM}^2 L_{EM}$ where D_{EM} is the diameter of the equipment module in feet, and L_{EM} is the length of the equipment module in feet.

2.3.2.3 Power Subsystem. The model for the power subsystem is shown in Figure 2-22. The deviation of the prime power requirements and the power ratings of each element are as follows:

For N_V video channels with N_A audio channels per video channel.

P_{TV} = Power output from video transmitter (avg)

P_{TA} = Power output from audio transmitter (avg)

Now $$P_{LCF} = \frac{P_{TV}}{\eta_{TV}} \quad \text{(AM only)}$$

$$P_{PCU} = P_L + N_V \left(\frac{P_{TV}}{\eta_{TV}\ \eta_{LCF}} + N_A \frac{P_{TA}}{\eta_{TA}} \right)$$

$$P_{PC} = \frac{P_{PCU}}{\eta_{PCU}}$$

$$P_{PT2} = P_B = \frac{P_{PC}}{\eta_{PC}}$$

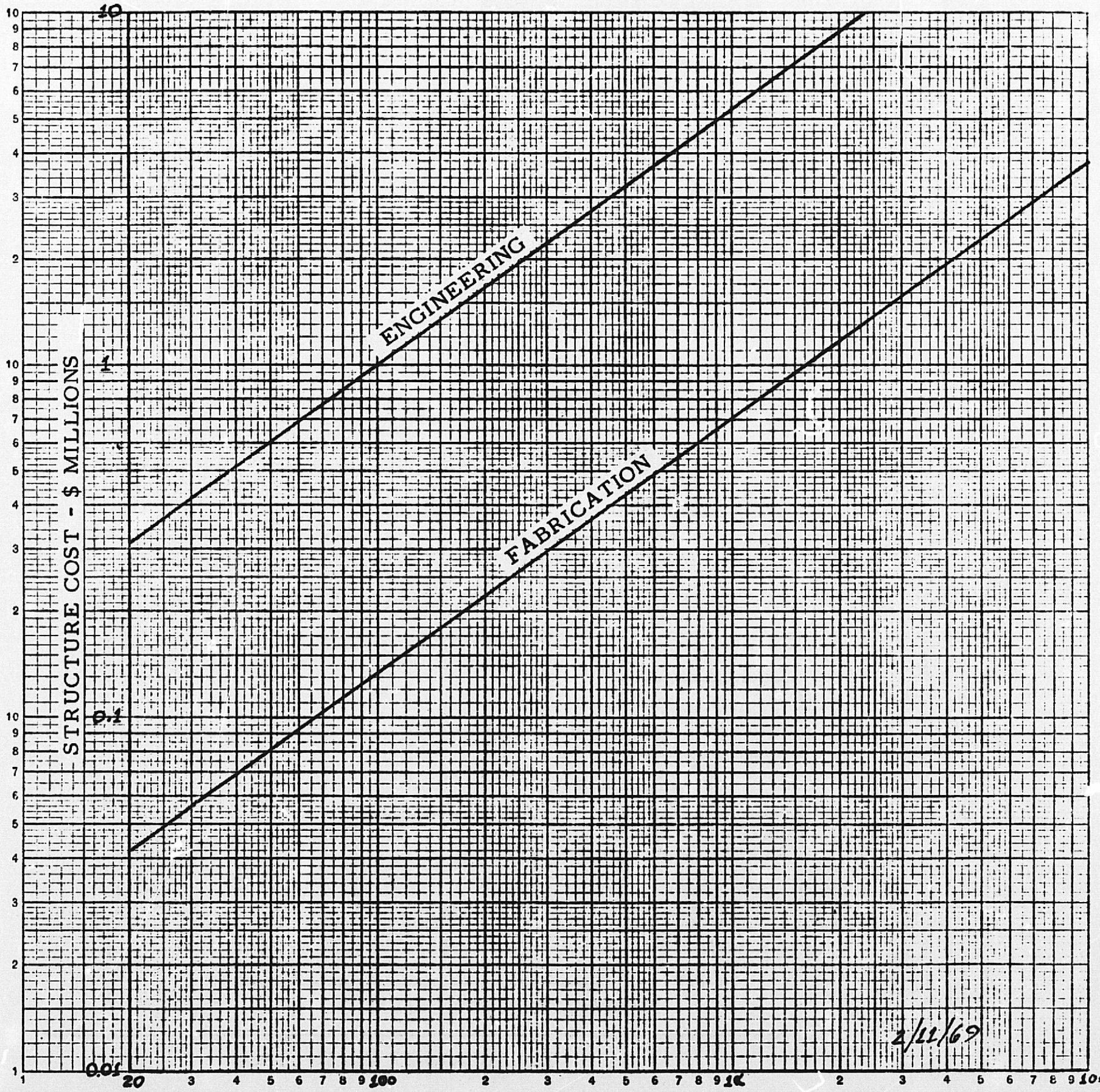


Figure 2-21. Structure Costs

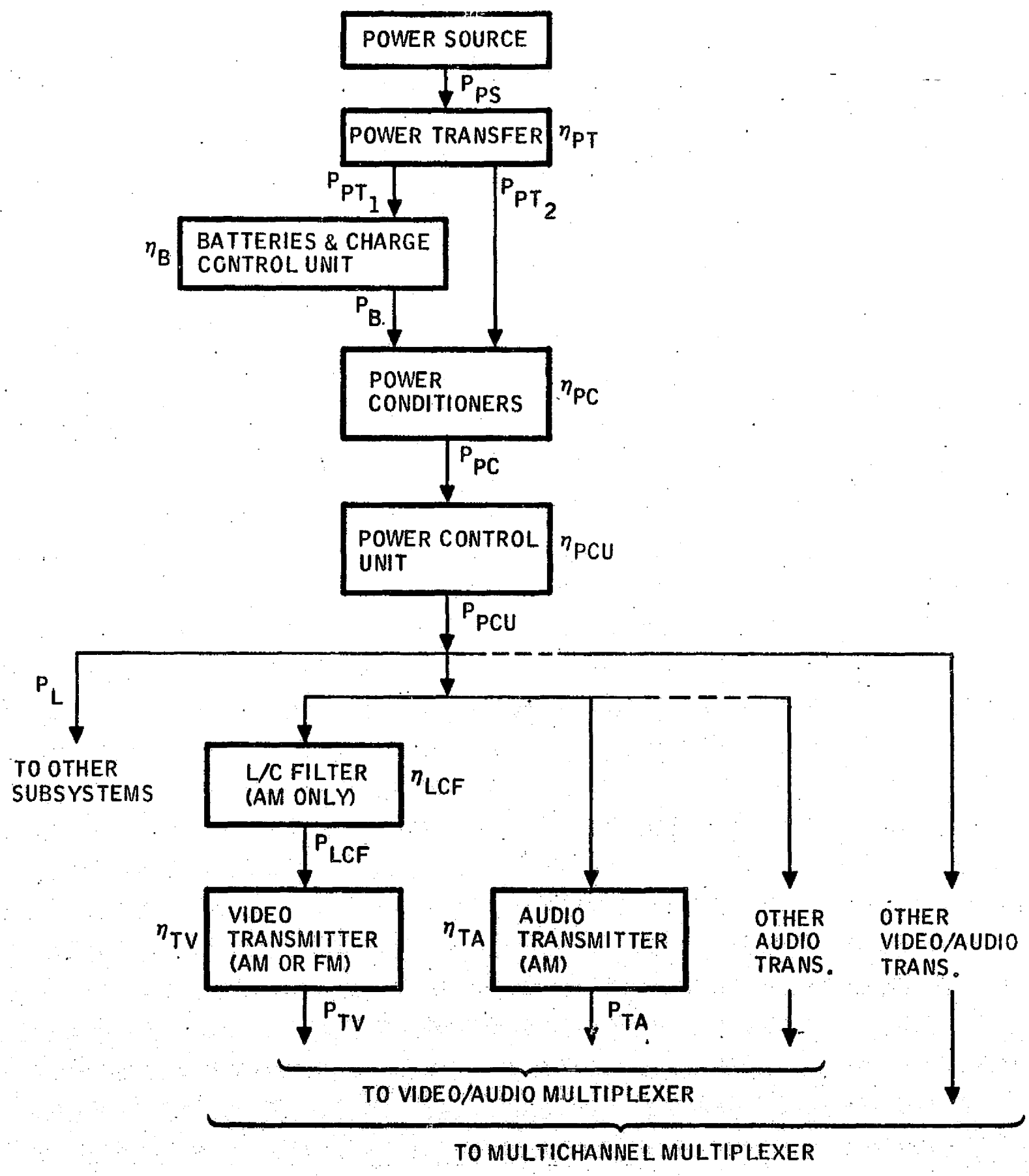


Figure 2-22. Power model.

$$P_{PT} = \left(P_{T1} + P_{T2}\right) = \frac{P_B}{\eta_B} + \frac{P_{PC}}{\eta_{PC}} = P_{PC}\left(\frac{1}{\eta_{PC}} + \frac{\rho}{\eta_{PC}\,\eta_B}\right)$$

where ρ = ratio of dark time to sunlight time per orbit $\left(\frac{1.2}{22.8}\right)$

$$P_{PS} = \frac{P_{PT}}{\eta_{PT}}$$

a) Prime Power Source — The characteristics of the prime power sources considered — solar array and reactor — are given in Figures 2-23 through 2-26. The data was obtained from manufacturers, such as Electro Optical Systems, as well as previous experience and studies.

b) Secondary Power Source — Batteries were provided to allow operations during times of solar occultation. Three types were available: nickel-cadmium with a lifetime of 5 years; silver-cadmium with a lifetime of 2 years, and silver-zinc with a lifetime of one year. Charge-discharge efficiency of 85 per cent is assumed with a 50 per cent depth of discharge. The cost, weight and volume of the battery types are given in Figures 2-27 through 2-29.

c) Power conditioning — The power conditioning subsystem includes the following elements:

1. Regulators
2. DC-DC converters
3. DC-AC inverters
4. Battery charge control unit

The ground rules for developing this data (Figures 2-30 through 2-32) are as follows:

1. Input voltage of 50 to 300 volts; 2. Output voltages to 20 kV;
3. Standard thermal techniques of conduction to a baseplate which is maintained at a nominal temperature.

The points on the curves identified by numbers refer to the table of Power Conditioning references in Table 2-28. The efficiency of the power conditioning is assumed to be 85 per cent.

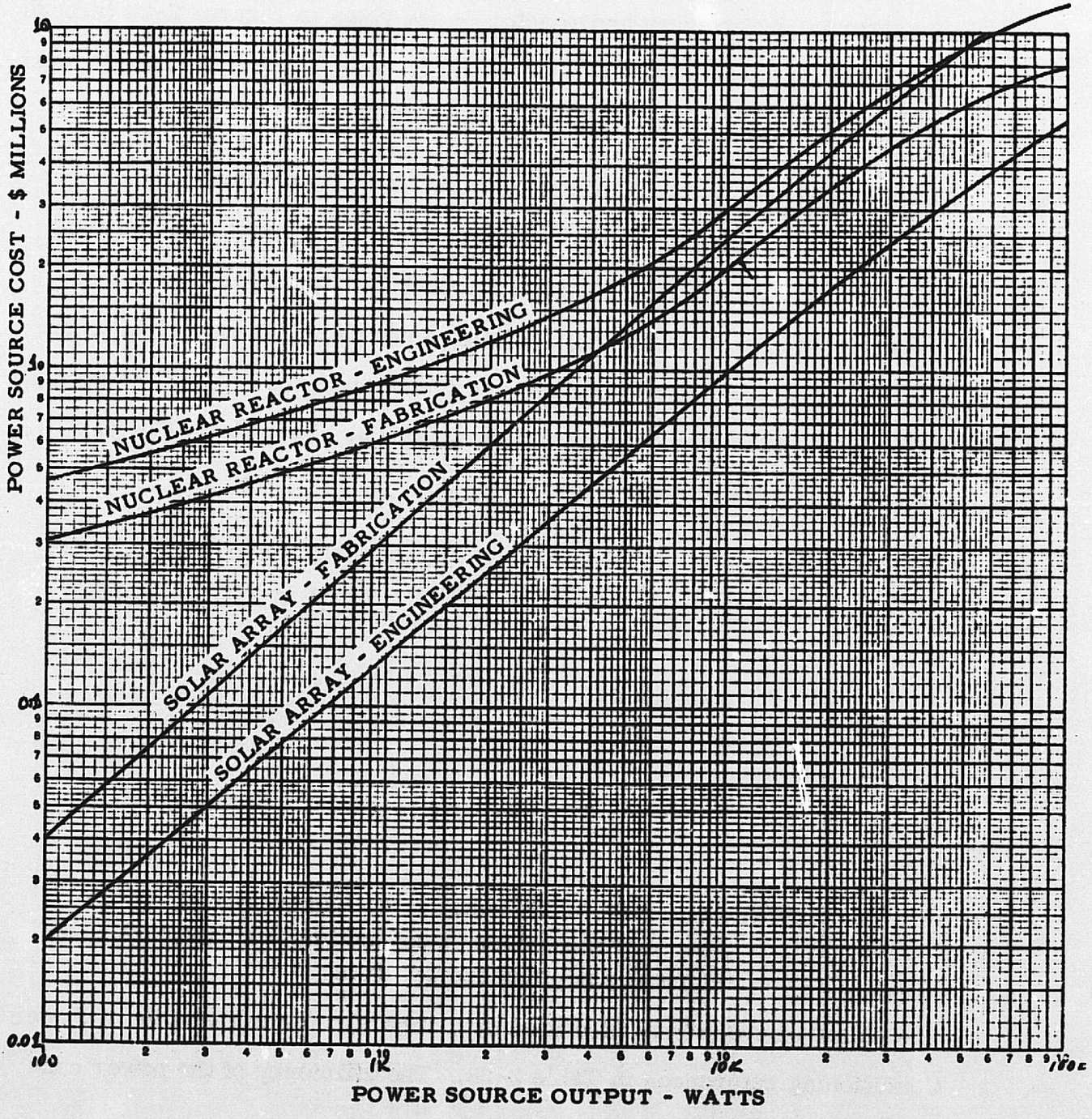


Figure 2-23. Prime Power Source Cost

K&E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

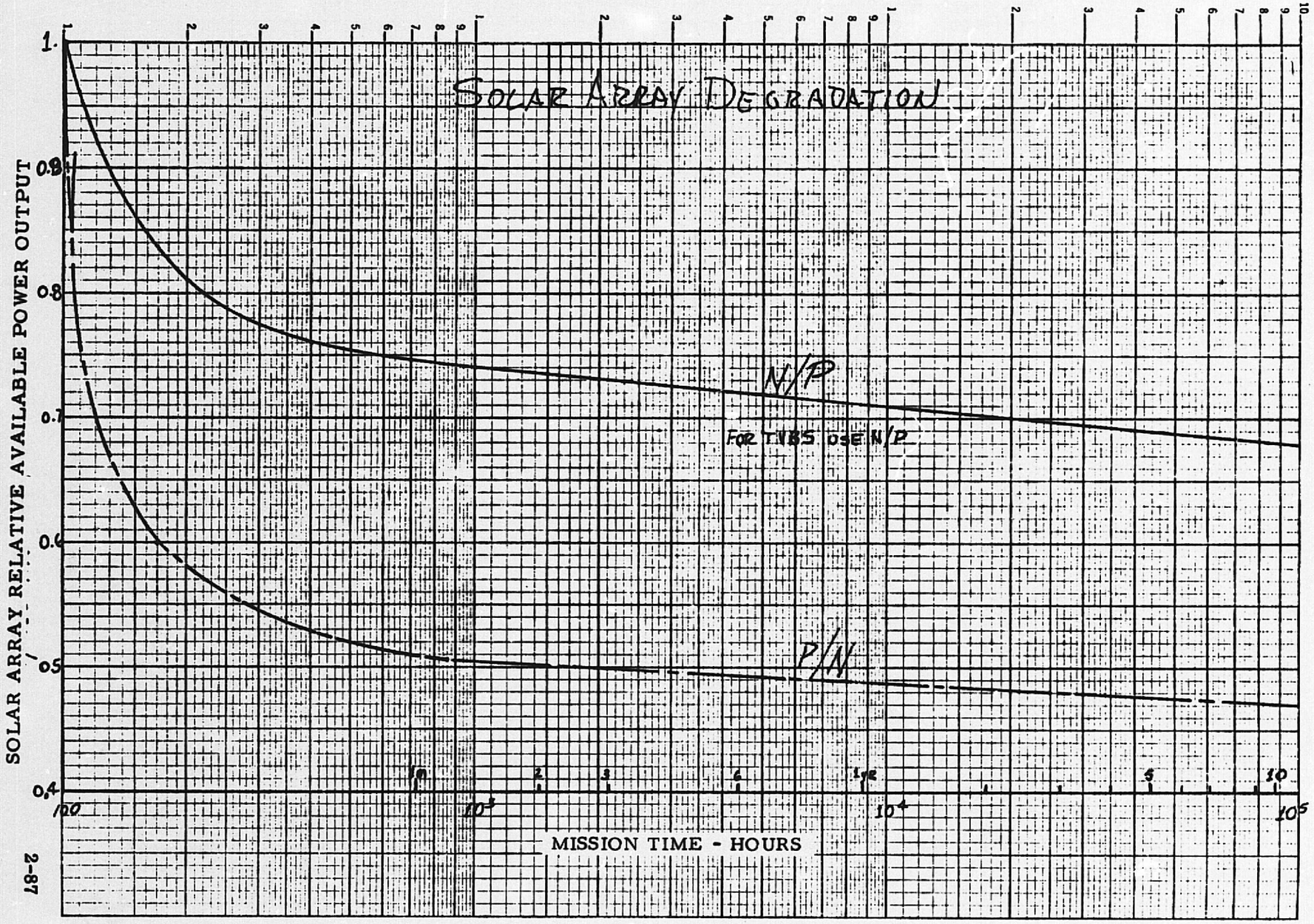


Figure 2-24. Solar Array Degradation

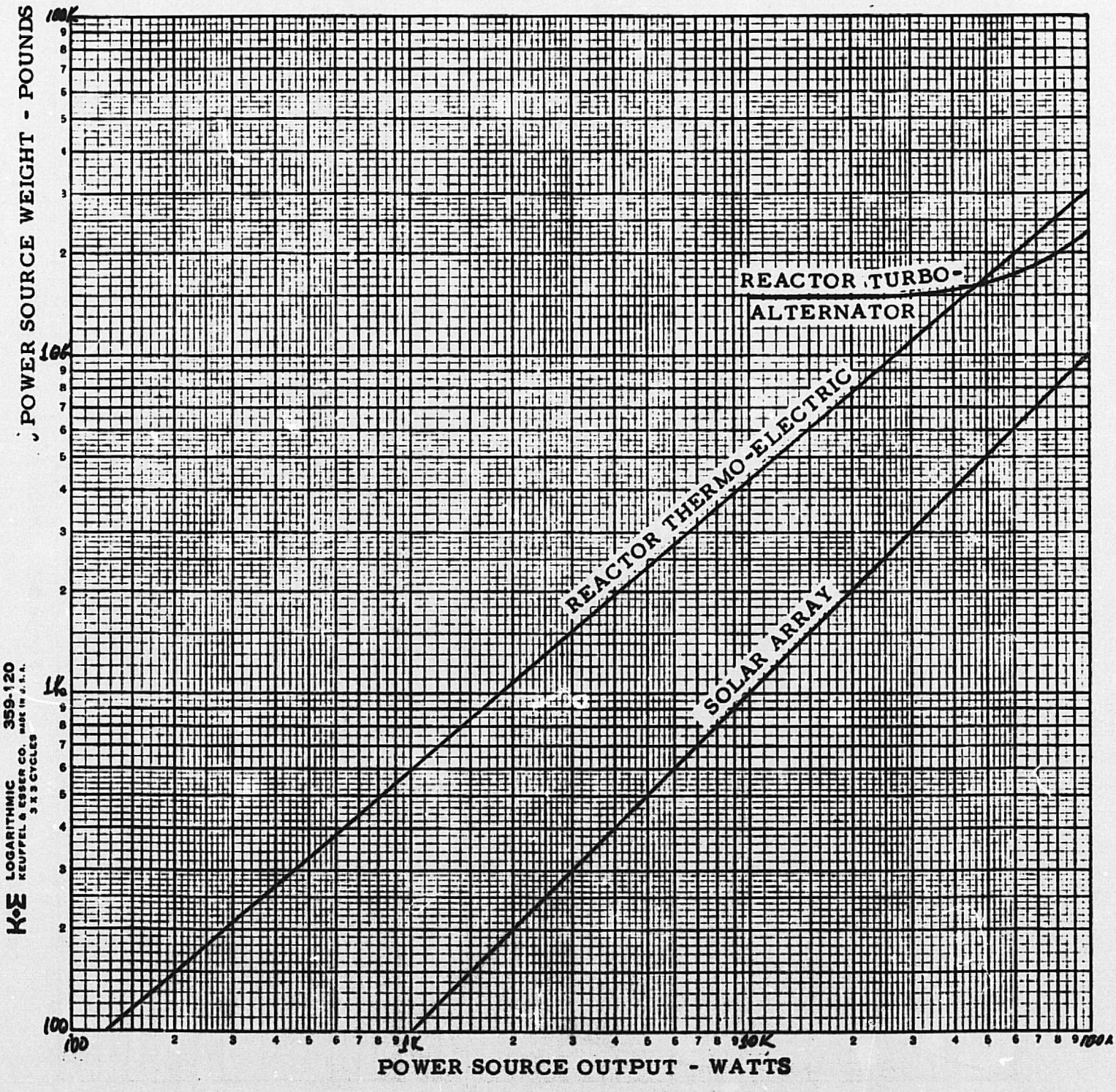


Figure 2-25. Prime Power Source Weight

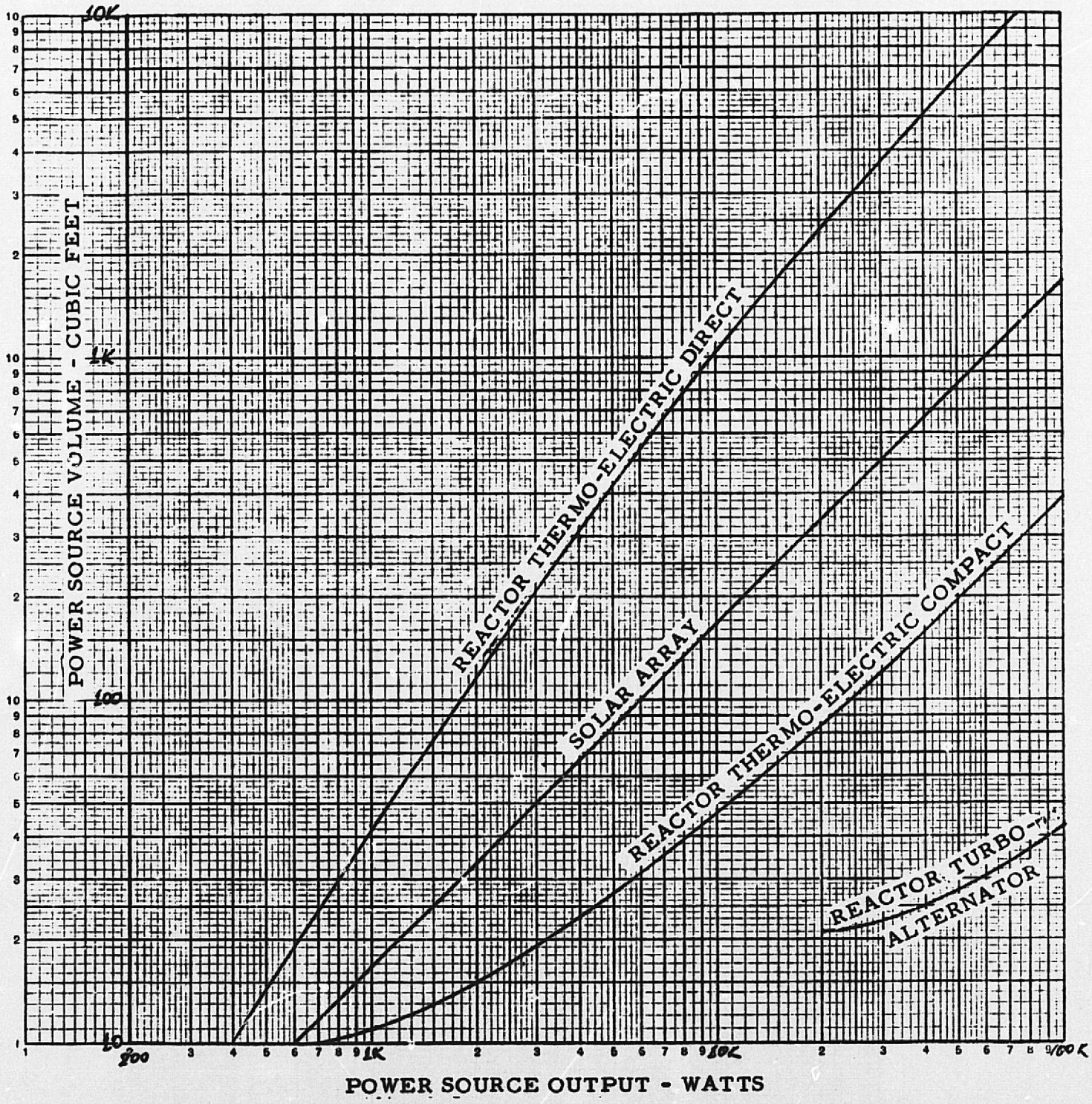


Figure 2-26. Prime Power Source Volume

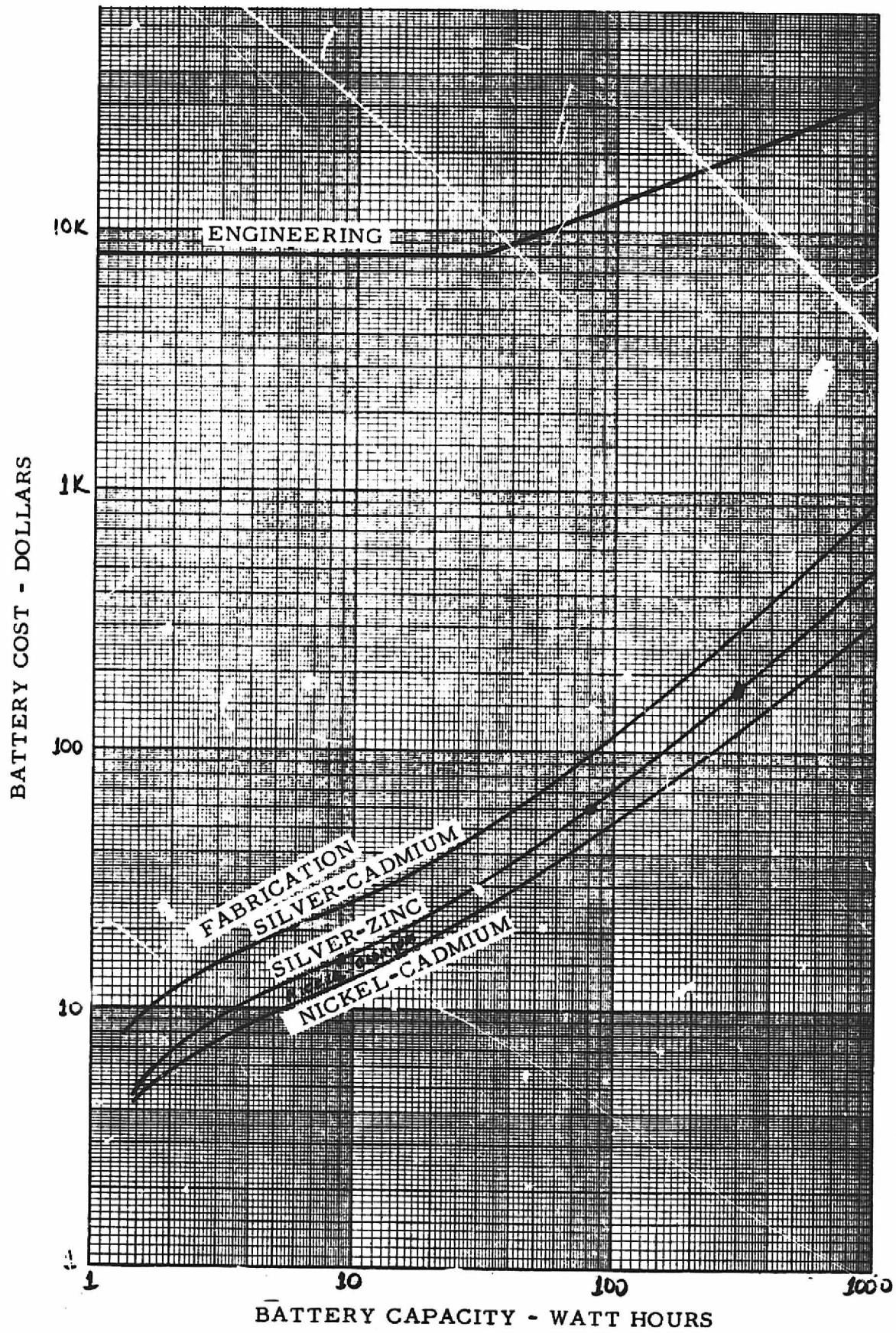


Figure 2-27. Battery Cost

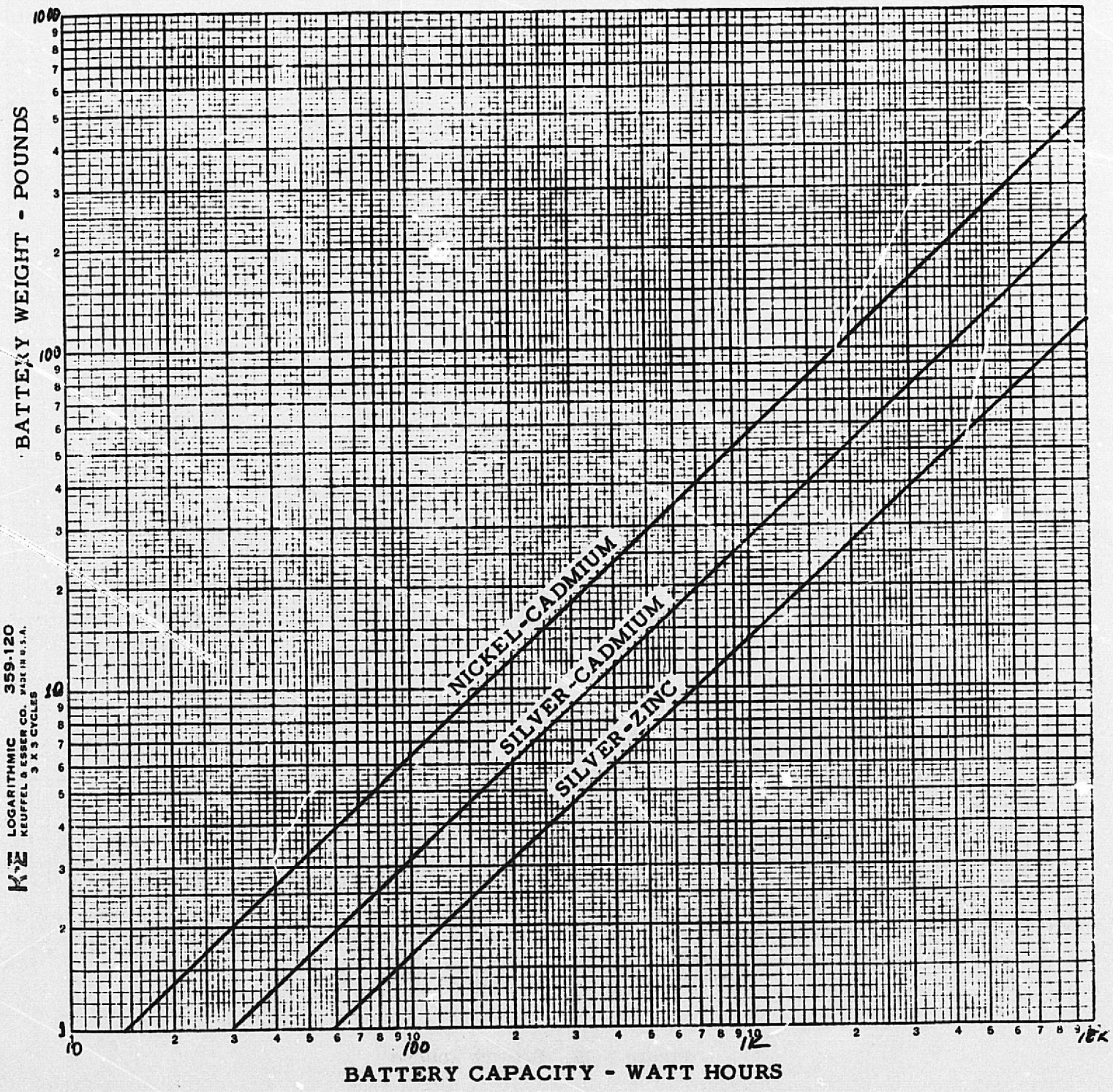


Figure 2-28. Battery Weight

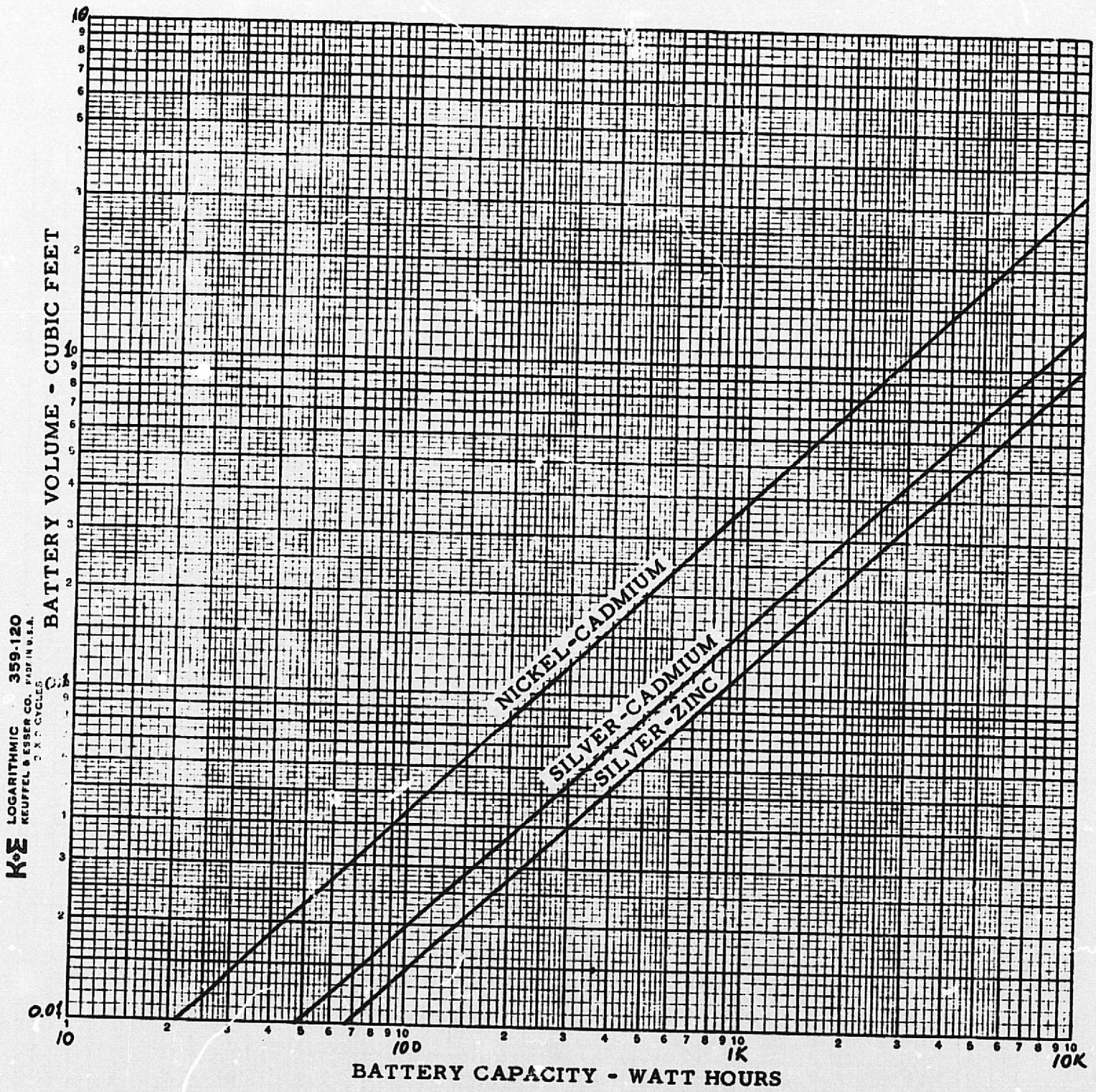


Figure 2-29. Battery Volume

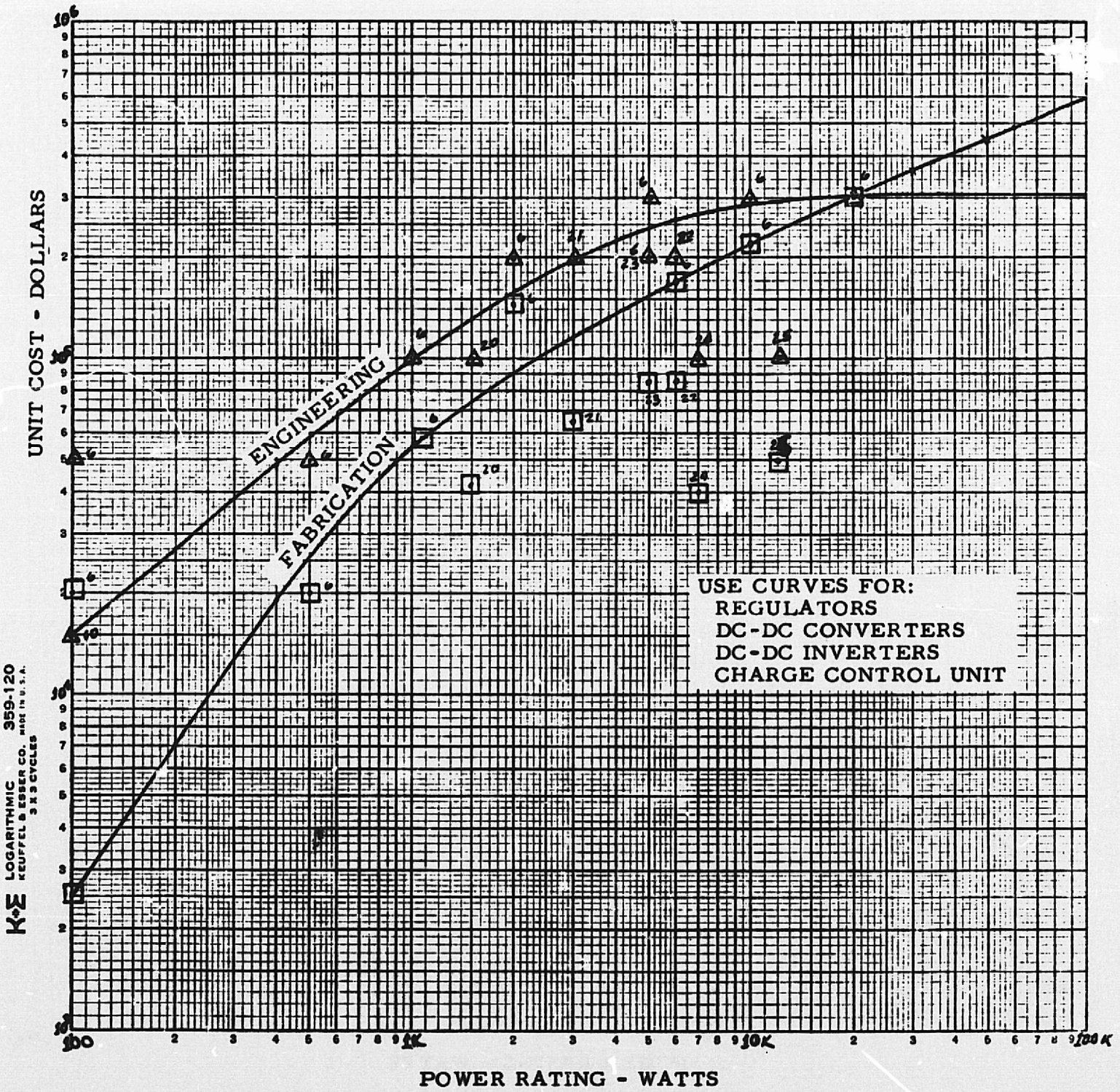


Figure 2-30. Power Conditioning Cost

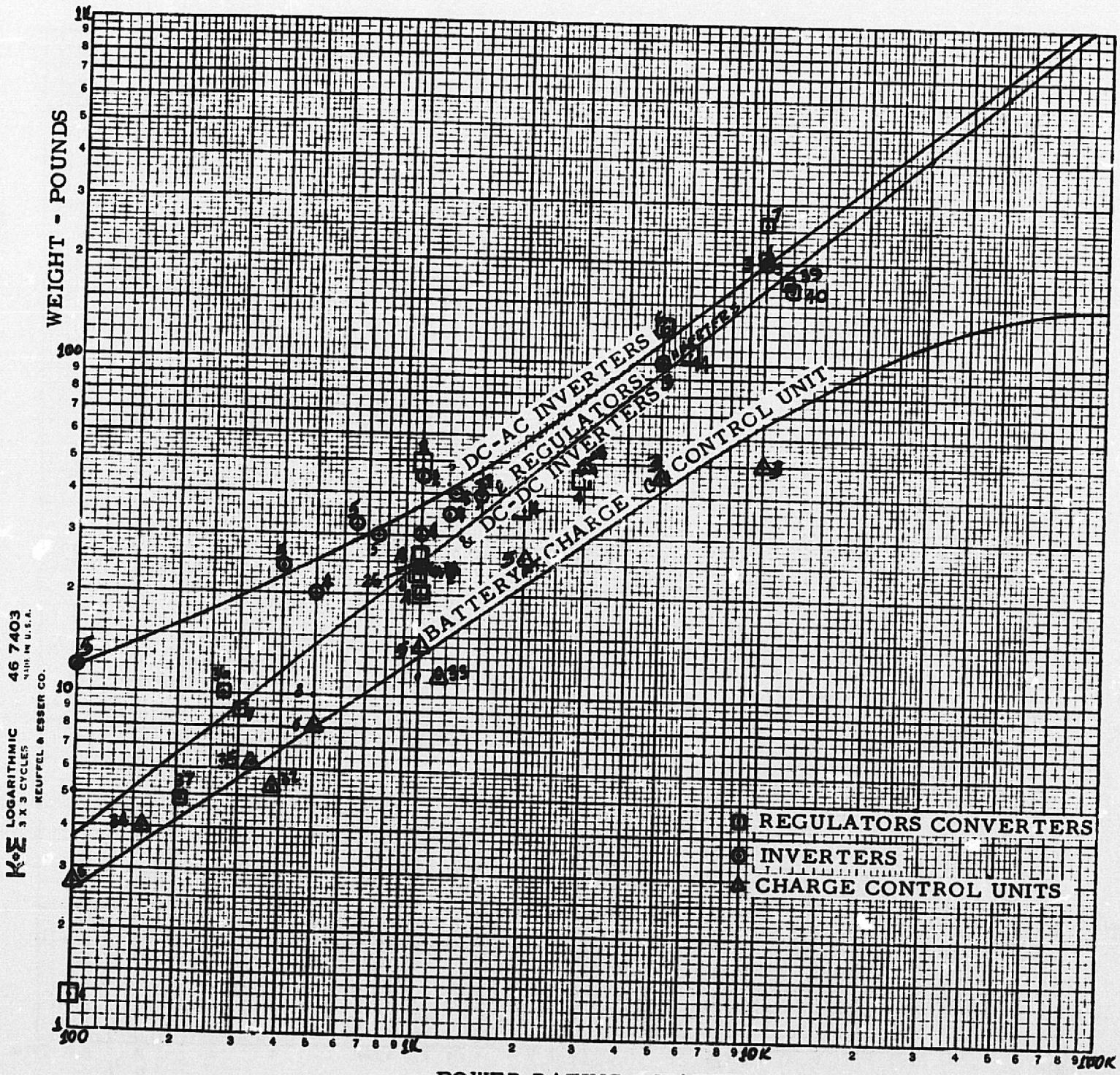


Figure 2-31. Power Conditioning Weight

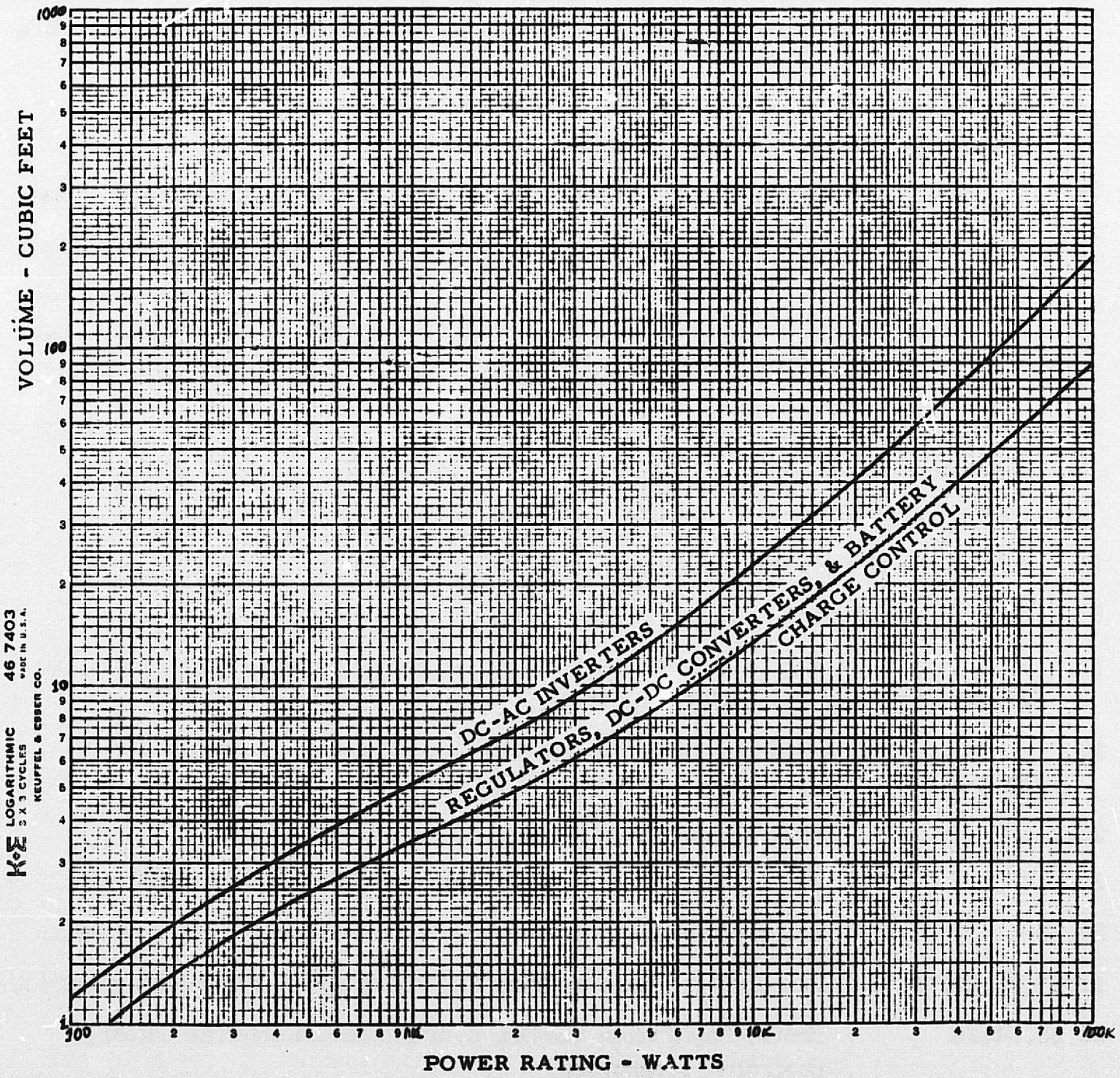


Figure 2-32. Power Conditioning Volume

Table 2-28. Power Conditioning References

1. John G. Krisilas and H. J. Killian, Aerospace Corporation, "An Evaluation and Comparison of Power Systems for long Duration Manned Space Vehicles," IECEC, 1966.

2. George Barna and Richard Newell, RCA Astro-Electronics Division, "Design of a Multi-kilowatt Photovoltaic Power System for Manned Space Stations," IECEC, 1967.

3. GDC-DAB67-003 Convair, "Study for Basic Subsystem Module, Preliminary Definition: Electrical Power Systems," 1967.

4. TIF No. 2552, Westinghouse, "Power Conditioning Subsystems for Space," 1966.

5. GDA-ERR-AN-511-1, E. F. Schraith, Convair, "Electrical Power Conditioning," 1964.

6. 68SD4268, GE Space Systems, "Multikilowatt Transmitter Study for Space Communications Satellites: Volume II," 1968.

7. EDUSAT - W.V.U.

8. ASCEND - Stanford U.

9. STRIDE - W.V.U.

10. ITT, PR - 1045-A High Efficiency Regulator.

11. SAINT - Stanford U.

12. R. B. Beltz, et al, TRW Systems, "OGO Solar Array Design, Fabrication and Flight Performance, IECEC, 1967.

13. A. D. Tonelli, Douglas MSSD, "Design and Comparison of Secondary Power Systems for Advanced Space Vehicles," IECEC, 1968.

20,21,22	Extrapolated from present-day Ion engine cost data.
23	Extrapolated from present-day missile electronics cost data.
24,25	Extrapolated from present-day airborne electronics cost data.
26,27,28,29,30,31	Extrapolated from existing Ion engine power conditioning technology.
32,33,34,35	Extrapolated from existing communication satellite battery controller technology.
36	Extrapolated from existing deep space probe technology.
37,38	Extrapolated from existing missile electronics technology.
39,40,41,42	Extrapolated from existing airborne electronics technology.

d) Power Distribution — Power distribution includes the power transfer unit to couple the power from the source to the equipment module and the power control unit. The curves of Figures 2-33 through 2-35 define the characteristics of these elements. The labels on the points refer to Table 2-28.

e) L/C Filter — L/C filters are used for power averaging of transmitters employed for Amplitude Modulation. The three parameters affecting filter design are 1) transmitter power, 2) transmitter type, and 3) frame rate. The frame rate selected is for 30 frames per second North American standard. The characteristics of such a filter are shown in Figures 2-36 through 2-38.

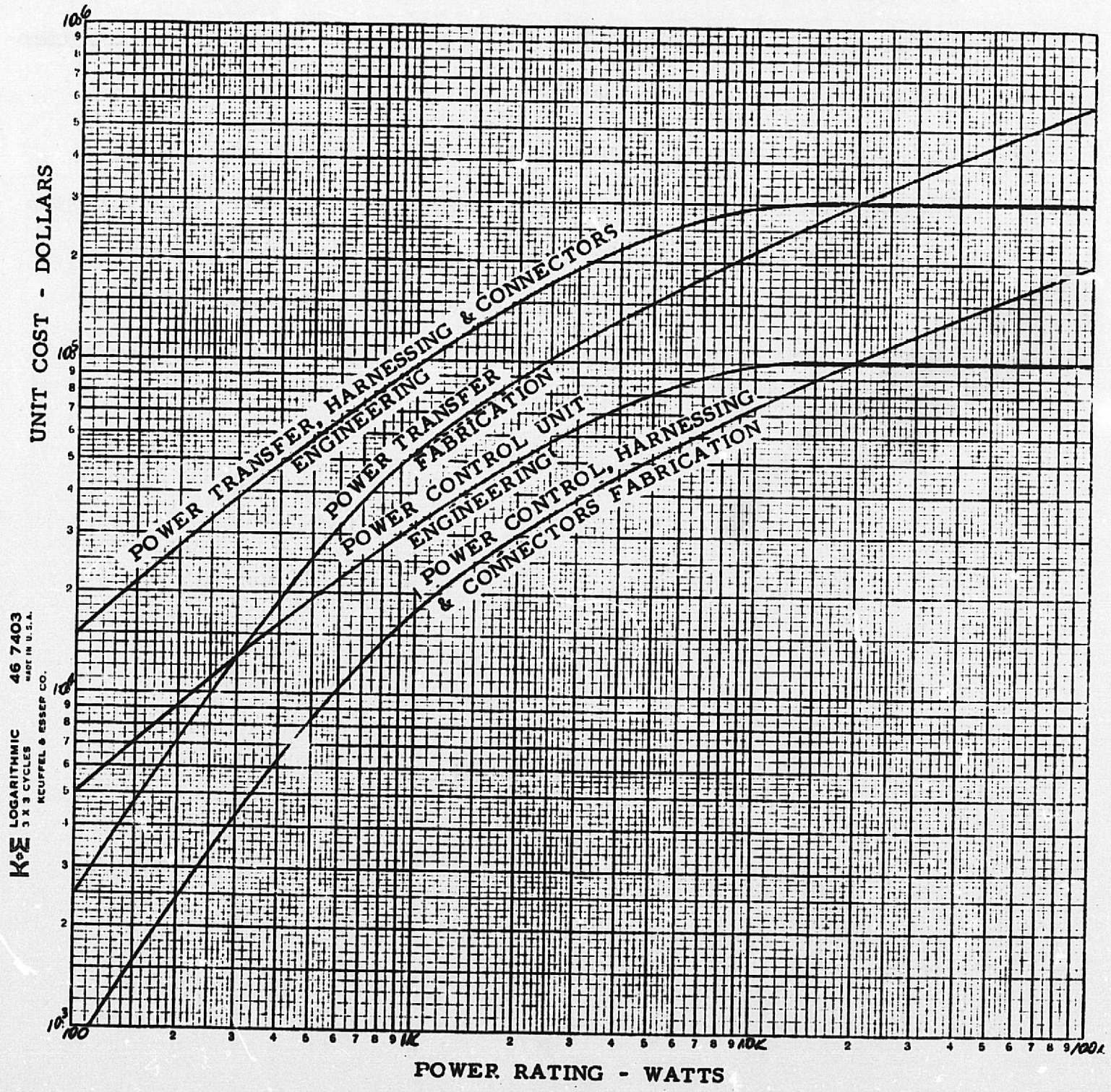


Figure 2-33. Power Distribution Costs

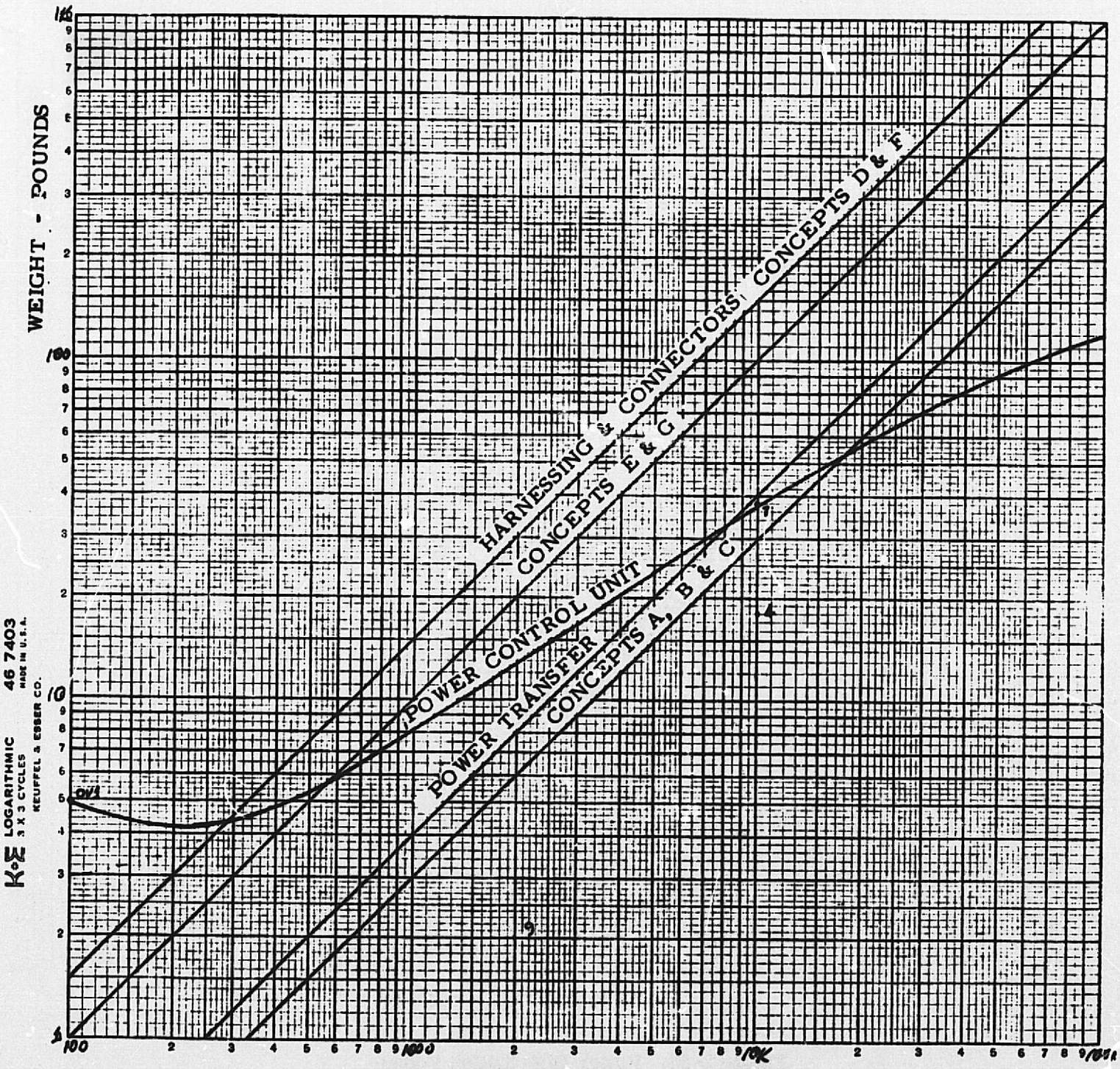


Figure 2-34. Power Distribution Weight

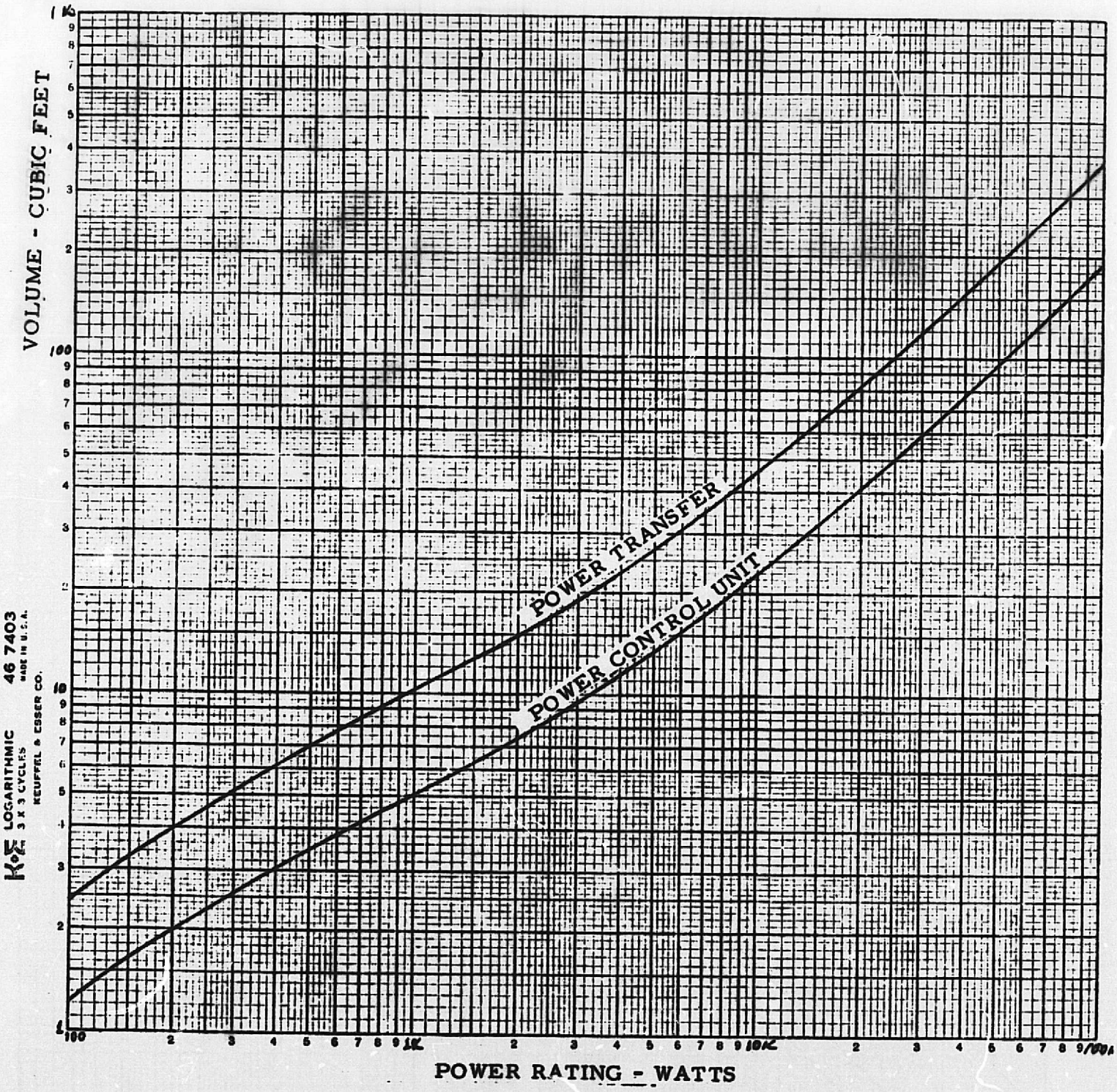


Figure 2-35. Power Distribution Volume

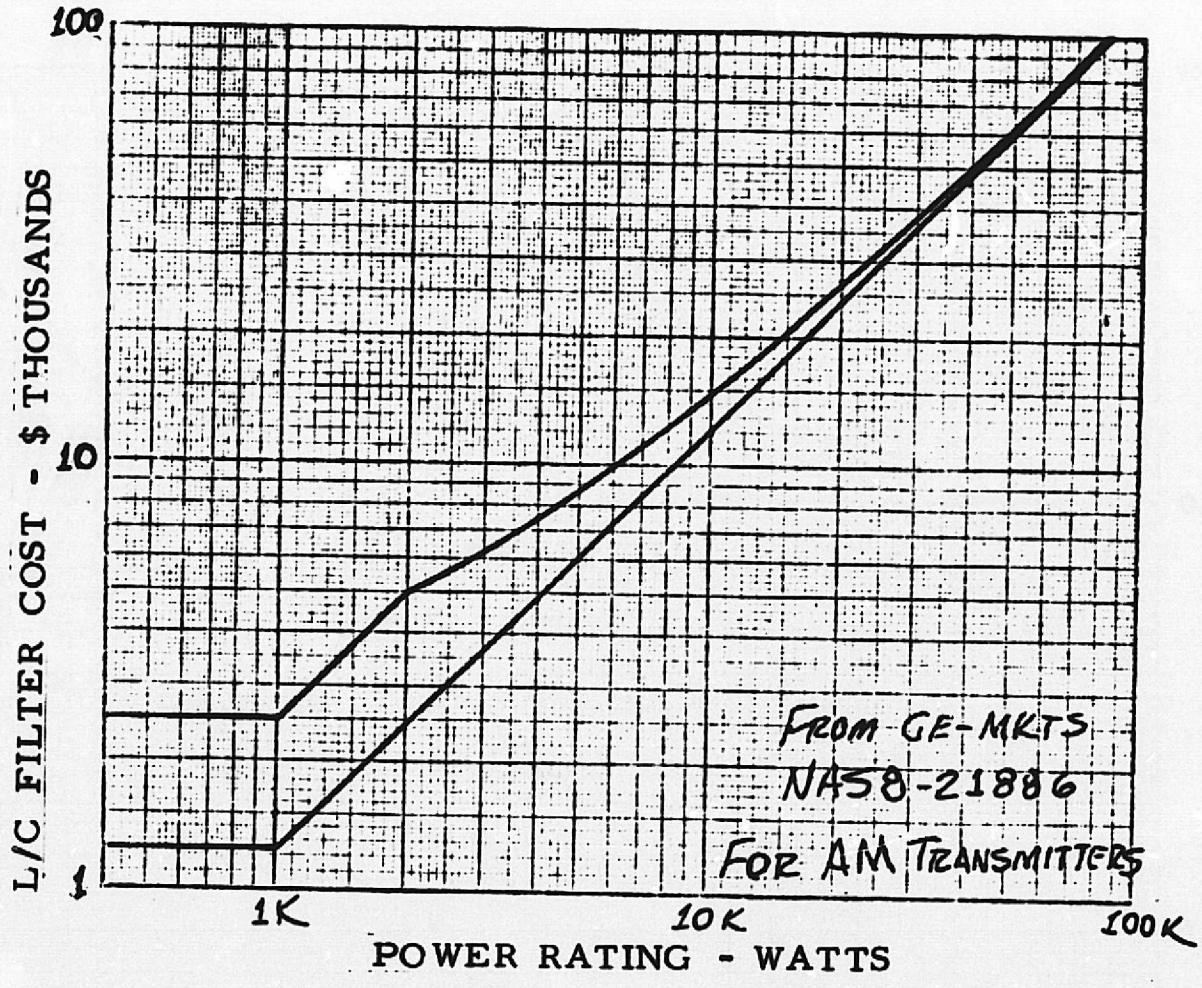


Figure 2-36. L/C Filter Costs

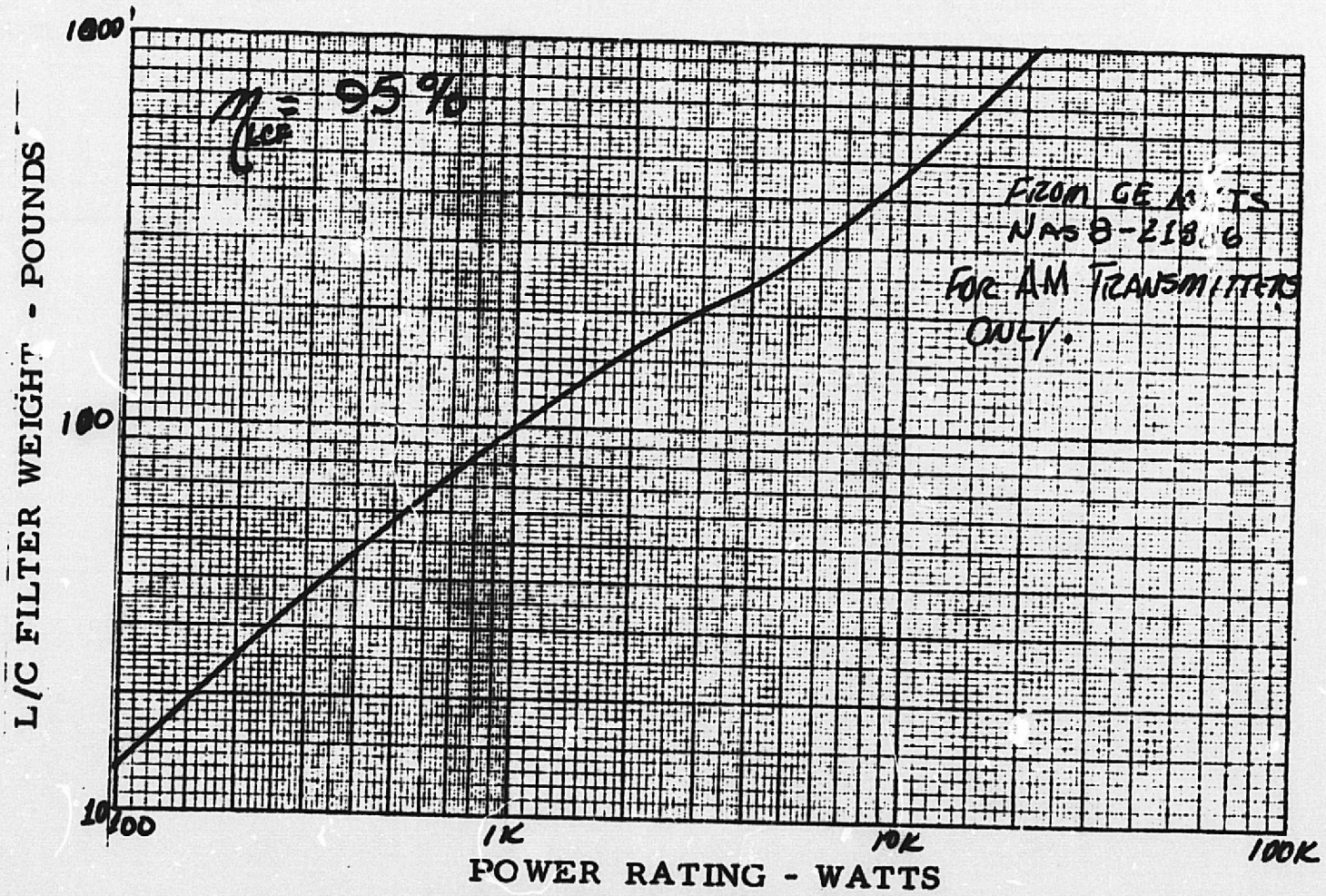


Figure 2-37. L/C Filter Weight

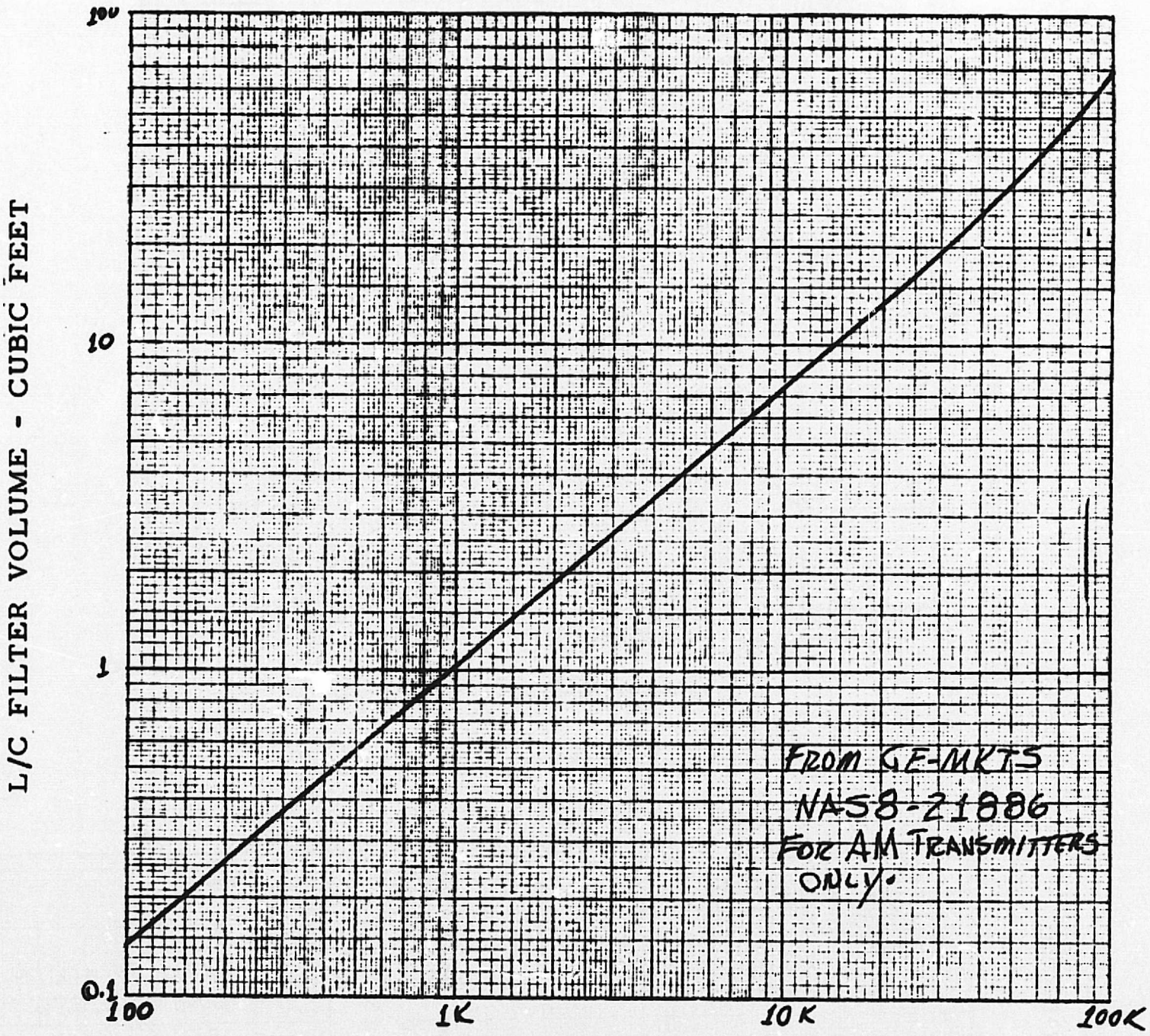


Figure 2-38. L/C Filter Volume

2.3.2.4 ATTITUDE CONTROL. The major source of attitude control perturbation at synchronous orbit is solar pressure. All other steady-state forces are one to two orders of magnitude lower. The tradeoffs discussed are therefore based on the frontal area and offset of the solar arrays, which are continuously orinented to the sun. Three other sources of attitude control impulse requirements exist which have not been considered. These are: 1) the requirement for initial orientation of the satellite after orbital insertion, 2) the requirement for stabilization during docking of the CSM for orbital refurbishment, and 3) the stabilization required during low orbit assembly and checkout of the manned systems. The latter requirement, it is assumed, can be adequately handled by the existing systems aboard the CSM.

The CSM system could also be used for stabilization during the refurbishment in synchronous orbit. However, the existing CSM system is a high torque setup which could lead to excessive control interaction with the large flexible solar array and antenna structures. The jet forces necessary to counter solar pressure are under 500 micropounds, assuming a conservative duty cycle of 20% on. A system sized for 5 year life at low thrust levels will be sluggish for the initial acquisition or docking control requirements. It is suggested, therefore, that two control systems be employed. The primary system would handle the low thrust long life requirement. A backup system employing a simple cold gas or monopropellant would be used to satisfy the one-time demands of initial acquisition and docking control. Thrust forces for the backup system would be on the order of 0.5 pound.

Two propulsive systems have been investigated for long term attitude control:

1. Ion propulsion
2. Ammonia resistojets

Sizing expressions have been generated for these systems. The equations are as follows:

Ion Propulsion

$$P = 1.46 \times 10^{-2} \left(\frac{AM}{L}\right) + 181 + 30 \qquad \text{(Watts)}$$

A = Solar panel area (Ft^2)

M = CP to CM distance (Ft)

L = Jet leverage (Jet to CM) (Ft)

$$W_{AC} = 16.9\left[7.14\times10^{-4}\left(\frac{AM}{L}\right)+1\right]^{1/2}$$ (Jet weight, lbs)

$$+ 1.37\times10^{-4}\left(\frac{AM}{L}\right) N + 60$$ (fuel & tankage)

$$V_{AC} = 5.97\times10^{-6}\left(\frac{AM}{L}\right) + .332$$ (Jet volume, CF)

$$+ 7\times10^{-8}\ (AM/L)\ N$$ (fuel)

$$+ 15.2\times10^{-8}\ (AM/L)\ N + 1$$ (tankage)

These expressions include parameters for 12 thrustors using mercury propellant and operating in banks of two at an Isp of 4500 sec. A mass balancing error of 0.02 maximum is included, and a pressure coefficient of 2.0 is assumed to convert solar pressure to unit panel static force. The solar pressure value is 9.65×10^{-8} psf. Note that the directed solar array gives a large, constant bias torque in the local vertical plane. Torques in the other two planes are small and cyclic. Consequently, momentum devices to store and dampen cyclic torques yield little weight reduction.

Ammonia Resistojet

$$P = 3.7\times10^{-3}\ (AM/L)$$ (Watts)

$$W = (.706 + 1.36\ N)\ 10^{-3}\left(\frac{AM}{L}\right)$$ (pounds)

$$V = 2\times10^{-5}\ (AM/L)\ N$$ (cubic feet)

The resistojet system employs six thrustors, but otherwise all assumptions are the same as for the ion propulsion system.

The cost, weight, volume, and power as a function of the spacecraft geometric parameter AM/L are plotted for these systems in Figures 2-39 through 2-42. Additional power requirements are significant for the ion propulsion system (which can require over 1 KW) but low for the other systems (up to about 20 watts). Weight of fuel for

3 4

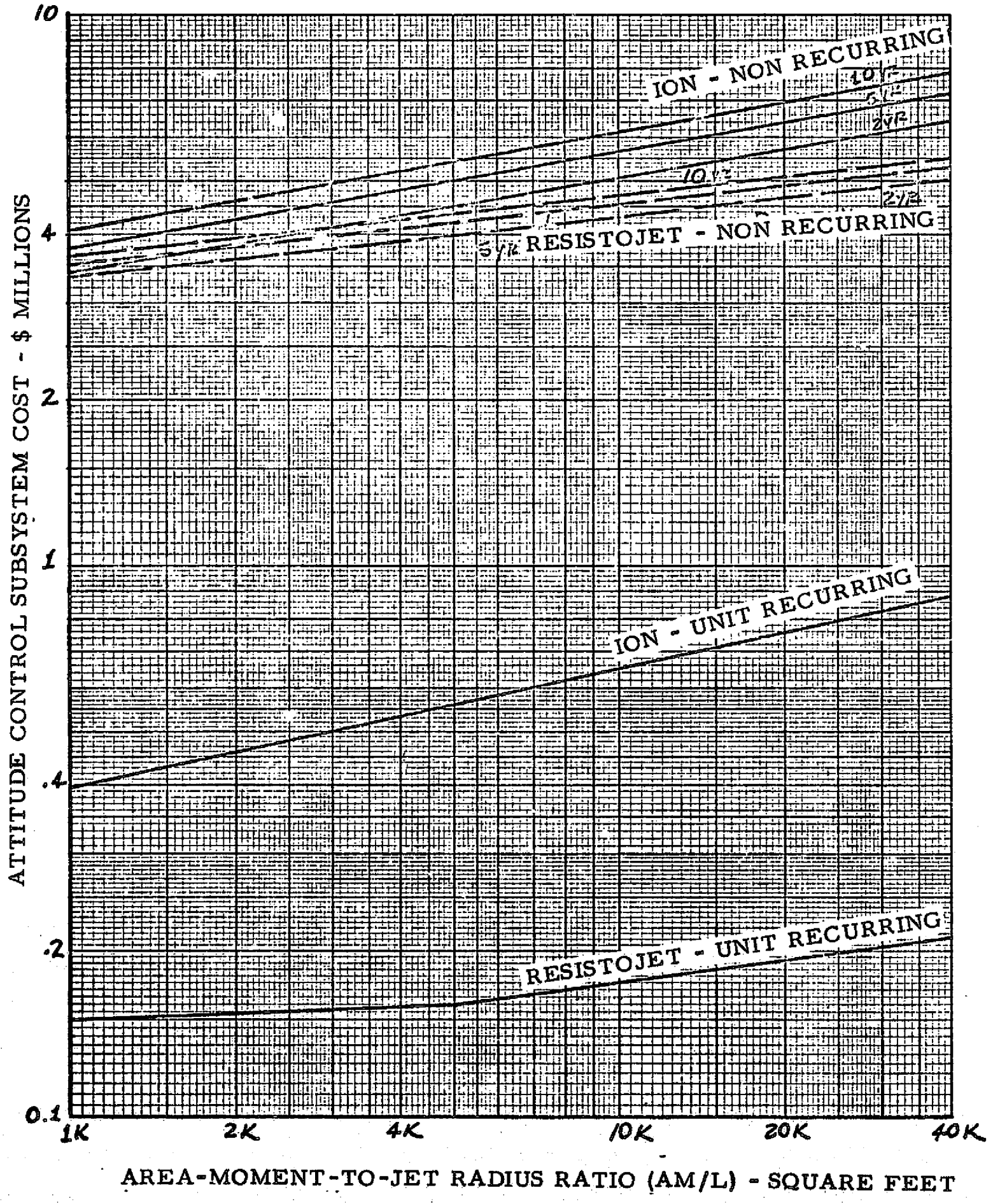


Figure 2-39. Attitude Control Subsystem Costs.

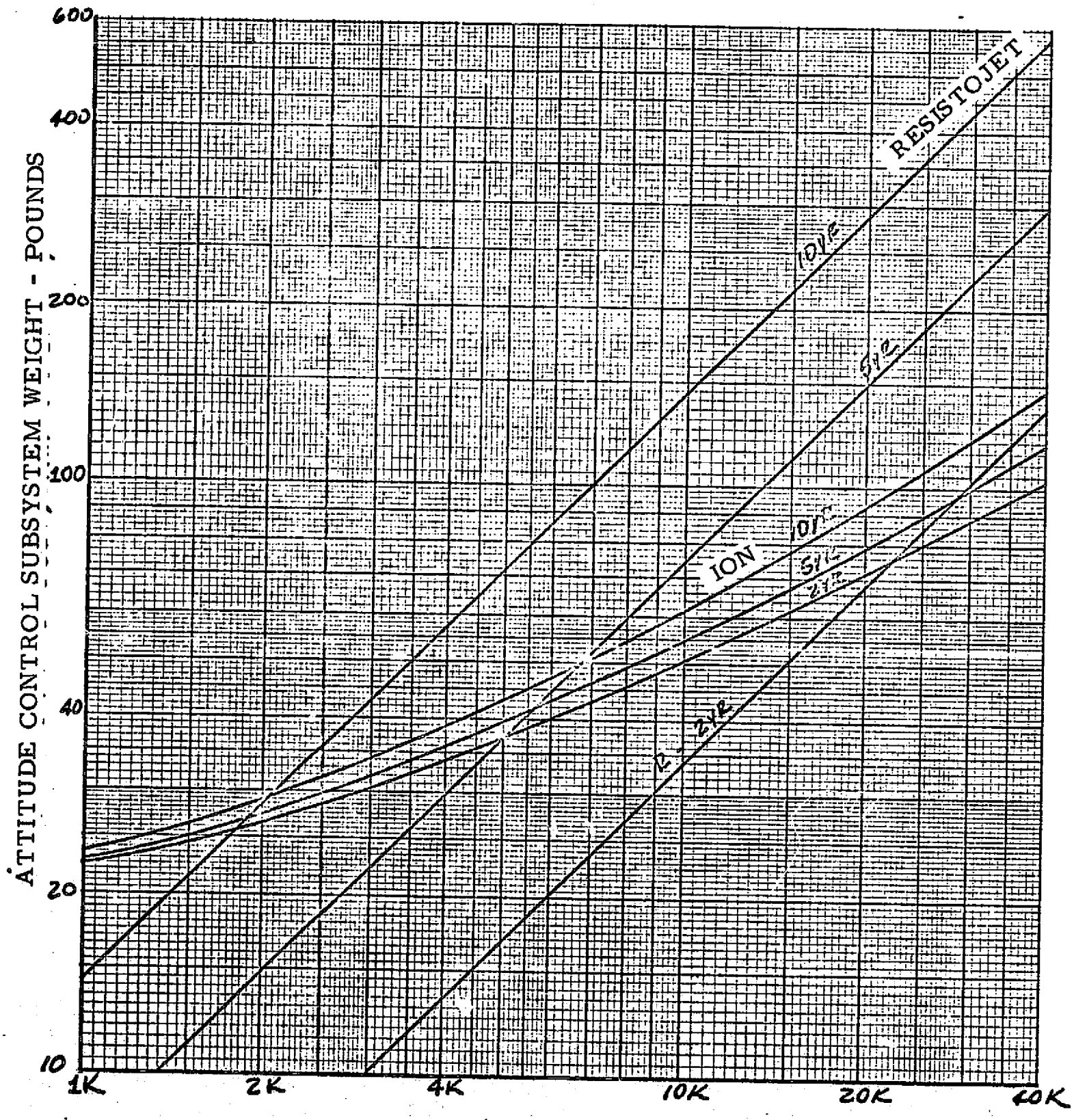


Figure 2-40. Attitude Control Subsystem Weights.

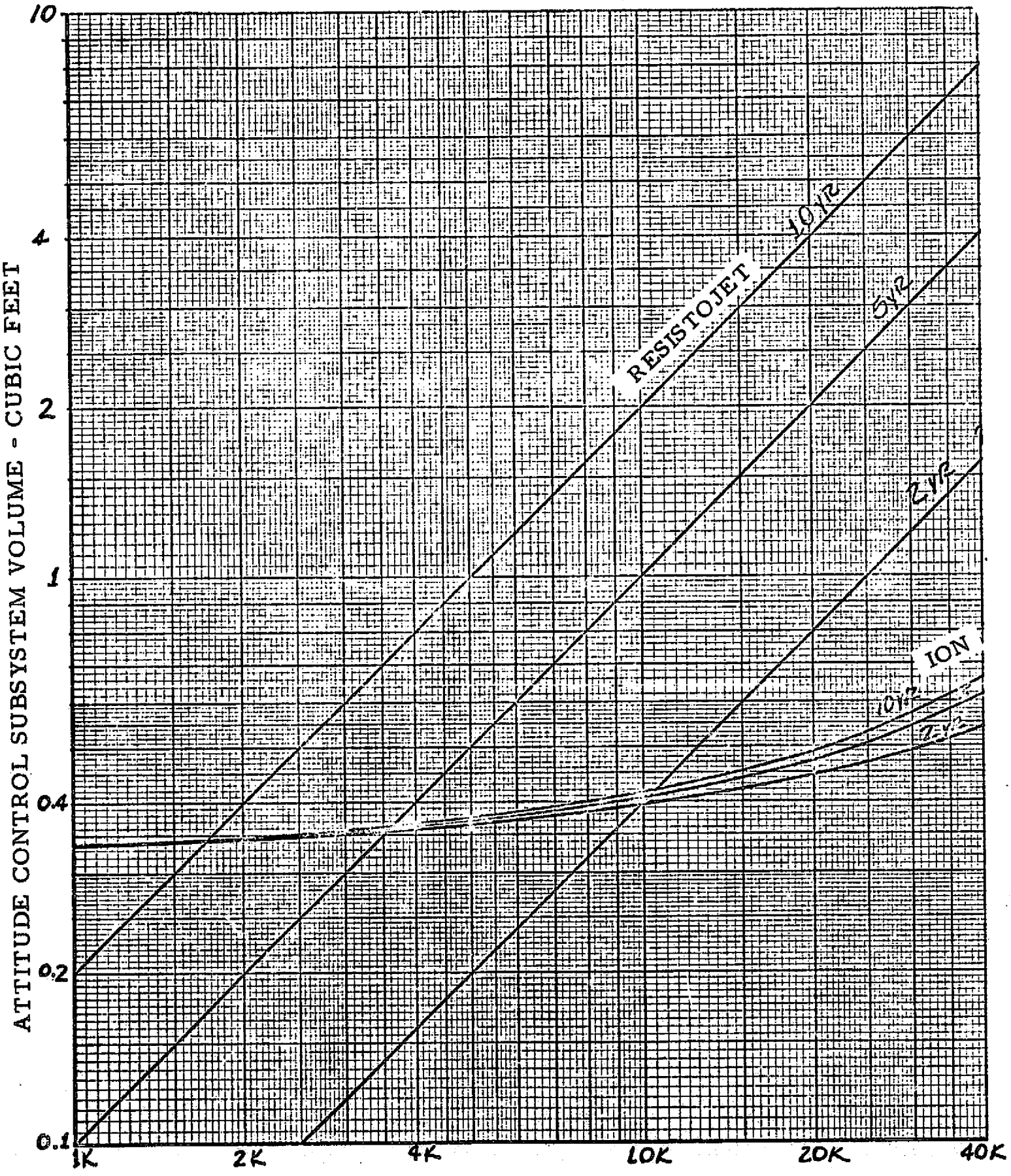


Figure 2-41. Attitude Control Subsystem Volumes.

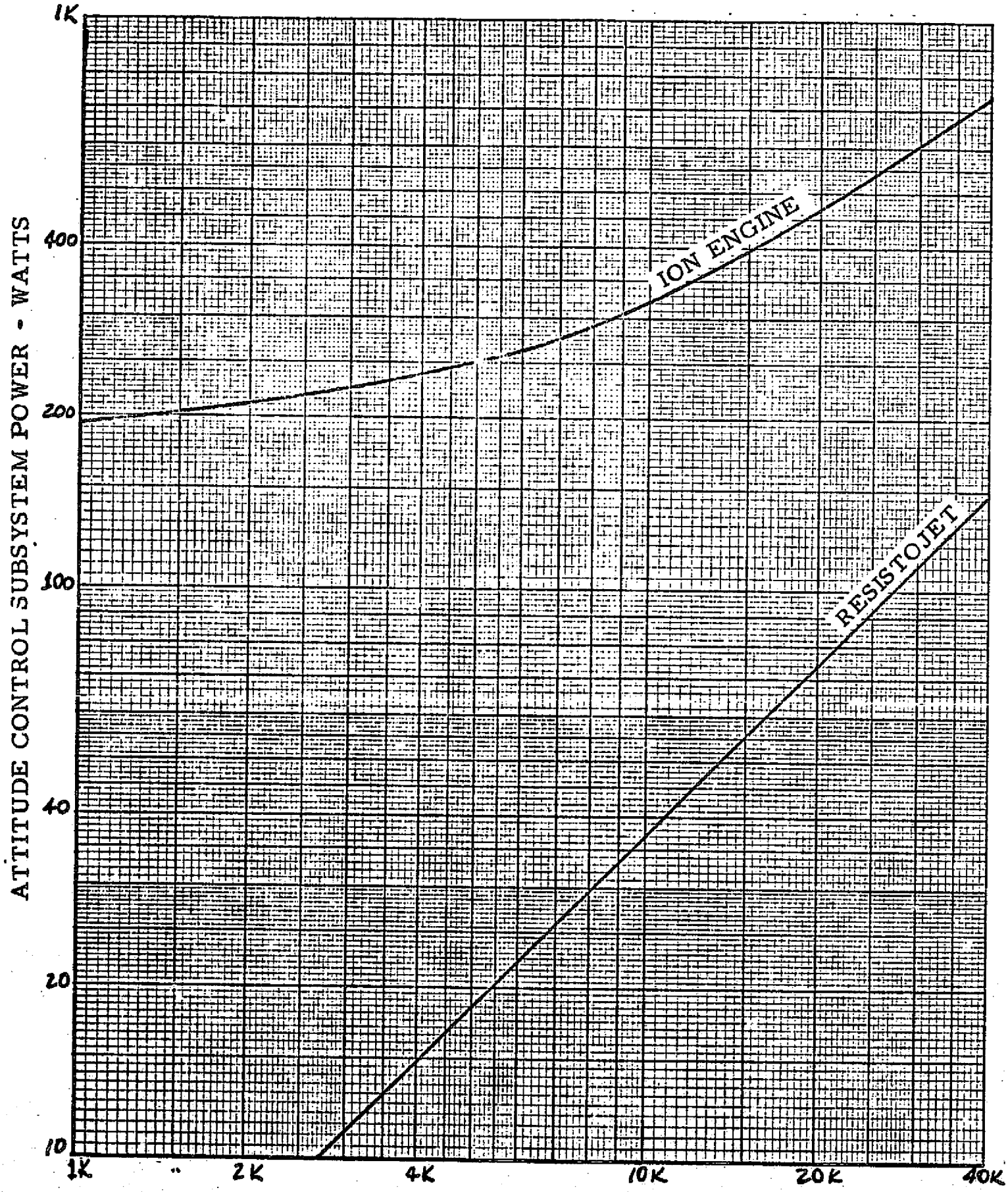


Figure 2-42. Attitude Control Subsystem Power Requirements.

the ion system is very low, consequently long life and a large AM/L have less impact on the total weight than the inerts. Consequently the ion system is lighter at high AM/L and life values than the jet systems but is heavier for small, short-lived satellites.

Of the two systems, the resistojet is the best developed and has the most flight and life testing. The propellant flow valve and seals are the major life limiters (other than fuel supply) for the resistojet system. However, the ATS-IV latch valve has proven most reliable and five-year system life is considered a reasonable extension of the state-of-the-art.

The SERT series ion engines have been flight-tested with reasonable success and are being extensively investigated and improved in ground tests. The state-of-the-art in ion systems in expected to be advanced sufficiently by 1975 to make it a strong candidate for the TV mission. It is recommended, therefore, that TV satellites with AM/L values up to about 15,000 employ the resistojet system, while satellites over AM/L = 15,000 use an ion propulsion system. An AM/L value of 5,000 corresponds to a satellite of concept C type with a 700 square foot (7 KW) solar array. An AM/L value of 65,000 corresponds to a type E or F satellite with a 100-foot diameter antenna and a 5.00 square foot (50 KW) solar array.

Consideration was also given to the location of the attitude control jets. As shown in the sizing expressions, the ammonia system power and weight is reduced directly with an increase in jet leverage arm. It is more efficient from a system weight standpoint to place the jets on the antenna periphery, therefore, than on the equipment module or feed module. It is also more difficult in terms of control connections to place the jets on the antenna, and the attitude control weight fraction (perhaps 5% of the total satellite) is small even with the jets located on the module. It is recommended for these reasons, that control jets be mounted directly to the equipment module.

2.3.2.5 STATION KEEPING. Both North-South and East-West Station Keeping have been considered. The maximum East-West force (resulting from earth surface ireegularities) of 17.5 fps per year was used. Total yearly correction for fine North-South and East-West combined is 200 fps. This value results from 152 fps for coarse N-S plus 30 fps for fine N-S oscillations plus the 17.5 fps for East-West. In some cases, when beam pointing accuracy can be fairly coarse, the North-South requirement can be ignored since it leads to a drift of only 0.85 degrees per year. It has been assumed for this study, however, that N-S correction will be made.

Sizing expressions for two potential propulsive systems have been generated. The systems considered are ammonia resistojet and ion propulsion. The sizing relationships for these systems are as follows:

Resistojet

$$P = 4 \times 10^{-3} W_s$$

$$W_{CS} = \frac{0.00354 N W_s}{1-0.00197N} + \frac{0.0346 N W_s}{1-0.0192N}$$

$$V_{CS} = 0.45 W_{CS}$$

Ion System

$$P = 44.69 \times 10^{-3} W_s + 181$$

W_{CS} = Summation of elements below

$$+ 2.82 \left[1.43 \times 10^{-3} W_s + 1\right]^{1/2} \quad \text{(2E-W thrustors)}$$

$$+ .658 (W_s)^{1/2} \quad \text{(4 N-S thrustors)}$$

$$+ 2 (1.192 \times 10^{-3} W_s N) = W_F \quad \text{(N-S fuel)}$$

$$+ 2 \left[3.61 + 0.056 W_{F/2}\right]^{2/3} \quad \text{(N-S tankage)}$$

$$+ 9.16 \times 10^{-5} W_s N \quad \text{(E-W fuel \& tanks)}$$

$$V_{CS} = +1.99 \times 10^{-6} W_s + 0.554 \quad \text{(2 E-W thrustors)}$$

$$+2.08 \times 10^{-5} W_s + .1108 \quad \text{(4 N-S thrustors)}$$

$$+ W_F/984 \quad \text{(fuel)}$$

$$+ W_T/450 \quad \text{(tanks)}$$

Figures 2-43 through 2-46 offer a system comparison of the two propulsion types as a function of total satellite weight. A strong weight advantage for the ion system is shown throughout the satellite weight range of 1,000 to 50,000 pounds. There is progressively less advantage for the ion system as required life is decreased. It is recommended that the following control system selections be made:

1. Resistojet for satellites with life of two years or less.
2. Ion system for satellites with life in excess of two years.

These recommendations are based on system weight and the reliability considerations discussed in Section 2.3.2.4. Note that the ion system employs two pairs of N-S jets and one opposed pair of E-W jets. The resistojet uses one pair of jets for E-W and one pair for N-S control.

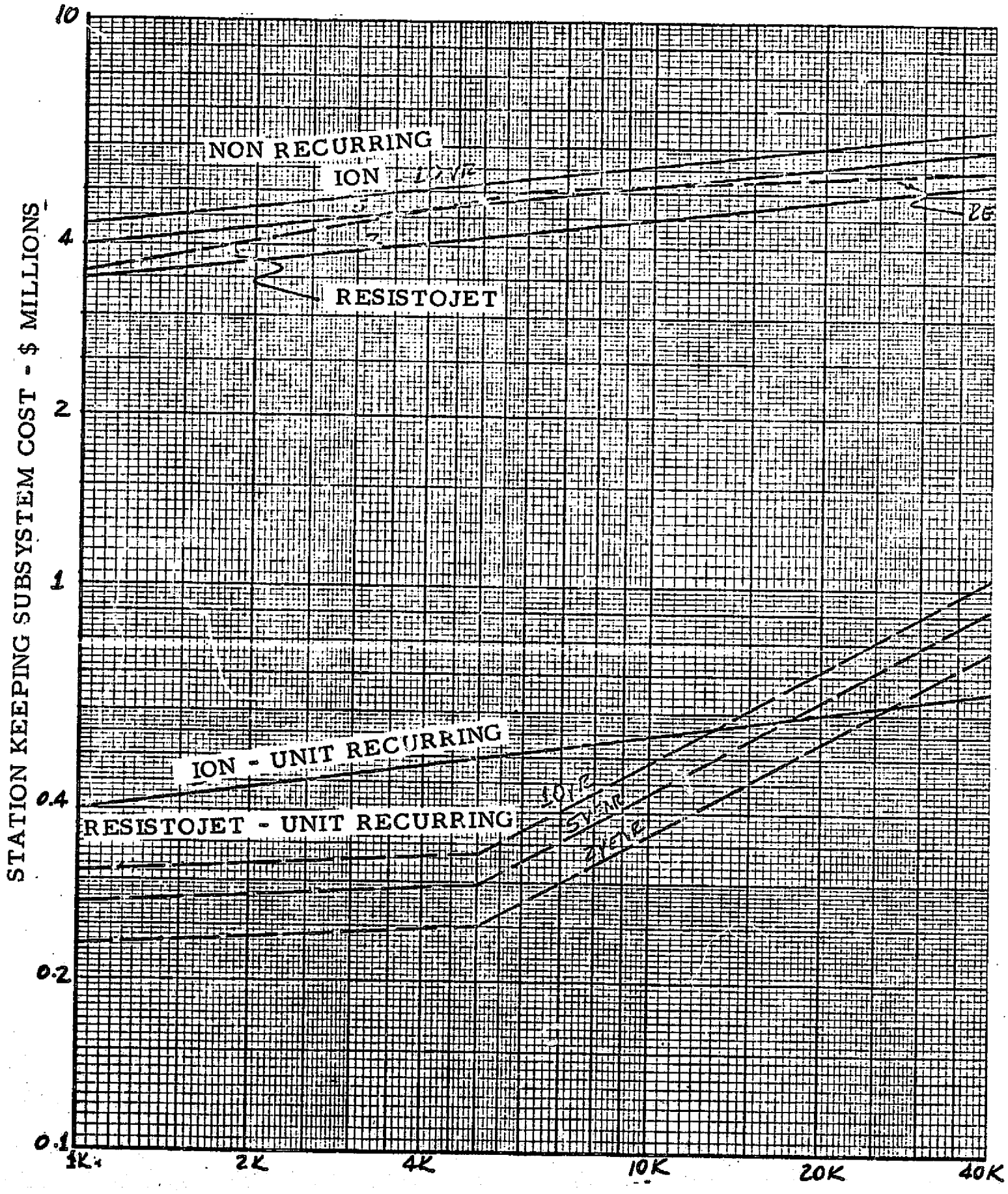


Figure 2-43. Stationkeeping Subsystem Costs.

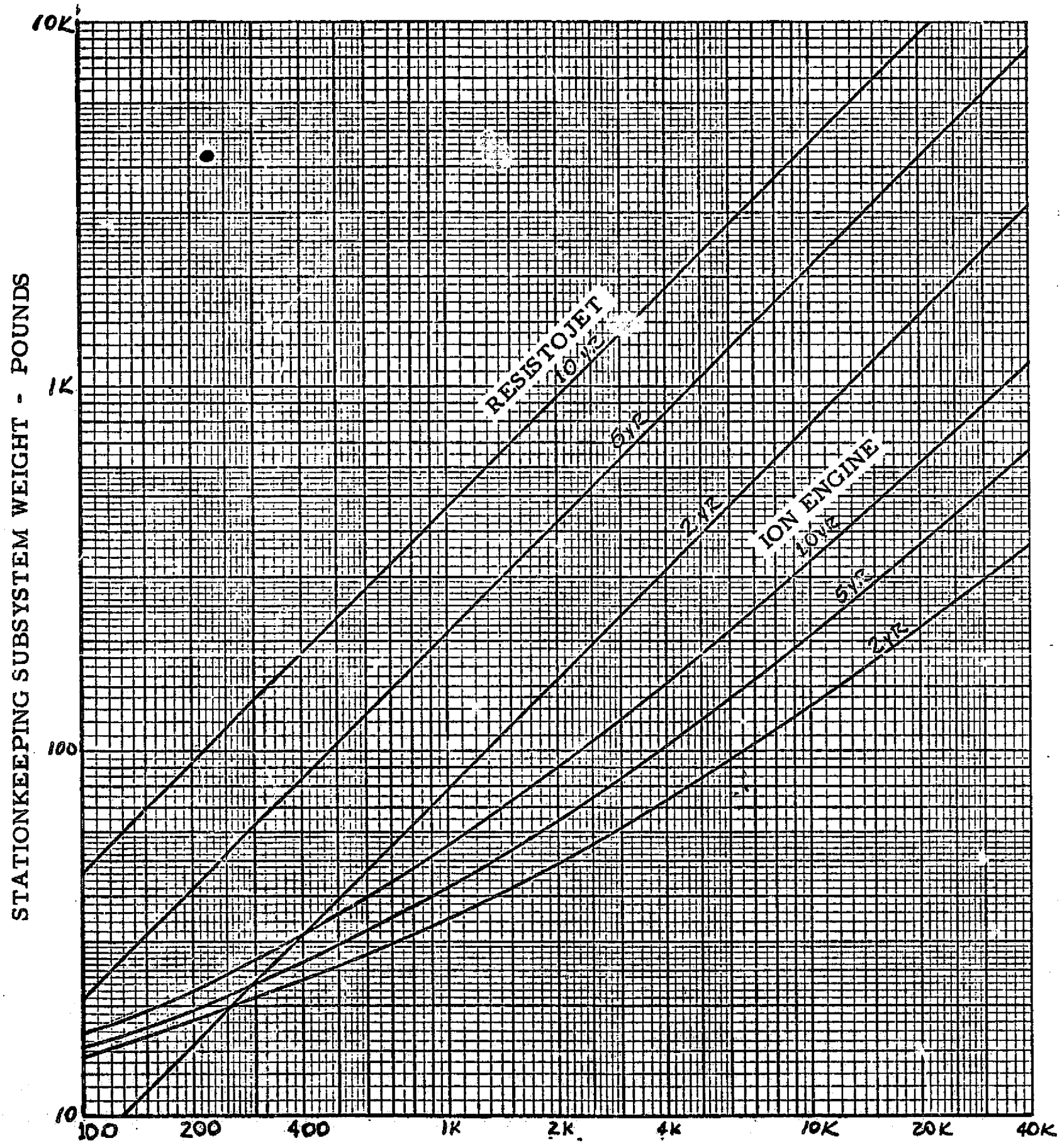


Figure 2-44. Stationkeeping Subsystem Weights.

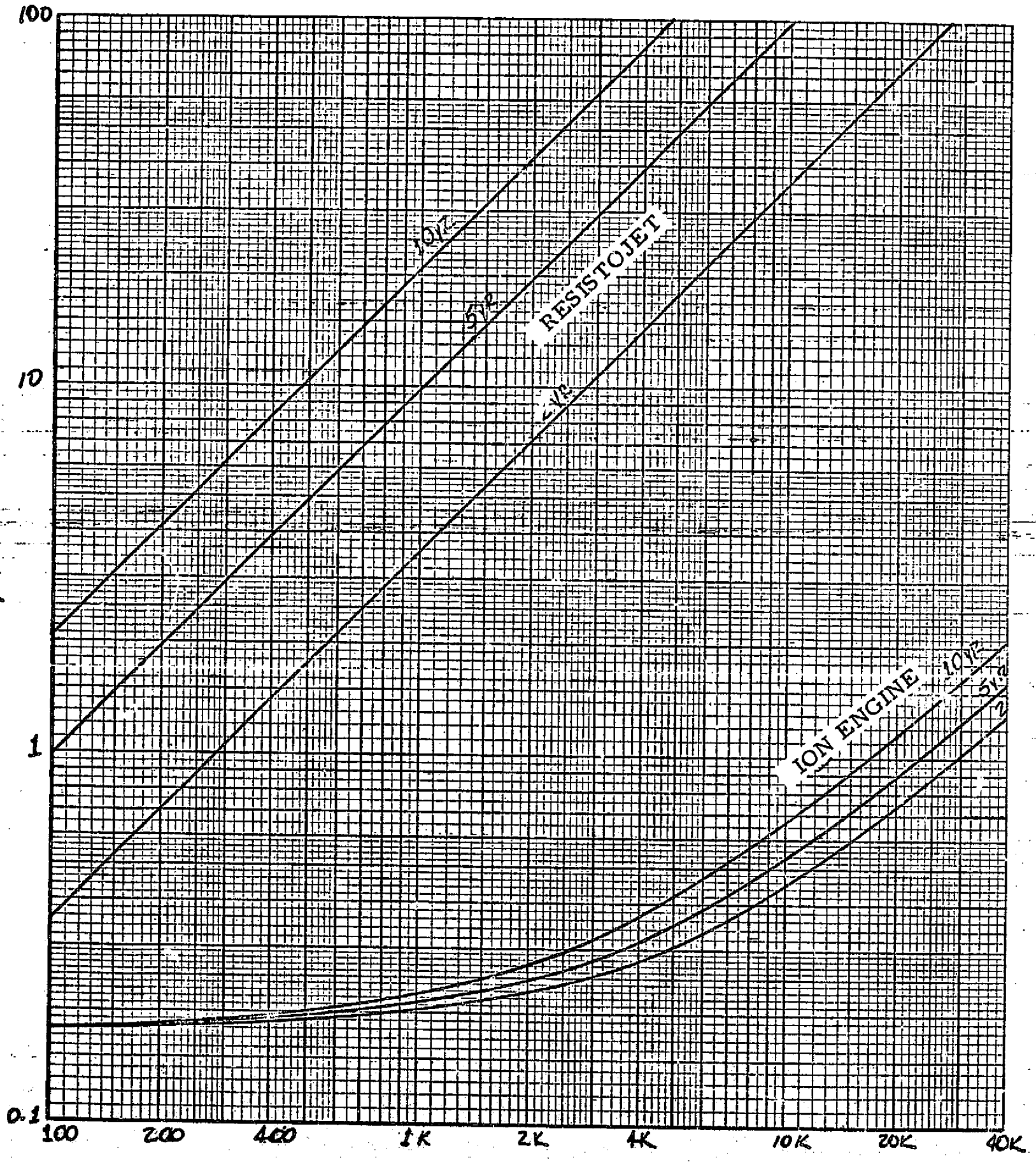


Figure 2-45. Stationkeeping Subsystem Volumes.

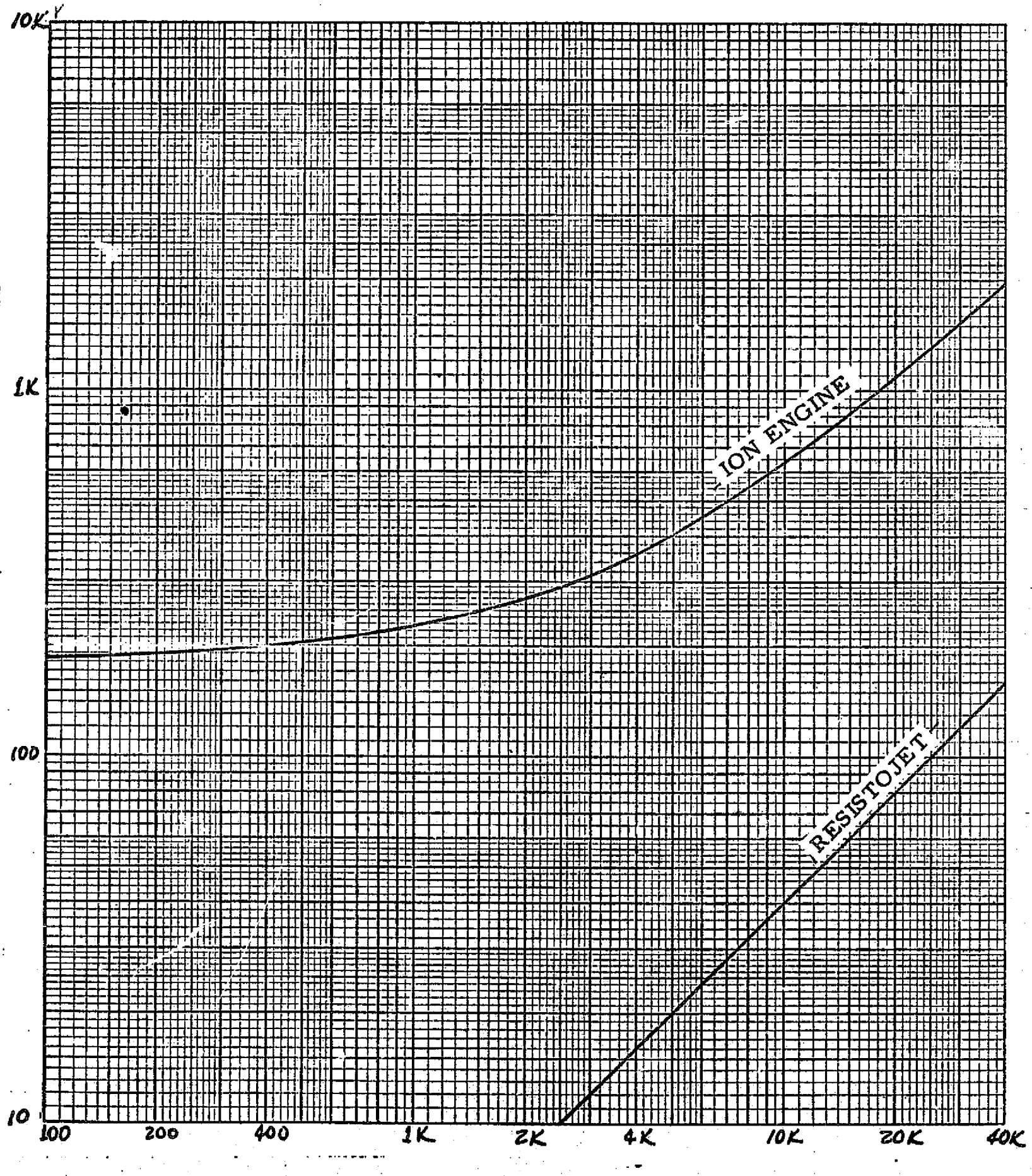


Figure 2-46. Stationkeeping Subsystem Power Requirements.

REFERENCES FOR SECTION 2.3.2.3 AND 2.3.2.4

1. Shukay, T. R. "Power and Weight Requirements for Ion Engine Systems as Functions of Mission Requirements", J. of Spacecraft, Vol. 4, No. 5, May 1967.

2. Stumm, J. E., et al, Utilization of Electric Propulsion for Interplanetary Spacecraft, General Dynamics Convair Report GDC-ERR-AN-1142, Spril 1968.

3. Bechtel, Robert T., Performance and Control of a 30-Centimeter Diameter, Low Impulse Kaufman Thruster, AIAA Paper 69-238.

4. Esker, D. W., et al, Design and Performance of Radiation-Cooled MPD Arc Thrustors, AIAA Paper 69-245.

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6. Page, Russell J., et al, Life Test of Six High Temperature Resistojets, AIAA Paper 69-294.

7. Frick, R. H. Orbital Regression of Synchronous Satellites Due to Combined Effects of the Sun, the Moon, and the Oblate Earth, Rand Corporation, Contract NAS R-21(02), Rpt. No. R-454-NASA, April 1967.

8. Babsan, R. E. and B. M. Angel, A Simplified Approach for Correction of Perturbations on a Stationary Orbit, AIAA paper 68-456.

2.3.2.6 THERMAL CONTROL SUBSYSTEM. The thermal control subsystem types considered are conventional radiators and heat pipes plus a hybrid system of conventional radiator on the equipment module and a heat pipe deployable panel.

The cost estimating relationships for the thermal control subsystem are given in Figure 2-47.

The sizing relations for the two types are as follows:

CONVENTIONAL RADIATOR

$$P_D = P_{PRIME} - P_{XMTR}$$

$$W_{TC} = 0.0548\ P_D - 2.5\ V_{EM}^{2/3}$$

$$V_{TC} = 0.0913\ P_D - 0.417\ V_{EM}^{2/3}$$

$$A_{TC} = 0.0548\ P_D - 2.5\ V_{EM}^{2/3}$$

where P_{PRIME} = total prime power

P_{XMTR} = total transmitter output power (circuit losses included)

V_{EM} = equipment module volume

HEAT PIPE

$$W_{TC} = 0.01125\ P_D$$

$$V_{TC} = 0.00225\ P_D$$

$$A_{TC} = 0.009\ P_D$$

2.3.2.7 LIFE SUPPORT SUBSYSTEM. The characteristics of the life support subsystem are given in Table 2-29. This subsystem is to provide a shirtsleeve environment for short periods (up to 14 days) during system checkout and/or hardware replacement.

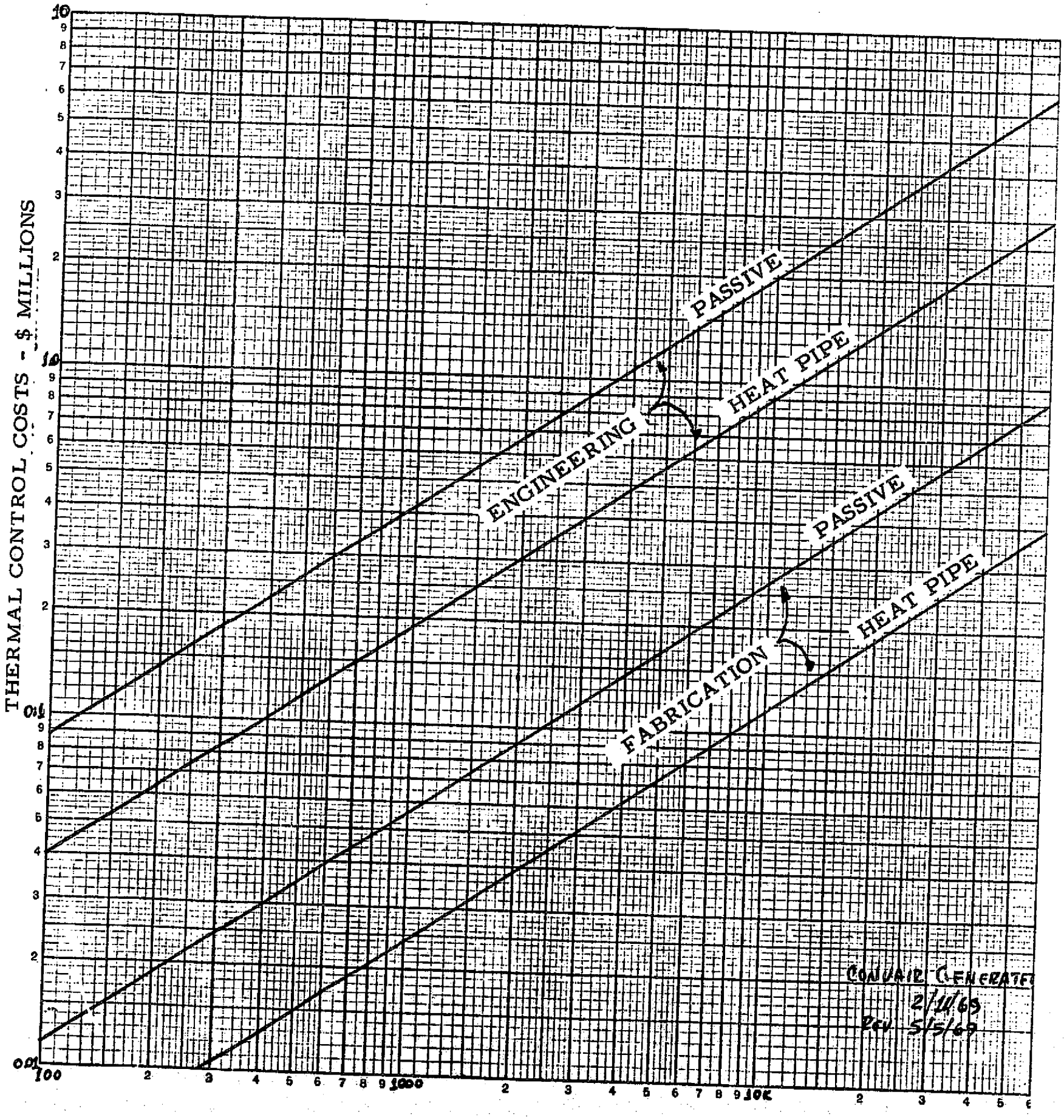


Figure 2-47. Thermal Control Subsystem Costs.

Table 2-29. Life Support Subsystem Characteristics.

Weight	3200 pounds
Volume	740 cubic feet
Power Requirements	3000 watts
Unit Recurring Cost	$1.8 millions
Non Recurring Cost	$24.9 millions

2.3.2.8 TELEMETRY AND COMMAND SUBSYSTEM. The T and C system suitable for the housekeeping functions for a TV Broadcast Satellite can be roughly sized on the basis of the following baseline description of the spacecraft and its mission.

1. The spacecraft is 3-axis attitude stabilized.
2. The spacecraft is intended to be operational which tends to reduce the T and C data load.
3. A fully redundant system is needed to meet spacecraft reliability objectives.

Command — A representative command group consists of redundant command receivers, redundant demodulator/decoders, and eight sets of redundant remote decoders. The subsystem is capable of accepting a standard NASA Pulse Code Modulation (PCM) Instruction Command. The subsystem is completely redundant and capable of executing 512 pulse commands and 32 8-bit magnitude commands via redundant paths.

Telemetry — A representative telemetry group consists of a redundant pair of central encoders and a number (approximately 70) of redundant remote multiplexers. The central encoder addresses each of the remote multiplexers in sequence and processes the telemetry data returning from them. The remote multiplexers are located near the TLM data sources, thereby reducing the system harness weight.

The system characteristics of the telemetry and command subsystem are given in Table 2-30.

Table 2-30. Telemetry and Command Subsystem Characteristics

Item	Weight (Lb.)	Volume ($Ft.^3$)	Power (W)	Cost ($M) Recurring	Cost ($M) Non-Recurring
Receiver	1.6	.04	0.5		
Demod/Decoder	5.6	.18	2.5		
Remote Decoder	11.2	.28	16.0		
Transmitter	2.0	.04	6.0		
Encoder	8.0	.18	1.0		
Multiplexer	42.0	1.22	140.0		
TOTAL	70.4	1.94	166.0	.850	.170

2.3.2.9 RECEIVER SUBSYSTEM. There are basically four types of receivers as follows:

a. Linear Translator performs a frequency translation between the uplink and downlink. If limiting is not included, this translator can handle either AM or FM; otherwise, only FM may be used.

b. Frequency multiplier repeater multiplies the uplink frequency by some factor to achieve the downlink frequency. This repeater is used only for FM.

c. Modulation Converter repeater changes the modulation from AM SSB to FM by the incorporation of a balanced linear IF phase modulator.

d. Demodulator-Modulator repeater converts the uplink signal to baseband and then remodulates the downlink carrier. The characteristics of the four types of receivers are given in Figures 2-48 and 2-49. Each transistor parametric amplifier is capable of handling up to 4 carriers. Therefore, the characteristics will increase in multiples of four to reflect the additional paramp.

2.3.2.10 TRANSMITTER SUBSYSTEM. The transmitter parametric data is extracted from the Multikilowatt Transmitter Study for Space Communications Satellites performed by General Electric Space System Division, NAS8-21886. The basic assumptions for the curves of Figures 2-50 through 2-56 are as follows:

Lifetime: 2 year minimum

Frequencies: 700 to 890 MHz; 2.0 to 3.0 GHz; 8.3 to 8.5 GHz; 11.7 to 12.7 GHz

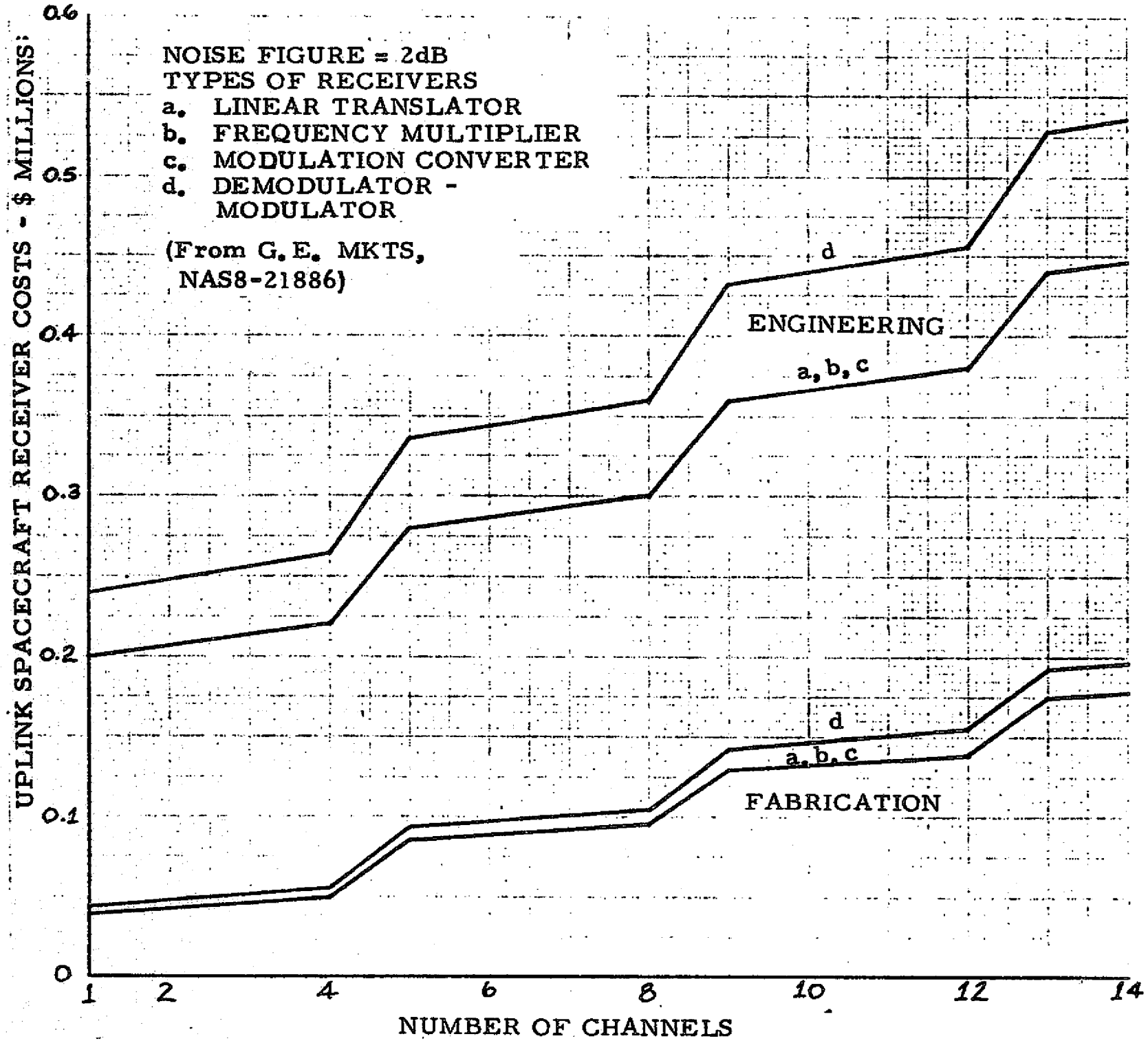


Figure 2-48. Uplink Receiver Subsystem Costs.

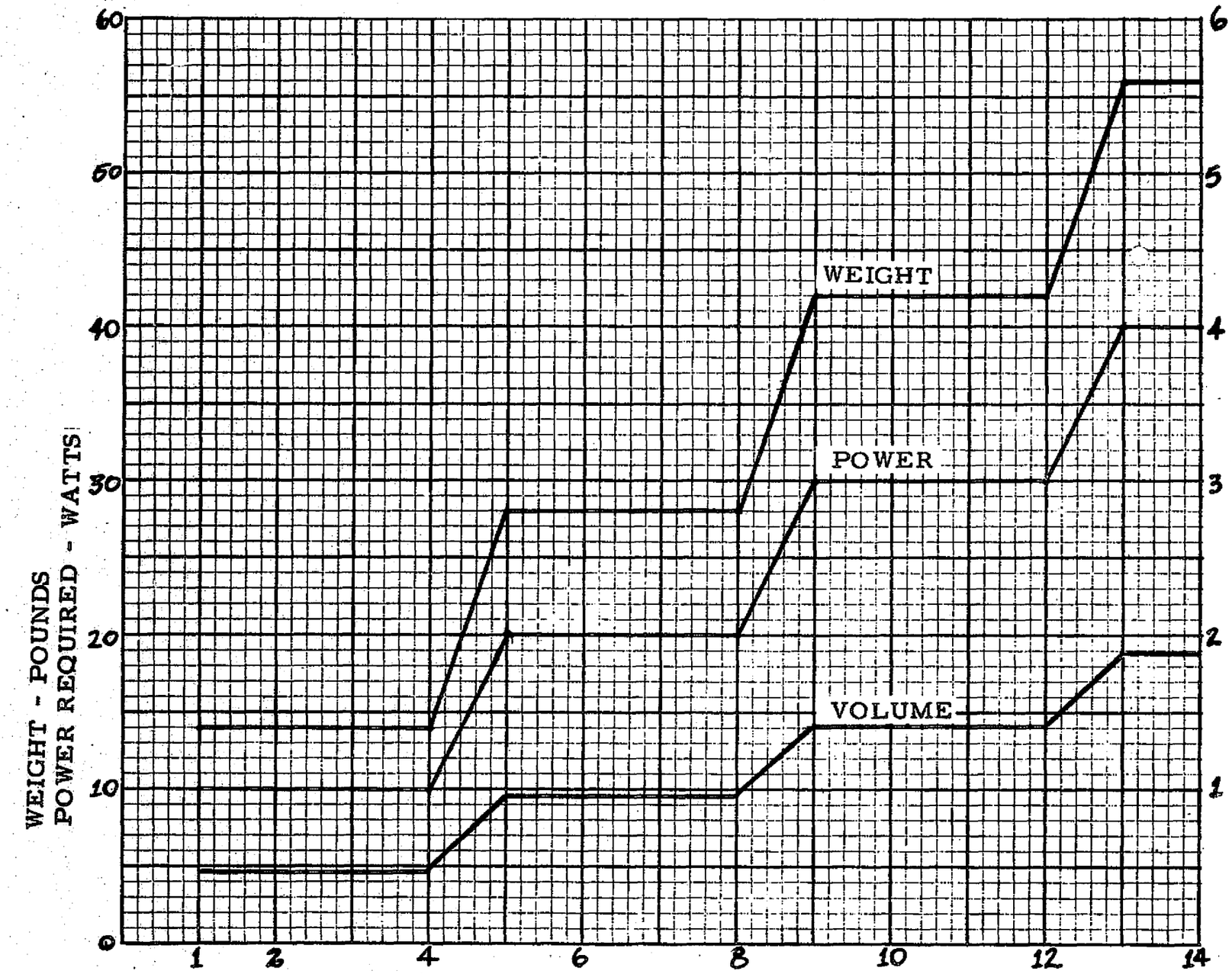


Figure 2-49. Receiver Subsystem Weight, Volume and Power.

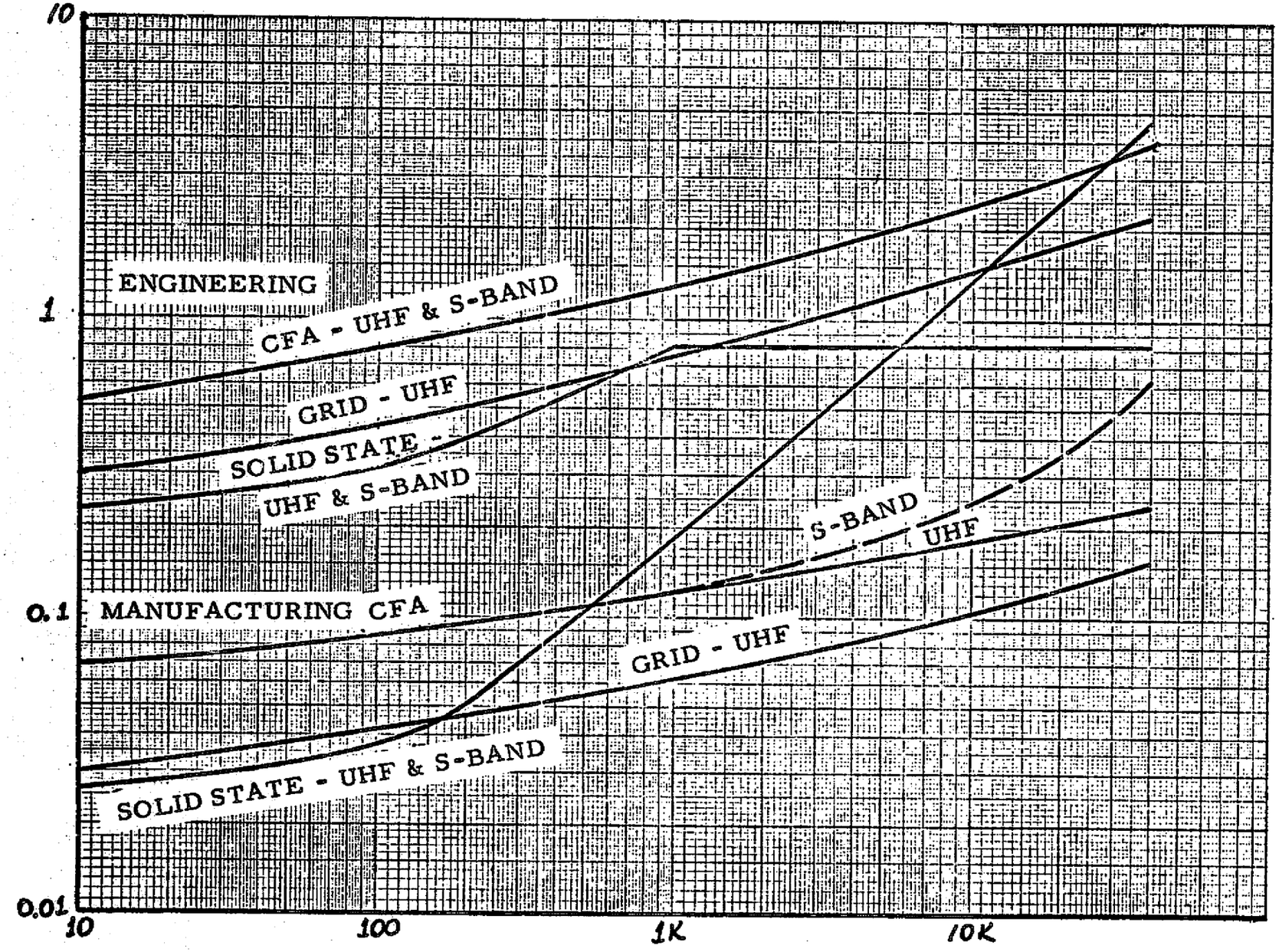


Figure 2-50. AM Transmitter Costs.

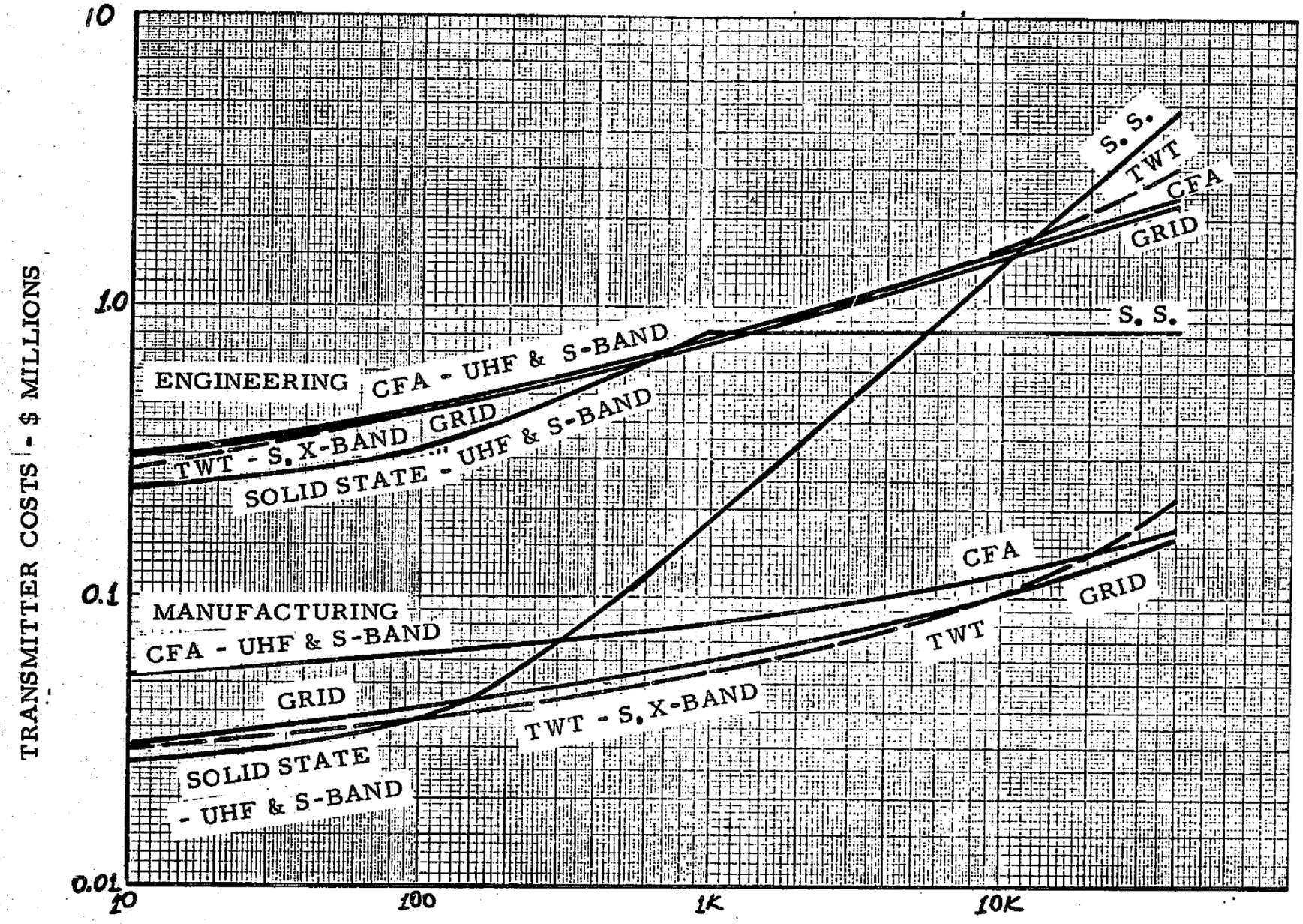


Figure 2-51. FM Transmitter Cost.

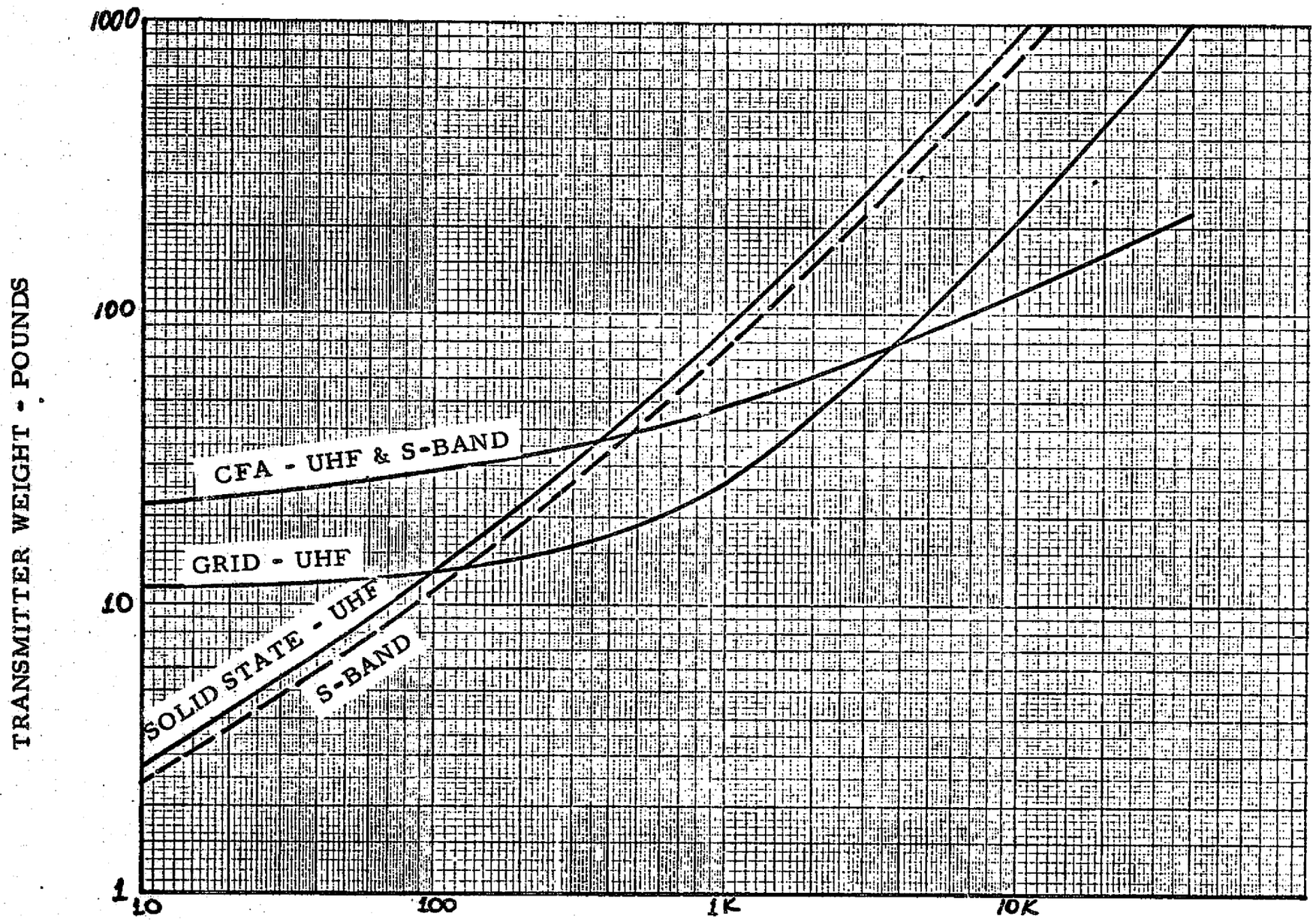


Figure 2-52. AM Transmitter Weight.

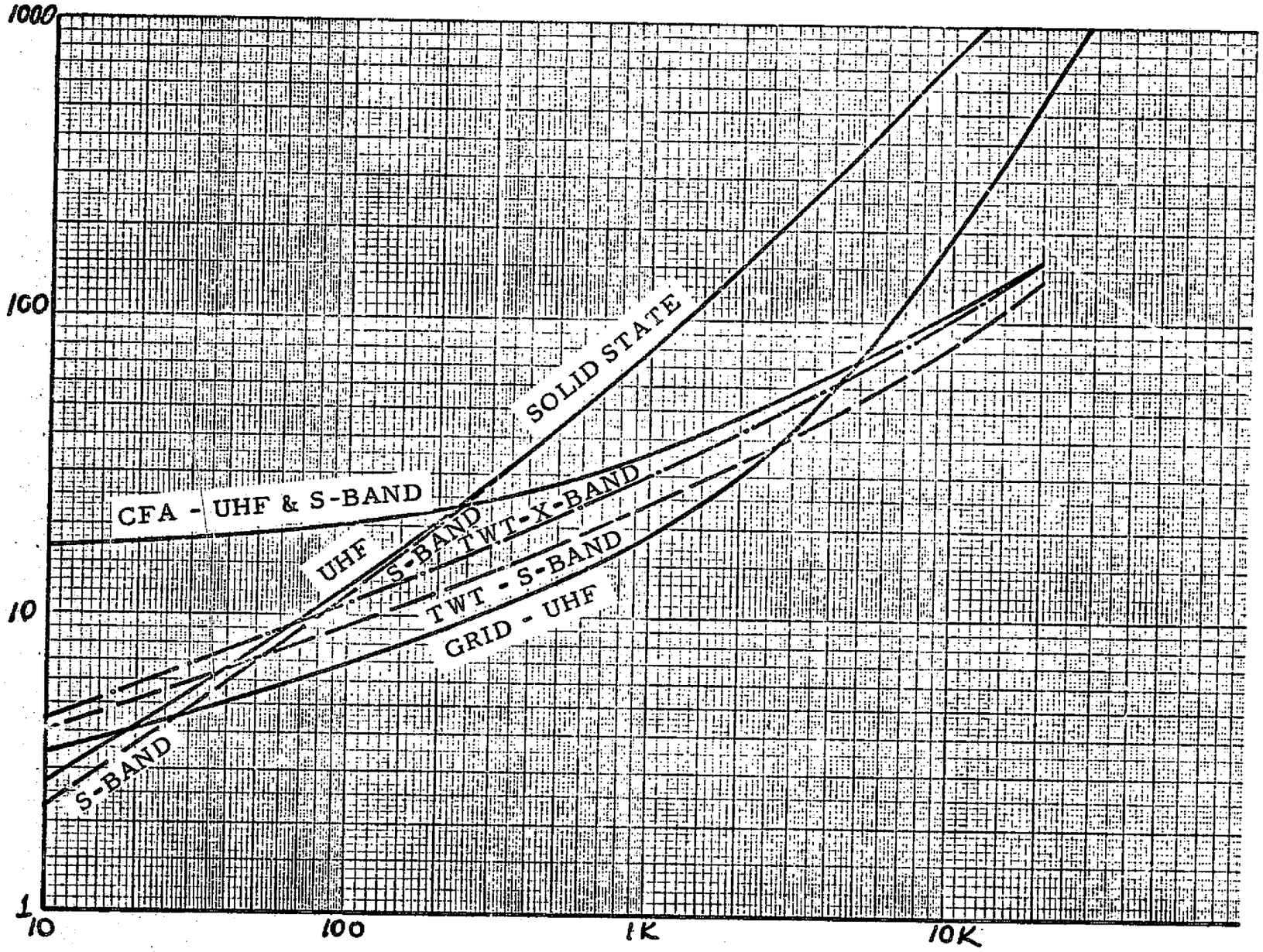


Figure 2-53. FM Transmitter Weight.

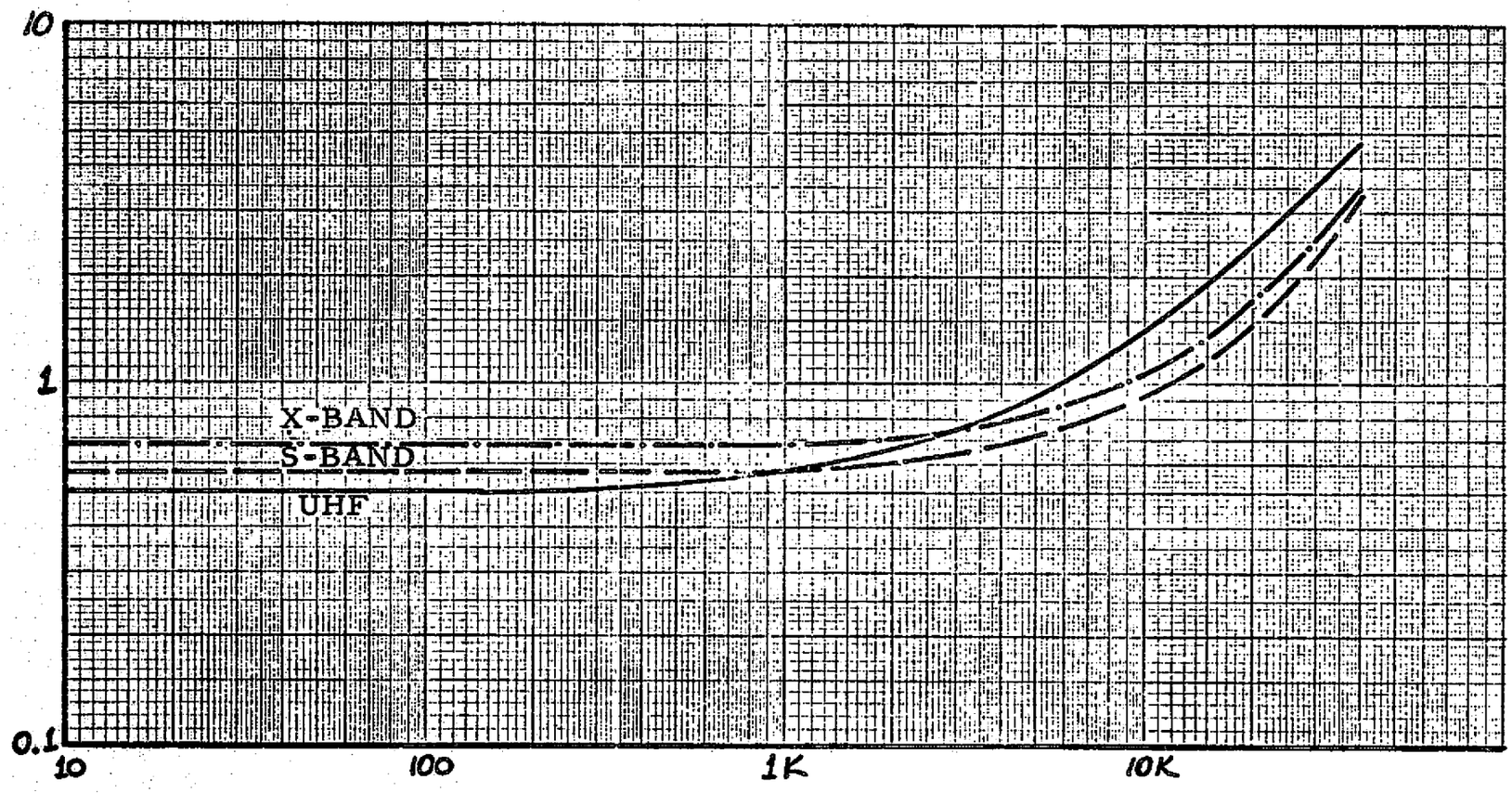


Figure 2-54. Transmitter Volume.

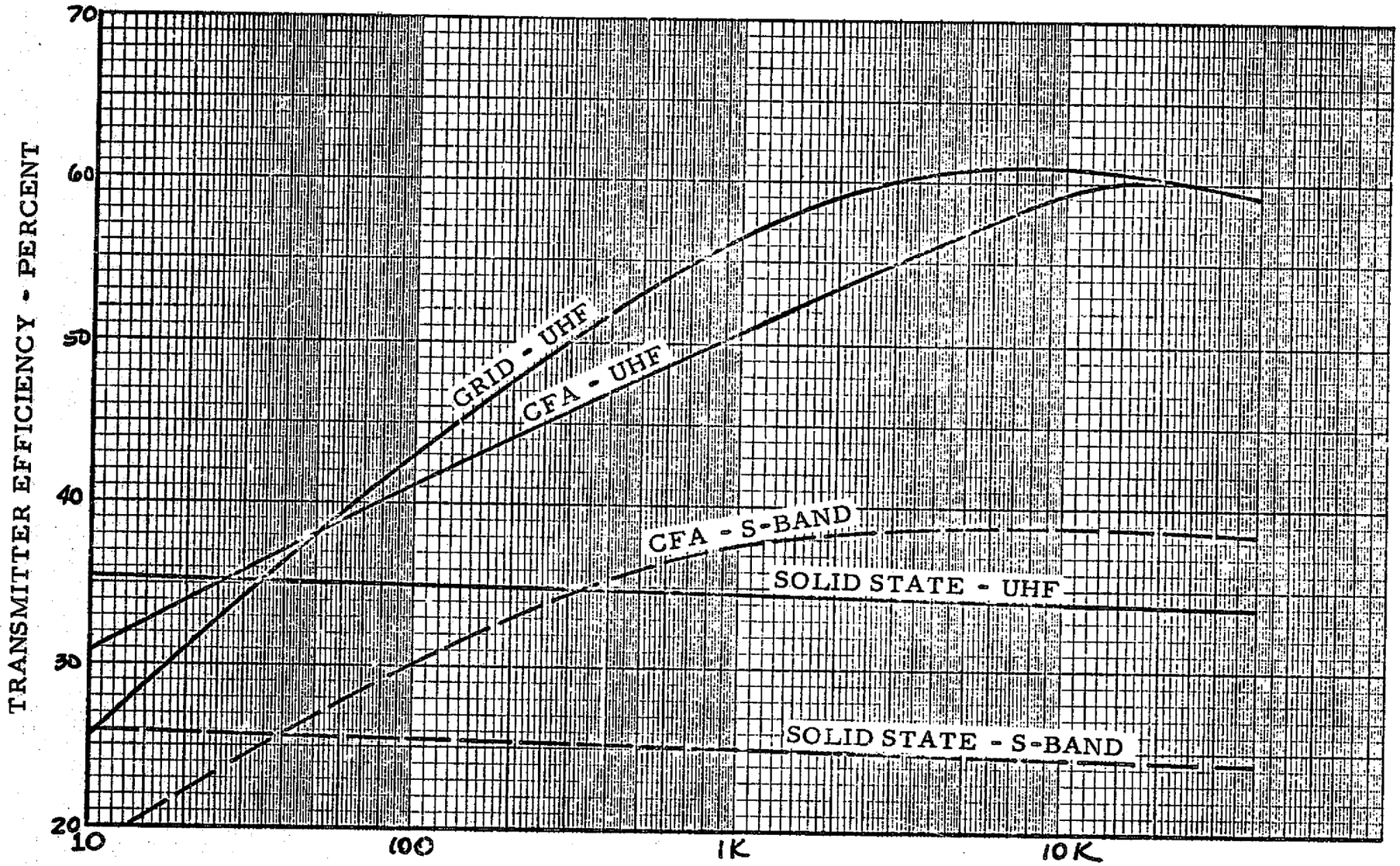


Figure 2-55. AM Transmitter Efficiency.

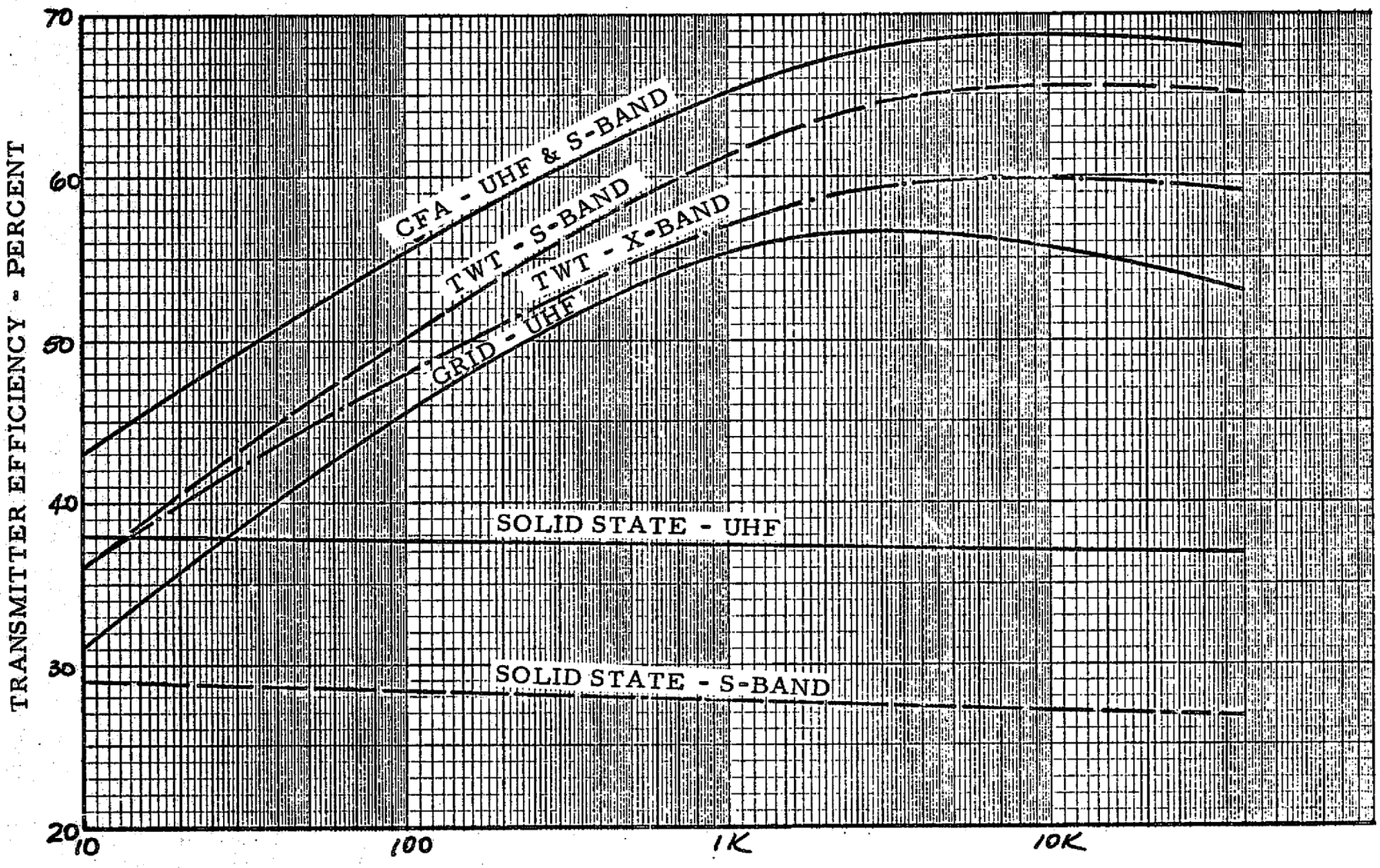


Figure 2-56. FM Transmitter Efficiency.

Modulation: AM and FM

Power Output: 50 watts to 20 kilowatts.

The multiplexer characteristics, shown in Figures 2-57 through 2-59, were also taken from the above study.

2.3.2.11 ANTENNA SUBSYSTEM. Antenna size requirements for RF transmission beamwidths are given in Figure 2-60 over a band of frequencies. At synchronous altitude, hemispherical earth coverage is approximately 20 degre s. U.S. time zone coverage requires a beamwidth of 2 to 3 degrees. Regional coverage for a 100-mile radius would require a 0.5-degree beamwidth. Eventually, there is an RF performance constraint on the antenna arising from environmentally induced distortions. Detailed tolerance and thermal analyses of a geostationary parabolic antenna show distortions to vary from approximately one part in 5,000 to 10,000 over the orbital cycle. From the Ruze gain equation, the latter values give maximum gains of 55 to 61 db. Thus, distortion losses begin to limit RF performance when the beamwidth is less than 0.5 degree and the required antenna gain is greater than 50 db. Below 50 db, nominal RF performance values of 55% efficiency can be achieved with space erectable antennas. Other considerations on antenna size are stowage volume, weight, and system cost, given in Figures 2-61 through 2-63.

2.3.3 GROUND DOWNLINK SYSTEM. The ground downlink system is composed of the receiving elements of the system — basically the antenna and the receiver/converter. In an effort to obtain realistic ground receiver cost characteristics for use in synthesizing television broadcast satellite systems, three major sources of data were used. They are (1) Technical and Cost Factors That Affect Television Reception From A Synchronous Satellite by Jansky and Bailey Systems Engineering Department of the Atlantic Research Corporation under NASA contract NASw-1305, (2) Television Broadcast Satellite Final Briefing by the Space Systems Division of the General Electric Company under NASA contract NAS3-9708 and (3) C.C.I.R. Study Group, USSG IV, Amendments to Report L.3.a(IV). In addition, point comparisons were made with data found in Appendix D of Technology Potentials for Satellite Spacing

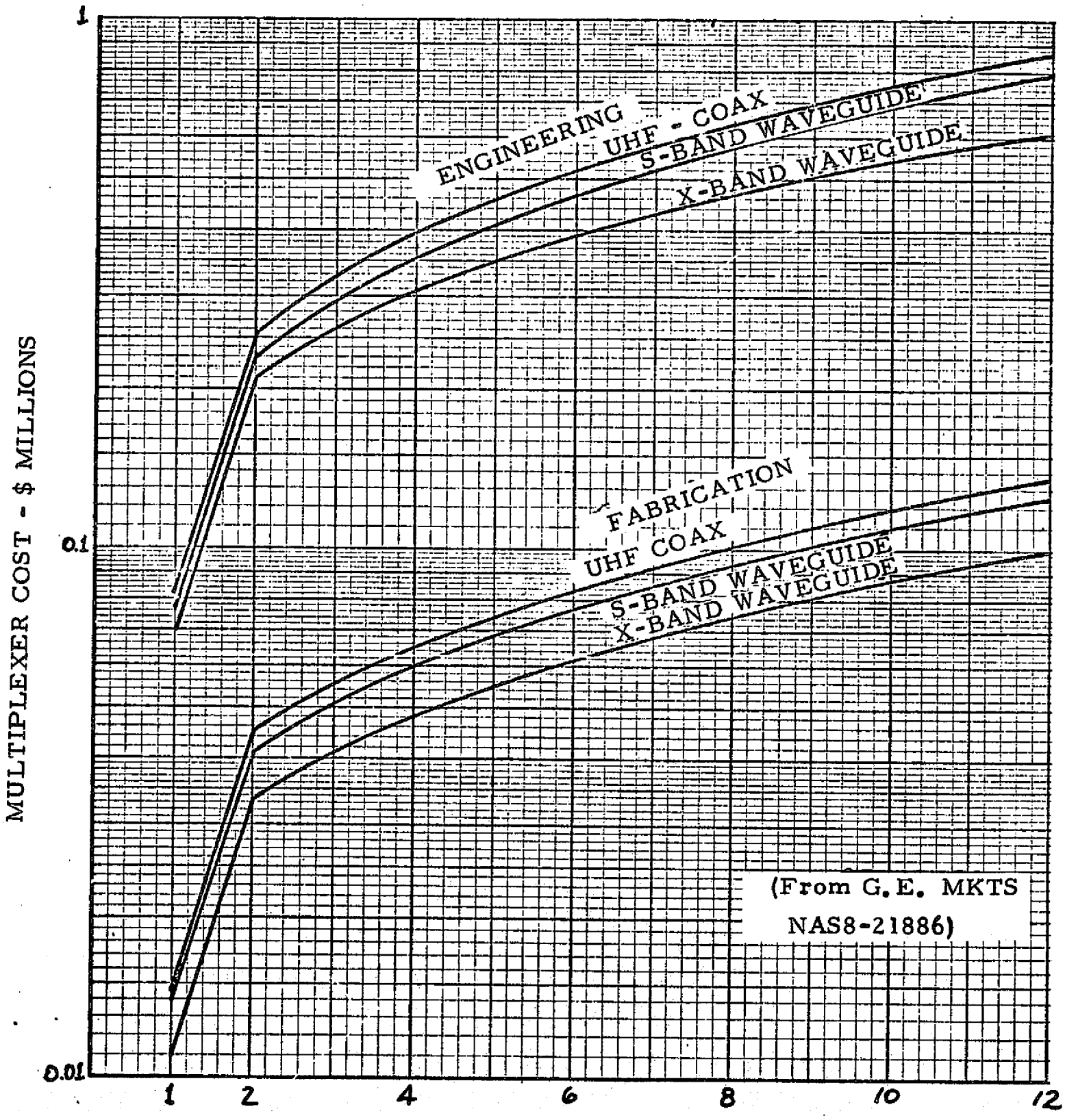


Figure 2-57. Multichannel Multiplexer Cost.

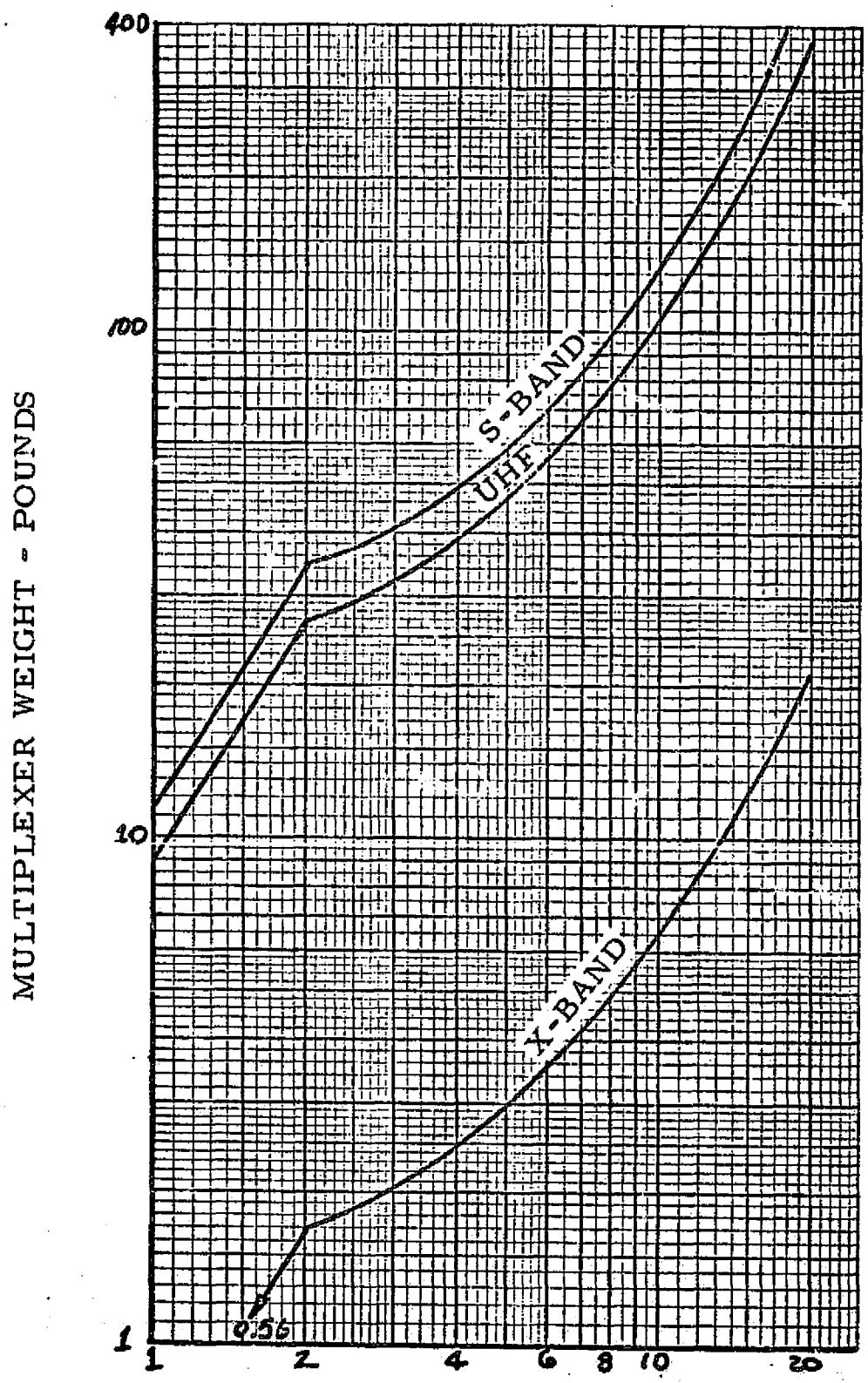


Figure 2-58. Multichannel Multiplexer Weight.

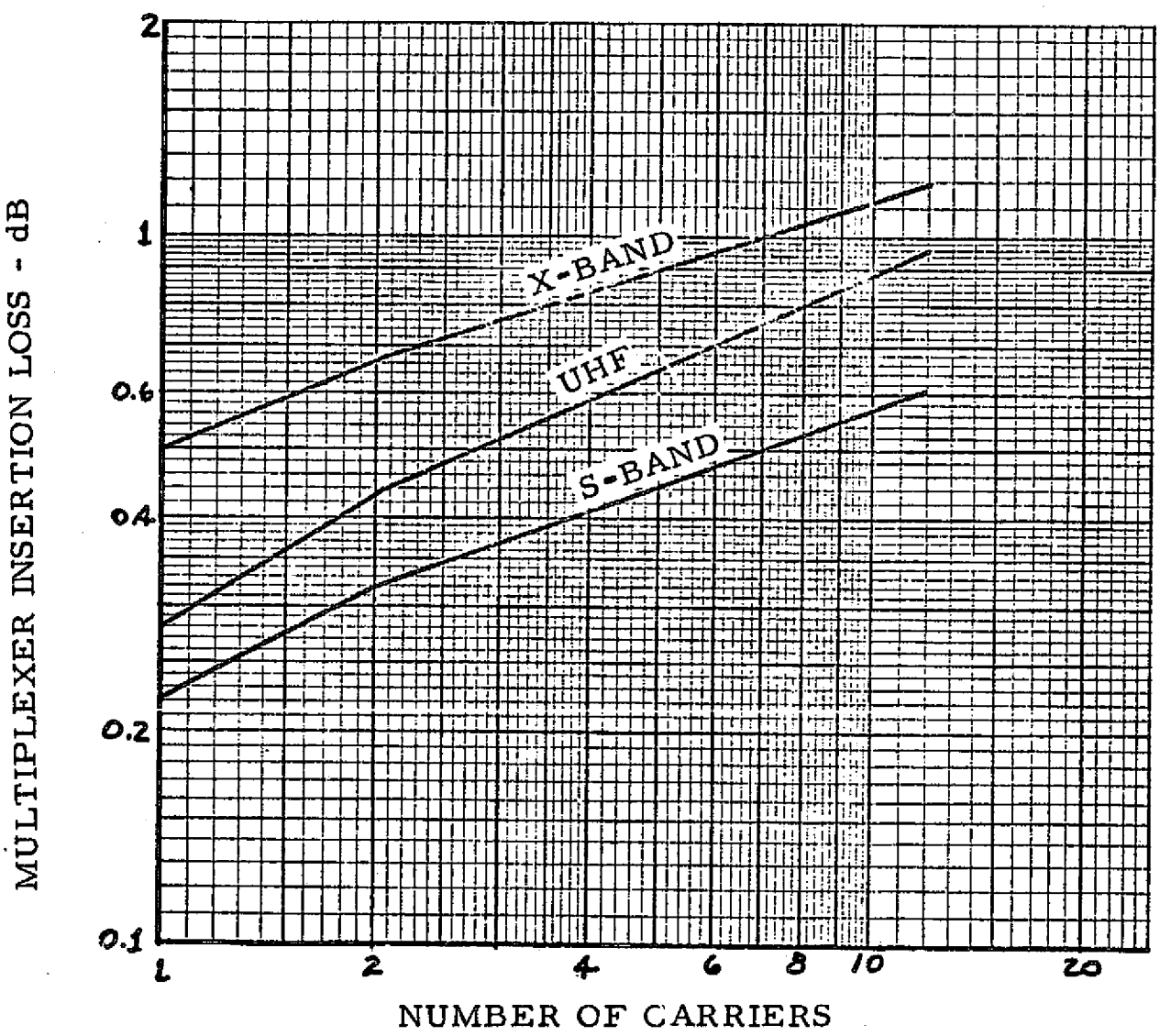


Figure 2-59. Multichannel Multiplexer Insertion Loss.

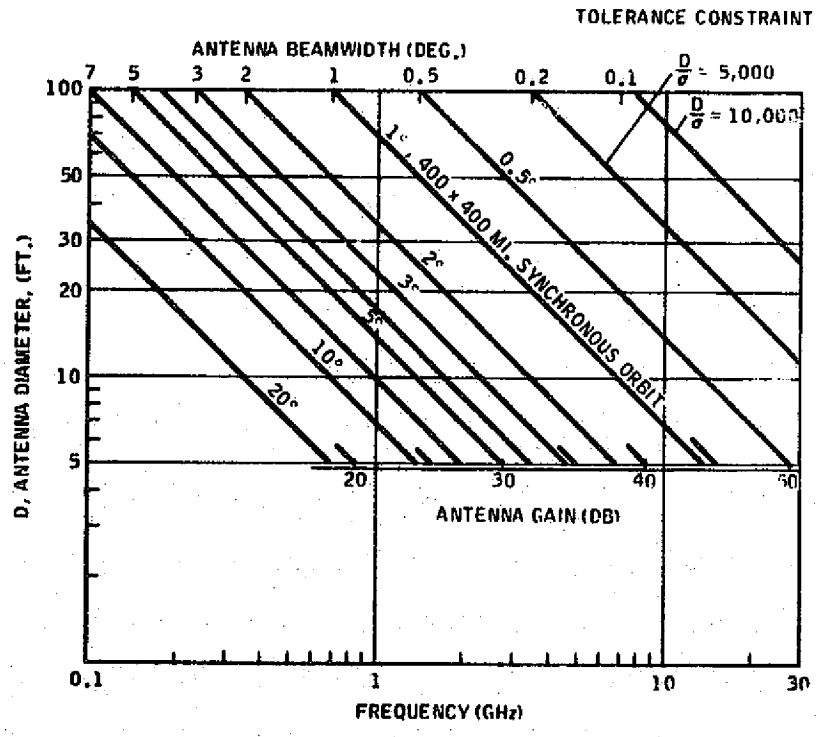


Figure 2-60. Antenna Size Requirements for a Given Beamwidth Versus Operation Frequency.

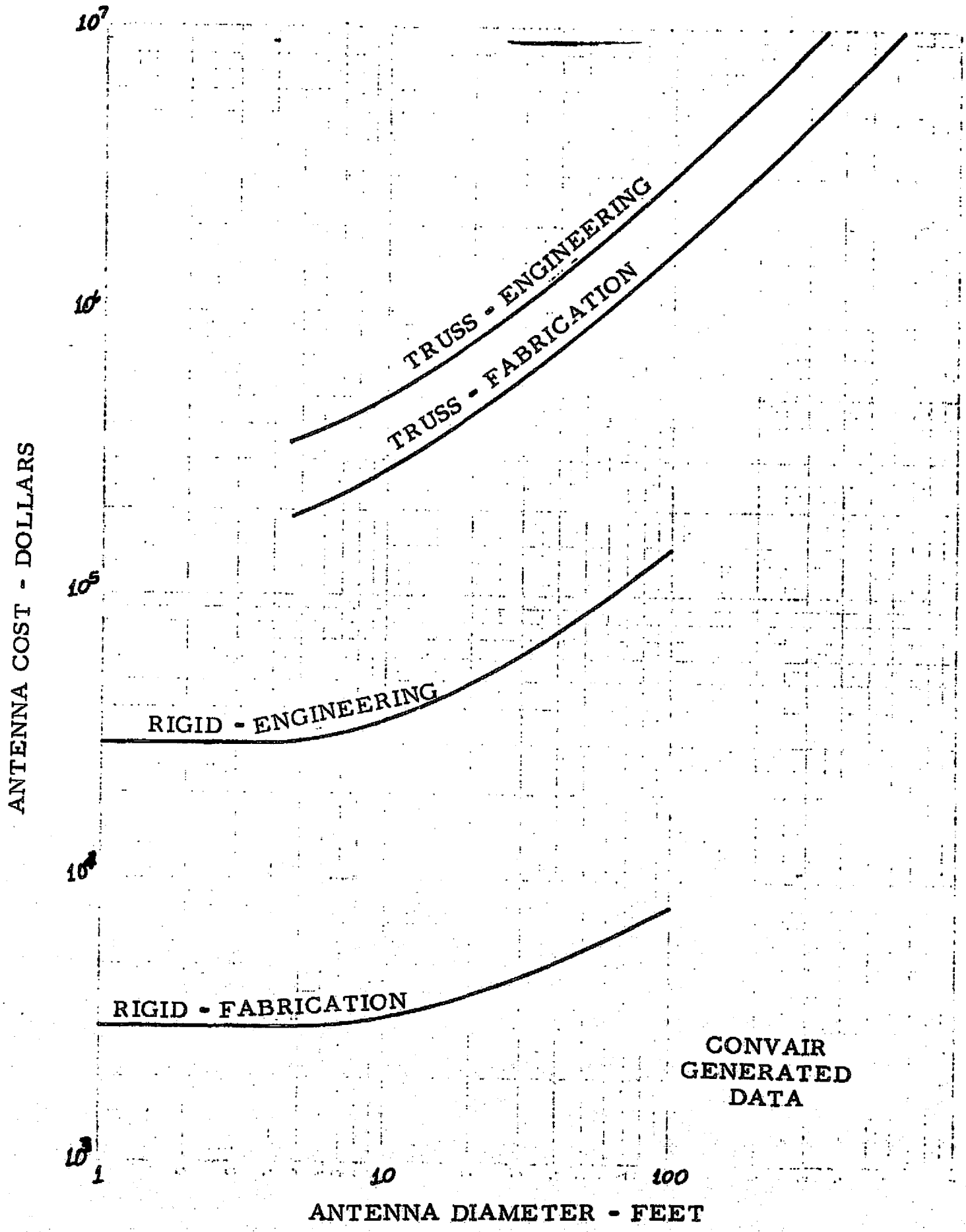


Figure 2-61. Antenna Costs.

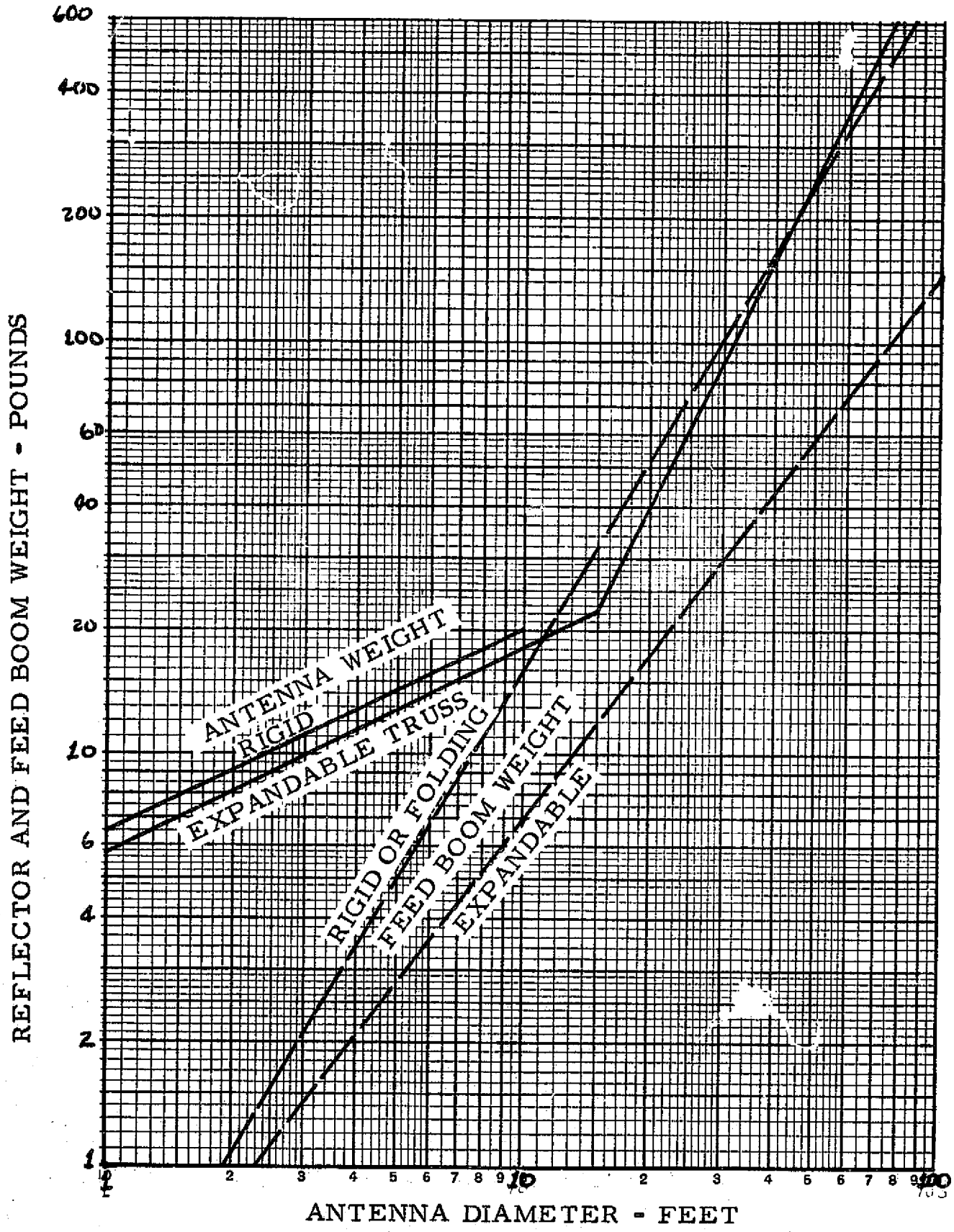


Figure 2-62. Antenna Weight.

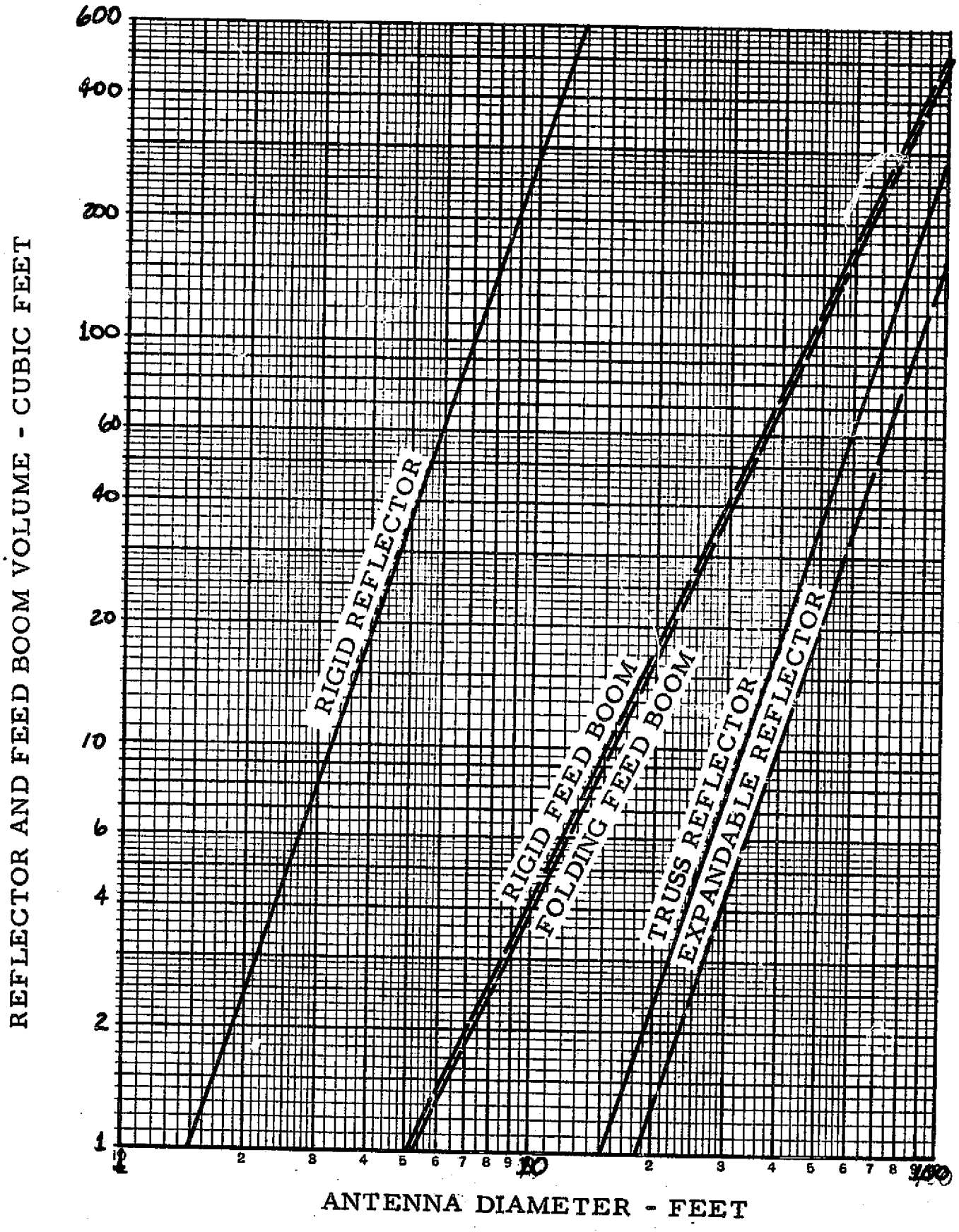


Figure 2-63. Antenna Volume.

and Frequency Sharing by the Rand Corporation under NASA contract NASr-21(02) and also with data obtained from Messrs. E. S. Miller and R. Alexovich of Lewis Research Center, Mr. Robert Walp of Hughes Aircraft and Mr. R. P. Haviland of General Electric.

2.3.3.1 GROUND DOWNLINK SYSTEM ECONOMIC MODEL. Table 2-32 itemizes the cost elements for the ground downlink system. In this case, a learning curve is used, rather than R&D cost, to estimate receiver costs. The basis of the learning curve is simply that if a certain number of units cost C_N dollars each, twice as many units will sell for KC_N where K is less than 1. By taking the average of this curve, the average cost of each unit may be determined. The resulting learning curves are shown in Figure 2-64.

2.3.3.2 GROUND RECEIVING ANTENNA. Jansky and Bailey Systems Engineering Department developed an extensive treatment of antenna costs, treating yagi and parabolic antennas as well as hybrids, such as parabolic cylinders, disks-on-rod, and corner reflectors. The retail costs are presented in Figures 2-65 and 2-66 for a quantity of one. For larger quantities a 95 per cent learning curve is applied for wideband antennas and an 89 per cent curve for parabolas. These costs generally agree with catalog cost data.

The General Electric TVBS final briefing presented antenna costs and installation costs for the four frequency bands of interest. Since the installation costs were plotted as a function of gain, it was desirable to convert to effective parabolic diameter as in Figures 2-65 and 2-66.

The C.C.I.R. UHF antenna costs agree closely with the General Electric data. In addition, a cost-frequency conversion table was given to project the antenna costs to the three other frequency bands (see Table 2-33). The results of this conversion are shown by the dashed lines in Figure 2-66.

Table 2-32. Ground Downlink System Economic Model.

IV. GROUND DOWNLINK SYSTEM		VALUE
A. Unit Recurring Cost		
	1. Downlink Receiving Antenna	Curve
	2. Downlink Receiver/Converter	Curve
	3. Total Unit Cost	IVA1 + IVA2
B. Non-recurring Cost (Research & Development)		
	1. Downlink Receiving Antenna	Learning Curve
	2. Downlink Receiver/Converter	Learning Curve
	3. Testing & Management	Incl. in above.
	4. Total Non-recurring Cost	Incl. in above.
C. Acquisition Cost		
	1. Unit Hardware	IVA3
	2. Unit Installation	
	a. Antenna	Curve
	b. Receiver/Converter	100% × IVA2
	3. Total Acquisition Cost	N_{DL} × (IVC1 + IVC2)
D. Operations Cost		
	1. Annual Maintenance Cost	10% × (IVC1)
	2. Total Operations Cost	$N_{DL} \times N_L \times$ IVD1

N_{DL} = Number of downlink stations.

N_L = System lifetime in years.

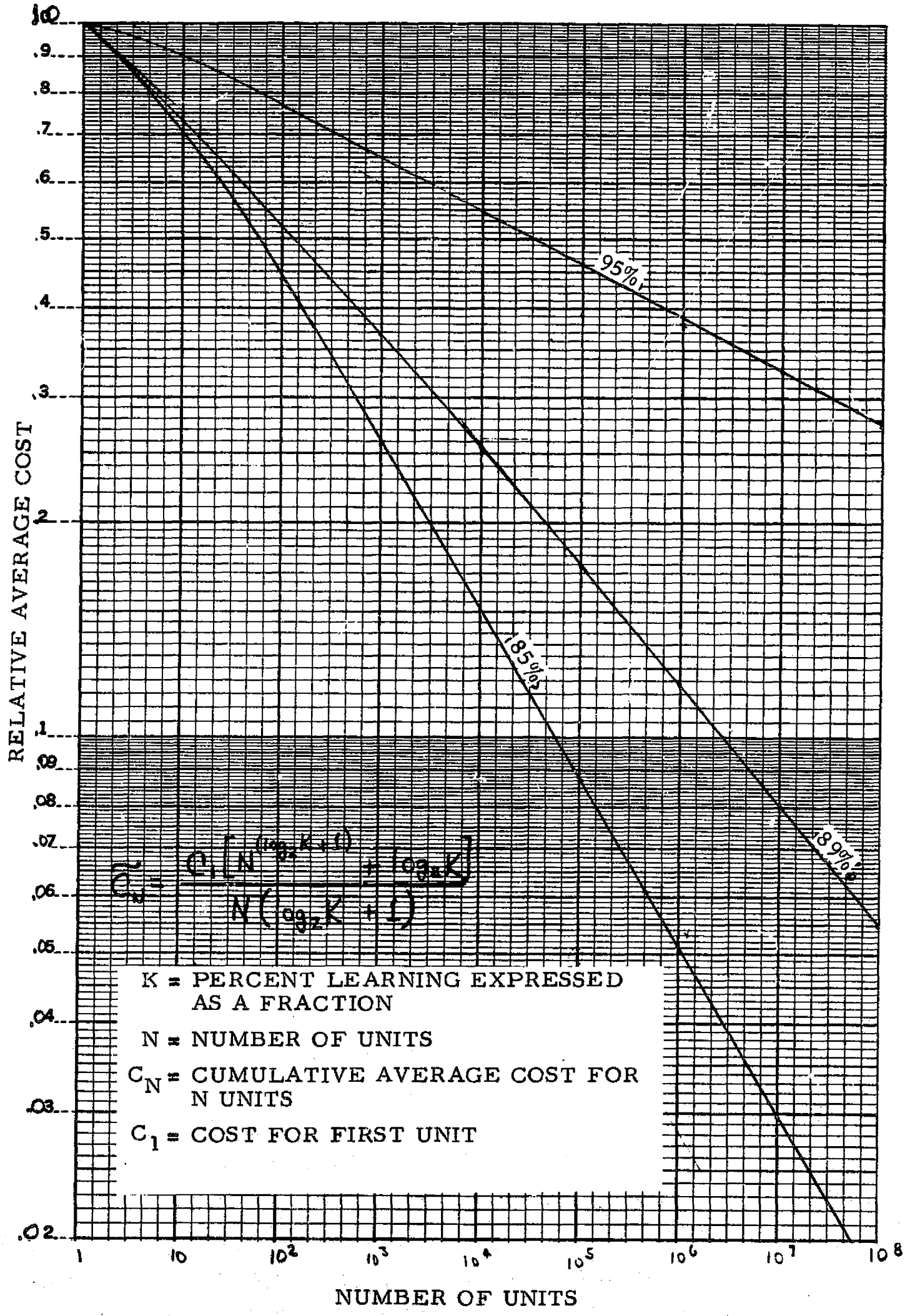


Figure 2-64. Manufacturing Learning Curves.

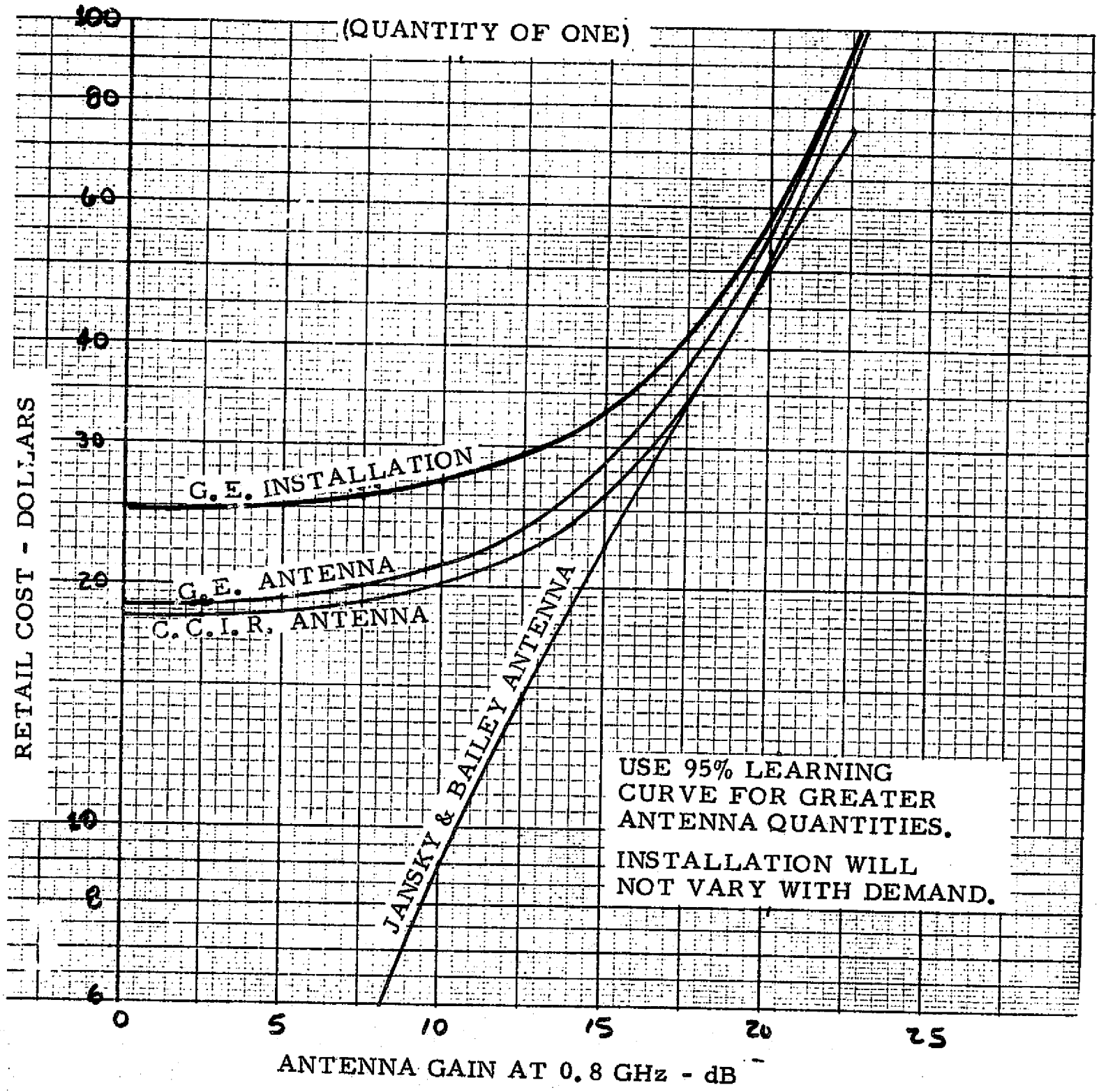


Figure 2-65. UHF Antenna Costs.

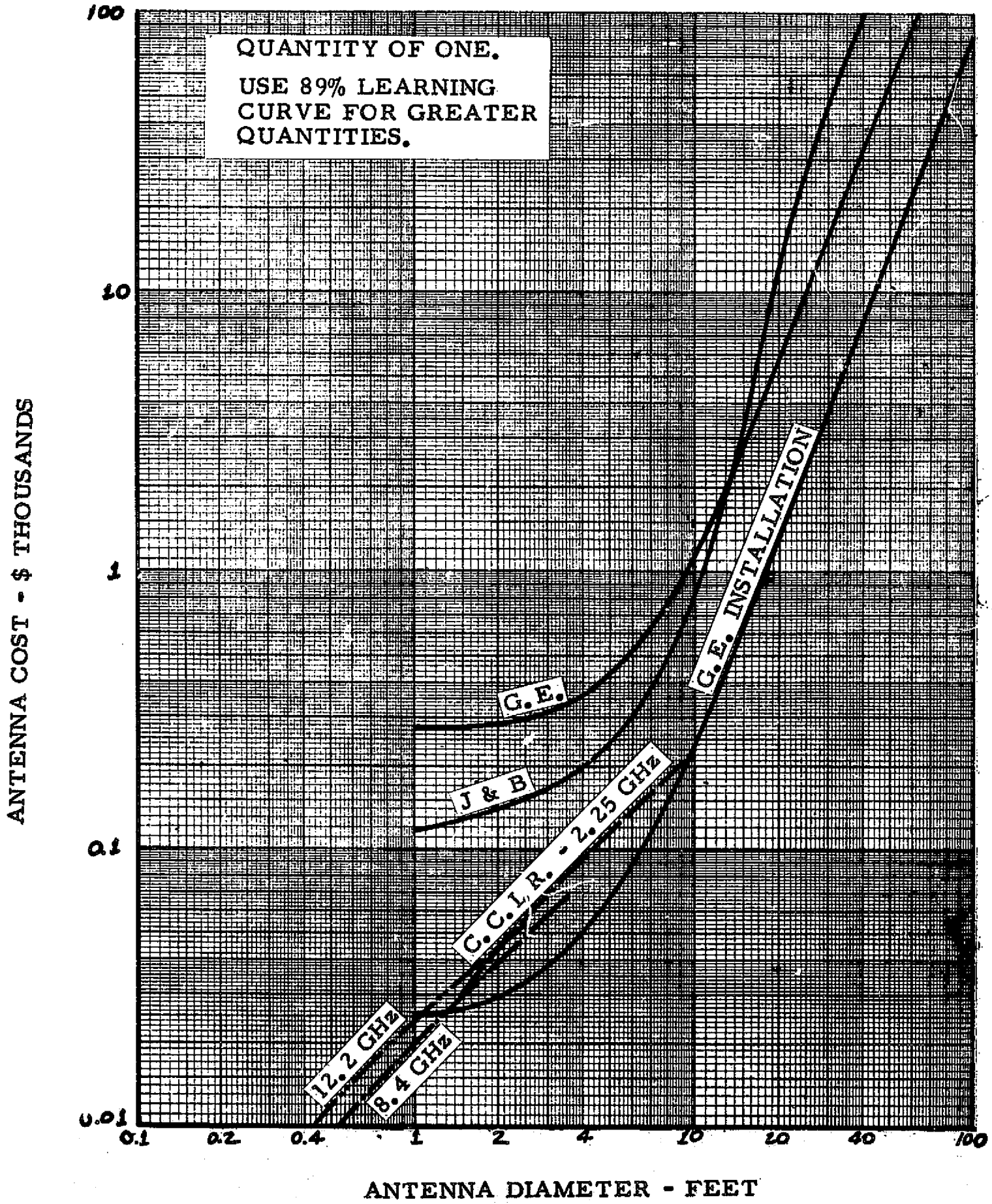


Figure 2-66. Parabolic Antenna Costs.

Table 2-33. Cost-frequency adjustment from C.C.I.R. report — Annex II.

Freq GHz	Gain dB	Cost Multiplying Factor
2.25	16	0.755
	25	0.391
	37	0.065
8.45	16	0.195
	25	0.101
	37	0.016
12.2	16	0.148
	25	0.081
	37	0.0127

Due to the vagueness and inconsistency of this conversion, catalog data was examined to determine increases in cost as a function of frequency. There appears to be an approximate 5 per cent increase per frequency band above the G.E. curve of Figure 2-66 as follows:

FREQUENCY (GHZ)	INCREASE IN COST ABOVE G.E. COST IN FIGURE 2-1 (%)
0.8	0
2.5	5
8.4	10
12.2	15

2.3.3.3 RECEIVER/CONVERTER SUBSYSTEM.

a. Commercial Quality Receivers — The study conducted by Jansky and Bailey included an extensive market survey of both AM and FM receiver/preamplifier/converters for use in reception from a geostationary satellite. A number of errors were found in the report (e.g. the wrong learning curve was used for projections to a unit quantity cost). These errors were corrected for the data in this study. In addition, vendors were contacted to spot check the Jansky and Bailey data. The resulting parametric data is shown in Figures 2-67 and 2-68.

b. Consumer Quality Receivers

Mass produced receiver cost data was obtained at a Phase I briefing of a NASA funded study by the General Electric Co. ("Ground Signal Processing Systems" NAS 3-11520). The following material is primarily based upon data obtained at that review and also from data listed in a report by the CCIR Study Group, USSG IV.

In order to meet the requirements of the current MSFC TV broadcast study a wide range of receiver sensitivity and cost data is necessary. It has also been determined by the GD/Convair user analysis that a multiple channel capability is generally required by all of the potential users who were contacted.

In view of these requirements the technical and cost data found in the referenced G.E. and CCIR studies has been utilized as a base to develop the range of ground receiver parametric data required for this study.

The data listed in Table 2-34 is a copy of the Phase I cost summary data published by G.E. This data is plotted in Figures 2-69 and 2-70. The projects from the single points noted in Figure 2-70 follow the same slope as those shown in Figure 2-69 for the FM systems. In developing the data shown in these figures, it was assumed that the initial production year was 1969 and that the indicated volume was produced each year through 1975.

The cost data from Table 2-34 has been multiplied by a factor of 2 prior to plotting in order to account for manufacturer's profit, distribution, and sales costs. (According to G.E. an approximate factor of 2 would be used to determine retail cost in a consumer oriented market while in the military or commercial quality market a factor of four or greater would probably be used, primarily because of more stringent specifications and service requirements.)

Production estimates vs. time for annual production volumes of 10^3 and 10^6 for the three cases analyzed were published in the Phase I briefing and this data is plotted in Figures 2-71 through 2-73.

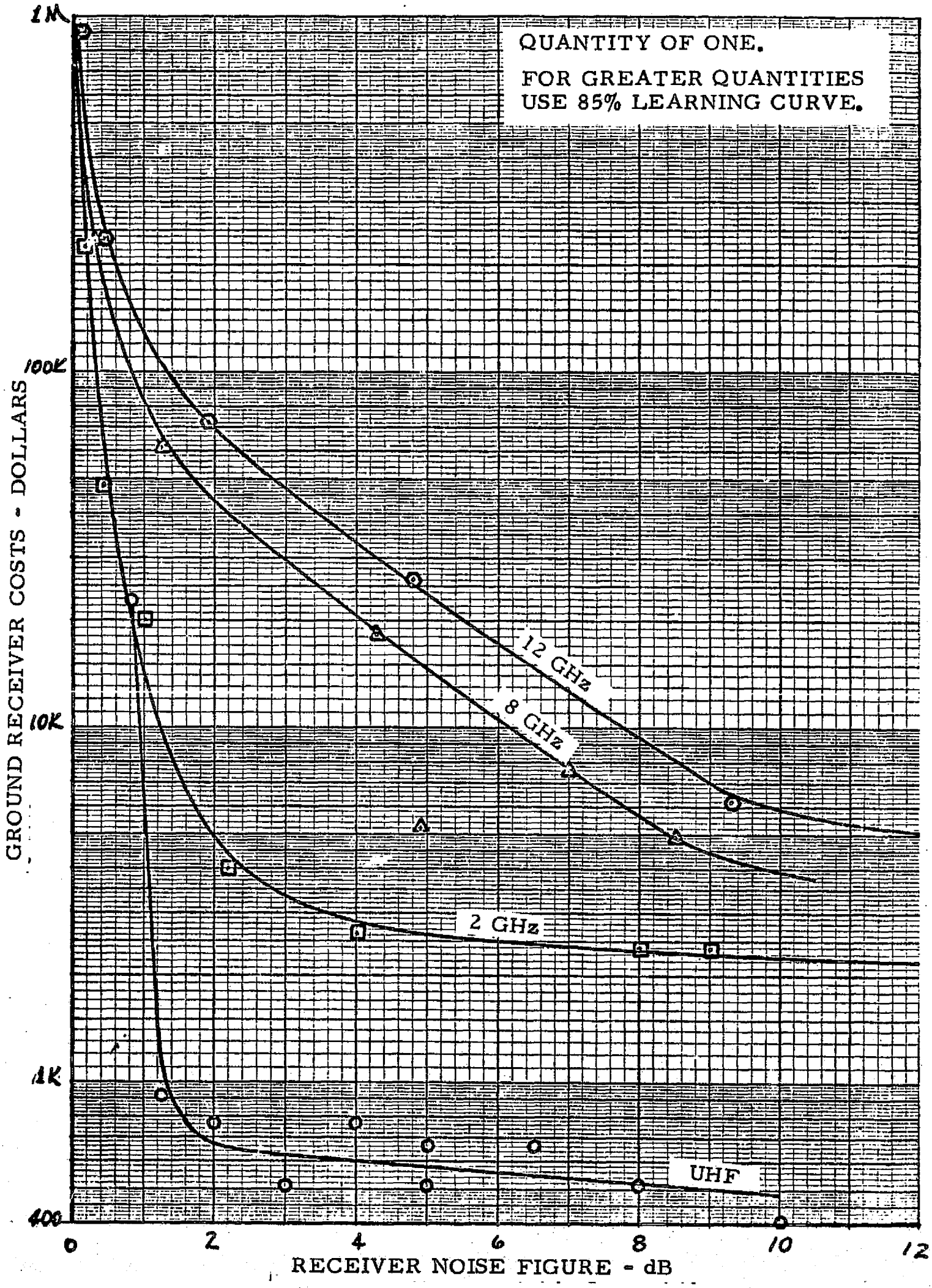


Figure 2-67. Commercial Quality AM Receiver Costs.

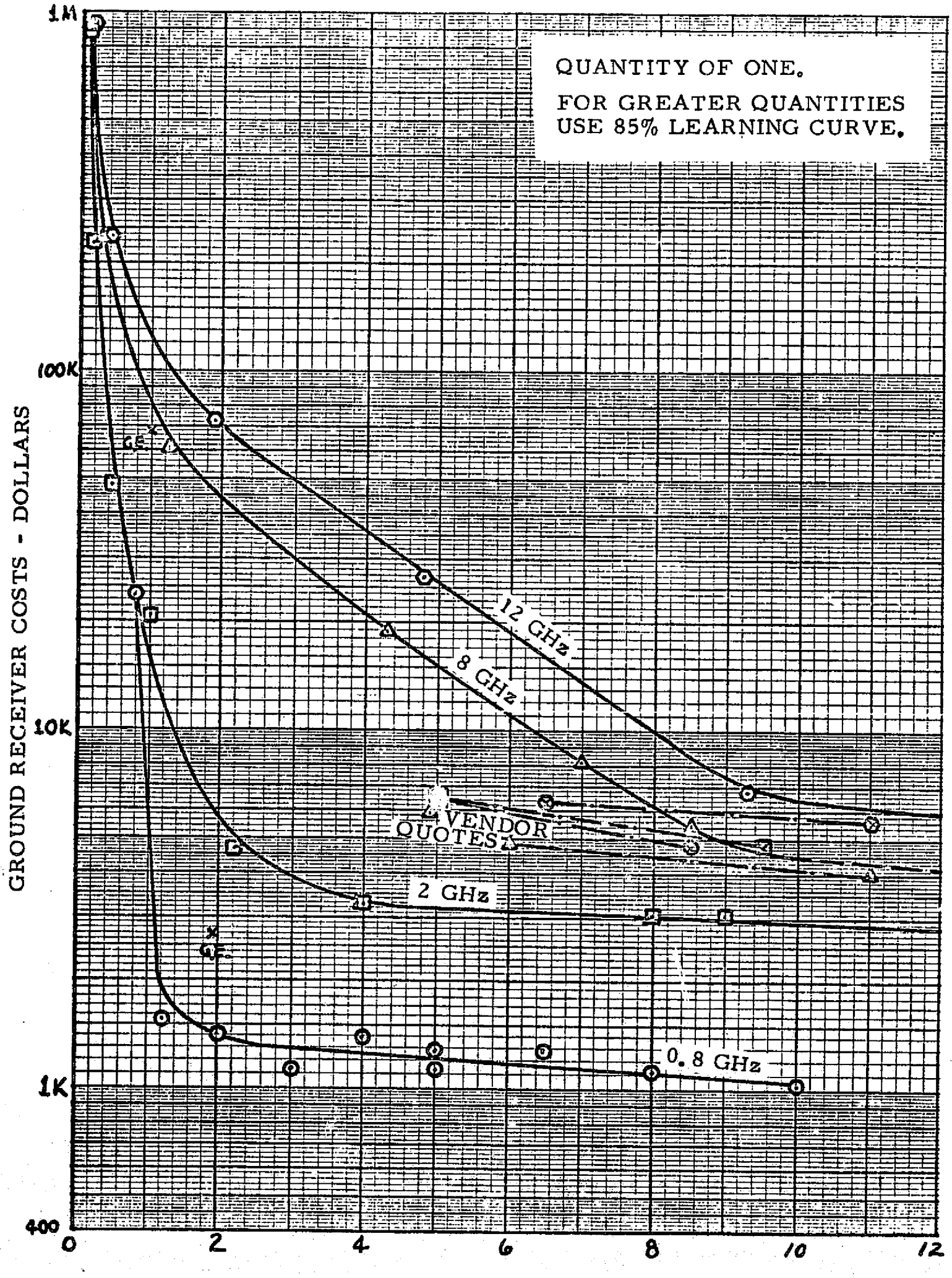


Figure 2-68. Commercial Quality FM Receiver Costs.

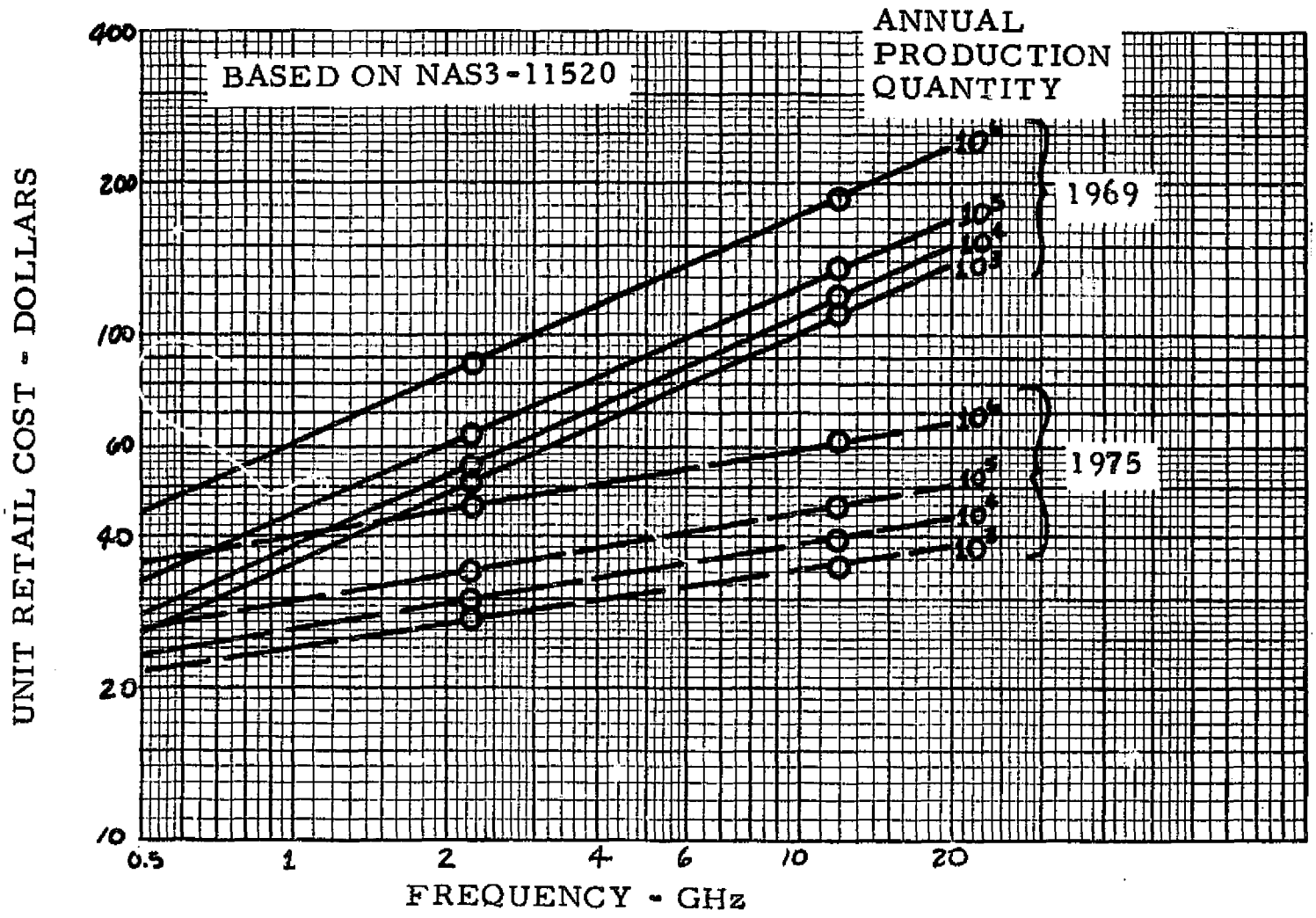


Figure 2-69. FM Receiver Cost Projections.

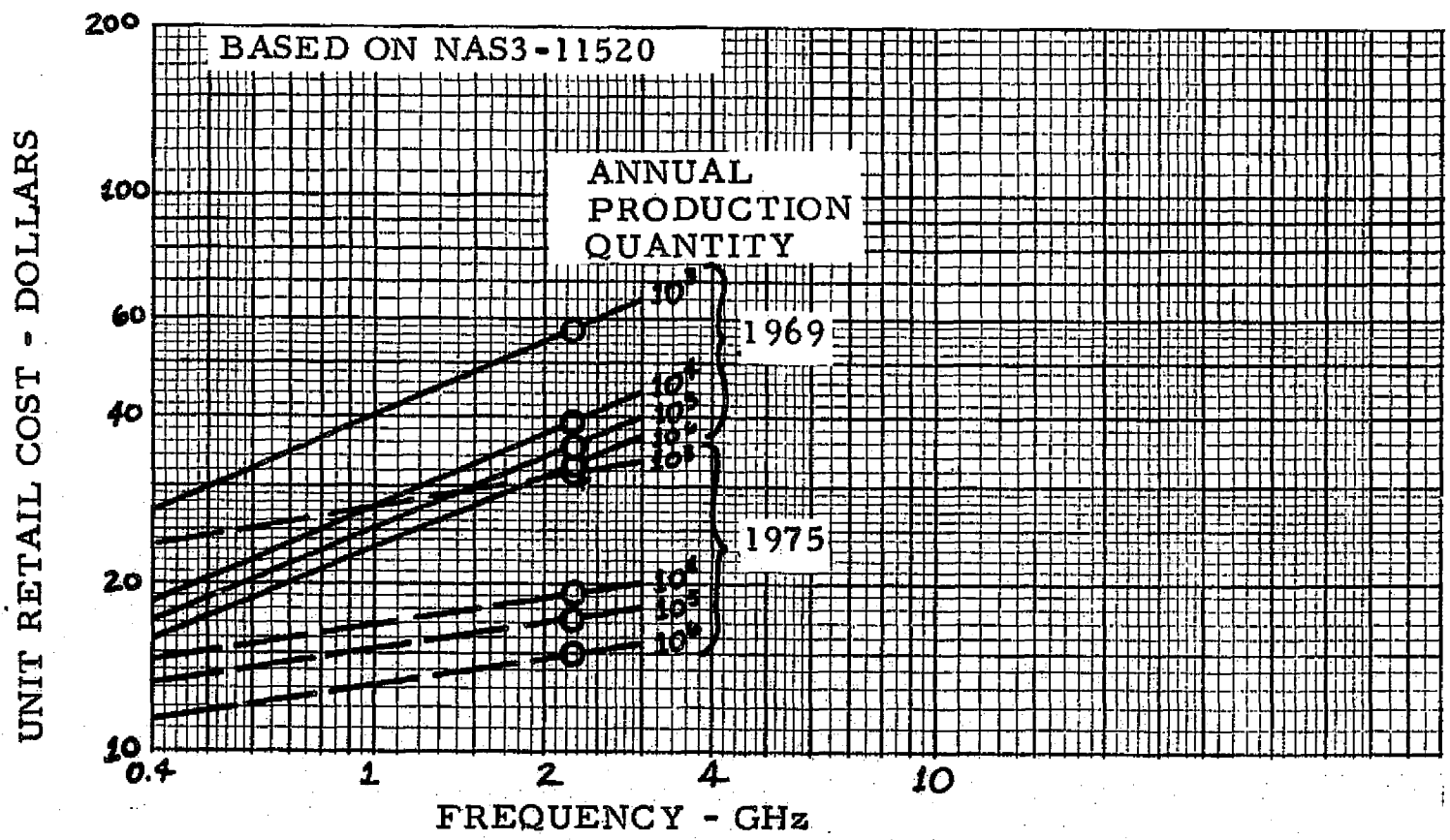


Figure 2-70. AM Receiver Cost Projections.

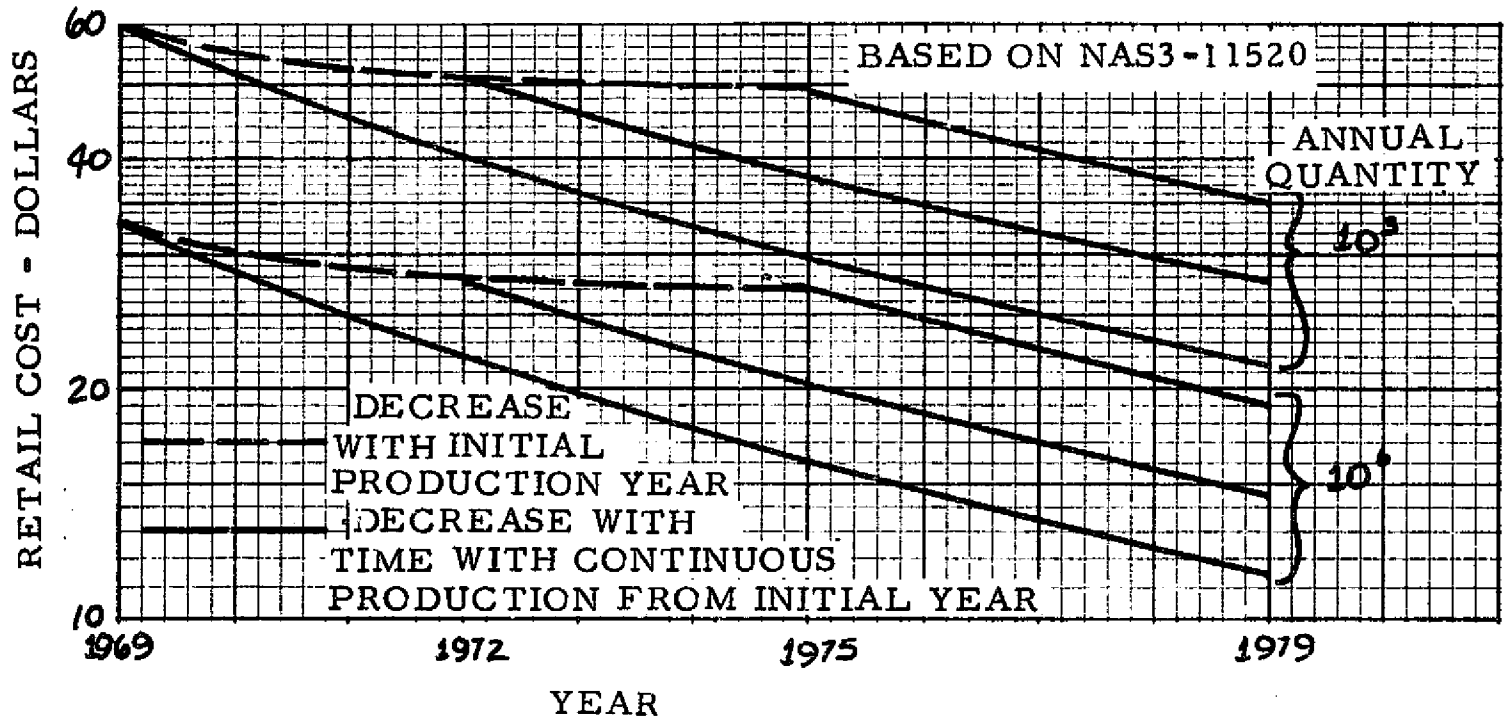


Figure 2-71. 2.25 GHz AM Production Cost Estimates.

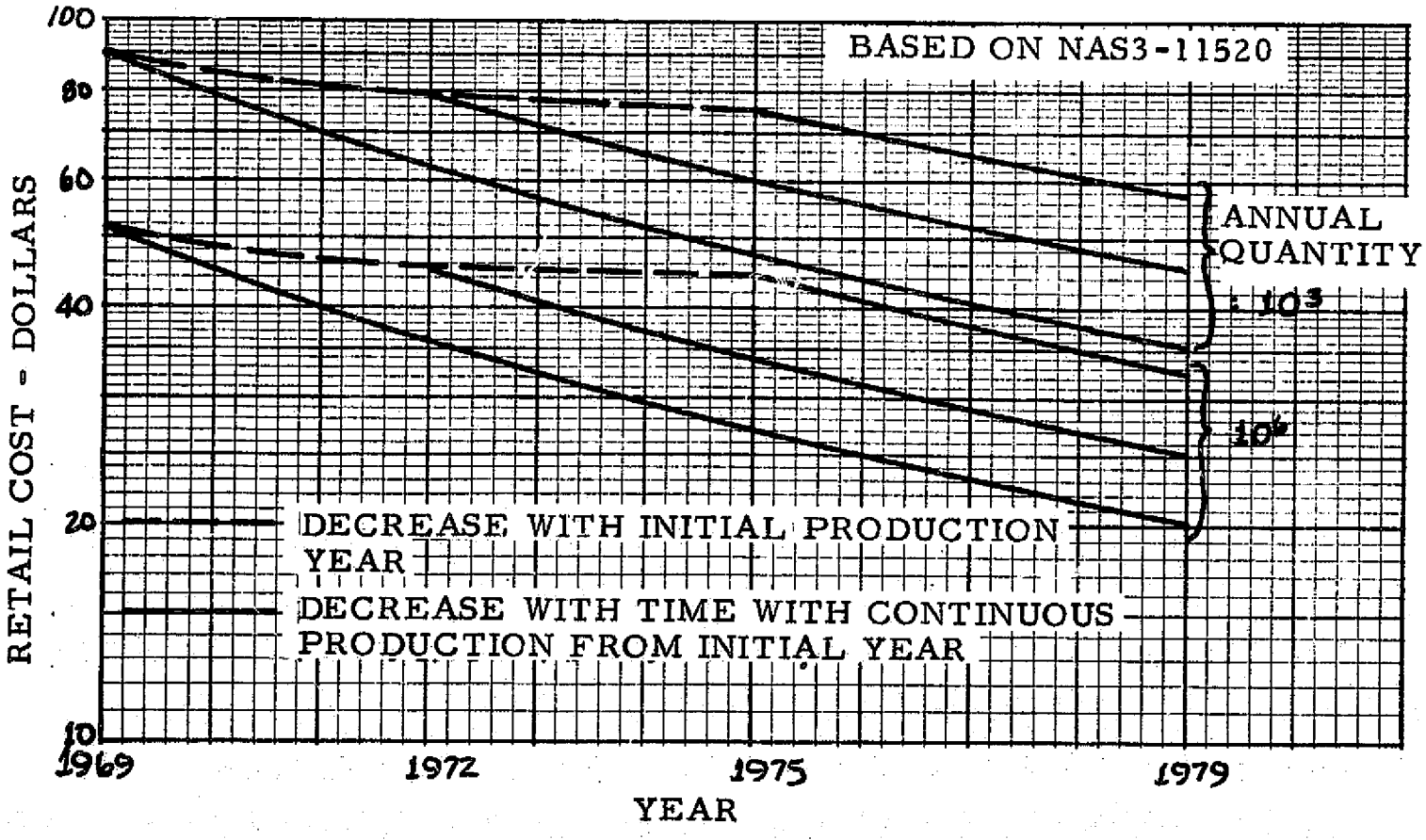


Figure 2-72. 2.25 GHz FM Production Cost Estimates.

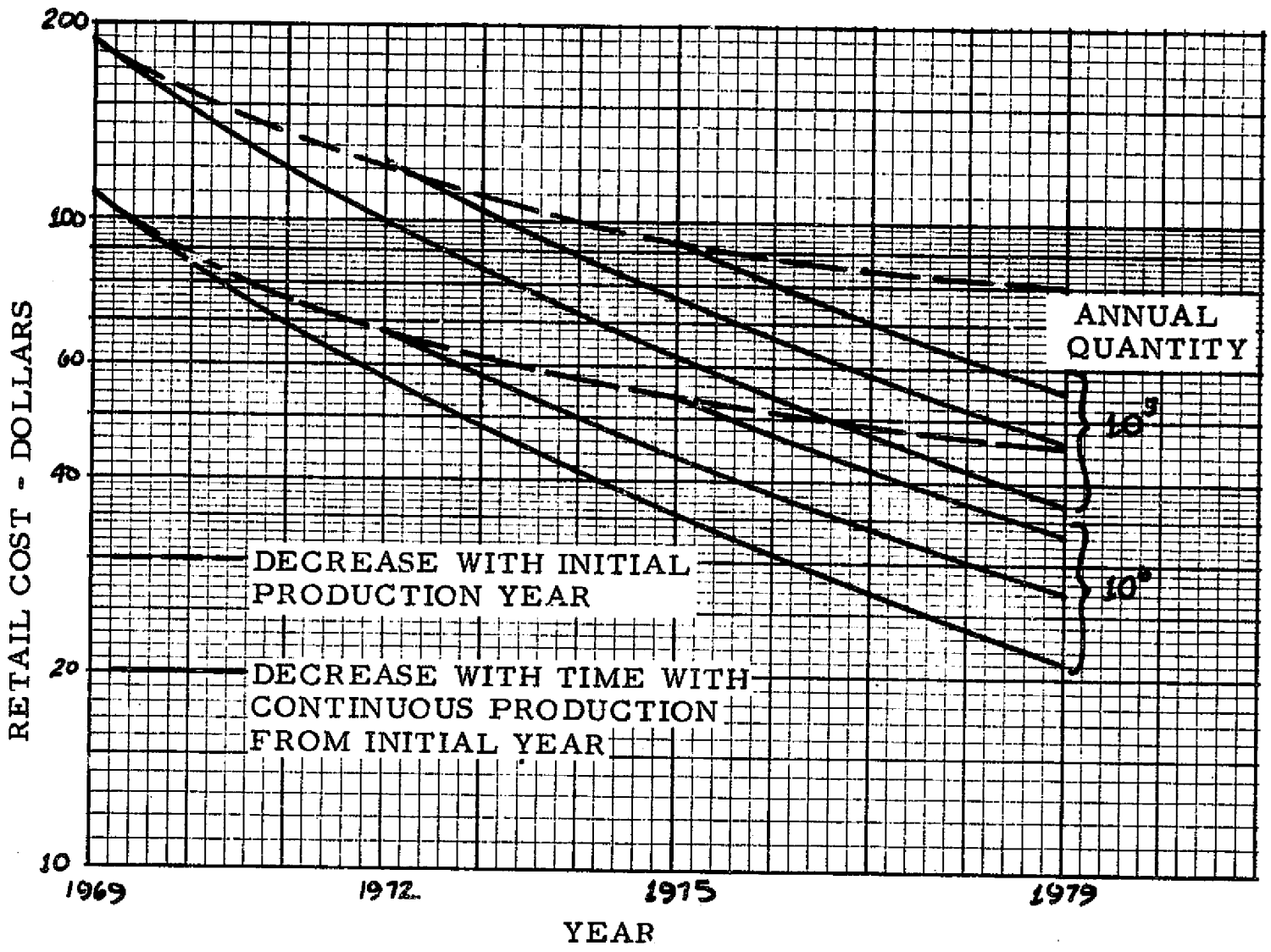


Figure 2-73. 12 GHz FM Production Cost Estimates.

Table 2-34. Summary of NAS3-11520 Phase I Results.

	Unit Manufacturing Cost — Dollars							
	1969				1975			
Annual Quantity	10^3	10^4	10^5	10^6	10^3	10^4	10^5	10^6
2.25 GHz AM	29.47	19.98	17.75	16.51	16.45	9.65	8.60	8.01
2.25 GHz FM	44.38	31.53	27.50	25.66	23.60	16.80	14.60	13.69
12.0 GHz FM	93.94	69.14	59.29	54.29	30.90	22.75	19.50	17.87

Preamplifier retail costs were generated for three frequency bands based upon the General Electric study and the C.C.I.R. study report. These costs are shown in Figure 2-74.

The preamplifier costs and the data from Figures 2-72 and 2-73 were combined to give combined preamp/receiver costs. Typical noise figures for these devices were obtained from the C.C.I.R. study group IV data and the resulting cost data of Figure 2-75 was derived. The cost reduction as a function of production quantity is given in Figure 2-76.

The type of tuning or channel selection system selected for use in conjunction with a low cost ground receiving system will be determined by several factors, such as frequency allocations, adjacent band or channel frequency proximity and signal characteristics, the physical location of adjacent or co-channel stations and the sensitivity required of the ground station. In order to constrain the receiver cost analysis within the bounds of the current TVBS study the G.E. NAS 3-11520 and CCIR Study Group IV data was utilized to derive multiple channel receiving system cost data.

It is assumed that the bandwidth of the balanced mixers and preamplifiers is sufficient to operate over the frequency ranges considered. It is also assumed that suitable preselector and image frequency filtering will be incorporated as required since etched circuit filters may be used which will probably have an insignificant cost impact upon the mass produced TV signal processor overall cost.

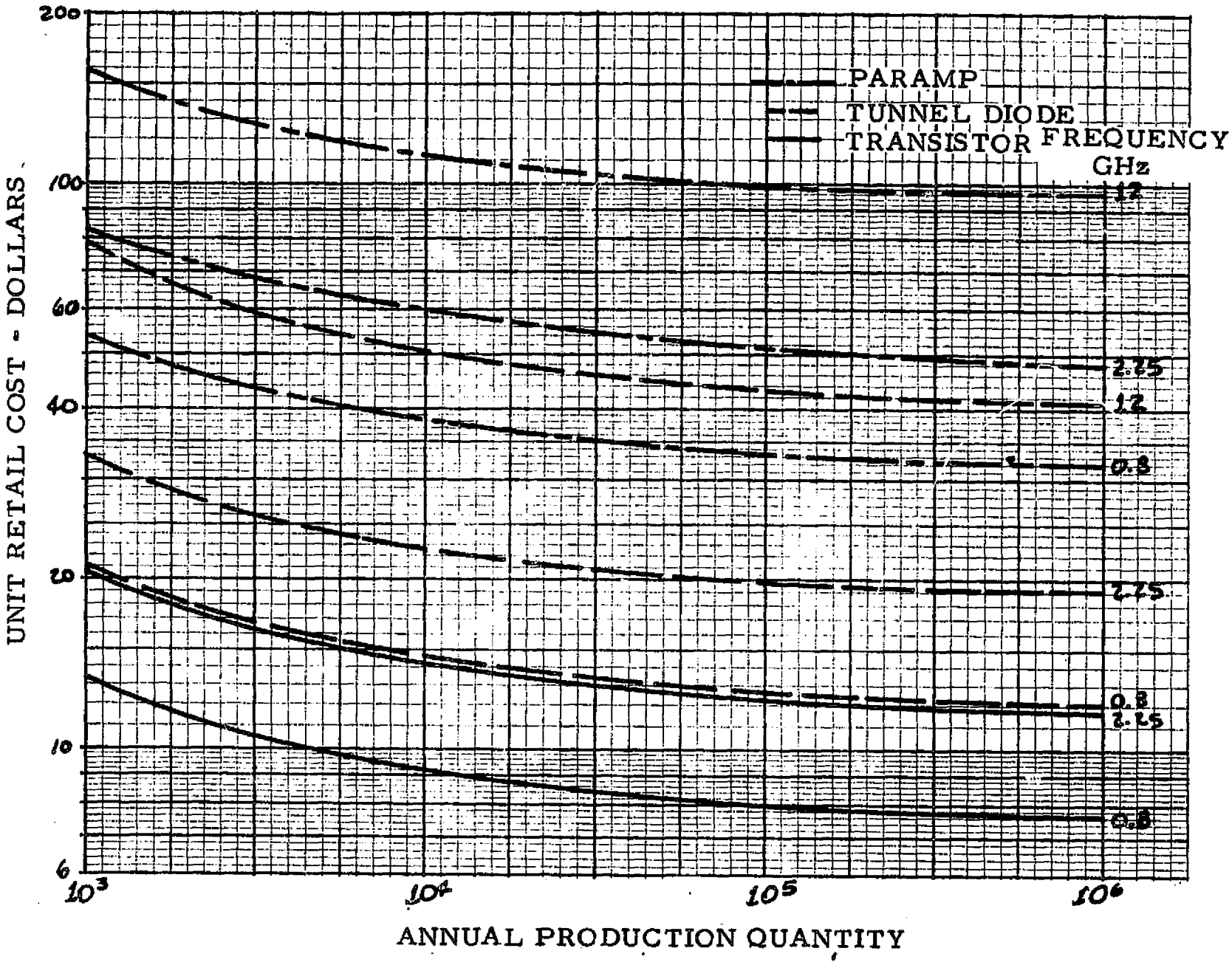


Figure 2-74. Preamplifier Cost.

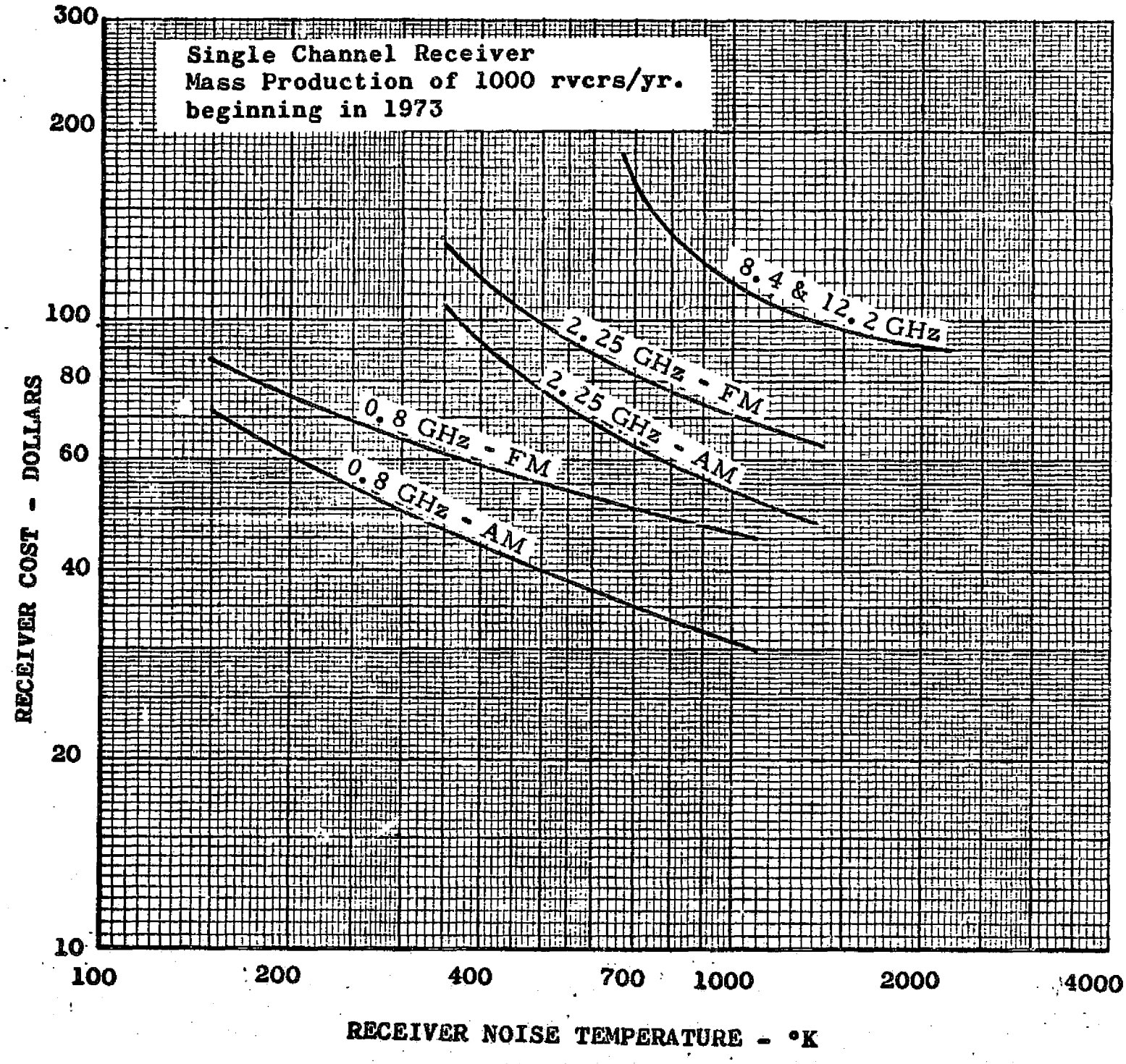


Figure 2-75. Consumer Quality Receiver Costs.

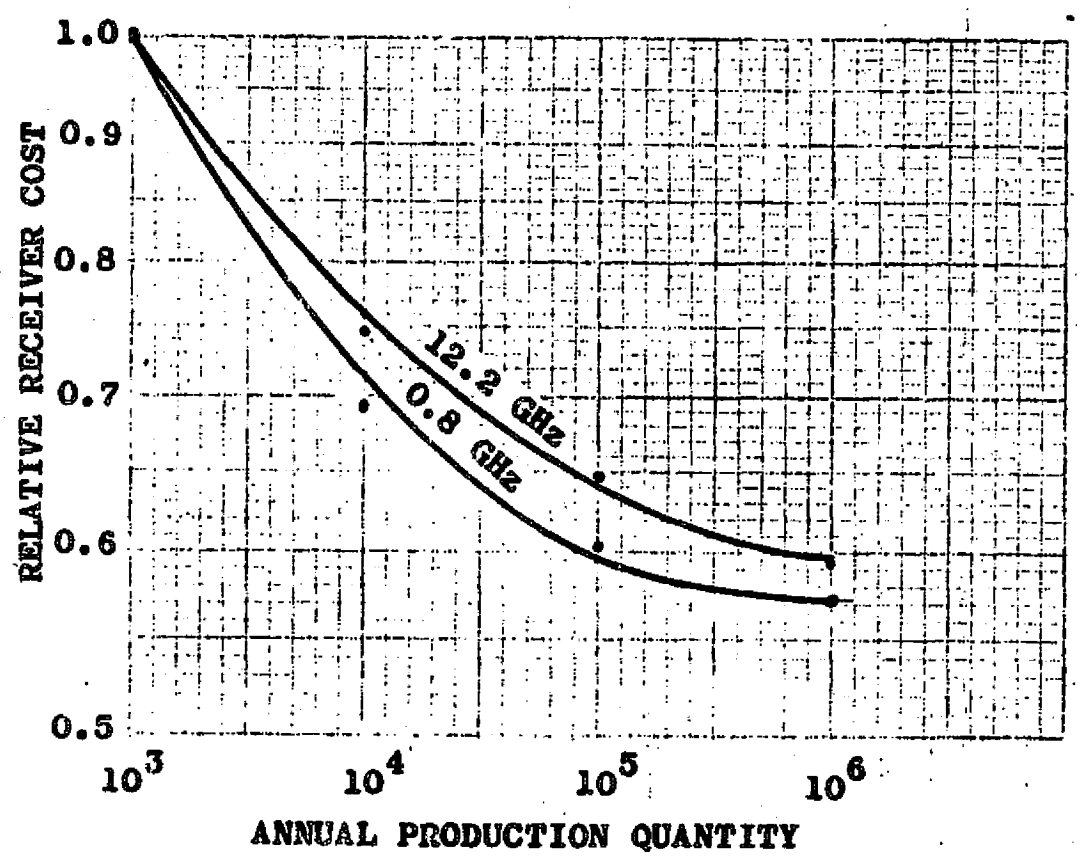


Figure 2-76. Cost Reductions for Mass Produced Components.

In the AM-VSB case a three channel capability is available in conjunction with the G.E. design since sufficient IF bandwidth was incorporated to allow tuning over three AM-VSB channels by means of the conventional unmodified TV set UHF tuner.

The cost of a multiple channel receiving system signal processor is given by

$$C_M = C_B + C_2 + (N-2)\, C_3, \quad N \geq 2$$

where

C_M = Total cost of multiple channel processor.

C_B = Basic single receiver cost for a specified frequency range and modulation type from Figures 2-75 and 2-76

C_2 = Cost of adding required hardware to facilitate addition of one channel (a triple channel capability with AMVSB modulation). This also includes the cost of additional hardware required to add a greater channel capability, namely the selection switch located near the conventional TV set and a ground wire running to the antenna unit. (See Figure 2-77).

C_3 = Cost of adding additional channel capability after C_2 has been implemented. (See Figure 2-77).

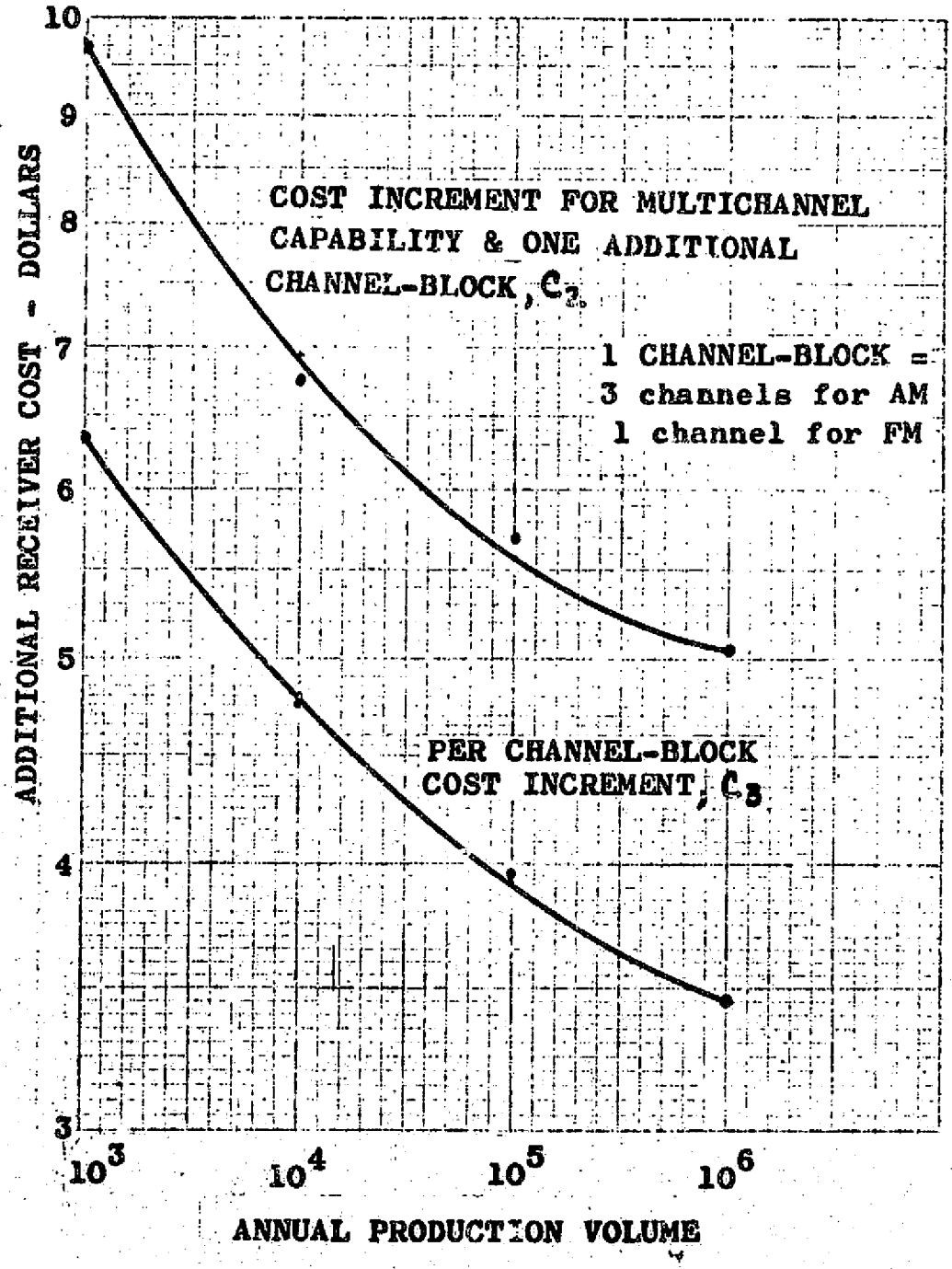


Figure 2-77. Multiple Channel Cost Increments.

2.4 LAUNCH VEHICLES

The launch vehicles considered in the study were the Titan IIIC, Titan IIID/Centaur, the Saturn IB/Centaur, and manned and unmanned versions of the Saturn V. Configurations of the Saturn vehicle were used to set payload weights and envelopes for optimization of the TV broadcast satellites. The Saturn IB/Centaur is not an operational launch vehicle. The Saturn V provides valid baseline performance and payload envelope constraints, although a Saturn vehicle for a TVBS launch will most probably be one of a new series with the Saturn V as the design point of departure. The Titan configurations are essentially unchanged.

2.4.1 TITAN III LAUNCH VEHICLES - The current Titan III family building blocks (reference 1) are the standard 2-stage core, the stretched core, the five-segment solid rocket motor, the Transtage, Agena and Centaur upper stages.

The Titan IIIC comprises the standard core, two 5-segment solids and a Transtage. The vehicle is operational at ETR. The Titan IIID/Centaur uses Centaur in lieu of the Transtage. All elements are operational with the integrated vehicle being developed for the NASA Viking program. The integrated Centaur/Titan III launch facility will be at ETR with first launch scheduled for 1973.

The Titan IIIM program for a man-rated vehicle for MOL was essentially completed for WTR launch. Final development of the stretched core is in progress, and the 7-segment solids have been demonstration fixed. A Titan IIID7/Centaur is also a possibility for increased payload, but would also require ETR launch facilities not presently being developed.

1 "Performance and Characteristics Handbook, Titan III Vehicle Family," Martin Marietta Denver Division, August 1970.

The Titan IIIC performance is based on the improved Transtage scheduled for availability in 1972. Flight performance margin for Transtage is assumed to be 1.7% of ideal velocity, vehicle is Titan IIIC-26 configuration, and a 90-n.mi. parking orbit is used. Payload to synchronous equatorial orbit is 2,600 lb.

For the TIIID /Centaur, performance margin is set at 1.425% of mission ideal velocity. Sufficient coast capability for injection into synchronous orbit by a third Centaur burn is assumed. Synchronous payload is 7100 lb.

2.4.2 SATURN V CONFIGURATIONS.

The Saturn V is a three-stage launch vehicle developed by NASA to support the Apollo Lunar Landing program. In this configuration, at lift off, it stands about 363 feet tall and weighs nearly 3200 tons.

The S-IC stage is 138 feet tall and 33 feet in diameter. Five F-1 engines generate a total of 7.5 million pounds of thrust at lift off.

The S-II stage is 81.5 feet tall and 33 feet in diameter. Five 205,000 lbf thrust J-2 engines propell the vehicle to a 90 to 100 n.mi. altitude at burn-out.

The S-IVB stage is 58.5 feet tall and 22 feet in diameter. This stage is powered by a single J-2 engine of 205,000 lbf thrust.

The S-IVB stage can be used for departure from parking orbit and for final injection of the payload into synchronous equatorial orbit. Maximum payload in synchronous equatorial orbit, with allowances made for the required 3-start and coast capabilities for the S-IVB, is 62,000 lb.

Launch operations for the Saturn V vehicle are conducted at Complex 39 at E.T.R.

2.4.3 PAYLOAD ENVELOPE

Several payload fairings and stage shrouds are in use or under development for the Titan III programs. The Titan IIIC fairing (Figure 2-78)is currently used on all Titan IIIC vehicles. The sections of the fairing are joined along longitudinal seams that form separation joints permitting the fairing to be jettisoned in three separate trisectors. Silicon insulation protects the payload from ascent heating. Estimated jettison weight of the fairing is 2580 lb. A similar shroud may be used with Centaur (Figure 2-79). Reduced insulation and shorter separable length reduces the estimated jettison weight to 2485 lb.

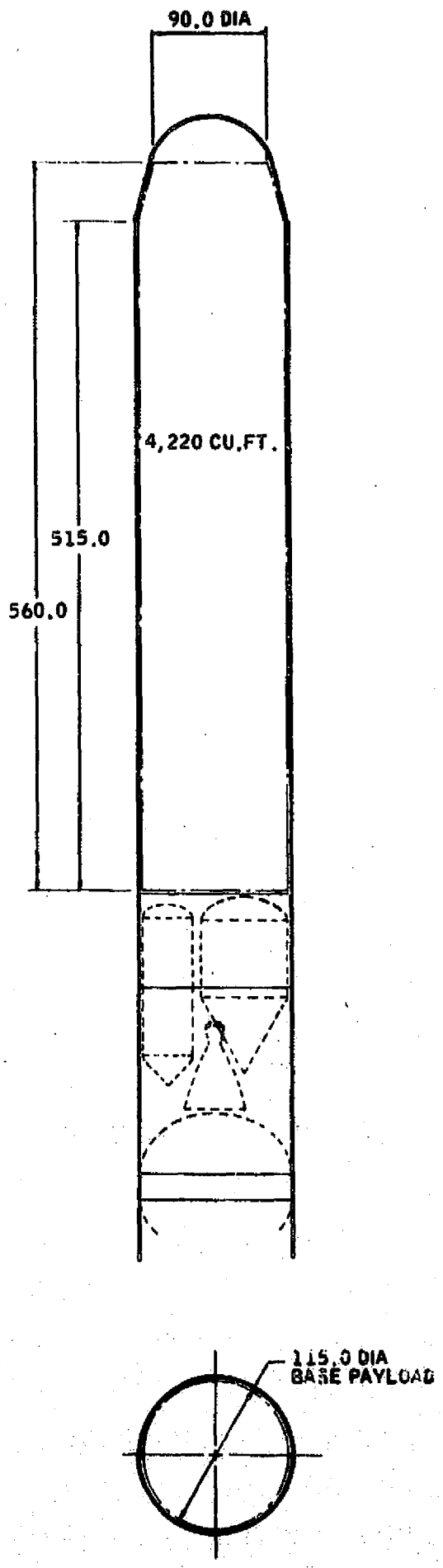
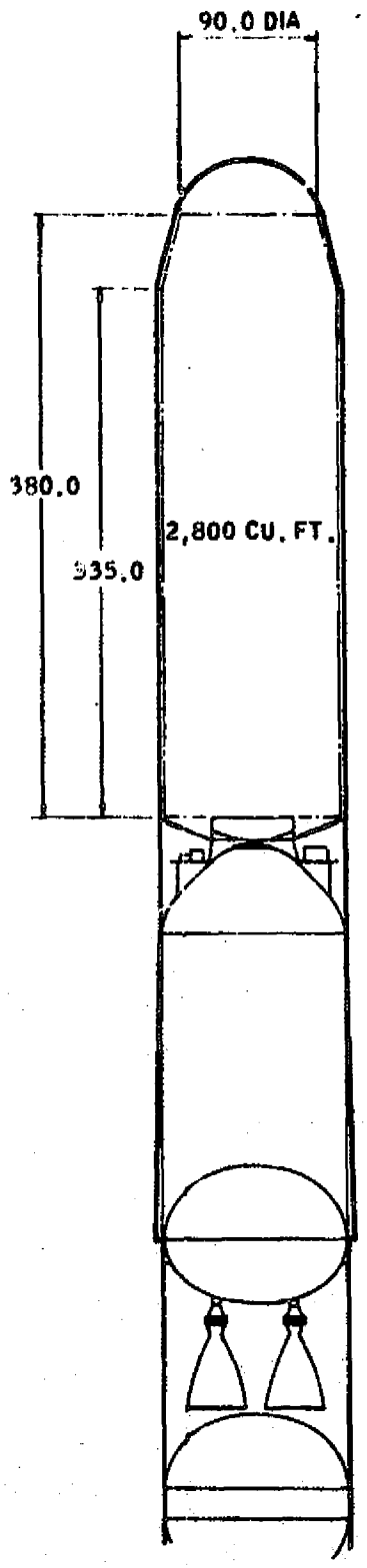


Figure 2-78. Titan IIIC



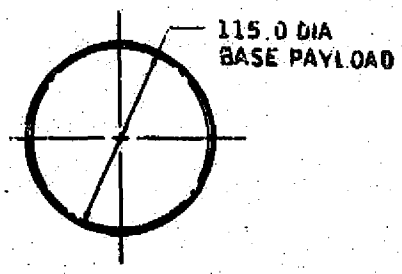


Figure 2-79. Titan IIID/Centaur

The Viking shroud for Centaur is shown in Figure 2-80. The combination payload fairing/stage shroud is jettisoned in two separate halves, and the estimated jettison weight is 4350 lb.

Center segments can be added or removed from the IIIC type shroud and the length of the Viking shroud can be increased to accommodate payloads of various lengths.

Saturn fairings are available to protect the payload from aerodynamic loads and temperatures while in flight. They may also be used for payload thermal conditioning on the launch pad. A typical fairing configuration suitable for a Saturn IB/Centaur is shown in Figure 2-81.

In a manned configuration, the payload volume (Figure 2-82)is that available when the LEM is not used. A payload volume of 3,230 cu. ft. and a weight of 29,500 lb. can be accommodated in this space.

For unmanned launches of the Saturn V, a large fairing was developed for the Voyager spacecraft. It provided a volume of approximately 2,900 cu. ft. Approximate weight of the fairing is 2,500 lb. (aluminum honeycomb configuration). In Figure 2-83, the Voyager fairing is essentially the structure forward of Station 3386.6. With the addition of an S-IVB forward skirt, as shown in Figure 2-83, the volume increases to approximately 6000 cu. ft. and shroud weight is approximately 3,600 lb.

2.4.4 LAUNCH VEHICLE COSTS - Launch vehicle costs are shown in Table 2-35. The cost of the Saturn V, 213 million dollars, which was used in the program, was based on the lunar exploration configuration and production rates. The cost of the manned provisions that are part of the satellite are included in the satellite costs. The cost of the command module, service modules and other equipment required for manned support is not included in the model.

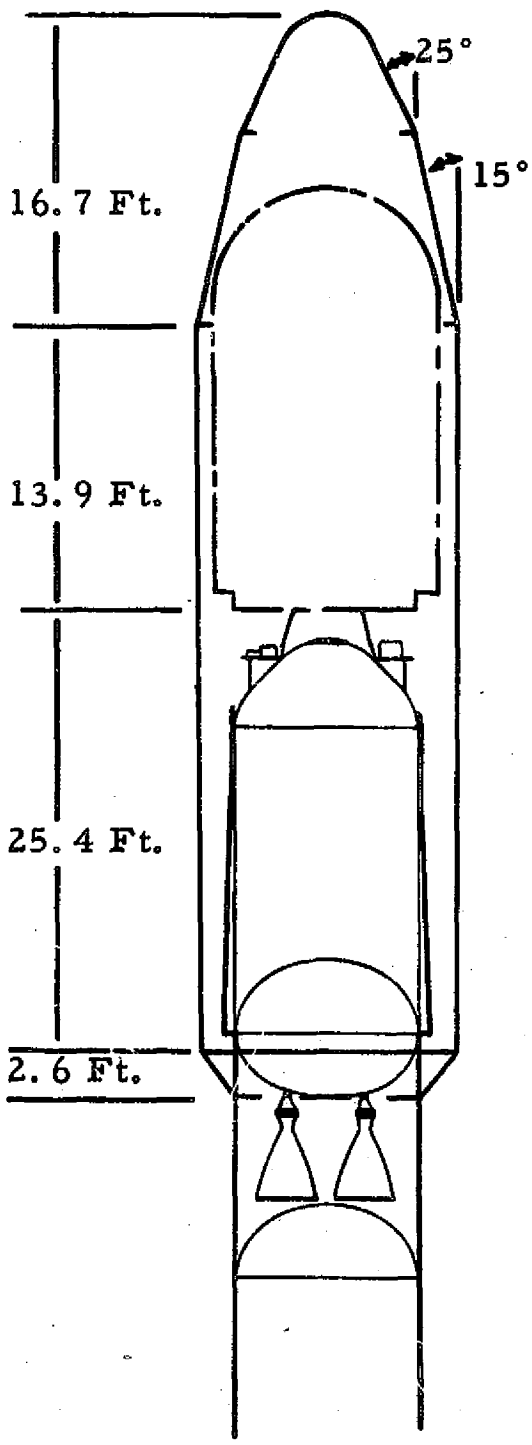
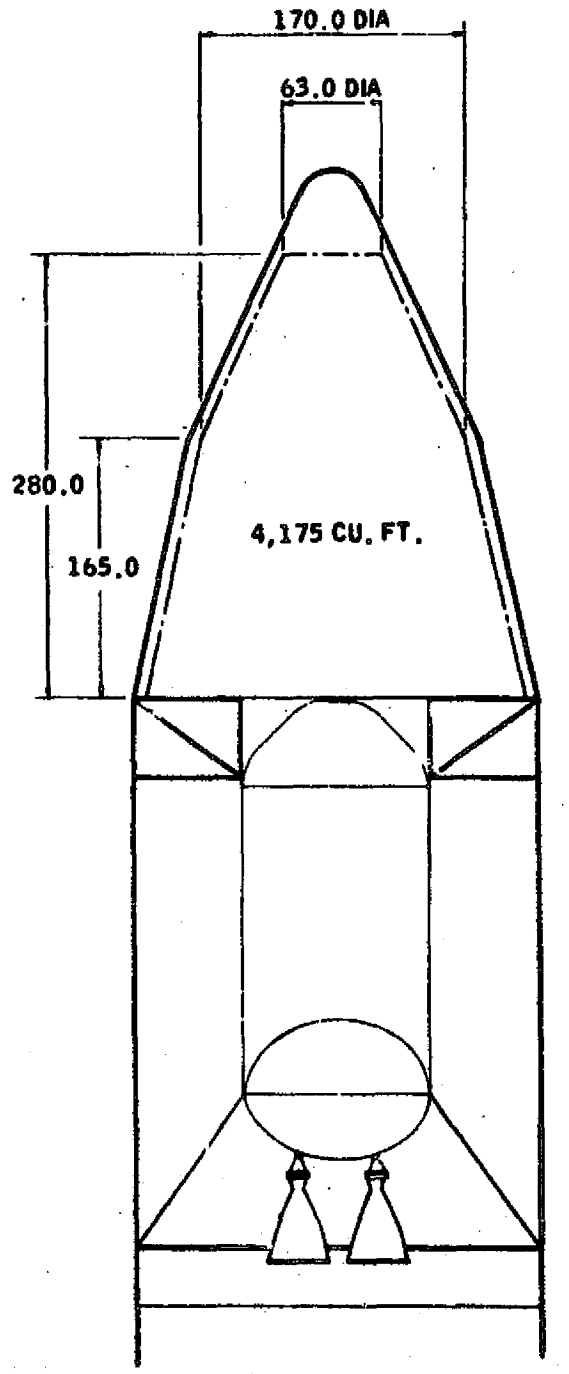
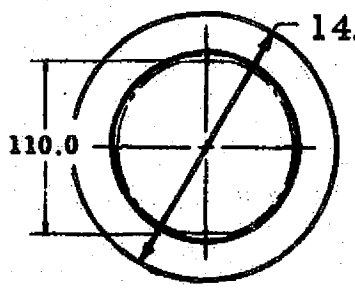


Figure 2-80. Titan IIID/Centaur with Viking Shroud





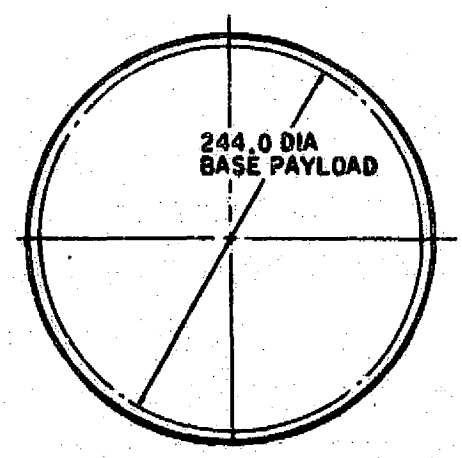


Figure 2-81. Saturn IB/Centaur

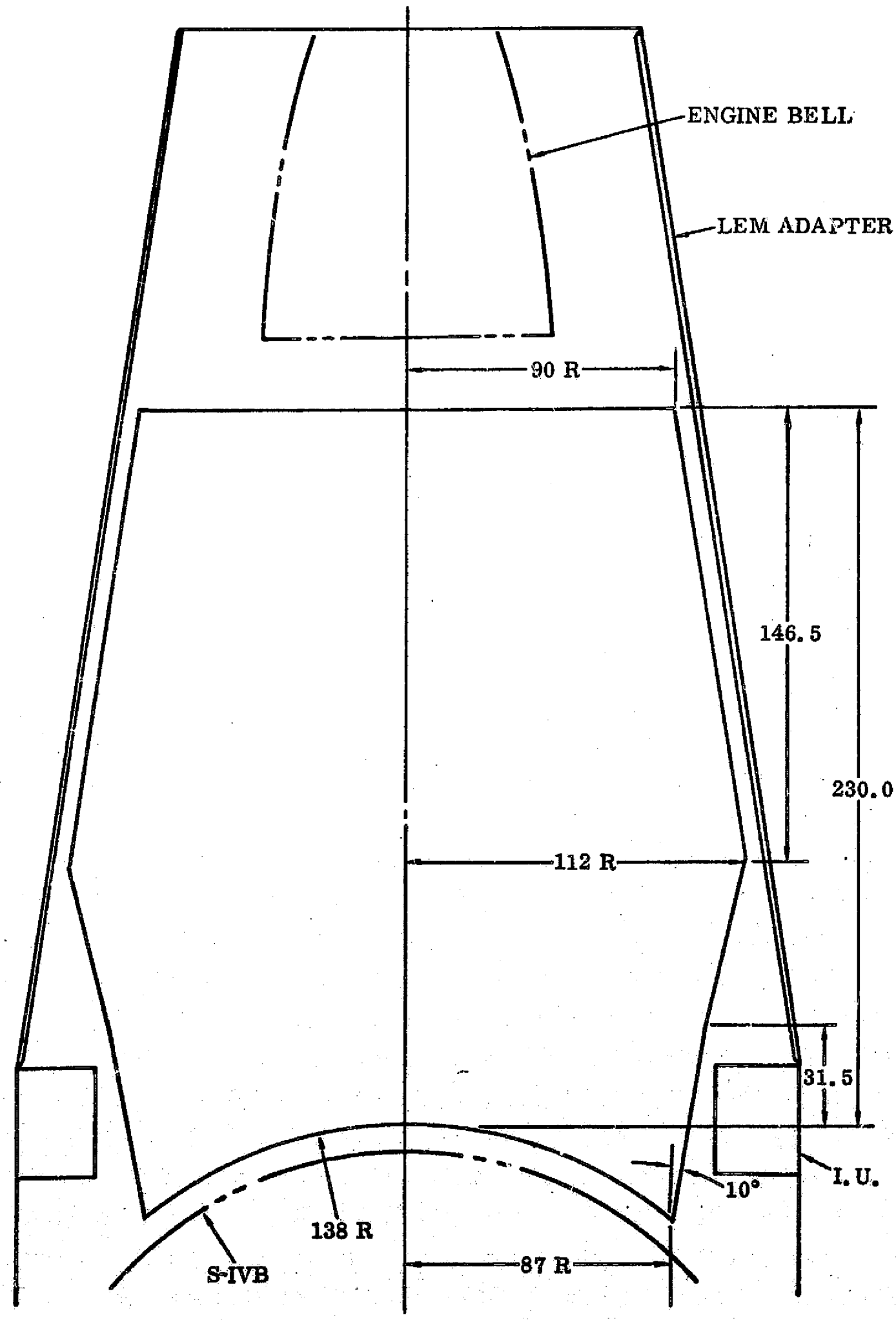
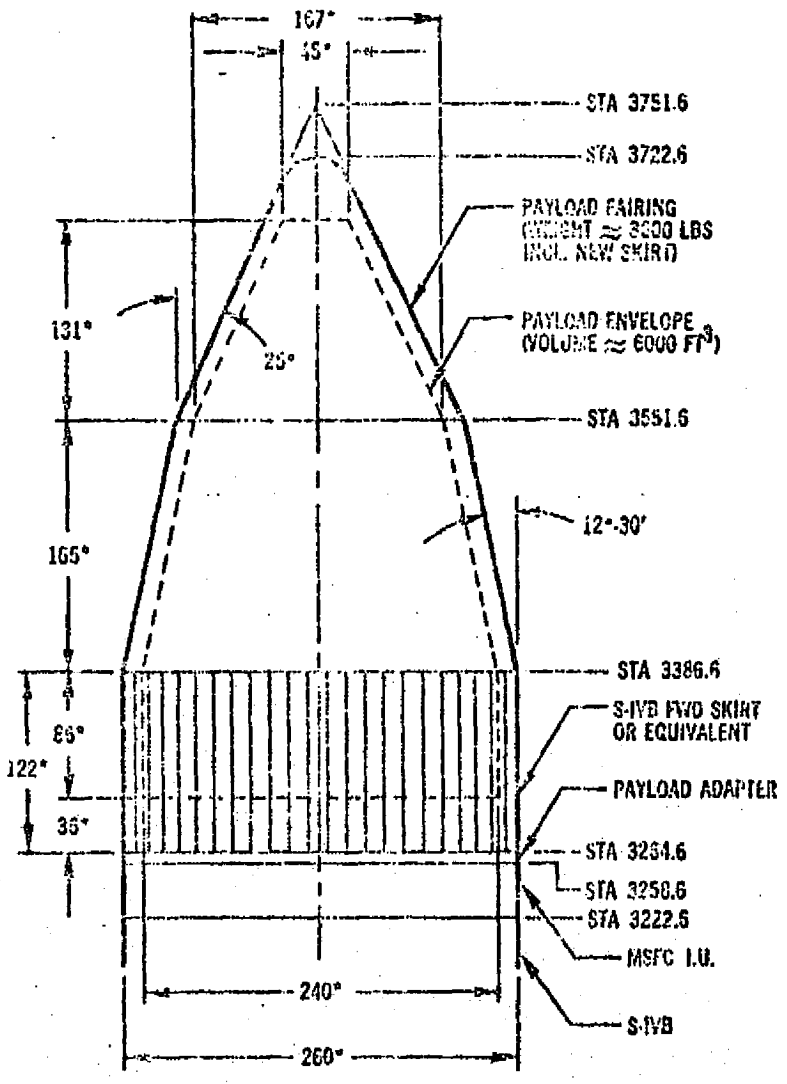


Figure 2-82. Saturn V (Manned Configuration)



* APPROXIMATE DIMENSIONS TO BE USED FOR PRELIMINARY LAYOUT ONLY.

Figure 2-83. Saturn V (Unmanned Configuration)

Table 2-35. Launch Vehicle Costs

	Titan IIIC	Titan IIID/ Centaur	Saturn V
NONRECURRING			
La unch Vehicle Development			$10.0
Fairing and Adapter			5.0
Mission Integration	$4.3	$4.6	10.0
RECURRING			
Launch Vehicle	15.3	15.4	99.4
Fairing & Adapter	1.0	1,2	1.5
Launch Services	3.2	3.4	37.0
Spares,Etc.	1.5	1.6	50.3

3. OPTIMIZATION PROGRAM

3.1 PROGRAM DESCRIPTION

The TVBS system synthesis/optimization program developed by Convair provides the user with a flexible tool for the analysis of TVBS system requirements. While obtaining minimum cost design points, the program enables the user to perform studies over a wide range of user requirements and spacecraft configurations. The program utilizes a total systems approach in which the ground uplink, spacecraft, launch vehicle, and ground downlink systems are simultaneously synthesized. A steepest-descent algorithm is employed to determine the minimum total system cost design for each configuration considered. In the process of converging to the solution, the pertinent subsystem trade-offs are resolved.

The program provides the system designer with the capability to consider a wide choice of system configurations. By appropriate specification of the pertinent input variables, the program can be made to cycle through the various types of subsystem elements and user requirements to be considered. The minimum cost solutions obtained for each configuration can be compared to determine that configuration which has the minimum cost.

The program can also be used as a tool in performing sensitivity analyses. For example, it can be employed to determine the change in the total system cost resulting from a perturbation of the design parameters, the configuration sizing constraints, and the subsystem parametric relationships, as well as the user requirements (S/N, frequency, etc.).

The TVBS computer program is comprised of a driver and nine subroutines (see Figure 3-1). The components are as listed.

TVBS DRIVER	-	initializes and control execution
SUBROUTINE INIT	-	initializes and sets boundary constraints
SUBROUTINE CONV	-	controls execution of the convergence technique
SUBROUTINE SYSEQ	-	computes value of dependent parameters
SUBROUTINE PLACE	-	sets coefficients for transmitter curves
SUBROUTINE PRTIAL	-	computes required partial derivatives
SUBROUTINE BCHECK	-	checks system parameters for boundary violations
SUBROUTINE ERROR	-	controls output of diagnostic messages under certain conditions
SUBROUTINE OUT	-	provides intermediate output of iteration results
SUBROUTINE OUTPTX	-	provides final summary output

These do not include the required general purpose system routines.

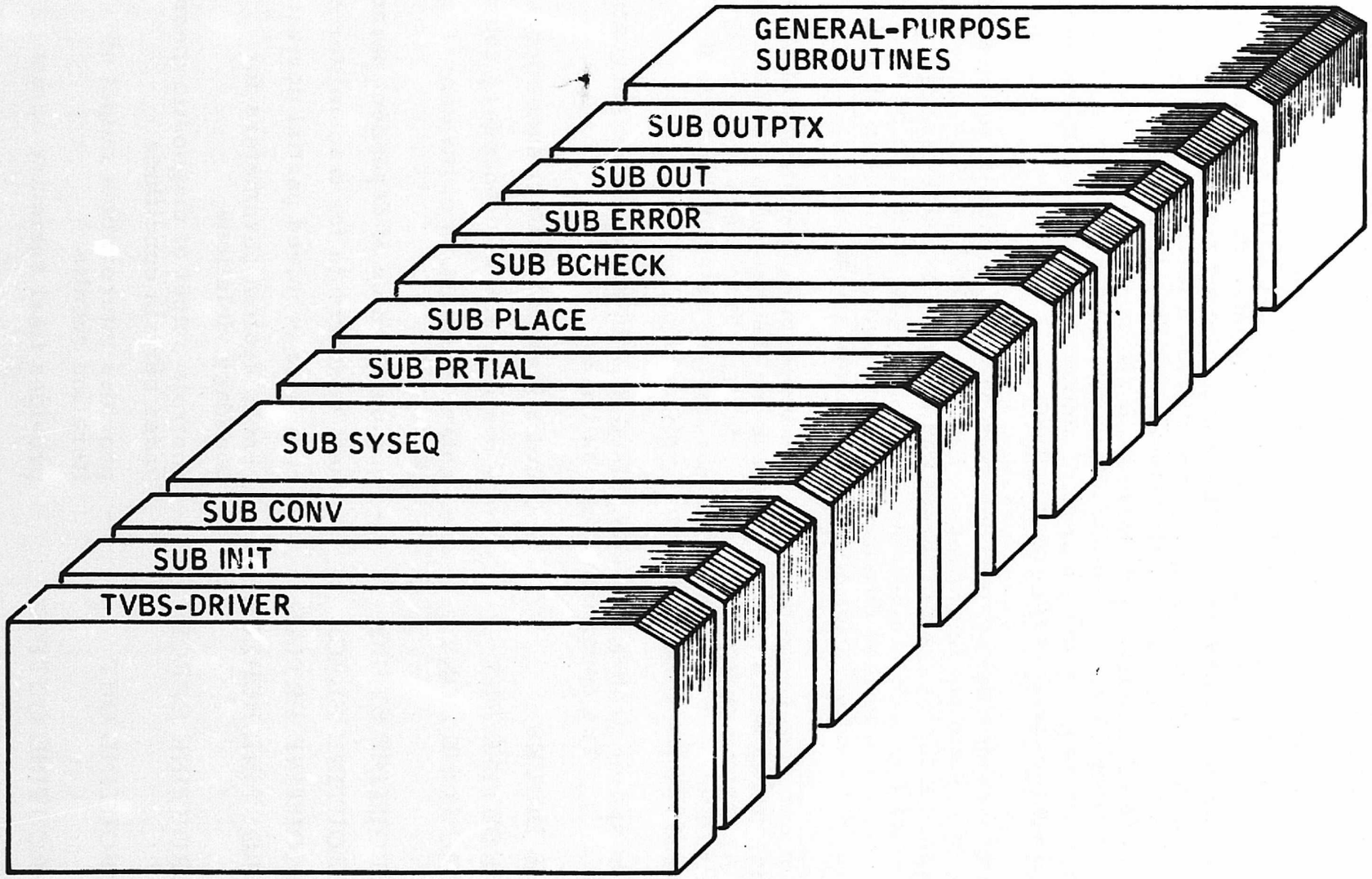


Figure 3-1. TVBS Deck Setup

The general logic flow of the computer program is given in Figure 3-2. The program was specifically designed for use on Convair's CDC 6400 computer system using FORTRAN IV, CDC Version 3.2 programming language.

On the basis of 100 cases run, the average required central processor (CP) time per run was 4.6 seconds. Core requirement for execution is approximately $47K_8$ including routines required by the operating system.

A more complete description of the computer program may be found in Volume V.

3.2 MATHEMATICAL DESIGN OPTIMIZATION TECHNIQUE

The Convair TVBS system design optimization program uses a steepest descent iterative process, which is a modified gradient technique to determine the minimum cost design point for a given system configuration. At each iteration the nominal design point is perturbed in such a way as to cause the maximum rate of decrease in total system cost to be consistent with the design constraints.

If Δy_j is the amount by which the jth boundary is violated and g represents the gradient of total system cost, then the perturbation in X, the vector of independent design parameters, is given by

$$\Delta X = - K_c \left[I - \Phi(\Phi^T\Phi)^{-1} \Phi^T \right] g - K_y \Phi(\Phi^T\Phi)^{-1} \Delta y_j$$

where Φ is the gradient of the constraint relationship. The derivation of this equation is given in Appendix B.

If K_y is set equal to unity, the second term represents, to first order terms, the amount by which X must be changed to reduce Δy_j to zero. If K_y is less than one, the boundary violation is partially reduced. The first term represents the component of the cost gradient parallel to the constraint boundary and is orthogonal to the second term. For small ΔX (so that the linear approximation is valid), the first term reduces the cost and contributes nothing directly to the boundary violation. If no boundaries are violated, then Δy_j and Φ are zero, so that the equation reduces to

$$\Delta X = - K_c \, g$$

which represents a perturbation in the direction of the negative of the cost gradient.

Since K_c is arbitrary some control over the step-size must be introduced. The principle used in determining the magnitude of the step is that if successive steps have been in the same direction it is desirable to increase the step-size in order to speed up the convergence process. On the other hand, if successive steps have been in opposite directions, it is desirable to decrease the step-size since the optimum design point has been overshot. Furthermore, it appears that larger step-sizes are most desirable in the early iterations to hasten arrival to the vicinity of the optimum design point. Once in the

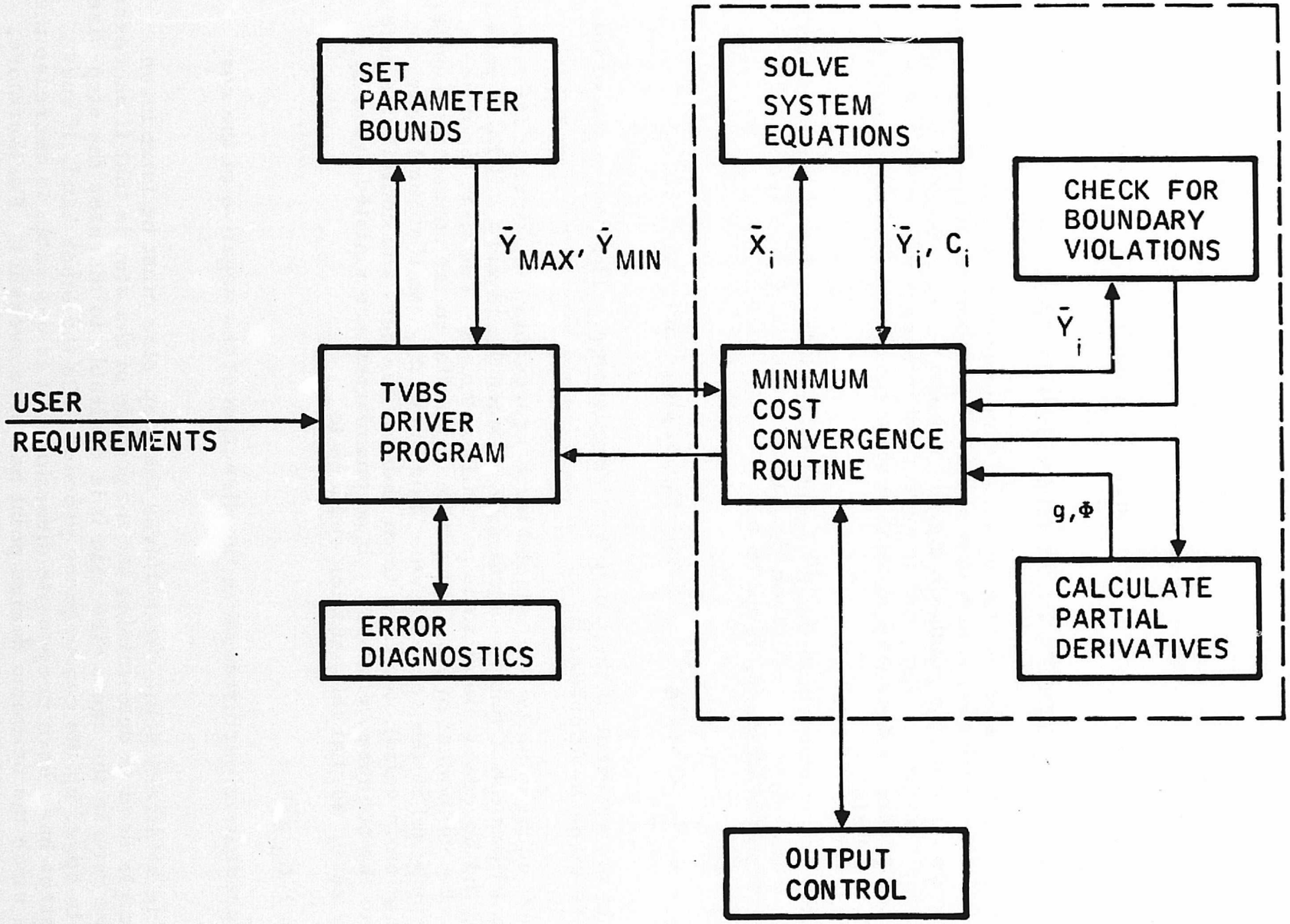


Figure 3-2. TVBS General Flow Diagram

vicinity of the optimum, smaller steps would prove more practical. With this in mind, the following step-size control algorithm has been implemented. Let α be the angle between two successive step vectors, ΔX_{i-1} and ΔX_{i-2}, and let S_i be the magnitude of the ith step, $|\Delta X_i|$

$$S_i = (.75 + .25 \cos \alpha) S_{i-1} \qquad \text{if } \cos \alpha < 0$$

$$S_i = (.5 + 1.5 \cos \alpha) S_{i-1} \qquad \text{if } \cos \alpha \geq 0 \text{ and } i \leq 10$$

$$S_i = (.55 + .45 \cos \alpha) S_{i-1} \qquad \text{if } \cos \alpha \geq 0 \text{ and } i > 10$$

$$S_i = 20 \qquad \text{if } S_i > 20$$

where i = iteration index.

With the step-size, S_i, thus specified, the appropriate value of K_c can be determined from

$$K_c = \sqrt{\frac{S_i^2 - K_y^2 \cdot \Delta y_j^T \ (\Phi^T \Phi)^{-1} \ y_j}{H^T H}} \ , \quad H = \left[I - \Phi (\Phi^T \Phi)^{-1} \ \Phi^T \right] \ g$$

in the event of a boundary violation. If the solution is unconstrained K_c is determined from

$$K_c = \frac{S_i}{|g|}$$

These are the equations used by the TVBS convergence routine. It is important to keep S_i from growing to a point at which a large number of iterations would be required to bring it down. Therefore the upper bound is placed on S_i.

The rate of convergence to the minimum cost design point is dependent upon the relative sensitivities of the cost to each of the design parameters. Since the algorithm operates on the most sensitive parameters, convergence to the optimum value of the less sensitive parameters can be slow. For this reason it is often desirable to rescale the units of the design parameters to equalize these sensitivities.

In this application, the vector of independent variables X is given as

$$X = (x_1, x_2, x_3) = (D_1, D_4, T_R)$$

where

D_1 = diameter of the ground uplink antenna,

D_4 = diameter of the ground downlink antenna, and

T_R = temperature of the receiver on the ground,

Y, the vector of dependent parameters, is given as

$Y = (y_1, \ldots y_6)$ where

$y_1 = P_{TR}$ = spacecraft transmitter power output/channel

$y_2 = W_{TOT}$ = total weight of spacecraft payload

$y_3 = V_{EM}$ = total volume of equipment module

$y_4 = V_{TOT}$ = total volume of spacecraft payload

$y_5 = P_G$ = ground uplink power output/channel

$y_6 = V_{PP}$ = total volume of power supply

3.3 PARAMETRIC SUBSYSTEM MODELS

The TVBS subsystem models include the perinent elements required to obtain a complete synthesis of the total system. The cost, weight, and volume curves of the various subsystems modeled in the program are given in Volume V. The coefficients and the general forms of the equations representing the curves are found in Volume V.

The curves used during the study are applicable over a wide range of parametric values. Where it was impossible to obtain an accurate fit with a single equation, the curve was fit in more than one piece. The breakpoint, in most cases, is variable and included in the input list.

The system synthesis incorporates a loss model for both the uplink and downlink, a noise model, and scale factors to account for redundancy. The loss model and noise model are discussed in Section 3.6 while the redundancy scale factors are found in Section 3.7.

The cost elements employed in the subsystem cost models are located in tabular form in Section 34.

The list of dependent system parameters includes transmitter output power per channel (ground uplink and spacecraft), total spacecraft weight and volume, volume of the spacecraft equipment module, and, when constrained, the volume of the power supply. The list of independent design parameters includes the diameter of the ground uplink and downlink antenna and the noise temperature of the ground receiver.

3.4 COST MODEL

The TVBS cost model, summarized in Figure 3-3, has a unique feature of a unit cost submodel which uses mission parameters to calculate unit hardware costs in the various subsystems. The model then computes the non-recurring costs (development), acquisition costs, and operational costs to form the total program cost. The non-recurring costs include all design, development, and analysis costs necessary to bring the program to the point of first operational configuration. The acquisition submocel accumulates the costs associated with the fabrication and launching necessary to establish the initial operational system. Operational costs include all costs associated with the operational phase of the mission including replacement satellites.

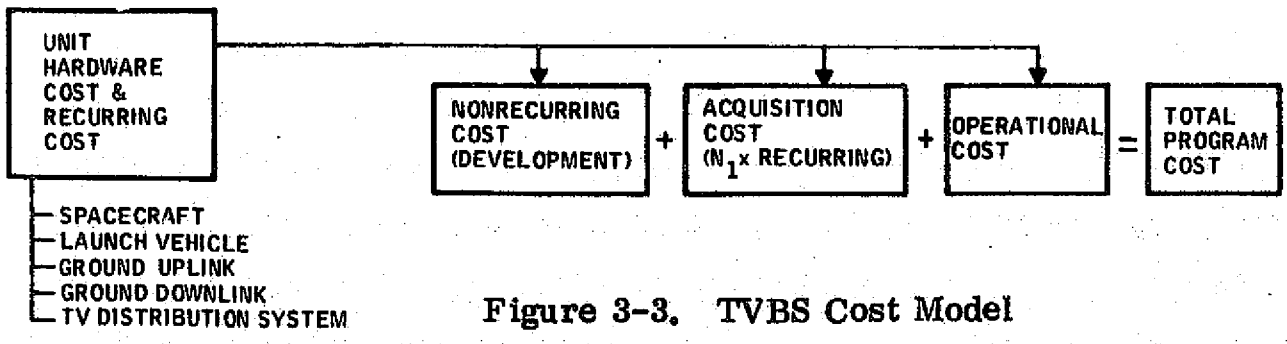


Figure 3-3. TVBS Cost Model

4

SYSTEM SELECTION

Systems were defined for each of the selected users by:

1. Defining a set of requirements representative of their needs.
2. Synthesizing baseline systems in response to these requirements.
3. Exercising available options of frequency and system configuration to examine cost sensitivities.

Results of these analyses were reviewed and three systems selected for preliminary design.

4.1 CANDIDATE SYSTEMS

The order in which systems are discussed in the following subsections is that from greatest to least critical user need.

In the course of the study, these user requirements were input to the computer optimization program and lowest cost solutions were found for each. In some cases alternate solutions were made for varying TASO grade or other input options.

Subsequent to these runs, the computer program was expanded to include more detailed cost models and additional system cost elements (e.g., ground system facilities). Most of the original cases were rerun using more recent data and programming and the results are also included. The designation used to identify these current runs is "updated." In the following subsections all runs are presented as originally prepared, then updated versions are provided where applicable.

4.1.1 U.S. ARMED FORCES RADIO AND TV SERVICES

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
GLOBAL COVERAGE (SPECIFICALLY EXCLUDING U.S.) 3 SATELLITES 3 BEAMS/SATELLITE 5 CHANNELS/BEAM 10^6 SQ. MI./BEAM	10×10^6 PEOPLE (MILITARY PERSONNEL PLUS DEPENDENTS & ON-BASE STAFF) ASSUME: UNIFORM DISTRIBUTION 5 PEOPLE/RECEIVER	TWO ORIGINATING STATIONS WASHINGTON LOS ANGELES	3 CHANNELS 100% 2 CHANNELS 5:00 - 8:00 A.M. 5:00 P.M. - MIDNIGHT

The inputs defined reflect the provision of 5 channels of color TV -- 3 commercial channels and 2 non-commercial channels. Nine regions of the world are covered (11.3×10^6 sq. mi.) by three satellites, each with 3 beams. As many as 10 million people can be reached with this system, counting approximately 2 million U.S. nationals and staff. The remainder would be desirable local "eavesdroppers." Programming for this system would originate in Washington, D.C. and Los Angeles, California. Results for the direct system are shown in Table 4-1. From this table it can be seen that this would constitute an expensive operation -- approximately $200M/year. Concepts D and F yield the lowest cost systems. Concept A did not result in a solution primarily because of inconsistent boundary limits resulting in boundary violations in the solution. The systems optimized at a 2.56 GHz operating frequency. The larger (>27,000 lb.), high-powered systems proved more cost-effective because of the large audience.

Placing as much of the system complexity and cost in the satellite results in an overall cost reduction to the system.

A second case, in which a CATV type redistribution system was used on the ground, was examined (Table 4-2). In this alternative approach, the system cost is substantially reduced, primarily because the number of receivers is reduced by a factor of 20,000 (although individual receiver cost increases), and the redistribution system cost is not included. The latter because this capability is now available at many of the installations as part of their CCTV systems.

Table 4-3 shows the results of the updated direct AFRTS, optimization run. Costs are reduced by a factor of 2, primarily by dropping frequency to 0.8 GHz. which yields lower ground receiver costs. Other changes, such as new satellite packaging concepts help reduce satellite weight and cost. Concept B, which yields minimum cost, forms a basis for preliminary design of an AFRTS system in Chapter 5.

Table 4-4 shows the updated redistribution system approach to the AFRTS. Again costs are lower than for the direct system. Five and ten year satellite lifetimes were considered. Concept B shows a small cost reduction over the next best, Concept F. Best performance was obtained at 2.5 GHz compared to the 0.8 GHz selection for the direct broadcast alternative.

Table 4-1. U.S. Armed Forces Radio & TV Services-Direct

USER : U. S. ARMED FORCES RADIO & TV
SERVICE : 45 CHANNELS, 9 STATIONS, 24-Hr., Color
COVERAGE : $1.26 \times 10^6 \times 9 = 11.3$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITE REQD.	XMTR TYPE	MODULATION	DOWNLINK ANTENNA GAIN (DB)	DOWNLINK RCVR NOISE FIG.	DOWNLINK RCVR NOISE TEMP.	SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
A	1	2.5	18	TWT	FM				BOUNDARY VIOLATION						
B	1	2.5	18	TWT	FM	36.1/11.2	2.1	178°	2,707	3.4	212	60.7	607	2,412	121
C	1	2.5	18	TWT	FM	33.2/8.0	2.5	220°	4,502	7.0	255	63.7	225	2,219	111
D	1	2.5	6	TWT	FM	32.2/7.1	2.5	220°	34,601	40.0	233	81.2	191	1,991	100
E						NOT APPLICABLE									
F	1	2.5	4	TWT	FM	34.9/9.7	2.3	206°	27,678	33.3	201	81.3	296	2,092	105

Table 4-2. U.S. Armed Forces Radio & TV Services-Hybrid

USER : U. S. ARMED FORCES RADIO & TV (HYBRID WITH CATV)
SERVICE : 45 CHANNELS, 9 STATIONS, 24-Hr., Color
COVERAGE : $9 \times 1.26 \times 10^6 = 11.3$ million Sq. Mi.
LIFE : 10-yr. System, 10-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMLER SATELLITES REQD.	XMTR TYPE	MODULATION	ANTENNA GAIN (DB)	DOWNLINK RCVR NOISE FIG.	RCVR NOISE TEMP.	SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
A	0	2.5	9	TWT	FM				BOUNDARY VIOLATION						
B	0	2.5	9	TWT	FM	46.1/35.6	1.2	90°	2,909	2.6	174	63.4	6,515	1,525	76
C	0	2.5	9	TWT	FM	45.7/33.9	1.2	93°	3,005	2.7	172	68.4	6,500	1,887	94
D	0	2.5	3	TWT	FM	45.4/32.5	1.2	96°	24,278	14.7	152	99.8	6,490	1,864	93
E						NOT APPLICABLE									
F	0	2.5	2	TWT	FM	45.6/33.4	1.2	94°	22,858	17.7	160	99.8	6,496	1,699	85

Table 4-3. Updated AFRTS Direct System

User: U.S. Armed Forces Radio & TV (Direct Distribution)
Service: 5 Channels, 2 Stations, 24-Hour, Color
Coverage: $1.26 \times 10^6 \times 9 = 11.3$ Million Square Miles
Life: 10-Year System, 2-5 Year Satellites.

Orbit	TASO Grade	Downlink Freq (GHz)	No. Satellites Required	Late Type	Modulation	Receiving Station			Sat. Weight (lbs)	Satellite Prime Power (Expended) (kw)	Unit Costs			Total System Cost ($M)	Total Cost/Year/Receive ($)
						Ant. Gain (dB)	Ant Dia (Ft)	Rcve Noise Figure (dB)			Sat ($M)	Uplink ($M)	Rcve ($)		
B	1	0.8	(2)x 9	CFA	FM	16.3	3.4	5.4	3140	7.0	8.45	18.27	159	908.8	45.40
B	1	2.5	(2)x 9	TWT	FM	25.1	3.0	6.3	4201	10.9	9.24	18.24	301	1206.0	60.30
D	1	0.8	(2)x 2	CFA	FM	16.3	3.4	5.3	19446	35.4	50.51	18.22	160	960.3	48.00
D	1	2.5	(2)x 2	TWT	FM	25.4	3.1	7.5	28596	69.7	59.61	18.26	292	1637.5	81.90
F	1	0.8	(2)x 2	CFA	FM	16.3	3.4	5.3	20894	3[illegible]	49.88	18.22	161	957.6	47.90
F	1	2.5	(2)x 2	TWT	FM	24.6	2.9	6.8	29839	68.9	58.70	18.27	292	1633.2	81.70

Table 4-4. Updated AFRTS Redistribution System

USER: U.S. ARMED FORCES RADIO & TV (REDISTRIBUTION)
SERVICE: 5 CHANNELS/REGION; 100 RECEIVING SYSTEMS (TOTAL)
COVERAGE: 9 REGIONS (2 SATELLITES)
LIFE: 10 YEAR S.STEM; 10 YEAR SATELLITE

Orbit	TASO Grade	Downlink Freq (GHz)	No. Satellites Required	Late Type	Modulation	Receiving Stations			Sat. Weight (lbs)	Satellite Prime Power (Expended) (kw)	Unit Costs			Total System Cost ($M)	Total Cost/Year/Receive ($)
						Ant. Gain (dB)	Ant Dia (Ft)	Rcve Noise Figure (dB)			Sat ($M)	Uplink ($M)	Rcve ($)		
B	0	0.8	9	CFA	FM	30.7	35.3	1.2	1620	1.06	7.83	22.5	3.02	630.56	631
B	0	2.5	9	TWT	FM	31.5	45.4	2.2	1240	1.12	6.46	22.6	3.03	619.90	620
B	0	12.2	9	TWT	FM	52.2	60.7	2.8	4380	6.52	11.34	22.6	3.30	690.31	690
D	0	0.8	2	CFA	FM	35.6	31.9	1.2	12795	6.46	63.48	22.5	3.01	686.62	687
D	0	2.5	2	TWT	FM	45.4	31.7	2.2	10880	6.80	54.10	22.6	3.03	669.36	669
D	0	12.2	2	TWT	FM	60.8	51.8	2.7	22980	30.9	74.94	22.7	3.30	738.47	738
F	0	0.8	2	CFA	FM	35.6	31.6	1.2	14340	6.51	62.84	22.5	3.01	685.29	685
F	0	2.5	2	TWT	FM	45.4	31.5	2.2	12428	6.87	53.56	22.6	3.03	668.19	668
F	0	12.2	2	TWT	FM	60.8	51.8	2.8	24770	31.5	74.56	22.6	3.29	736.45	736

4.1.2 U.S. NATIONAL ETV SYSTEM (PROGRAM DISTRIBUTION)

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES 2 CHANNELS/ZONE	TO GROUND STATIONS FOR REBROADCAST 50 ETV RECEIVERS PER ZONE	ONE N.Y.C. ORIGIN	100%

The existing family of 200 ETV broadcasters is served by this system in providing 2 channels of continuous TV throughout the U.S. on a time zone basis. Total system costs for this service range from $38.8M/year to $72M/year (Table 4-5). Concepts B and F showed favorably at $38.2M/year and $49.1M/year, respectively. Concepts A and E did not yield good results for this case.

A single large satellite, with beams for each of four time zones is sufficient for area coverage, however, an array of four smaller, B concept satellites provides the lower cost approach.

Table 4-6 shows the comparable updated system optimization.

4.1.3 U.S. PAROCHIAL SCHOOL SYSTEM

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES HAWAII ALASKA U.S. PACIFIC TERR. VIRGIN IS., ETC. 2 CHANNELS/AREA	PAROCHIAL SCHOOL/ SYSTEM 14,000 SCHOOLS ITFS INTERFACE	ONE ORIGINATING STATION N.Y.C.	100%

Table 4-5. U.S. ETV - Program Distribution

USER : U. S. ETV - PROGRAM DISTRIBUTION
SERVICE : 8 CHANNELS, 4 STATIONS; 24-Hr., Color
COVERAGE : $1.26 \times 10^6 \times 4 = 5$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Life Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	0	2.5	8	TWT	FM			BOUNDARY VIOLATION							LARGE
B	0	2.5	8	TWT	FM	43.6/26.6	1.4	113°	1,336	1.3	97	13.9	27,343	382	191,327
C	0	2.5	8	TWT	FM	43.4/26.0	1.5	115°	1,374	1.4	97	14.9	25,160	720	360,113
D	0	2.5	2	TWT	FM	43.2/25.2	1.5	118°	21,074	10.1	91	20.5	22,374	699	349,681
E								NOT APPLICABLE							
F	0	2.5	2	TWT	FM	43/24.8	1.5	119°	17,860	12.9	75	20.5	21,178	491	245,391

Table 4-6. Updated U.S. ETV Program Distribution

USER: U.S. ETV - PROGRAM DISTRIBUTION
SERVICE: 8 CHANNELS, 1 STATION, 24-HOUR COLOR
COVERAGE: $1.26 \times 10^6 \times 4 = 5$ MILLION SQUARE MILE
LIFE: 10-YEAR SYSTEM: 10-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	XMTR TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END-OF-LIFE) (KW)	UNIT COSTS			TOTAL SYSTEM COST ($M)	TOTAL COST PER YEAR/ RECEIVE ($M)
						ANT. GAIN (dB)	ANT DIA (Ft)	RCVR NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M) (CL. I)	RCVR ($M) (CL. II)		
B	CCIR	2.5	4	TWT	FM	40.1	17.1	2.59	998	0.99	8.53	6.25	1.39	460.3	230.2
B	CCIR	12.2	4	TWT	FM	56.3	24.1	7.34	1222	1.40	8.81	6.27	1.41	465.4	232.7
D	CCIR	2.5	1	TWT	FM	40.1	17.2	2.60	9536	6.00	83.14	6.38	1.39	583.2	291.5
D	CCIR	12.2	1	TWT	FM	56.1	23.7	7.43	10324	7.64	83.24	6.27	1.41	587.7	293.9
F	CCIR	2.5	1	TWT	FM	40.1	16.9	2.60	11982	6.06	82.12	6.24	1.39	582.1	291.1
F	CCIR	12.2	1	TWT	FM	56.1	23.6	7.50	11891	7.74	82.34	6.27	1.41	586.0	293.0

This system would serve approximately 14,000 schools:

10,603 elementary schools
2,356 high schools
339 colleges and universities
436 seminaries
260 schools for atypical children.

These schools are distributed thorughout the nation in 147 dioceses. They serve approximately 6×10^6 students -- 12-1/3% of the U.S. elementary school pupils and 10% of the U.S. high school and college students. This satellite system would need to interface with the 2.5 GHz Instructional Television Fixed Service (ITFS) systems being implemented by many dioceses. Two channels are planned for each area. A 100% duty cycle is indicated to permit instructional use throughout the normal school day, adult education during evening hours along with administrative use, and program preview selection and, possible, taping during overnight hours.

Results for this system, for TASO 1 (Excellent) high-quality TV, are shown in Table 4-7. Concepts B and F represent the lower cost systems. Table 4-8 gives the results for TASO 3 (Acceptable) quality TV. The reduced quality permits lower power systems, with a corresponding reduction in overall systems costs. The lower systems are also reflected in reduced satellite weight. The lower power shown in Table 4-8 also permits the use of solid state transmitters in the satellite as opposed to the Crossed-Field Amplifiers required for TASO 1.

This system was rerun using the topology shown in Table 4-9. The use of Concept B (and its selection as the lowest cost system) results in 1 satellite for each of the regions being covered. Optimal coverage, in turn, disperses the satellites along the equator making the link from one ground station to the most remote satellite marginal. A second uplink station was added to obviate this situation. A 10-year satellite was used to fully exploit the payload capability of the launch vehicle in terms of the added weight required for the redundant components used to achieve this lifetime. These variations in the system, plus the general update in the synthesis program result in significantly lower costs -- lower for the new TASO 1 than the previous TASO 3.

Table 4-7. U.S. Parochial Schools - TASO 1

USER : U. S. PAROCHIAL SCHOOLS
SERVICE : 16 CHANNELS, 8 STATIONS, 24-Hr. Broadcast, Color
COVERAGE : $8 \times 1.26\ 10^6$ sq. mi. = 10.0×10^6 Sq. Mi.
LIFE : 10-yr. System, 5-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1	2.5	16	CFA	AM	54.7/100	0.7	50°	1,022	0.5	147	23.4	$>10^6$	43,600	273,000
B	1	2.5	16			39.6/16.6	1.4	109°	3,161	3.7	197	23.4	4,619	852	5,328
C	1	2.5	16			38.4/14.6	1.8	148°	4,225	5.7	219	26.2	3,067	1,482	9,262
D	1	2.5	4			38.4/14.9	1.8	151°	31,295	28.4	189	41.6	3,011	1,351	8,446
E						NOT APPLICABLE									
F	1	2.5	4	CFA	AM	38.6/14.9	1.7	143°	31,706	37.5	196	40.4	3,245	1,053	6,582

Table 4-8. U.S. Parochial Schools - TASO 3

USER : U. S. PAROCHIAL SCHOOLS
SERVICE : 16 CHANNELS, 8 STATIONS, 24-HR. BROADCAST, COLOR
COVERAGE : $8 \times 1.26 \times 10^6$ = 10 million sq. mi.
LIFE : 10-yr. System, 5-yr. satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	3	2.5	16	SS	AM	54.7/100	LARGE	LARGE	1,296	1.2	102	26.5	$>10^6$	43,900	271,900
B	3	2.5	16			36.0/11	2.3	201°	930	0.7	91	25.0	1,642	670	4,213
C	3	2.5	16			36.8	3.8	408°	1,064	0.9	95	25.9	1,570	1,320	8,252
D	3	2.5	4			35.0	2.7	250°	19,917	7.4	90	29.1	1,213	1,196	7,476
E									NOT APPLICABLE						
F	3	2.5	4	SS	AM	35.0	2.7	250°	16,000	8.0	96	29.1	1,220	891	5,571

Table 4-9. Updated U.S. Parochial Schools, TASO-1

USER: U.S. PAROCHIAL SCHOOLS
SERVICE: 14000 SCHOOLS; 2 CHANNELS/REGION (16 TOTAL); 2 UPLINK STATIONS
COVERAGE: 8 REGIONS
LIFE: 10 YEAR SYSTEM; 10 YEAR SATELLITE

CONCEPT	TASO GROUP	DOWNLINK FREQ (GHz)	No. SIMULTAN. EARTH BEAMS	SATELLITE TYPE	MODULATION	RECEIVING STATION ANT. GAIN (dB)	RECEIVING STATION ANT. DIA (Ft)	RECEIVING STATION ABOVE NOISE FIGURE (dB)	SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (Expendable) (kW)	UNIT COSTS SAT ($M)	UNIT COSTS UPLINK ($M)	UNIT COSTS ABOVE ($K)	TOTAL SYSTEM COST ($M)	TOTAL COST/YEAR/ RECEIVER ($)
B	1	0.8	8	CFA	FM	19.4	4.9	1.5	1328	30.6	6.75	6.63	1.12	296.16	2115
		2.5	8	TWT	FM	29.9	5.3	3.9	1049	42.4	5.80	6.61	2.36	305.85	2185
D		0.8	2	CFA	FM	19.5	5.0	1.5	10880	30.0	51.6	6.60	1.12	345.31	2466
		2.5	2	TWT	FM	30.0	5.3	3.9	9790	41.8	47.5	6.62	2.36	354.45	2532
F		0.8	2	CFA	FM	19.4	4.9	1.5	12420	30.6	51.0	6.60	1.12	343.99	2457
		2.5	2	TWT	FM	29.9	5.3	3.9	11340	42.6	46.9	6.61	2.35	353.12	2522

4.1.4 NATIONAL ETV/ITV SYSTEM FOR INDIA

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
INDIA 1.3 MILLION SQ. MI. 1 TIME ZONE 1 BEAM 1 VIDEO CHANNEL 15 AUDIO CHANNELS	511×10^6 PEOPLE 568,000 VILLAGES 1 RCVR/VILLAGE	ONE ORIGINATING STATION DELHI	100%

This system has been proposed in several instances prior to this study as a service to a developing nation. A baseline system of a single TV channel to a receiver in each of 568,000 villages of India is set as the requirement for the present analysis. One beam can conveniently cover the entire area, however, 15 voice channels are provided to satisfy the requirements for language diversity throughout the area. Results are shown in Table 4-10.

Concept D provides a satellite capability allowing use of very low cost ground receives ($166 ea.) and a cost of $60/year/receiver for total system cost.

A system of this type, with a nominal satellite cost of $17M, would cost approximately $30M/year to implement. Concepts D and C are preferred, in that order. Despite the lower costs shown for Concept F it should be noted that Concept F is a 6-beam satellite and its costs are prorated for this single-beam user. It might have been more appropriate to have labelled Concept F "NOT APPLICABLE" for this mission. However, it does show that shared systems can result in cost reductions for the individual users.

The updated results are presented in Table 4-11. With no other system change beside extending the satellite lifetime from 5 to 10 years the resulting costs are seen to reduce to approximately half of those previously derived (Table 4-10). Two factors contribute to this reduction. First, the configuration has optimized on Concept B which is smaller and cheaper than D. Second the downrank frequency has optimized at 0.8 GHz which permits the use of standard TV receivers.

4.1.5 U.S. BIOMEDICAL NETWORK

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. ALASKA HAWAII U.S. PACIFIC TERR. VIRGIN IS., ETC.	20 MEDICENTERS PER STATE & AREA 1,040 TOTAL	FIVE ORIGINATING GROUND STATIONS 1 PER TIME ZONE	2 CHANNELS 100% 1 CHANNEL ON DEMAND ASSUME 20%
3 CHANNELS/AREA (NOTE: MAY NEED AN ADDITIONAL CHANNEL FOR TALK-BACK FROM MULTIPLE STATIONS)			

A 3-channel system is suggested to support the immediate requirements of the U.S. Biomedical Communications Network. Two of these channels would be used for full-time instruction, continuing education programming, and administrative matter. The third channel would be reserved for special programming - e.g., a heart-transplant or other innovative operation. Full U.S. coverage, including the non-CONUS status and trust territories; is required.

Table 4-10. India ETV System

USER : INDIA ETV SYSTEM
SERVICE : 1 VIDEO, 15 AUDIO CHANNELS, 24-Hr., Color
COVERAGE : 1 million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK: ANTENNA GAIN (DB)	DOWNLINK: RCVR NOISE FIG.	DOWNLINK: RCVR NOISE TEMP.	SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
A						BOUNDARY VIOLATION									
B	1	2.5	2	TWT	FM	34/8.7	2.5	220°	2,724	3.4	67	6.1	338	360	72
C	1	2.5	2	TWT	FM	30.7/6.0	2.6	242°	4,554	7.0	77	6.1	170	355	71
D	1	2.5	2	TWT	FM	30.6/5.9	2.7	246°	32,327	34.4	34	6.5	166	302	60
E						NOT APPLICABLE									
F	1	2.5	2	TWT	FM	33.8/8.6	2.5	220°	24,187	25.3	23	6.5	228	343	69

Table 4-11. Updated India ETV System

USER: INDIA ETV
SERVICE: 1 TV CHANNEL, 15 AUDIO CHANNELS; 568,000 VILLAGES
COVERAGE: 1 BEAM
LIFE: 10 YEAR SYSTEM; 10 YEAR SATELLITE

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	XMTR TYPE	MODULATION	RECEIVING STATION: ANT. GAIN (dB)	RECEIVING STATION: ANT DIA (Ft)	RECEIVING STATION: 3dVE NOISE FIGURE (dB)	SAT. WEIGHT (lbs)	SATELLITE PEAK POWER (END-OF-LIFE) (kw)	UNIT COSTS: SAT ($M)	UNIT COSTS: UPLINK ($M)	UNIT COSTS: RCVR ($)	TOTAL SYSTEM COST ($M)	TOTAL COST/YEAR/RECEIVER ($)
B	1	0.8	1	CFA	FM	13.9	2.6	8.0	3040	1510	35.8	658	110	153.38	27.00
	1	2.5	1	TWT	FM	22.7	2.3	7.9	3720	2110	36.2	1.26	249	232.84	40.99
	1	12.2	1	TWT	FM	36.4	2.3	9.3	5050	3510	35.2	1.52	291	417.41	73.49
D	1	0.8	1	CFA	FM	13.2	2.4	8.9	11300	2220	84.6	1.12	106	361.24	63.60
	1	2.5	1	TWT	FM	21.7	2.1	7.9	11600	2610	83.4	.692	246	439.04	77.30
	1	12.2	1	TWT	FM	36.2	2.2	9.3	12950	3660	86.7	1.47	290	468.44	82.47
F	1	0.8	1	CFA	FM	13.1	2.4	9.2	13000	2400	84.7	1.12	105	359.83	63.35
	1	2.5	1	TWT	FM	2.17	2.1	7.0	13140	2640	82.3	.665	245	437.76	77.07
	1	12.2	1	TWT	FM	36.2	2.2	9.3	14490	3700	85.6	1.40	290	467.16	82.25

Results for this mission are presented in Table 4-12. Concepts B and F are preferred, representing total system costs of $10 million per year and $12.7 million per year respectively.

The Biomedical Network was changed to extend the satellite lifetime from 5 to 10 years. The updated results are shown in Table 4-13. The potential benefit of this change was not realized because the number of uplinks was increased from 5 to 52 resulting in an overall Total System Cost increase from $1,019 million to $2,402.5 million.

4.1.6 U.S. ETV SYSTEM -- DIRECT

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES PLUS HAWAII & ALASKA 2 CHANNELS/AREA (12 TOTAL)	DIRECT-TO-HOME ASSUME 80% OF TOTAL U.S. RECEIVERS	ONE UPLINK IN EACH AREA ON ONE CHANNEL TIME-SHARED FOR LOCAL PROGRAMMING N.Y.C. ORIGIN FOR SECOND CHANNEL	6:00 A.M. TO 9:00 A.M. & 5:00 P.M. TO MIDNIGHT

This is similar to Mission No. 2 in that the intent is to provide 2 channels of non-commercial TV to the viewing aduience. It is different since the in-between ETV stations are bypassed and the service is direct to the home. Approximately 50×10^6 homes could be reached.

Results for the system are shown in Table 4-14. Concepts A and E are not appropriate; D and F are preferred. Both of these are large multi-beam systems. Overall total systems costs are $700 - $839M/year. Costs to the individual home per year are $11.75 or $13.98 -- quite modest when compared to an average of $60/year for CATV service.

Table 4-15 shows the slight cost incrase resulting from the increase in the number of uplink stations from 6 to 7 — a correction over previous data to accommodate the New York City station for Channel No. 2.

Table 4-12. U.S. Biomedical Network

USER : U. S. BIOMEDICAL NETWORK
SERVICE : 24 CHANNELS, 8 STATIONS, 24-Hr., Color
COVERAGE : $8 \times 1.26 \times 10^6$ = 10 million sq. mi.
LIFE : 10-yr. System, 5-yr. Life Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1	2.5	16		FM	54.7/100	0.7	50°	733	0.4	140	393	4×10^6	8,526	531,381
B	1	2.5	16		FM	40.7/19.0	1.7	142°	1,147	0.9	146	343	6,575	1,019	98,062
C	1	2.5	16		FM	40.5/18.6	1.8	145°	1,176	0.9	146	354	6,101	1,673	160,916
D	1	2.5	4		FM	39.9/17.3	1.8	153°	20,445	8.8	121	401	4,705	1,578	151,797
E						NOT APPLICABLE									
F	1.	2.5	4		FM	40.1/17.7	1.8	150°	16,676	9.9	125	401	5,128	1,273	122,427

Table 4-13. Updated U.S. Biomedical Network

USER: U.S. BIOMEDICAL T.V. NETWORK
SERVICE: 3 CHANNELS/REGION (24 TOTAL); 52 UPLINKS; 1040 DOWNLINKS
COVERAGE: 8 REGIONS
LIFE: 10 YEAR SYSTEM; 10 YEAR SATELLITE

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	SATELLITE TYPE	MODULATION	RECEIVING STATIONS			SAT. WEIGHT (lbs)	SATELLITE PEAK POWER (END OF LIFE) (KW)	UNIT COSTS			TOTAL SYSTEM COST ($ M)	TOTAL COST/YEAR/ RECEIVER ($)
						ANT. GAIN (dB)	ANT DIA (Ft)	ABOVE NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M)	RCVR ($)		
B	CCIR	2.5	8	TWT	FM	39.0	15.0	2.9	1142	1737	6.47	2.55	1.93	2402.5	231.0
	CCIR	12.2	8	TWT	FM	55.3	21.2	8.5	1693	3131	7.29	2.61	1.94	2424.7	233.1
D	CCIR	2.5	2	TWT	FM	38.7	14.5	2.9	10290	10140	50.33	2.55	1.93	2451.1	235.7
	CCIR	12.2	2	TWT	FM	57.6	20.7	8.7	12310	15970	52.61	2.61	1.94	2470.6	237.6
F	CCIR	2.5	2	TWT	FM	38.0	13.4	2.9	11940	10480	49.94	2.55	1.93	2449.9	235.6
	CCIR	12.2	2	TWT	FM	55.1	20.6	8.7	13860	16060	52.02	2.61	1.94	2469.0	237.4

Table 4-14. U.S. ETV - Direct

USER : U. S. ETV - OPERATIONAL DIRECT SYSTEM
SERVICE : 12 CHANNELS; 6 STATIONS, 24-Hr. Broadcast, Color
COVERAGE: $6 \times 1.26 \times 10^6 = 7.5$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (lbs)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1	2.5	12		FM	BOUNDARY VIOLATION									LARGE
B	1	2.5	12		FM	31.9/6.9	2.5	220°	2,763	3.9	151	34.4	145	11,290	18.76
C	1	2.5	12		FM	29.4/5.1	2.5	220°	4,223	7.0	177	34.8	97	8,412	14.02
D	1	2.5	4		FM	28/4.4	2.7	244°	36,900	48.0	187	36.6	79	7,049	11.75
E						NOT APPLICABLE									
F	1	2.5	2		FM	29.7/5.3	2.5	230°	31,191	44.8	166	36.7	101	8,390	13.98

Table 4-15. Updated U.S. ETV - Direct

USER: U.S. ETV - OPERATIONAL DIRECT SYSTEM
SERVICE: 12 CHANNELS, 7 STATIONS, 24-HOUR BROADCAST COLOR
COVERAGE: $6 \times 1.2 \times 10^6 = 7.5$ MILLION-SQUARE MILE
LIFE: 10-YEAR SYSTEM; 5-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	NO. SATELLITES REQUIRED	SATE TYPE	MODULA-TION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END-OF-LIFE) (kW)	UNIT COSTS			TOTAL SYSTEM COST ($M)	TOTAL COST/YR/ RECEIVER ($)
						ANT. GAIN (dB)	ANT DIR. (Ft)	RCVR NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M) (CL.D)	RCVR ($)		
D	1	0.8	(2)x1	CFA	FM	11.1	1.9	10.0	29166	68.9	88.89	1.849	131	8478	14.10
D	1	2.5	(2)x1	TWT	FM	19.3	1.6	7.9	27719	68.9	83.99	1.869	290	17967	29.90
F	1	0.8	(2)x1	CFA	FM	11.0	1.9	10.0	30616	68.9	87.69	1.848	131	8473	14.10
F	1	2.5	(2)x1	TWT	FM	19.2	1.5	7.9	29173	68.9	82.91	1.869	290	17963	29.90
F	1	12	(2)x1	TWT	FM	36.4	2.3	9.3	29065	68.9	80.34	1.907	318	19667	32.90
H	1	0.8	(2)x6	CFA	FM	7.2	1.2	10.0	9174	26.7	17.07	2.048	128	8513	14.20
H	1	2.5	(2)x6	TWT	FM	15.9	1.1	7.9	7100	20.9	13.98	2.065	287	17842	29.70
H	1	12	(2)x6	TWT	FM	31.0	1.2	9.3	11889	37.0	19.61	2.416	308	19549	32.60

4.1.7 U.S. NATIONAL ITV DISTRIBUTION SYSTEM

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES HAWAII ALASKA U.S. PACIFIC TERR. VIRGIN IS. 4 CHANNELS/AREA	PUBLIC ELEMENTARY & SECONDARY SCHOOLS (~300,000) ASSUME 80% COVERAGE (~240,000 RECEIVERS)	TWO ORIGINATING STATIONS IN EACH TIME ZONE PLUS ONE EACH IN HAWAII & ALASKA	3 CHANNELS 8:00 A.M. TO 4:00 P.M. 1 CHANNEL/AREA 100% FOR PROGRAM PRE-VIEWING

This system is defined to provide 4 channels of instructional TV to approximately 240,000 schools in the U.S. Three of the channels would be used during normal school hours. The foruth channel would be operational continuously for program pre-viewing, selection and taping. In the distribution mode the system operates at a high quality of TASO 0 (C.C.I.R. Relay quality).

Results for the system are shown in Table 4-16. Preferred systems, on the basis of least cost, are Concepts D and F. Both of these versions are multi-beam systems and capable of accommodating large systems, weight and power.

Table 4-16. U.S. ITV - Distribution

USER : U. S. ITV - OPERATIONAL SYST (RELAY QUALITY)
SERVICE :
COVERAGE : } SAME AS FOR TASO 1 DIRECT
LIFE :

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK ANTENNA GAIN (DB)	DOWNLINK RCVR NOISE FIG.	DOWNLINK RCVR NOISE TEMP.	SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($ M)	TOTAL COST PER RCVR
A	0	2.5	16	TWT	FM	54.7/100	0.7	50°	884	0.5	143	50.6	Large	Large	Large
B	0	2.5	16	TWT	FM	41.5/20.8	1.5	120°	2,766	3.7	191	59.5	4,847	2,528	1,053
C	0	2.5	16	TWT	FM	39/18.6	1.8	147°	4,377	7.0	226	61.5	1,948	2,121	884
D	0	2.5	8	TWT	FM	38.0/13.8	1.9	161°	35,437	43.1	218	73.0	1,322	1,784	741
E									NOT APPLICABLE						
F	0	2.5	8	TWT	FM	40/17.5	1.7	136°	28,967	37.7	189	73.1	2,773	1,975	823

4.1.8 MEXICO NATIONAL ETV SYSTEM, DIRECT

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
MEXICO 800,000 SQ.MI. 2 BEAMS (EA. 400,000 SQ.MI.) 4 CHANNELS/BEAM	45.7×10^6 PEOPLE 60 PER SQ.MI. 20,000 SCHOOLS	ONE ORIGINATING STATION MEXICO CITY	2 CHANNELS 100% 2 CHANNELS 50% (6:00 A.M. TO 6:00 P.M.)

As defined, this system provides four channels of non-commercial TV to the Mexican population during early morning and evening hours. Two beams supply the geographic coverage.

Results are shown in Table 4-17. The least cost systems are reflected by Concepts C and D. Concept A and E did not yield suitable solutions. Systems costs are on the order of $100 million per year. User costs per year are $45 to $50 depending on the concept.

Table 4-17. Mexico ETV - Direct

USER : MEXICAN ETV DIRECT SYSTEM
SERVICE : 8 CHANNELS, 2 STATIONS, 24-Hr., Color
COVERAGE: $2 \times .94 \times 10^6 = \sim 2$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1					VIOLATES BOUNDS									
B	1	2.5	4	TWT	FM	35.5/10.6	2.1	182°	2,779	3.6	89	13.6	526	1,574	79
C	1	2.5	4	TWT	FM	33/7.8	2.9	220°	4,481	7.0	102	14.1	218	1,000	50
D	1	2.5	2	TWT	FM	32.2/7.1	2.5	220°	33,913	38.6	76	16.9	191	894	45
E						NOT APPLICABLE									
F	1	2.5	2	TWT	FM	34.9/9.7	2.3	202°	26,633	31.2	54	16.9	306	1,286	64

This system was rerun with a 10-year life satellite with the results shown in Table 4-18. Concept D again results in the lowest cost system - approximately one-third of the costs previously derived. In addition to the savings resulting from the longer life satellite, the new data shows a change to operations at UHF which permits the use of standard TV receivers.

Table 4-18. ETV for Mexico

USER: ETV FOR MEXICO
SERVICE: 1 MILLION HOMES, 4 CHANNELS/BEAM
COVERAGE: 2 BEAMS
LIFE: 10 YEAR SYSTEM; 10 YEAR SATELLITE

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	NO. SATELLITES REQUIRED	MOD. TYPE	MODULATION TYPE	RECEIVING STATIONS: ANT. GAIN (dB)	RECEIVING STATIONS: ANT DIA (Ft)	RECEIVING STATIONS: EQUIV NOISE FIGURE (dB)	SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (Expended) (kW)	UNIT COSTS: SAT ($M)	UNIT COSTS: UPLINK ($M)	UNIT COSTS: EQUIP ($)	TOTAL SYSTEM COST ($M)	TOTAL COST PER/ RECEIVER ($)
D	1	0.8	1	CFA	FM	14.5	2.8	7.6	17310	30050	106.0	1.82	131	325.92	32.6
	1	2.5	1	TWT	FM	23.3	2.5	7.9	19610	39490	107.4	1.86	265	469.56	47.0
	1	12.2	1	TWT	FM	39.0	3.1	9.3	21960	46600	110.1	1.89	319	534.39	53.4
F	1	0.8	1	CFA	FM	14.3	2.7	7.6	19060	30840	114.8	1.82	110	319.93	34.0
	1	2.5	1	TWT	FM	23.3	2.5	7.9	21060	39340	105.7	1.86	264	656.30	65.6
	1	12.2	1	TWT	FM	38.9	3.1	9.3	23320	46510	108.6	1.92	319	538.02	53.8
H	1	0.8	1	CFA	FM	14.4	2.8	7.4	9500	22770	57.0	1.82	131	248.92	24.9
	1	2.5	1	TWT	FM	23.4	2.5	7.9	11730	31900	57.4	1.86	265	391.36	39.1
	1	12.2	1	TWT	FM	37.2	2.5	9.3	19600	57512	70.4	1.88	306	473.58	47.4

4.1.9 U.S. NATIONAL ITV SYSTEM -- DIRECT

This mission is similar in most respects to Mission No. 7. The main difference lies in the quality of TV service offered.

Results for this system are shown in Table 4-19. Concepts B and F yield the least cost systems - $92.5 million per year and $100 million per year respectively. Investment per school is $385 per year or $547 per year.

This system was also rerun with the results whown in Table 4-20. Concept B remains the lowest cost system. However, the new cost results are very much higher than the previous data. This results from the addition of facilities, operating personnel and standby power elements to the cost model. The unit receiver cost alone is shown in Table 4-20 to be $540,000. This includes $360,000 for operating personnel, leaving $180,000 as the acquisition cost of the receiving system.

Table 4-19. U.S. ITV -- Direct

USER : U. S. ITV - OPERATIONAL DIRECT SYSTEM
SERVICE : 32 CHANNELS, 8 STATIONS, 24-Hr. Broadcast, Color
COVERAGE : $1.26 \times 10^6 \times 8 = 10$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Life Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1	2.5	16	TWT	FM	54.7/100	0.7	50°	785	0.38	147	58.8	Large	Large	Large
B*	1	2.5	16	TWT	FM	35.2/10	2.3	205°	2,766	3.7	191	58.8	490	925	385
C	1	2.5	16	TWT	FM	33.2/8	2.5	220°	3,785	5.8	213	59.2	304	1,034	639
D	1	2.5	8	TWT	FM	32.7/7.5	2.6	237°	31,183	32.7	192	64.9	244	1,387	578
E									NOT APPLICABLE						
F	1	2.5	8	TWT	FM	33.5/8.3	2.5	220°	28,968	37.7	189	65.1	325	1,097	457

Table 4-20. Updated U.S. ITV -- Direct

USER: U.S. ITV - OPERATIONAL DIRECT SYSTEM
SERVICE: 32 CHANNELS, 10 STATIONS, 24-HOUR BROADCAST COLOR
COVERAGE: $1.26 \times 10^6 \times 8 = 10$ MILLION SQUARE MILE
LIFE: 10-YEAR SYSTEM; 5-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	XMTR TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE TRANSPONDER POWER (KW)	UNIT COSTS			TOTAL SYSTEM COST ($M)	TOTAL COST/YR./RECEIVER ($K)
						ANT. GAIN (dB)	ANT DIA (FT)	RCVR NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M) (CL. I)	RCVR ($M) (CL. II)		
B	1	2.5	(2)x8	TWT	FM	29.0	4.6	9.4	1619	3.37	5.63	1.27	0.54	130602	54.4
B	1	12.2	(2)x8	TWT	FM	45.2	6.3	14.0	3031	7.66	7.52	1.29	0.54	130926	54.5
D	1	2.5	(2)x2	TWT	FM	29.7	5.1	11.6	13102	19.93	36.32	1.27	0.62	148313	62.0
D	1	12.2	(2)x2	TWT	FM	45.1	6.2	14.0	17193	33.44	41.53	1.29	0.62	148704	62.0
F	1	2.5	(2)x2	TWT	FM	29.9	5.1	11.7	14633	20.07	35.90	1.27	0.62	148311	62.0
F	1	12.2	(2)x2	TWT	FM	45.1	6.2	14.0	18679	33.46	41.06	1.29	0.62	148702	62.0

4.1.10 MEXICO NATIONAL ITV SYSTEM -- DIRECT

This mission is similar to Mission No. 8 except for the user. Here the user/audience is the Mexican school system consisting of approximately 200,000 schools. The system provides 4 channels of instructional TV to each of 2 areas during normal school hours.

Results for the system are shown in Table 4-21. Concepts B and F represent the least cost systems. Concepts A and E do not yield acceptable solutions.

It is apparent that an additional mission can be postulated by combining Missions No. 8 and No. 10.

Table 4-21. Mexico ITV System

USER : MEXICAN ITV SCHOOL SYSTEM
SERVICE : 8 CHANNELS, 2 STATIONS, 24-Hr. Broadcast, Color
COVERAGE: $2 \times .94 \times 10^6 = 2$ million Sq. Mi.
LIFE : 10-yr. System, 5-yr. Life Satellite

CONCEPT	TASO GRADE	DOWN-LINK FREQUENCY (GHz)	NUMBER SATELLITES REQD.	XMTR TYPE	MODULATION	DOWNLINK			SATELLITE WT. (LB.)	SATELLITE POWER (KW)	SATELLITE COST ($M)	UPLINK COST ($M)	RCVR COST ($)	TOTAL SYST. COST ($M)	TOTAL COST/YR. PER RCVR
						ANTENNA GAIN (DB)	RCVR NOISE FIG.	RCVR NOISE TEMP.							
A	1	2.5	4	TWT	FM				VIOLATES BOUNDARY						
B	1	2.5	4	TWT	FM	36/11	2.3	201°	2,779	3.6	89	13.6	782	255	1,278
C	1	2.5	4	TWT	FM	35.2/10.0	2.4	215°	3,171	4.4	91	14.1	587	427	2,138
D	1	2.5	2	TWT	FM	35.2/10	2.5	220°	27,100	22.5	62.5	16.9	975	386	1,929
E									NOT APPLICABLE						
F	1	2.5	2	TWT	FM	35.2/10	2.4	216°	26,988	31.1	54	16.9	984	281	1,405

This case was rerun using the system topology shown in Table 4-22. The input is similar except that the satellite lifetime was extended from 5 to 10 years. This change, plus the optimization at 0.8GHz instead of 2.5 GHz, results in a total system cost of $104 million compared to $255 million previously. Concept B is still the preferred concept.

Table 4-22. Updated ITV for Mexico

USER: ITV FOR MEXICO
SERVICE: 20,000 SCHOOLS; 4 CHANNELS/BEAM
COVERAGE: 2 BEAMS
LIFE: 10 YEAR SYSTEM; 10 YEAR SATELLITE

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES SUPPORTED	SATELLITE TYPE	MODULATION	RECEIVING STATION ANT. GAIN (dB)	RECEIVING STATION ANT. DIA (Ft)	RECEIVING STATION SYSTEM NOISE FIGURE (dB)	SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (EXPENDABLE) (kW)	UNIT COSTS SAT ($M)	UNIT COSTS UPLINK ($M)	UNIT COSTS RCVR ($)	TOTAL SYSTEM COST ($M)	TOTAL COST PER RECEIVER ($)
B	1	0.8	1	CFA	FM	19.7	5.1	1.6	2520	2580	36.5	1.80	1.59	104.14	521
	1	2.5	1	TWT	FM	30.7	5.8	4.8	2250	3720	33.9	1.82	3.48	138.38	692
	1	12.2	1	TWT	FM	48.1	8.8	13.9	6160	14440	46.8	2.71	5.97	216.01	1080
D	1	0.8	1	CFA	FM	19.4	4.9	3.8	10750	10360	89.0	1.79	1.50	184.39	922
	1	2.5	1	TWT	FM	30.7	5.8	7.2	10730	12260	86.1	1.83	3.34	214.33	1072
	1	12.2	1	TWT	FM	47.3	8.1	14.0	14210	22540	93.5	1.87	5.85	288.37	1442
F	1	0.8	1	CFA	FM	19.3	4.9	3.8	12310	10480	87.8	1.79	1.50	188.69	943
	1	2.5	1	TWT	FM	30.7	5.8	7.6	12370	12620	85.3	1.83	3.33	223.13	1116
	1	12.2	1	TWT	FM	47.2	8.0	14.0	15760	22680	92.2	1.86	5.85	292.56	1463

4.2 SYSTEMS COMPARISON

Results from the previous analysis are shown in Table 4-23, which also shows the technique used in ranking the systems. Three elements are included:

1. User Ranking. This was derived previously.
2. Satellite System Data. This is taken directly from the outputs of the synthesis program.
3. Competitive Ground System Data. A detailed ground system model was not generated as part of this study. Data was used by direct reference where available -- India ETV-Direct, Ground System Cost of $141 million was taken from the G.E. TV Broadcast S tellite (TVBS) Study, Contract NAS3-9708, Report NASA CR-72579. Data was derived for the U.S. by considering a simple distribution of cable and microwave systems to provide the required service.

Combination of this data, in the given formulation , results in very high rating for the U.S. Armed Forces Radio and TV Services, U.S. Parochial Schools and the U.S. Biomedical Network. Medium ratings are achieved by U.S. ETV distribution, India ETV-Direct and U.S. ITV-Direct. These missions reflect

Table 4-23. System Selection

User	Minimum Cost Concept	Satellite				Total System Cost ($M)	Competing Ground System Cost ($M)	Implementation Time (yr.)		User Ranking *	System Ranking **
		Unit Wt. (lb.)	Unit Vol. (cu.ft.)	Unit Life (yr.)	Total Cost ($M)			Sat	Gnd		
U.S. Armed Forces Radio & TV (9 x 2 Sats. Req'd)	B	3,140	332	5	152	909	Unfeasible	5	-	10	Very High
U.S. Parochial Schools (8 Sats. Req'd)	B	1,328	287	10	54	314.5	1,814	4	10	8	115
U.S. Biomedical Network (8 Sats. Req'd)	B	1,142	81	10	51.8	407	1,814	4	10	6	67
India ETV - Direct	B	3,041	229	10	36	153	141	3	10	7	21
U.S. ETV - Distribution	B	998	72	10	34	460	384	4	5	9	10
Mexican ETV - Direct	D	9,495	765	10	57	326	212	3	10	3	8
Mexican ITV - Direct	B	2,519	323	10	36.5	104	212	3	10	1	7
U.S. ITV - TASO Gr. O	F	42,000	4,230	5	280	2,246	1,814	5	10	4	6
U.S. ETV - Direct	F	30,616	4,251	5	175	8,473	1,814	5	10	5	2
U.S. ITV - Direct (8 Sats. Req'd)	B	1,619	157	5	90	130,602	1,814	4	10	2	1

*User need ranked on 1 to 10 scale, with 10 greatest need.

**System Rank = $\frac{\text{competing ground system cost}}{\text{satellite system cost}} \times \frac{\text{ground implementation time}}{\text{satellite implementation time}} \times \text{User Need}$

the choice of Concepts F, B, and D, in that order. Remaining system scores are low. Further details of the optimum systems are presented in Table 4-24. Between Tables 4-23 and 4-24, it can be seen that a wide range of satellites, from 2,400 lb. to 42,000 lb. are considered along with an appropriate range of costs. There is a corresponding range in prime electrical power from 1.0 KW to 100 KW. Four of the cases optimized at 2.5 GHz downlink frequency -- primarily because of the existence of the atmospheric window at this frequency. Six cases optimized at 0.8 GHz because of the direct service offered to a very large receiver population ($2x10^6$ and $60x10^6$). Pre-existing UHF TV receivers (unaugmented) predominate in these cases.

Reviewing all of the data in terms of the utilization of the different satellite concepts results in Table 4-25. From this table it can be seen that the top three candidates are B, F, and D, in that order. Re-analysis of the systems has changed some of the specific details but has not affected the choice of concepts.

4.3 SELECTED SYSTEMS

The selected systems are summarized in Figure 4-1 along with recommended users. These concepts offer a wide range of weight and volume and can support a corresponding wide range of system options - e.g. 1 to 12 beams, 5 to 100 KW prime power, unmanned and manned operations.

The indicated users are:

1. U.S. Armed Forces Radio and TV Services. This system is discussed throughout the report. It is representative of a service that is being offered to a far-flung audience.

2. U.S. Educational and Instructional TV System. This user system has been derived by combining the following missions:
   a. Mission 2 -- U.S. ETV, Distribution
   b. Mission 6 -- U.S. ETV, Direct
   c. Mission 7 -- U.S. ITV, Distribution
   d. Mission 9 -- U.S. ITV, Direct

3. Alaska and Western States. This user system is representative of that offered to a remote area (similar to Mission 4, India) characterized by:
   a. Large area

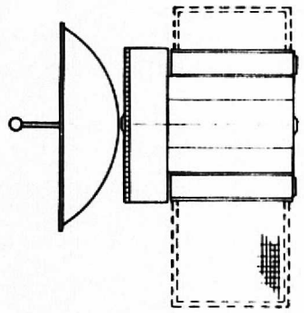
Table 4-24. Optimum Systems

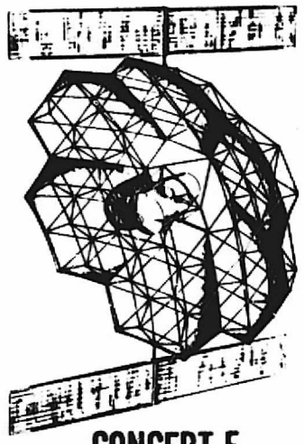
User	Ground Downlink System					Ground Uplink System					Satellite System		
	No.	Freq. (GHz)	RCVR NF(°K)	Ant. Dia. (ft.)	Initial Cost ($)	No.	Freq. (GHz)	Xmtr. Type	Ant. Dia. (ft.)	Total Cost ($M)	Prime Power (KW)	Ant. Dia. (ft.)	Xmtr. Type
U.S. Armed Forces Radio & TV	2×10^6	0.8	706	3.4	108	2	12.0	TWT	43.8	36.5	10.2	29.7	CFA
U.S. Parochial Schools	14,000	0.8	116	4.90	1,120	2	12.0	TWT	36.4	13.26	1.5	57x29	CFA
U.S. Biomedical Network	1,040	2.5	271	15.0	633	52	2.25	TWT	31.6	132.8	1.74	9x18	TWT
U.S. ETV - Distribution	200	2.5	236	17	453,470	1	12.0	TWT	39.1	6.3	1.5	9x18	TWT
India ETV - Direct	568×10^6	0.8	1549	2.6	77	1	0.85	TWT	20.5	0.66	6.6	26.9	CFA
U.S. ITV - Direct	240×10^3	2.5	2252	4.8	136,000	10	12.0	TWT	33.0	12.7	4.9	9x18	TWT
U.S. ITV - TASO Gr. O	240,000	2.5	250	12.5	3,267	10	8.2	TWT	54.5	73.0	87.4	11.4	TWT
Mexican ITV - Direct	20×10^3	0.8	130	5.1	149,000	1	0.85	TWT	32.7	1.8	2.6	33.1	CFA
Mexican ETV - Direct	1×10^6	0.8	1306	2.8	100	1	0.85	TWT	37.4	1.8	22.7	33.1	CFA
U.S. ETV - Direct	60×10^6	0.8	2610	1.9	88	7	0.85	TWT	39.7	12.94	100	29x57	CFA

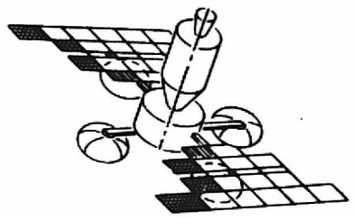
Table 4-25. Satellite Concept Comparison

Concept	Number of Users* Midterm	Post-Mid.	Final	Frequency Range (GHz)	Max. No. Beams	Weight Range (lb.)	Volume Range (cu. ft.)	Satellite Cost Range ($M)	Range of Cost/RCVR/Yr $	Orbital Refurb. Possible?	Rank	Reason For Ranking
A	0**	0**	0**							No	6	Too small
B	5	4	1/2	UHF to 12.7	1	1,100 to 4,200	≤262	5 to 36	385 to 191,000	No	2	Wide user range good single-purpose concept
C	2	2	0	2.5 to 12.7	1	4,000 to 5,000	<810	10 to 11	50 to 71	No	4	Volume limited, seldom optimum
D	6	2	4	UHF to 12.7	4	13,000 to 42,000	<6,000	28 to 106	12 to 743	Yes	3	Wide user range, good multi-purpose concept (high volume)
E	0***	1	0	UHF only	1	9,800	570	14.5	30	Yes	5	Antenna too large, volume too small
F	9	11	4	UHF to 12.7	6	12,000 to 42,000	<6,000	18 to 88	14 to 245,000	Yes	1	Satisfies wide user range

*Concept was first or second choice
**Size insufficient for all systems considered
***Applicable only at UHF, which is not optimum frequency







	CONCEPT B	CONCEPT F	CONCEPT D
SIZE	TO 5,000 LB. 262 CU. FT.	42,000 LB. 6,000 CU. FT.	42,000 LB. 6,000 CU. FT.
BEAMS	1 OR 2 MAX.	6 TO 12 MAX.	4 TO 8 MAX.
POWER	5 KW MAX.	ABOUT 50 KW MAX.	ABOUT 100 KW MAX.
FREQUENCY	2.5 TO 12.7 GHz	800 MHz TO 12.7 GHz	2.5 GHz TO 12.7 GHz
MANNED	NO	YES	YES

USERS: 1. U.S. Armed Forces Radio and Television Services
2. U.S. ETV/ITV System
3. TV Services for Alaska and Western States

Figure 4-1. Selected Systems

b. Small, widely-dispersed population

c. Rugged Terrain

The economics of a terrestrial system for this type of area would be prohibitive.

5

PRELIMINARY DESIGN

The system requirements and consequent costs were studied for seven services, India Educational Television, Mexican Educational and Instructional Television, and United States Alaska and Western States Television, Armed Forces Radio and Television System, Biomedical Network, and Educational and Instructional Television for general public and Parochial schools. Three of these, U.S. AFRTS, U.S. ETV/ITV and Alaska & Western states have been selected for analysis in Phase III and are discussed in this section. Table 5-1 summarizes several feasible links to provide these services.

5.1 U.S. ARMED FORCES RADIO AND TELEVISION SERVICE

The AFRTS exists now as a worldwide system operating 281 radio ground stations, 71 television ground stations with 23 channels, and communications services with teletype, voice and data capability.

Table 5-1. Summary of Services Feasible

User			Satellite Config.	Signal Quality and Net Description
U.S. Armed Forces Radio and Television Services, AFRTS, All Direct			9-B 2-D 2-F	TASO 1, 5 Channels, 2 Stations TASO 1, 5 Channels, 2 Stations TASO 1, 5 Channels, 2 Stations
U.S. Educational and Instructional Television				
U.S. ETV/ITV	ETV	Direct	1-F 1-D 6-H	TASO 1, 12 Channels, 7 Stations TASO 1, 12 Channels, 7 Stations TASO 1, 12 Channels, 7 Stations
		Dist.	4-B	CCIR, 8 Channels, 1 Station
	ITV	Direct	3-H 2-D	TASO 1, 32 Channels, 10 Stations TASO 1, 32 Channels, 10 Stations
Alaska and Western States, Television Service, DIRECT				TASO 1, 3 Channels, 1 Station

5.1.1 OBJECTIVES. The system discussed herein for AFRTS is to provide high quality television service (TASO grade 1 or 0) to the large military personnel and military dependent viewing audience. Table 5-2 and Figure 5-1 show the scope and coverage of the systems analyzed through use of the synthesis program.

Table 5-2.

U.S. ARMED FORCES RADIO & TV SERVICES

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
GLOBAL COVERAGE (SPECIFICALLY EXCLUDING U.S.) 9.2 SATELLITES 1.5 BEAMS/SATELLITE 5 CHANNELS/BEAM 10^6 SQ. MI./BEAM	10×10^6 PEOPLE (MILITARY PERSONNEL PLUS DEPENDENTS & ON-BASE STAFF) ASSUME: UNIFORM DISTRIBUTION 5 PEOPLE/RECEIVER	TWO ORIGINATING STATIONS WASHINGTON LOS ANGELES	3 CHANNELS 100% 2 CHANNELS 5:00 - 8:00 A.M. 5:00 P.M. - MIDNIGHT

U.S. ARMED FORCES RADIO & TV SERVICES

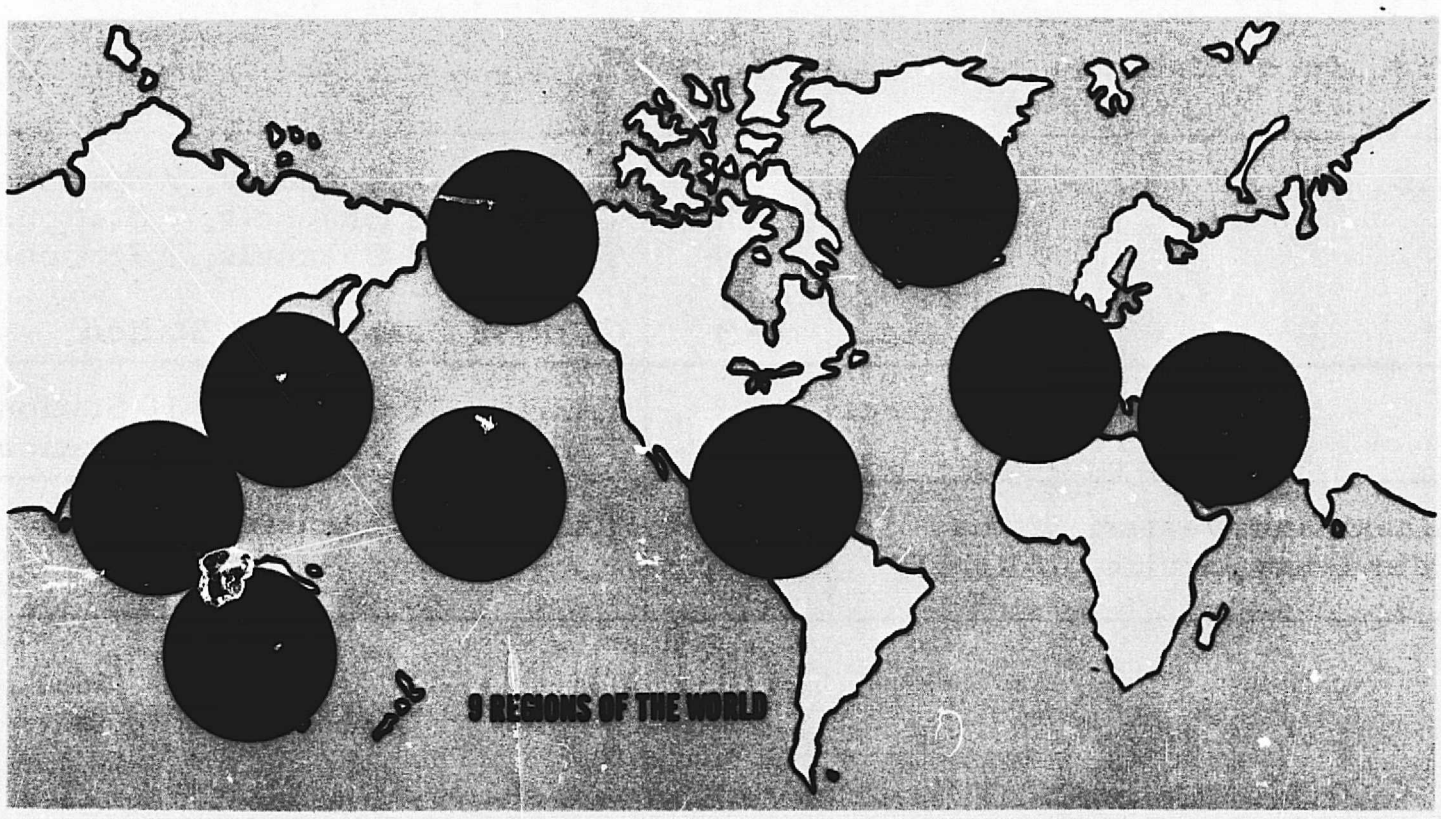


Figure 5-1.

5.1.2 LINK ANALYSIS. The Pacific and Atlantic distribution systems are sufficiently similar that one uplink and one downlink are analyzed in detail for power budgeting to provide the desired service. The minimum cost system using 9-B concept satellites is analyzed. It will be noted that an uplink receiver location loss of -2.0 db is allowed. This permits the originating station (Class 1) to be located anywhere since the satellite receiving antenna gives full earth coverage. Table 5-3 summarizes the user requirements reflected in the link analysis in the following paragraphs.

Table 5-3. User Requirements

	Pacific Area	Atlantic Area
Area of Coverage*		
Major Axis (mi.)	2669	2669
Minor Axis (mi.)	1236	1236
Area (10^6 mi.^{2})		
Receiver Population	5.5×10^6	4.45×10^6
Beam Center Latitude	5 beams	4 beams
Beam Center Longitude	See Fig. 5-1	See Fig. 5-1
Spacecraft Longitude	~-170°	~-10°
Taso Grade	1	1
No. of Video Channels	5	5
No. of Audio Channels/Video	1	1
No. of Uplink Facilities	1	1
No. of Video Channels/Facility	25	20
Total System Lifetime	10 years	10 years
Satellite Lifetime	2 @ 5 years	2 @ 5 years
Downlink Frequency (GHz)	0.8	0.8
Duty Cycle	Up to 24 Hrs.	Up to 24 Hrs.

*Typical beam coverage.

5.1.2.1 Uplink Power Budget, 12.0 Hz

a.	Transmitter power (1.1 kW)		+ 30.4 dBW
b.	Trans. antenna gain (43.8 ft. diam).		+ 59.9 dB
c.	Trans, circuit losses		- 3.0 dB
d.	EIRP		+ 87.3 dBW
e.	Total propagation losses		
	1) Free space (23,700 Stat. Mi),	-205.7 dB	
	2) Atmosphere and rain (36.6° elev),	- 5.4 dB	
	3) Location and pointing,	- 2.2 dB	
f.	Sat. receiving ant. gain (0.3 ft. x 0.3 ft.),		+ 19.6 dB
g.	Receiver circuit losses		- 1.0 dB
h	Total available carrier power,		-107.4 dBW
i.	Total system noise power (kTB),		-125.9 dBW
	1) Receiver (3.0 dB N.F.),	290.0°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	230.0°K	
	4) Effective system temperature,	579.6°K	
	5) Noise bandwidth,	32.63 MHz	
j.	Available carrier-to-noise ratio		18.5 dB

5.1.2.2 Downlink Power Budget, 0.8 GHz

a.	Transponder output power (550W),		+ 27.4 dBW
b.	Trans. ant. gain (29.7 ft. diam)		+ 35.0 dB
c.	Trans. circuit loss,		- 1.7 dB
d.	EIRP		+ 60.7 dBW
e.	Total propagation losses		-188.4 dB
	1) Free space (25,700 Stat. Mi),	-182.8 dB	
	2) Atmosphere and rain (6.4° elev),	- 0.4 dB	
	3) Location and pointing	- 2.2 dB	
	4) Polarization (circ. to lin),	- 3.0 dB	
f.	Direct receiving ant. gain (3.4 ft. diam. equiv.)		+ 16.2 Db
g.	Direct Rcvr. circ. loss,		- 2.0 dB
h.	Total available carrier power,		-113.5 dB
i.	Total system noise power (kTB),		-123.6 dBW
	1) Receiver (5.4 dB N.F.),	706.2°K	
	2) Receiver input circuitry	107.0°K	
	3) Antenna (-2.0 dB, item g),	80.8°K	
	sky, 0.537 x 68.3 = 36.7		
	envir, 0.036 x 72.1 = 2.6		
	earth, 0.305 x 290.0 = 88.5		
	127.8		
	4) Uplink contribution,	89.4°K	
	5) Effective system temperature,	983.4°K	
	6) Noise bandwidth,	32.63 MHz	
j.	Available carrier-to-noise ratio		10.1 dB
k.	Total improvement factors		+ 34.5 dB
	1) Weighting (EIA/BELL)	+ 7.0 dB	
	2) Peaking & TASO conversion	+ 7.6 dB	
	3) FM, $3m^2(m+1)$, m=2.88,	+19.9 dB	
l.	Available signal-to-noise ratio		+ 44.6 dB

5.1.3 COMMUNICATIONS SYSTEM DESCRIPTION. The user's requirements, Table 5-3, resulted in the system analyzed in the power budget. This system may be described in greater detail. Table 5-4 summarizes six cases analyzed using the system synthesis program. The two lowest cost cases are indicated.

5.1.3.1 Satellite System Description. Several cases were run through the computer synthesis program. The minimum cost case described in the link analysis is for five year life unmanned satellites. Two cases with provisions for life support for maintenance purposes reflect increased costs approximately equal to the manned provisions cost even though two large satellites are used in lieu of nine smaller ones. Table 5-5 describes the different satellite concepts employed in various system syntheses.

The uplink receiving antenna may be a small rigid aperture type (0.4 ft. x 0.4 ft) which offers sufficient gain at the higher frequency, 12.0 GHz employed.

Table 5-4.

User: U.S. Armed Forces Radio & TV (Direct Distribution)
Service: 5 Channels, 2 Stations, 24-Hour, Color
Coverage: $1.26 \times 10^6 \times 9 = 11.3$ Million Square Miles
Life: 10-Year System, 2-5 Year Satellites

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	SATE TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END OF LIFE) (kW)	UNIT COSTS			TOTAL SYSTEM COST ($m)	TOTAL COST/ YEAR/ RECEIVER ($)
						ANT. GAIN (dB)	ANT DIA (ft)	RCVR NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M)	RCVR ($)		
B	1	0.8	(2)x 9	CFA	FM	16.3	3.4	5.4	3140	7.0	8.45	18.27	159	908.8	45.40
B	1	2.5	(2)x 9	TWT	FM	25.1	3.0	6.3	4201	10.9	9.24	18.24	301	1206.0	60.30
D	1	0.8	(2)x 2	CFA	FM	16.3	3.4	5.3	19446	35.4	50.51	18.22	160	960.3	48.00
D	1	2.5	(2)x 2	TWT	FM	25.4	3.1	7.5	28596	69.7	59.61	18.26	292	1637.5	81.90
F	1	0.8	(2)x 2	CFA	FM	16.3	3.4	5.3	20894	35.3	49.88	18.22	161	957.6	47.90
F	1	2.5	(2)x 2	TWT	FM	24.6	2.9	6.8	29839	68.9	58.70	18.27	292	1633.2	81.70

Table 5-5. Concept Summary

SATELLITE CONCEPT COMPARISON

CONCEPT	NUMBER POTENTIAL USERS *	FREQUENCY RANGE (GHz)	MAX.NO. BEAMS	WEIGHT RANGE (LB.)	VOLUME RANGE (CU.FT.)	SATELLITE COST RANGE ($M)	RANGE OF COST/RCVR/YR ($)	ORBITAL REFURB. POSSIBLE?	RANK	REASON FOR RANKING
A	0 **							NO	6	TOO SMALL
B	5	2.5 to 12.7	1	1,100 to 3,200	< 262	6 to 9	385 to 191,000	NO	2	WIDE USER RANGE GOOD SINGLE-PURPOSE CONCEPT
C	2	2.5 to 12.7	1	4,000 to 5,000	< 810	10 to 11	50 to 71	NO	4	VOLUME LIMITED, SELDOM OPTIMUM
D	6	2.5 to 12.7	4	32,000 to 42,000	< 6,000	28 to 40	12 to 743	YES	3	WIDE USER RANGE, GOOD MULTI-PURPOSE CONCEPT (HIGH VOLUME)
E	0 ***	UHF ONLY						YES	5	ANTENNA TOO LARGE, VOLUME TOO SMALL
F	9	UHF to 12.7	6	16,000 to 42,000	< 6,000	18 to 40	14 to 245,000	YES	1	SATISFIES WIDEST USER RANGE

* CONCEPT WAS FIRST OR SECOND CHOICE

** SIZE INSUFFICIENT FOR ALL SYSTEMS CONSIDERED

*** APPLICABLE ONLYAT UHF, WHICH IS NOT OPTIMUM FREQUENCY

The downlink satellite antenna is a 29.7 ft. diameter truss antenna (such as Convair's PETA, parabolic expandable truss antenna).

Prime power is supplied by two folding solar arrays providing 6.996 kW of power at the end of the five year lifetime. Nickel-cadmium battery banks of 15.0 kW-Hrs capacity supply the satellite when it is in the earth's shadow.

The downlink operation at 0.8 GHz permits use of UHF crossed field amplifiers for the satellite transponder output. Redundancy increases the reliability of service for the full life span.

5.1.3.2 Ground Uplink System Description. The AFRTS analysis presents two originating (Class 1) stations, one in the Washington, D.C. area and one near Los Angeles, California. These are used as likely locations. There is nothing in the synthesis that restricts class 1 stations to these two locations. The service offers five channels to each user area. Thus the Washington, D.C. and Los Angeles stations would have 20 and 25 1.1 kilowatt transmitters respectively to permit complete freedom of scheduling programs to each area. The antenna is rigid parabola approximately 45 feet in diameter. Video-tape recorders, physical plant, stand-by power, test equipment and a telemetry and command subsystem are included in the synthesis. The cost of program generation and studios is not included.

5.1.3.3 Ground Receiving System Description. The ultimate user is assumed to have a conventional VHF-UHF television receiver. The modification for the AFRTS application includes an antenna and a pre-amplifier converter. The incident beam is frequency modulated at 0.8 GHz carrier frequency. The 5.4 dB noise figure converter provides FM demodulation and channel selection. The converter output is directly to the existing receiver video and audio circuits. The antenna of 3.4 feet equivalent diameter would most likely be a low cost ribbed parabolic type.

5.1.3.4 Ground Coverage. The nine concentrations of receivers are shown in Figure 5-1. Each of these is supplied by a beam from a satellite or by a beam from a multi-beam antenna if two satellite coverage is used. Figure 5-2 illustrates the coverage for the five Pacific region user areas as provided by a satellite with a five beam antenna.

5.1.4 RESULTS OF COST ANALYSIS. The U.S. Armed Forces Radio and Television services study has been based upon ten million viewers requiring two million direct receivers. The weight of the smallest cost item, the receiver, in large quantities shows clearly in Table 5-6 where the total costs of all major system subparts are compared for two frequencies. This data applies to the first two cases as summarized in Table 5-4. It may be noted that the class 1 station and launch vehicle costs are the same while the satellite, direct receiver and total system costs increase when the downlink frequency is increased from 0.8 to 2.5 GHz. However, the satellite cost increased by only nine per cent while the eighty-nine percent receiver cost brought the total system cost up thirty-three per cent showing the large effect of the receivers whose unit costs are only $301 and $159 respectively. Costs and further discussion of different parts of the system follow. The cost items used in the concluding summary are identified by circumscribed dashed lines.

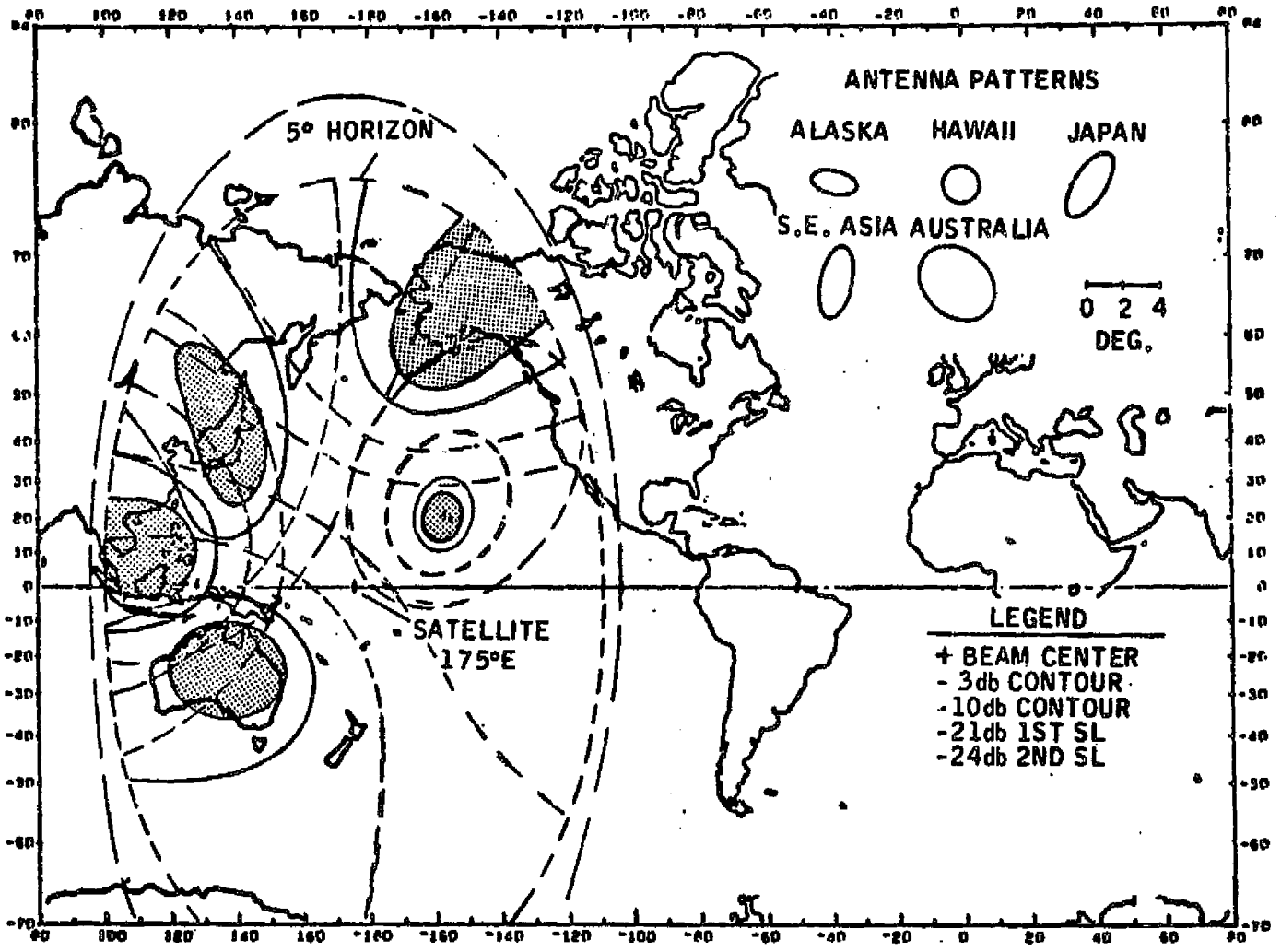


Figure 5-2. Typical Satellite Antenna Coverage

Table 5-6. Cost Dependence Upon Frequency

Freq, GHz	Cost in Millions of Dollars				
	Total System	2 Class 1 Stations	All Launch Vehicles	Total For All Satellites	Total for 2×10^6 Receivers
$f_1 = 2.5$	1206	36.5	401	166	602
$f_2 = 0.8$	909	36.5	401	152	319
Ratio of f_1 costs to f_2 costs	1.33	1	1	1.09	1.89

5.1.4.1 Cost of Satellites. The satellite analysis considers numerous cost contributing items as structure, power generation and storage, electronics, station keeping and other factors. Table 5-7 shows spacecraft subsystem costs.

5.1.4.2 Cost of Ground Uplink Subsystem. The originating station costs include all significant items. As previously mentioned, costs do not include production of programs. Table 5-8 summarizes these costs.

5.1.4.3 Cost of Direct Receiving Station. Paragraph 5.1.3.3 described the ultimate using station. The cost associated with this analysis was indicated to be only those to modify conventional television receiving sets. Table 5-9 gives the associated costs.

5.1.4.3 Total System Cost. The total system costs are tabulated in Table 5-10. The eight cases listed are the same as in Table 5-4. The top case is the one detailed in the link analysis and cost summaries for USAFRTS.

Table 5-7.

A R M E D F O R C E S R A D I O + T V S Y S T E M

SATELLITE SUBSYSTEM COSTS

SATELLITE SUBSYSTEMS	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT (LBS.)	VOLUME (CU FT)
POWER SUBSYSTEM					
PRIME POWER	2.29	.95	2.34	1015.4	169.57
SECONDARY POWER	.03	.16	.04	749.3	5.93
CONDITIONING	.09	.28	.11	345.5	4.63
DISTRIBUTION	.21	.40	.23	99.7	8.45
ANTENNA	.29	1.08	.35	120.7	77.21
TRANSMITTER	.95	.67	.99	358.5	6.69
MULTIPLEXER	.07	.46	.10	47.8	1.59
RECEIVERS	.21	.28	.23	70.0	1.25
STRUCTURE	.06	.20	.07	29.2	42.57
THERMAL CONTROL	.07	.53	.10	51.9	10.38
STATION KEEPING	.46	3.38	.65	86.3	.28
ATTITUDE CONTROL	.68	4.46	.92	96.0	1.36
TELEMETRY + COMMAND	.17	.85	.22	70.0	2.00
PROTOTYPE	-	3.63	.20		
INTEG, ASSY + CHECK	.42	-	.42		
DESIGN, INTEG + MGMT	-	6.84	.38		
CENTER SUPPORT	.90	1.03	.96		
GRD SUPPORT EQUIP	-	2.79	.16		
TOTAL/SATELLITE	6.90	1.55	8.45	3140.3	331.93
SYSTEM TOTAL	124.19	27.98	152.17		

Table 5-8. Class 1 Ground Station Costs

GROUND STATIONS - BEAM 1 (THOUSANDS)

CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	530.00	-	-	10.60	536.00
TERMINAL EQUIP-VIDEO	3000.00	600.00	450.00	300.00	*100.00
TRANSMITTERS-VIDEO	1581.17	316.23	1.46	158.12	3493.21
ANTENNA + MUX	212.38	0.00	-	21.24	424.76
STANDBY POWER	201.75	4.04	-	10.09	306.67
TEST EQUIPMENT	50.00	-	-	-	50.00
PERSONNEL	-	-	150.00	-	1500.00
DESIGN, INTEG + MGMT	-	719.03	-	-	719.03
TOTAL/FACILITY	5575.30	1639.30	601.46	500.04	18229.67

Table 5-9. Direct Receiving Station Costs

GROUND STATIONS - BEAM 2

DIRECT STATIONS	ACQUISITION	INSTALL	MAINT/YR	TOTAL
ANTENNA	11.60	36.87	1.16	60.08
RECEIVER	39.73	19.87	3.97	99.33
	51.33	56.74	5.13	159.40

TABLE 5-10. TOTAL SYSTEM COSTS IN MILLIONS OF DOLLARS

SAT. CONCEPT	FREQ. IN GHz	UNIT COSTS				TEN YEAR SYSTEM COSTS				TOTAL SYSTEM
		CLASS I	DIRECT *	SAT.	L.V.	CLASS I	DIRECT	SAT.	L.V.	
B	0.8	18.23	159	8.45	213.2	36.46	318.8	152.2	401.4	908.8
B	2.5	18.24	301	9.24	213.2	36.48	601.9	166.3	401.4	1206.0
D	0.8	18.22	160	50.5	213.2	36.44	320.4	202.0	401.4	960.3
D	2.5	18.26	292	59.6	213.2	36.52	584.7	238.4	777.8	1637.5
F	0.8	18.22	160	49.9	213.2	36.44	320.2	199.5	401.4	957.6
F	2.5	18.27	292	58.7	213.2	3654	584.1	234.8	777.8	1633.2

* DIRECT RECEIVER UNIT COST IS IN DOLLARS

5.2 U.S. EDUCATIONAL AND INSTRUCTIONAL TELEVISION

U.S. ETV and ITV were developed as studies of separate systems during the course of the contract study. They are presented together in this report since they have a common goal of contributing to the educational process. The viewing audience, however, is not identical. This distinction must be borne in mind when considering U.S. ETV/ITV in detail.

5.2.1 OBJECTIVES. The educational objective is to provide for both children and adults high quality instructional material of a scope in subject matter beyond that generally available and providing geographical coverage to regions offering little or no educational programs. The technical objective is to provide high quality television displays to the viewing audience taking advantage of the extensive coverage possible through use of geostationary satellites. The cost objective is to provide the extensive system reaching a large proportion of those receiving instruction at cost less than the equivalent coverage may be obtained using conventional teaching, distribution and display techniques.

Table 5-11 summarizes typical audiences, proposed uplinks and presentation hours. In all cases high quality imaging (TASO 1 and TASO 0 or CCIR Relay Quality) would result.

5.2.2 LINK ANALYSIS. The three services tabulated in Table 5-11 employ 7, 1, and 10 Class I originating stations. The downlinks connect with 60,000,000 Direct, 200 Class II and 240,000 Class III stations. One link from originating station to satellite transponder to ground receiver is analyzed for power budget to give the signal-to-noise required for the quality of service required. Table 5-12 gives typical requirements and beam description for ETV Direct, ETV Distribution and ITV Direct respectively. The associated link analyses are given in the following paragraph.

Table 5-11.

U.S. NATIONAL ETV SYSTEM

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES PLUS HAWAII & ALASKA 2 CHANNELS/AREA (12 TOTAL)	DIRECT-TO-HOME ASSUME 80% OF TOTAL U.S. RECEIVERS	ONE UPLINK IN EACH AREA ON ONE CHANNEL TIME-SHARED FOR LOCAL PROGRAMMING N.Y.C. ORIGIN FOR SECOND CHANNEL	6:00 A.M. TO 9:00 A.M. & 5:00 P.M. TO MIDNIGHT

U.S. NATIONAL ETV SYSTEM
Program Distribution

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES 2 CHANNELS/ZONE	TO GROUND STATIONS FOR REBROADCAST 50 ETV RECEIVERS PER ZONE	ONE N.Y.C. ORIGIN	100%

U.S. NATIONAL ITV SYSTEM

COVERAGE	POTENTIAL AUDIENCE	UPLINK	DUTY CYCLE
FULL U.S. 4 TIME ZONES HAWAII ALASKA U.S. PACIFIC TERR. VIRGIN IS. 4 CHANNELS/AREA	PUBLIC ELEMENTARY & SECONDARY SCHOOLS (~300,000) ASSUME 80% COVERAGE (~240,000 RECEIVERS)	TWO ORIGINATING STATIONS IN EACH TIME ZONE PLUS ONE EACH IN HAWAII & ALASKA	3 CHANNELS 8:00 A.M. TO 4:00 P.M. 1 CHANNEL/AREA 100% FOR PROGRAM PRE-VIEWING

Table 5-12. Typical User Requirements and Beam Descriptions

Service Type Distribution Method Zone	U.S. ETV Direct PST	U.S. ETV Distribution PST	U.S. ITV Direct CST
Area of Coverage (approx.)			
Major Axis (mi.)	2,186	2,186	1,998
Minor Axis (mi.)	619	619	615
Area (10^6 mi^2)	1	1	1
Receiver Population	8 x 10^6 (approx.)	50	60,000
Beam Center Latitude	38° N	38° N	35° N
Beam Center Longitude	125° W	125° W	95° W
Spacecraft Longitude	100° W	100° W	120° W
Taso Grade	1	CCIR	1
No. of Video Channels	2	2	4
No. of Audio Channels/Video	1	1	1
No. of Uplink Facilities	1	1	2
No. of Video Channels/Facility	2	2	2
Total System Lifetime (years)	10	10	10
Satellite Lifetime (years)	5	10	5
Downlink Frequency (GHz)	0.8	2.5	2.5
Duty Cycle	0600 - 2400 each area	100%	100%

5.2.2.1 U.S. ETV Direct

Uplink Power Budget, 0.85 GHz

a.	Transmitter power (6 W)		+ 7.8 dBW
b.	Trans. antenna gain (39.7 ft. diam).		+ 38.1 dB
c.	Trans. circuit losses		- 3.0 dB
d.	EIRP		42.9 dBW
e.	Total propagation losses		-185.3 dB
	1) Free space (23,800 Stat. Mi),	-182.7 dB	
	2) Atmosphere and rain (33.3° elev),	- 0.1 dB	
	3) Location and pointing,	- 2.5 dB	
f.	Sat. receiving ant. gain (28.7 ft. x 57.3 ft),		+ 38.2 dB
g.	Receiver circuit losses,		- 1.0 dB
h.	Total available carrier power,		-105.2 dBW
i.	Total system noise power (kTB),		-125.9 dBW
	1) Receiver (3.0 dB N.F.)	290.0°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	230.0°K	
	4) Effective system temperature,	579.6°K	
	5) Noise bandwidth,	32.63 MHz	
j.	Available carrier-to-noise ratio		+ 20.7 dB

5.2.2.1 U.S. ETV Direct

Downlink Power Budget, 0.8 GHz

a.	Transponder output power (2.49 kW),		+ 34.0 dBW
b.	Trans. ant. gain (28.7 ft. x 57.3 ft),		+ 37.7 dB
c.	Trans. circuit loss,		- 1.4 dB
d.	EIRP		+ 70.3 dBW
e.	Total propagation losses		-187.7 dB
	1) Free space (24,000 Stat. Mi),	-182.4 dB	
	2) Atmosphere and rain (23.1°elev.)	- 0.1 dB	
	3) Location and pointing	- 2.2 dB	
	4) Polarization (circ. to lin),	- 3.0 dB	
f.	Direct receiving ant. gain (1.9 ft. diam equiv.)		+ 11.0 dB
g.	Dir. rcvr. circ. loss,		- 2.0 dB
h.	Total available carrier power,		-108.4 dB
i.	Total system noise power (kTB),		-118.6 dBW
	1) Receiver (11.0 dB N.F.),	2610.0°K	
	2) Receiver input circuitry	107.0°K	
	3) Antenna (-2.0 dB, item g),	116.2°K	
	sky, 0.537 x 54.2 = 29.1		
	envir, 0.036 x 1846.5 = 66.5		
	earth, 0.305 x 290.0 = 88.5		
	184.1		
	4) Uplink contribution	283.3°K	
	5) Effective system temperature,	3116.5°K	
	6) Noise bandwidth,	32.63 MHz	
j.	Available carrier-to-noise ratio		+ 10.2 dB
k.	Total improvement factors		+ 34.5 dB
	1) Weighting (EIA/BELL)	+ 7.0 dB	
	2) Peaking & TASO conversion	+ 7.6 dB	
	3) FM, $3m^2(m+1)$, m = 2.88,	+ 19.9 dB	
l.	Available signal-to-noise ratio		+ 44.7 dB

5.1.2.2 U.S. ETV Distribution (Class I, II)

Uplink Power Budget, 12.0 Hz

a.	Transmitter power (510 W),		+ 27.1 dBW
b.	Trans. antenna gain (39.1 ft. diam),		+ 59.4 dB
c.	Trans. circuit losses		- 3.0 dB
d.	EIRP		+ 83.5 dBW
e.	Total propagation losses		-209.8 dB
	1) Free space (23,700 Stat. Mi),	-205.7 dB	
	2) Atmosphere and rain (33.3° elev),	- 1.9 dB	
	3) Location and pointing,	- 2.2 dB	
d.	Sat. receiving ant. gain (1.9 ft. x 0.8 ft.),		+ 31.0 dB
g.	Receiver circuit losses,		- 1.0 dB
h.	Total available carrier power,		- 96.3 dBW
i.	Total system noise power (kTB),		-125.9 dBW
	1) Receiver (3.0 dB N.F.),	290.0°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	230.0°K	
	4) Effective system temperature,	579.6°K	
	5) Noise bandwidth,	32.60 MHz	
j.	Available carrier-to-noise ratio		+ 29.6 dB

5.1.2.2 U.S. ETV Distribution (Class I, II)

Downlink Power Budget, 2.5 GHz

a.	Transponder output power (22 W),		+ 13.4 dBW
b.	Trans. ant. gain (9.2 ft. x 18.3 ft.),		+ 37.7 dB
c.	Trans. circuit loss,		- 1.4 dB
d.	EIRP		+ 49.7 dBW
e.	Total propagation losses		-197.7 dB
	1) Free space (24,400 Stat. Mi),	-192.3 dB	
	2) Atmosphere and rain (23.1° elev),	- 0.2 dB	
	3) Location and pointing,	- 2.2 dB	
	4) Polarization (circ. to lin),	- 3.0 dB	
f.	Cl. II receiving ant. gain (17.1 ft. diam. equiv.)		+ 40.1 dB
g.	Cl. II rcvr. circ. loss,		- 1.0 dB
h.	Total available carrier power,		-108.9 dB
i.	Total system noise power (kTB),		-128.2 dBW
	1) Receiver (2.59 dB N.F.),	236.3°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	16.2°K	
	sky, 0.867 x 15.7 = 13.6		
	envir, 0.010 x 102.9 = 1.0		
	earth, 0.020 x 290.0 = 5.8		
	20.4		
	4) Uplink contribution,	31.2°K	
	5) Effective system temperature,	344.3°K	
	6) Noise bandwidth,	32.60 MHz	
j.	Available carrier-to-noise ratio		+ 19.3 dB
k.	Total improvement factors		+ 34.9 dB
	1) Weighting (EIA/BELL),	+ 7.0 dB	
	2) Peaking & TASO conversion	+ 7.6 dB	
	3) FM, $3m^2(m+1)$, m = 3.0,	+ 20.3 dB	
l.	Available signal-to-noise ratio		+ 54.2 dB

5.1.2.3 U.S. ITV Direct (Class I, II)

Uplink Power Budget, 12.0 GHz

a.	Transmitter power (1.59 kW)		+ 32.0 dBW
b.	Trans. antenna gain (33.0 ft. diam),		+ 58.3 dB
c.	Trans. circuit losses		- 3.0 dB
d.	EIRP		87.3 dBW
e.	Total propagation losses		-213.3 dB
	1) Free space (23,700 Stat. Mi),	-205.7 dB	
	2) Atmosphere and rain (36.6° elev),	- 5.4 dB	
	3) Location and pointing,	- 2.2 dB	
f.	Sat. receiving ant. gain (0.3 ft. x 0.3 ft.),		+ 19.6 dB
g.	Receiver circuit losses,		- 1.0 dB
h.	Total available carrier power,		-107.4 dBW
i.	Total system noise power (kTB),		-125.9 dBW
	1) Receiver (3.0 dB N.F.),	290.0°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	230.0°K	
	4) Effective system temperature,	579.6°K	
	5) Noise bandwidth	32.63 MHz	
j.	Available carrier-to-noise ratio		+ 18.5 dB

5.1.2.3 U.S. ITV Direct (Class I, II)

Downlink Power Budget, 2.5 GHz

a.	Transponder output power (256 W.),		+ 24.1 dBW
b.	Trans. ant. gain (9.2 ft. x 18.3 ft.),		+ 37.7 dB
c.	Trans. circuit loss,		- 1.4 dB
d.	EIRP		+ 60.4 dBW
e.	Total propagation losses		-197.6 dB
	1) Free space (24,400 Stat. Mi),	-192.2 dB	
	2) Atmosphere and rain (6.4° elev),	- 0.2 dB	
	3) Location and pointing,	- 2.2 dB	
	4) Polarization (circ. to lin),	- 3.0 dB	
f.	Cl. II. receiving ant. gain (4.8 ft. diam. equiv.)		+ 29.0 dB
g.	Cl. II. rcvr. circ. loss,		- 1.0 dB
h.	Total available carrier power,		-109.2 dB
i.	Total system noise power (kTB),		-119.4 dBW
	1) Receiver (9.43 dB N.F.),	2252.0°K	
	2) Receiver input circuitry	59.6°K	
	3) Antenna (-1.0 dB, item g),	38.6°K	
	sky, 0.709 x 14.0 = 9.9		
	envir, 0.019 x 102.9 = 2.0		
	earth, 0.130 x 290.0 = 37.7		
	48.6		
	4) Uplink contribution,	235.1°K	
	5) Effective system temperature,	2585.3°K	
	6) Noise bandwidth,	32.63 MHz	
j.	Available carrier-to-noise ratio		+ 10.2 dB
k.	Total improvement factors		+ 34.5 dB
	1) Weighting (EIA/BELL)	+ 7.0 dB	
	2) Peaking & TASO conversion	+ 7.6 dB	
	3) FM, $3m^2(m+1)$, m = 2.88,	+ 19.9 dB	
l.	Available signal-to-noise ratio		+ 44.7 dB

5.2.3 COMMUNICATIONS SYSTEM DESCRIPTION. The link analysis resulting from the iteration of the system synthesis program gives some essential requirements that largely determine satellite size (i.e., rf power, prime power consumption, antenna gain, and satellite stability). In the entire synthesis process the cost of implementing a satellite design is traded against associated costs for the ground transmitting and receiving systems.

Table 5-5 describes 6 satellite concepts considered (concept H not listed is 1 large concept C). Those concepts found feasible were shown previously in Table 5-1. Other satellite concepts are either not applicable to the service objectives or incompatible with necessary system constraints. Tables 5-13, 5-14 and 5-15 describe the total satellite and ground systems that meet the technical television objectives and are feasible to accomplish.

5.2.3.1 Satellite System Description. The tables 5-13 to 5-15, show that each service synthesized is accomplished by different satellites, uplinks and receiving stations. Thus ETV Direct, ETV Distribution and ITV Direct must be discussed separately.

a. ETV DIRECT. Table 5-13 shows a one satellite system to offer the lowest cost. This satellite, concept F, provides life support and docking for maintenance purposes. The large multiple beam antenna is of the folding truss type used for both up and down links. The satellite contains twelve cross-field redundant output amplifiers. Energy is generated by solar cells delivering 68.9 kW at end of the five year lifetime. Nickel-cadmium batteries provide storage capacity of 2.12 kW-hrs.

b. ETV DISTRIBUTION. Six cases were analyzed. The lowest cost system as analyzed in 5.1.2.2 employs four ten year life concept B satellites with no provision for life support and docking. The uplink at 12 GHz employs a small aperture type antenna. The downlink at 2.5 GHz uses a single beam truss antenna. Each satellite contains two TWT transmitters. The solar cells deliver at least 0.99 kW with the nickel-cadmium batteries storing 2.12 kW-hrs.

c. ITV DIRECT. The six cases studied are listed in Table 5-15 where the cost system is seen to use 8 five year satellites without manned provisions. As in the case of ETV DISTRIBUTION the uplink at 12 GHz uses a small rigid antenna providing full earth coverage. All eight satellites are at 120°W longitude. The down links are at 2.5 GHz and employ folding truss antennas. Each satellite has four TWT transponders. In this case the solar cells assure 3.37 kW which is stored in nickel-cadmium batteries of 7.22 kW-hrs. capacity.

5.2.3.2 Ground Uplink System Description.

a. ETV DIRECT. This network basically provides a class I originating station for each time zone and Alaska and Hawaii. However the Eastern Standard Time Zone has two stations permitting transmission from both Washington D.C. and New York City areas. Two channels are directed to each of the six service areas via cross-field amplifier transmitters. The ground antenna is a 39.7 ft. diameter rigid parabola. As listed in

TABLE 5-13

USER: U.S. ETV - OPERATIONAL DIRECT SYSTEM
SERVICE: 12 CHANNELS, 7 STATIONS, 24-HOUR BROADCAST COLOR
COVERAGE: $6 \times 1.2 \times 10^6 = 7.5$ MILLION SQUARE MILE
LIFE: 10-YEAR SYSTEM; 5-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	LIMITER TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END OF LIFE) (kw)	UNIT COSTS			TOTAL SYSTEM COST ($m)	TOTAL COST/ YEAR/ RECEIVER ($)
						ANT. GAIN (dB)	ANT DIR (ft)	RCVR NOISE FIGURE (dB)			SAT ($m)	UPLINK ($M) (CL. I)	RCVR ($)		
D	1	0.8	(2)x1	CFA	FM	11.1	1.9	10.0	29166	68.9	88.89	1.849	131	8478	14.10
D	1	2.5	(2)x1	TWT	FM	19.3	1.6	7.9	27719	68.9	83.99	1.869	290	17967	29.90
F	1	0.8	(2)x1	CFA	FM	11.0	1.9	10.0	30616	68.9	87.69	1.848	131	8473	14.10
F	1	2.5	(2)x1	TWT	FM	19.2	1.5	7.9	29173	68.9	82.91	1.869	290	17963	29.90
F	1	12	(2)x1	TWT	FM	36.4	2.3	9.3	29065	68.9	80.34	1.907	318	19667	32.90
H	1	0.8	(2)x6	CFA	FM	7.2	1.2	10.0	9174	26.7	17.07	2.048	128	8513	14.20
H	1	2.5	(2)x6	TWT	FM	15.9	1.1	7.9	7100	20.9	13.98	2.065	287	17842	29.70
H	1	12	(2)x6	TWT	FM	31.0	1.2	9.3	11889	37.0	19.61	2.416	308	19549	32.60

TABLE 5-14

USER: U.S. ETV - PROGRAM DISTRIBUTION
SERVICE: 8 CHANNELS, 1 STATION, 24-HOUR COLOR
COVERAGE: $1.26 \times 10^6 \times 4 = 5$ MILLION SQUARE MILE
LIFE: 10-YEAR SYSTEM; 10-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	SATE TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END OF LIFE) (KW)	UNIT COSTS			TOTAL SYSTEM COST ($m)	TOTAL COST/YEAR/RECEIVER ($K)
						ANT. GAIN (dB)	ANT DIA (ft)	RCVR NOISE FIGURE (dB)			SAT ($m)	UPLINK ($M) (CL. I)	RCVR ($M) (CL. II)		
B	CCIR	2.5	4	TWT	FM	40.1	17.1	2.59	998	0.99	8.53	6.25	1.39	460.3	230.2
B	CCIR	12.2	4	TWT	FM	56.3	24.1	7.34	1222	1.40	8.81	6.27	1.41	465.4	232.7
D	CCIR	2.5	1	TWT	FM	40.1	17.2	2.60	9536	6.00	83.14	6.38	1.39	583.2	291.5
D	CCIR	12.2	1	TWT	FM	56.1	23.7	7.43	10324	7.64	83.24	6.27	1.41	587.7	293.9
F	CCIR	2.5	1	TWT	FM	40.1	16.9	2.60	11082	6.06	82.12	6.24	1.39	582.1	291.1
F	CCIR	12.2	1	TWT	FM	56.1	23.6	7.50	11891	7.74	82.34	6.27	1.41	586.0	293.0

TABLE 5-15

USER: U.S. ITV - OPERATIONAL DIRECT SYSTEM
SERVICE: 32 CHANNELS, 10 STATIONS, 24-HOUR BROADCAST COLOR
COVERAGE: $1.26 \times 10^6 \times 8 = 10$ MILLION SQUARE MILE
LIFE: 10-YEAR SYSTEM; 5-YEAR SATELLITES

CONCEPT	TASO GRADE	DOWNLINK FREQ (GHz)	No. SATELLITES REQUIRED	RATE TYPE	MODULATION	RECEIVING STATION			SAT. WEIGHT (lbs)	SATELLITE PRIME POWER (END OF LIFE) (KW)	UNIT COSTS			TOTAL SYSTEM COST ($M)	TOTAL COST/YEAR/RECEIVER ($K)
						ANT. GAIN (dB)	ANT DIA (ft)	RCVR NOISE FIGURE (dB)			SAT ($M)	UPLINK ($M) (CL. I)	RCVR ($M) (CL. II)		
H	1	2.5	(2)x8	TWT	FM	29.0	4.6	9.4	1619	3.37	5.63	1.27	0.54	130602	54.4
H	1	12.2	(2)x8	TWT	FM	45.2	6.3	14.0	3031	7.66	7.52	1.29	0.54	130926	54.5
D	1	2.5	(2)x2	TWT	FM	29.7	5.1	11.6	13102	19.93	36.32	1.27	0.62	148313	62.0
D	1	12.2	(2)x2	TWT	FM	45.1	6.2	14.0	17193	33.44	41.53	1.29	0.62	148704	62.0
F	1	2.5	(2)x2	TWT	FM	29.9	5.1	11.7	14633	20.07	35.90	1.27	0.62	148311	62.0
F	1	12.2	(2)x2	TWT	FM	45.1	6.2	14.0	18679	33.46	41.06	1.29	0.62	148702	62.0

5.1.3.2 this station includes all plant and facility for operation and maintenance. No cost is allowed for program production and studios.

b. ETV DISTRIBUTION. This network is predicated on one originating station near New York City employing eight transmitters to direct two channels to each of the four satellites. 510 watt TWT transmitters are employed. The 39.1 ft. diameter rigid parabolic antenna provides 59.3 dB gain at the uplink frequency of 12 GHz. Station equippage is otherwise the same as for ETV DIRECT.

c. ITV DIRECT. Ten Class I stations originate transmissions at 12 GHz employing 33.0 ft. diameter rigid parabolas. Four channels are provided each service area from 2.5 GHz, 1.59 kW TWT amplifier transmitters. Here too, all plant and equipment are provided except for program production.

5.2.3.3 Ground Receiving System Description.

a. ETV DIRECT. This is a direct-to-home system. The analysis assumes an existing conventional television set available for a modification kit which is priced in the analysis. This modification includes a 1.9 ft. diameter, low cost antenna. The receiver modification includes a preamplifier converter with a 0.8 GHz input. FM demodulation and channel selection is provided by this 10.0 dB noise figure converter. The converter output, as in the case of U.S. AFRTS, goes to the existing receiver video and audio circuits.

b. ETV DISTRIBUTION. This network provides transmissions to 200 class II stations, 50 in each CONUS time zone. The analysis does not include further distribution by cable or surface microwave links. The class 2 stations receive two channels for distribution. The antenna is a 17.1 ft. diameter parabola. The 2.59 dB N.F. receiver at 2.50 GHz outputs in a manner compatible with the further distribution system to conventional television receivers.

c. ITV DIRECT. The ITV network assumes 240,000 class II receiving stations located at approximately 80% of the public elementary and secondary schools in the service area. Four channels are available. Additional distribution within the individual schools is not included in the analysis. A 4.75 ft. diameter antenna provides 29 dB gain at 2.5 GHz. The receiver has a 9.43 dB noise figure.

5.2.3.4 Ground Coverage. The ground coverage is essentially time zones in the United States. Some additional areas are included as indicated in Table 5-11. The approximate beam description for time zone coverage follows in Table 5-16.

5.2.4 RESULTS OF COST ANALYSIS. The ETV/ITV networks show the effects of very different receiving costs. The ETV-DIRECT is similar to AFRTS discussed in section 5.1, a large number of low cost modifications to existing television receivers. ETV-DISTRIBUTION has a relatively small number of (200) more expensive Class 2 receivers since the redistribution beyond these points is not included. ITV-DIRECT is an "in-between-category"

Table 5-16. ETV/ITV Pattern Coverage, Time Zone Beams

Characteristic	Service		
	ETV Direct (0.8 GHz)	ETV Distribution (2.5 GHz)	ITV Direct (2.5 GHz)
Antenna Dimensions	28.7 ft. x 57.3 ft.	9.2 ft. x 18.3 ft.	9.2 ft. x 18.3 ft.
Beamwidths	3.00^{o} x 1.50^{o}	3.00^{o} x 1.50^{o}	3.00^{o} x 1.50^{o}
Pattern Axes	2186 mi. x 619 mi.	2186 mi. x 619 mi.	1998 mi. x 615 mi.

having an intermediate number (240,000) Class 2 receivers. The effect of this relative distribution of units and the cost dependence upon frequency is shown in Table 5-17. ETV-DISTRIBUTION is the lowest cost networks as herein defined. This reflects the small number of Class 2 receivers and is little dependent upon frequency. Next in cost is ETV-DIRECT showing the weight of a large number of low cost receiver modifications. This increases system cost ant also is very dependent upon frequency since the higher frequency receiver modifications are more than double cost. The remaining network, ITV-DIRECT, is the highest cost by virtue of the rather large number of Class 2 receivers. However, there is very little frequency dependence.

5.2.4.1 Cost of Satellites. The subsystem costs contributing to the total satellite cost are given in Tables 5-18, 5-19 and 5-20 for ETV-DIRECT, ERV-DISTRIBUTION and ITV-DIRECT respectively. Satellite costs vary sidely since size, number of channels, size of antennas and other design factors are the consequence of the trade offs involved in the entire network. The costs for the different cases analyzed for each network show that the product of the satellite unit cost and the number of satellites is approximately the same for a given service (see Tables 5-13, 5-14 and 5-15).

5.2.4.2 Cost of Ground Uplink Station. The service requirements determine the number of originating, Class 1 stations. The individual cost items and station totals for the three networks are given in Tables 5-21, 5-23 and 5-25. These costs are not simple to compare. The number of channels, frequency and radiated power level are significant cost factors which vary with the user's needs. Table 5-25 does not show video terminal equipment costs because the synthesis program in its present form provides the same video terminal costs for both Class 1 and Class 2 stations in a network. This is likely to apply when the Class 2 redistributes via cable or link. In the case of ITV with direct distribution to 240,000 schools video terminal equipment such as video tape recorders is not expected and was eliminated. The consequent removal of this equipment from Class 1 stations reduces the station cost approximately 40%. This is a small fraction of one percent of the entire system cost which is dominated by the large number of Class 2 stations. The Class 1 cost in Table 5-17 includes telemetry and command which is not listed in the Class 1 breakdown (see Table 5-21), but must be included to reconcile the total system costs given in the various tables.

Table 5-17. U.S. ETV/ITV Networks Cost Dependence Upon Frequency

Frequency, in GHz	Costs In Millions of Dollars				
	Total System	Originating Stations	Launch Vehicles	Satellites	Receiving Stations
	U.S. ETV - DIRECT				
Type of Unit	-	Class 1	-	-	Direct
No. of Units	-	7	2	2	6×10^7
Costs, $f_1 = 0.8$	8,473	13	401	175	7,881
Costs, $f_2 = 2.5$	17,963	13	401	166	17,381
f_2/f_1 Cost Ratio	2.12	1	1	0.95	2.20
	U.S. ETV - DISTRIBUTION				
Type of Unit	-	Class 1	-	-	Class 2
No. of Units	-	1	1	4	200
Costs, $f_1 = 2.5$	460	15	133	34	278
Costs, $f_2 = 12.2$	465	15	133	35	282
f_2/f_1 Cost Ratio	1.01	1	1	1.03	1.01
	U.S. ITV - DIRECT				
Type of Unit	-	Class 1	-	-	Class 2
No. of Units	-	10	2	16	240,000
Costs, $f_1 = 2.5$	130,602	31	401	90	130,079
Costs, $f_2 = 12.2$	130,926	31	401	120	130,373
f_2/f_1 Cost Ratio	1	1	1	1.33	1

Table 5-18. U.S. ETV Direct Satellite Subsystem Costs

SATELLITE SUBSYSTEMS	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT (LBS.)	VOLUME (CU FT)
POWER SUBSYSTEM					
PRIME POWER	16.95	6.40	20.15	9998.0	1569.66
SECONDARY POWER	.16	.30	.31	6137.5	46.51
CONDITIONING	.35	.33	.51	2110.7	25.06
DISTRIBUTION	.78	.46	1.01	981.7	47.00
ANTENNA	2.23	2.07	3.26	1248.6	1183.37
TRANSMITTER	2.83	1.52	3.59	1529.2	20.83
MULTIPLEXER	.24	.37	.42	154.8	5.16
RECEIVERS	.65	.31	.80	210.0	3.75
STRUCTURE	.12	.41	.33	82.3	55.51
THERMAL CONTROL	.31	2.34	1.49	474.5	94.91
STATION KEEPING	.63	4.32	2.80	516.9	1.18
ATTITUDE CONTROL	.81	5.18	3.40	119.1	1.41
TELEMETRY + COMMAND	.17	.85	.59	70.0	2.00
MANNED PROVISIONS	1.80	24.90	14.25	6983.0	1094.17
PROTOTYPE	-	13.63	6.82		
INTEG, ASSY + CHECK	2.10	-	2.10		
DESIGN, INTEG + MGMT	-	24.89	12.44		
CENTER SUPPORT	4.52	3.73	6.39		
GRD SUPPORT EQUIP	-	14.02	7.01		
TOTAL/SATELLITE	34.67	53.02	87.69	30616.4	4250.54
SYSTEM TOTAL	69.33	106.04	175.38		

Table 5-19. U.S. ETV Distribution Satellite Subsystem Costs

SATELLITE SUBSYSTEMS	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT (LBS.)	VOLUME (CU FT)
POWER SUBSYSTEM					
PRIME POWER	.42	.19	.47	145.6	24.32
SECONDARY POWER	.02	.06	.03	249.0	2.29
CONDITIONING	.05	.08	.07	149.4	2.91
DISTRIBUTION	.13	.13	.16	23.5	5.68
ANTENNA	.16	.61	.31	34.2	7.11
TRANSMITTER	.32	.32	.40	50.0	5.70
MULTIPLEXER	.04	.22	.09	35.1	1.17
RECEIVERS	.22	.21	.27	70.0	1.25
STRUCTURE	.05	.18	.10	26.6	16.86
THERMAL CONTROL	.01	.11	.04	5.3	1.06
STATION KEEPING	.40	3.83	1.35	53.2	.22
ATTITUDE CONTROL	.71	4.11	1.74	85.8	1.34
TELEMETRY + COMMAND	.17	.85	.38	70.0	2.00
PROTOTYPE	-	2.33	.58		
INTEG, ASSY + CHECK	.20	-	.20		
DESIGN, INTEG + MGMT	-	5.45	1.36		
CENTER SUPPORT	.43	.82	.64		
GRD SUPPORT EQUIP	-	1.34	.34		
TOTAL/SATELLITE	3.33	5.21	8.53	997.7	71.82
SYSTEM TOTAL	13.30	20.83	34.14		

Table 5-20. U.S. ITV Direct Satellite Subsystem Costs

SATELLITE SUBSYSTEMS	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT (LBS.)	VOLUME (CU FT)
POWER SUBSYSTEM					
PRIME POWER	1.21	.51	1.24	488.5	81.58
SECONDARY POWER	.02	.12	.02	382.0	3.13
CONDITIONING	.06	.21	.07	195.8	2.96
DISTRIBUTION	.14	.33	.16	48.0	5.28
ANTENNA	.16	.61	.20	30.3	6.48
TRANSMITTER	.43	.56	.47	129.9	5.72
MULTIPLEXER	.06	.35	.08	49.1	1.64
RECEIVERS	.12	.22	.14	35.0	.63
STRUCTURE	.05	.18	.06	25.2	41.58
THERMAL CONTROL	.04	.32	.06	24.4	4.88
STATION KEEPING	.42	3.14	.62	55.6	.23
ATTITUDE CONTROL	.57	3.85	.81	84.8	1.34
TELEMETRY + COMMAND	.17	.85	.22	70.0	2.00
PROTOTYPE	-	2.43	.15		
INTEG, ASSY + CHECK	.26	-	.26		
DESIGN, INTEG + MGMT	-	5.62	.35		
CENTER SUPPORT	.56	.84	.61		
GRD SUPPORT EQUIP	-	1.73	.11		
TOTAL/SATELLITE	4.27	1.37	5.63	1618.5	157.44
SYSTEM TOTAL	69.28	21.86	90.14		

Table 5-21. ETV-Direct Class 1 Ground Station Costs

GROUND STATIONS - BEAM 1 (THOUSANDS)

CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	70.00	-	-	1.40	84.00
TEPMINAL EQUIP-VIDEO	240.00	48.00	36.00	24.00	888.00
TRANSMITTERS-VIDEO	32.46	6.49	1.11	3.25	82.47
ANTENNA + MUX	102.29	0.00	-	10.23	204.58
STANDBY POWER	37.94	.76	-	1.90	57.67
TEST EQUIPMENT	50.00	-	-	-	50.00
PERSONNEL	-	-	42.43	-	424.26
DESIGN, INTEG + MGMT	-	56.21	-	-	56.21
TOTAL/FACILITY	532.69	111.46	79.53	40.77	1847.19

Table 5-22. Direct Receiving Station Costs

DIRECT STATIONS	ACQUISITION	INSTALL	MAINT/YR	TOTAL	(DOLLARS)
ANTENNA	8.03	27.68	.80	43.74	
RECEIVER	35.04	17.52	3.50	87.61	
	43.07	45.20	4.31	131.35	

Table 5-23. ETV-Distribution Class 1 Ground Station Costs

GROUND STATIONS - BEAM 1			(THOUSANDS)		
CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	190.00	-	-	3.80	228.00
TERMINAL EQUIP-VIDEO	960.00	192.00	144.00	96.00	3552.00
TRANSMITTERS-VIDEO	389.28	77.86	1.40	38.93	870.45
ANTENNA + MUX	135.72	0.00	-	13.57	271.45
STANDBY POWER	133.20	2.66	-	6.66	202.46
TEST EQUIPMENT	50.00	-	-	-	50.00
PERSONNEL	-	-	84.85	-	848.53
DESIGN, INTEG + MGMT	-	222.75	-	-	222.75
TOTAL/FACILITY	1858.20	495.27	230.26	158.96	6245.64

Table 5-24. Class 2 Ground Receiving Station Costs

GROUND STATIONS - BEAM 2			(THOUSANDS)		
CLASS 2 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	50.00	-	-	1.00	60.00
TERMINAL EQUIP-VIDEO	240.00	48.00	36.00	24.00	888.00
ANTENNA + MUX	5.03	.71	-	.50	10.76
RECEIVERS	2.50	.37	.12	.25	6.62
STANDBY POWER	41.89	.84	-	2.09	63.64
TEST EQUIPMENT	25.00	-	-	-	25.00
PERSONNEL	-	-	30.00	-	300.00
DESIGN, INTEG + MGMT	-	37.13	-	-	37.13
TOTAL/FACILITY	364.42	87.05	66.12	27.85	1391.19

Table 5-25. ITV-Distribution Class 1 Ground Station Costs

GROUND STATIONS - BEAM 1 (THOUSANDS)

CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	70.00	-	-	1.40	84.00
TERMINAL EQUIP-VIDEO	0.00	0.00	0.00	0.00	0.00
TRANSMITTERS-VIDEO	144.18	28.84	1.49	14.42	332.13
ANTENNA + MUX	78.52	0.00	-	7.85	157.04
STANDBY POWER	126.22	2.52	-	6.31	191.86
TEST EQUIPMENT	50.00	-	-	-	50.00
PERSONNEL	-	-	42.43	-	424.26
DESIGN, INTEG + MGMT	-	33.41	-	-	33.41
TOTAL/FACILITY	468.92	64.77	43.92	29.98	1272.70

Table 5-26. Class 2 Ground Receiving Station Costs

GROUND STATIONS - BEAM 2 (THOUSANDS)

CLASS 2 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL
FACILITY	60.00	-	-	1.20	72.00
TERMINAL EQUIP-VIDEO	0.00	0.00	0.00	0.00	0.00
ANTENNA + MUX	3.07	.05	-	.31	6.18
RECEIVERS	.49	.07	.02	.05	1.31
STANDBY POWER	45.76	.92	-	2.29	69.55
TEST EQUIPMENT	25.00	-	-	-	25.00
PERSONNEL	-	-	36.74	-	367.42
DESIGN, INTEG + MGMT	-	.53	-	-	.53
TOTAL/FACILITY	134.32	1.58	36.77	3.84	542.00

5.2.4.3 Cost of Receiving Station. The receiving station costs are given in Tables 5-22, 5-24 and 5-26. These costs vary widely depending upon whether direct or Class 2. In all three networks presented the total receiving costs is the largest cost item due to the quantity.

5.2.4.4 Total System Costs. The cost of the total system and some unit costs are in Tables 5-13, 5-14, and 5-15. Table 5-17 gives sufficient total system costs to dependence upon frequency. Tables 5-27, 5-28, and 5-29 give unit and ten year total costs for all cases presented for ETV-DIRECT, ETV-DISTRIBUTION and ITV-DIRECT respectively.

Table 5-27. Total System Costs in Millions of Dollars, ETV - DIR.

Sat. Concept	Freq. in GHz	UNIT COSTS					TEN YEAR SYSTEM COSTS					Total System
		Class 1	Class 2	Direct*	Sat.	LV	Class 1	Class 2	Direct	Sat.	LV	
D	0.8	2.1	-	131	89	201	15	-	7,884	178	401	8,478
D	2.5	2.1	-	290	84	201	15	-	17,383	168	401	17,967
F	0.8	2.1	-	131	88	201	15	-	7,881	175	401	8,473
F	2.5	2.1	-	290	83	201	15	-	17,381	166	401	17,963
F	12.0	2.1	-	318	80	201	16	-	19,089	161	401	19,667
H	0.8	4.0	-	128	17	197	28	-	7,690	205	590	8,513
H	2.5	4.0	-	287	14	201	28	-	17,244	168	401	17,842
H	12.0	4.4	-	308	20	195	31	-	18,505	235	778	19,549

*Cost is in Dollars

Table 5-28. Total System Costs in Millions of Dollars, ETV - Distrib.

Sat. Concept	Freq. in GHz	UNIT COSTS					TEN YEAR SYSTEM COSTS					Total System
		Class 1	Class 2	Direct*	Sat.	LV	Class 1	Class 2	Direct	Sat.	LV	
B	2.5	15	1.4	-	8.5	133	15	278	-	34	133	460
B	12.2	15	1.4	-	8.8	133	15	282	-	35	133	465
D	2.5	8.7	1.4	-	83	213	8.7	278	-	83	213	583
D	12.2	8.6	1.4	-	83	213	8.6	282	-	83	213	588
F	2.5	8.5	1.4	-	82	213	8.5	278	-	82	213	582
F	12.2	8.5	1.4	-	82	213	8.5	282	-	82	213	586

*Cost is in Dollars

Table 5-29. Total System Costs in Millions of Dollars, ITV - Distrib.

Sat. Concept	Freq. in GHz	UNIT COSTS					TEN YEAR SYSTEM COSTS					Total System
		Class 1	Class 2	Direct*	Sat.	LV	Class 1	Class 2	Direct	Sat.	LV	
H	2.5	3.1	0.54	-	5.6	201	31	130,079	-	90	401	130,602
H	12.2	3.1	0.54	-	7.5	201	31	130,372	-	120	401	130,926
D	2.5	1.7	0.62	-	36.0	201	17	147,749	-	145	401	148,313
D	12.2	1.8	0.62	-	42.0	201	18	148,119	-	166	401	148,704
F	2.5	1.7	0.62	-	36.0	201	17	147,749	-	144	401	148,311
F	12.2	1.8	0.62	-	41.0	201	18	148,119	-	164	401	148,702

*Cost is in Dollars

5.3 ALASKA AND THE WESTERN STATES.

The state of Alaska at present has only 5 commercial television stations and no ETV or microwave services; the western states have access to only 23 ETV stations. This limited coverage and the vast sparsely settled areas make the consideration of using the extended coverage possible with a geostationary satellite very attractive.

5.3.1 OBJECTIVES. The objective of this service is to provide a complete educational (ETV/non-commercial TV) and instructional television (ITV) broadcast and reception capability for Alaska and the Western States. It is intended that this service will be made available to all homes, communities, schools (elementary and secondary), colleges and institutions in these states. If effect, the Western States comprise the Pacific Standard Time time zone of the continental U.S. This service will transfer television data from the originating station to the entire service area. It is assumed that, at this time, only a one-way transmission is required. Three TV channels, with one audio channel per video channel, will be required. Full color TV service will be provided on each channel with a quality of TASO Grade 1 (Signal-to-Noise Ratio, 44.5 db).

5.3.2 LINK ANALYSIS. This system extends from the originating terminal near Los Angeles, California, to the satellite and in turn to Alaska and the Western States via two down beams. Table 5-30 briefly describes the system. The three rf links are analyzed.

Table 5-30. User Requirements

	Alaska	Western States
Area of Coverage		
Major Axis (mi.)	1,390	1,520
Minor Axis (mi.)	2,200	590
Area (10^6 mi.^{2})	2.4	0.7
Receiver Population	100,000	8,600,000
Beam Center Latitude	60.2°N	36.8°N
Beam Center Longitude	144.8°W	118.6°W
Spacecraft Longitude	120°W	120°W
TASO Grade	1	1
No. of Video Channels	3	3
No. of Audio Channels/Video	1	1
No. of Uplink Facilities	1	
No. of Video Channels/Facility	6	
Total System Lifetime	10 Years	
Satellite Lifetime (2 req'd for 10 yr. system life)	5 Years	
Frequencies, Uplink/Downlink	8.2/0.8 GHz	
Duty Cycle	24 Hours/Day	

5.3.2.1 Uplink Power Budget 8.2 GHz

Transmitter Power - (50 watts)		17.0 dBw
Xmitter Antenna Gain - (22.8 ft.)		52.4 dB
Transmitter Circuit Losses		-2.0 dB
EIRP		67.4 dBw
Total Propagation Losses:		-203.5 dB
Free Space (23650 statute miles)	- 202.4 dB	
Atmospheric	- 0.9 dB	
Pointing (xmit and Rcvr.)	- 0.2 dB	
S/C Receiving Antenna Gain (8.4 ft.)		44.2 dB
Total Available Carrier Power		-91.9 dBw
Noise Temperatures:		
Receiver (2 dB Noise Figure)	170.0°K	
Antenna	290.0°K	
Total System Noise Power (BW_{RF} = 33.6 MHz)		-126.7 dBw
Available Carrier-to-Noise Ratio at Input to Spacecraft Receiver		34.8 dB

5.3.2.2 Downlink Power Budget for Alaska TV Service, 0.8 GHz

Transmitter Output Power (1740 watts)		32.4 dBw
S/C Antenna Gain (102 ft. × 19.5 ft.)		38.5 dB
Transmitter Circuit Losses		-2.0 dB
EIRP		68.9 dBw
Total Propagation Losses:		-190.0 dB
Free Space Loss (25250 St.mi.)	- 182.7 dB	
Atmospheric Loss (Elevation = 10°)	- 0.2 dB	
Pointing Loss (Xmit. & Rcvr.)	- 2.1 dB	
Typical Rcvr. Location Loss	- 2.0 dB	
Polarization Loss (Circular-to-Linear)	- 3.0 dB	
Receiving Antenna Gain (4.3 ft.)		18.0 dB
Receiver Transmission Line Loss (2 ft.)		-0.1 dB
Available Carrier Power		-103.2 dBw
System Noise Power (seen at input to Rcvr.)		-127.4 dBw
Antenna Temperature	122°K	
Xmission Line Temperature	6.6 K	
Receiver Temperature (2.5 dB N.F)	224.2°K	
Temperature Contributed by Uplink	35.3°K	
Noise Bandwidth	33.6 MHz	

Available Carrier-to-Noise Ratio		24.2 dB
FM Improvement Threshold	12.0 dB	
Margin Above Threshold	12.2 dB	
FM Improvement (Mod Index = 3)		20.3 dB
Available Signal-to-Noise Ratio		44.5 dB

5.3.2.3 Downlink Power Budget for Western States TV Service, 0.8 GHz

Transmitter Output Power (1550 watts)		31.9 dBw
S/C Antenna Gain (32 ft. × 55.5 ft.)		38.3 dB
Transmitter Circuit Losses		-2.0 dB
EIRP		68.2 dBw
Total Propagation Losses:		-189.4 dB
Free Space Loss (23650 st.mi.)	- 182.2 dB	
Atmospheric Loss (Elev. = 37°)	- 0.1 dB	
Pointing Loss (Smit and Rcvr.)	- 2.1 dB	
Typical Rcvr. Location Loss	- 2.0 dB	
Polarization Loss (Circular-to-Linear)	- 3.0 dB	
Receiving Antenna Gain (4.3 ft.)		18.0 dB
Receiver Transmission Line Loss (2 ft.)		-0.1 dB
Available Carrier Power		-103.3 dBw
System Noise Power (seen at Rcvr. Input)		-127.5 dBw
Antenna Temperature	117.5°K	
Xmission Line Temperature	6.6°K	
Receiver Temperature (2.5 dB N.F.)	224.2°K	
Temperature Contributed by Uplink	34.8	
Noise Bandwidth	33.6 MHz	
Available Carrier-To-Noise Ratio		24.2 dB
FM Improvement Threshold	12.0 dB	
Margin Above Threshold	12.2 dB	
FM Improvement (Mod Index = 3)		20.3 dB
Available Signal-To-Noise Ratio		44.5 dB

5.3.3 COMMUNICATIONS SYSTEM DESCRIPTION

The user requirements detailed in Table 5-30 were encoded into the TVBS synthesis program and a minimum cost solution, consistant with configuration constraints, was determined. The resulting solution will be discussed in the following sections.

5.3.3.1 Satellite System Description. The satellite system basically consists of two five year spacecraft designed around the Multiple Docking Adapter (MDA) as illustrated in Figure 5-3. The MDA is equipped with an atmospheric supply that allows short term manned support of the system in a shirt sleeve environment. Table 5-31 describes the satellite.

The two satellite antennas (Figure 5-3) are 19.5 feet by 102 feet and 32 feet by 55.5 feet for Alaska and the Western States, respectively. The Parabolic Expandable Truss Antenna was chosen for these antennas due to the rigidity of the deep truss structure. The uplink receiving antenna is 8.4 feet in diameter and is beamed to the Los Angeles area.

The prime power is supplied by two folding solar panels producing 85 kilowatts at the end of life. In addition, batteries are provided to allow the full 6 channel operation during periods of solar eclipse.

Redundant high efficiency UHF crossed field amplifiers produce the required 1740 and 1550 watts per channel for Alaska and the Western State, respectively. The communications system block diagram is given in Figure 5-4.

5.3.3.2 Ground Uplink System Description — One uplink facility, near Los Angeles, will provide the necessary program recording and transmission functions as well as the telemetry and command operations. The system, itemized in Table 5-32 consists of 50 watts per channel transmitters feeding a 22.8 foot parabolic antenna, 6 videotape recorders, the physical plant, stand-by power, test equipment and a telemetry and command system. Specifically excluded in the analysis was the cost of program generation and studios.

5.3.3.3 Ground Receiving System Description. It was assumed in the analysis that the consumer had a standard UHF-VHF television set and that the augmentation for the direct reception of the signals would include a separate antenna and a preamplifier-converter. In this case, the transmission is frequency modulated in the upper end of the UHF spectrum. The preamplifier-converter has a 2.5 db noise figure antenna-mounted front-end with the FM demodulator mounted on the consumer set. The channel selection will be made at the demodulator. The output of the demodulator is injected directly into the video and audio circuits of the set. The receiver installation cost of $71 is included in the analysis to cover this modification to the set (See Table 3-4, page 3-3).

The receiving antenna is a 4.3 foot, 18 db gain UHF ribbed parabolic reflector. The installation cost includes both materials and labor for roof mounting and proper orientation of the antenna.

5.3.3.4 Ground Coverage. The Antenna Pattern Projection program was utilized to determine the coverage areas and interference problems for the two regions. The resulting projections are given in Figure 5-5.

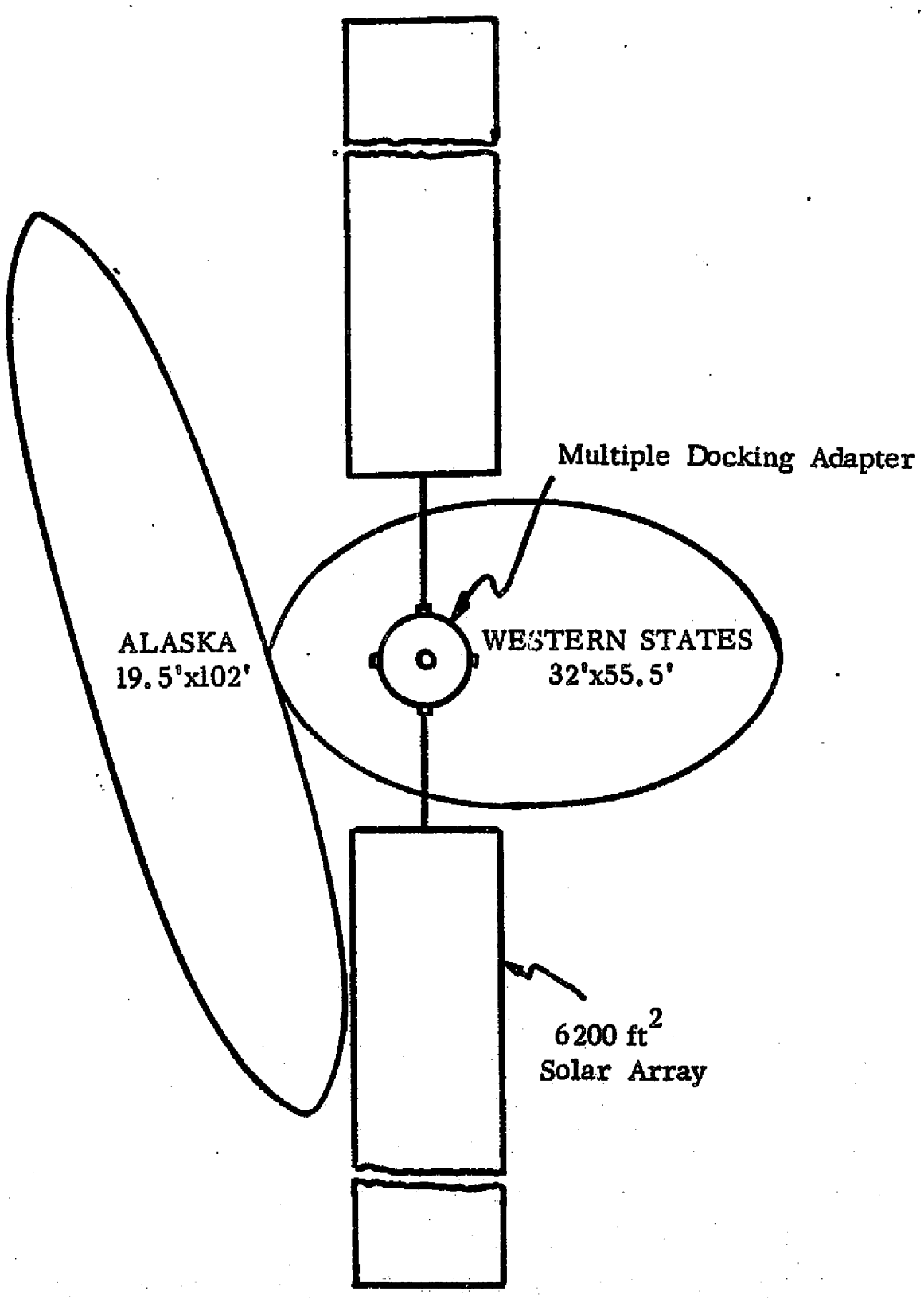


FIGURE 5-3. Alaska and Western States Satellite Configuration

TABLE 5-31.

SPACECRAFT SUBSYSTEM TABULATION

	SUBSYSTEM COST (MILLIONS) ACQUISITION	R&D	TOTAL	WEIGHT (lbs)	VOLUME (cu ft)		
Power Subsystem							
Power Source	29.575	50.533	109.684	12346.36	2061.84	Array	85070 watts
Batteries	.095	.527	.718	7548.17	49.93	Ni-Cd	182291 W-Hrs
Conditioning	4.591	8.703	17.886	8052.09	169.10		
Antenna (Downlink)	2.047	4.925	9.020	820.32	558.25	Truss	38.3, 38.5 db
Antenna (Uplink)	.000	.054	.055	18.55	106.91	Rigid	44.2 dB
Transmitter	8.683	13.064	30.429	2889.48	51.74	CFA	1740, 1550 w
Multiplexer	1.845	3.699	7.389	64.76	.20	Coax	
Receiver	.288	.695	1.271	70.00	1.25		2 db NF
Structure	2.015	20.414	24.443	2500.00	163.00	MDA	
Thermal Control	.483	5.244	6.210	666.39	133.28	Hybrid	59235 w rad.
Stationkeeping	.818	10.414	12.050	680.51	1.56	Ion	
Attitude Control	3.722	38.052	45.495	773.38	5.24	Ion	
Telemetry & Command	1.051	1.575	3.676	70.00	2.00		
Test Equipment	--	.750	.750	--	--		
Manned Provisions	21.170	66.030	108.370	5500.00	855.99	MDA	
Total/Satellite	76.384	224.678	377.446	42000.00	4160.28		
TOTAL FOR SYSTEM	152.768	224.678	377.446				

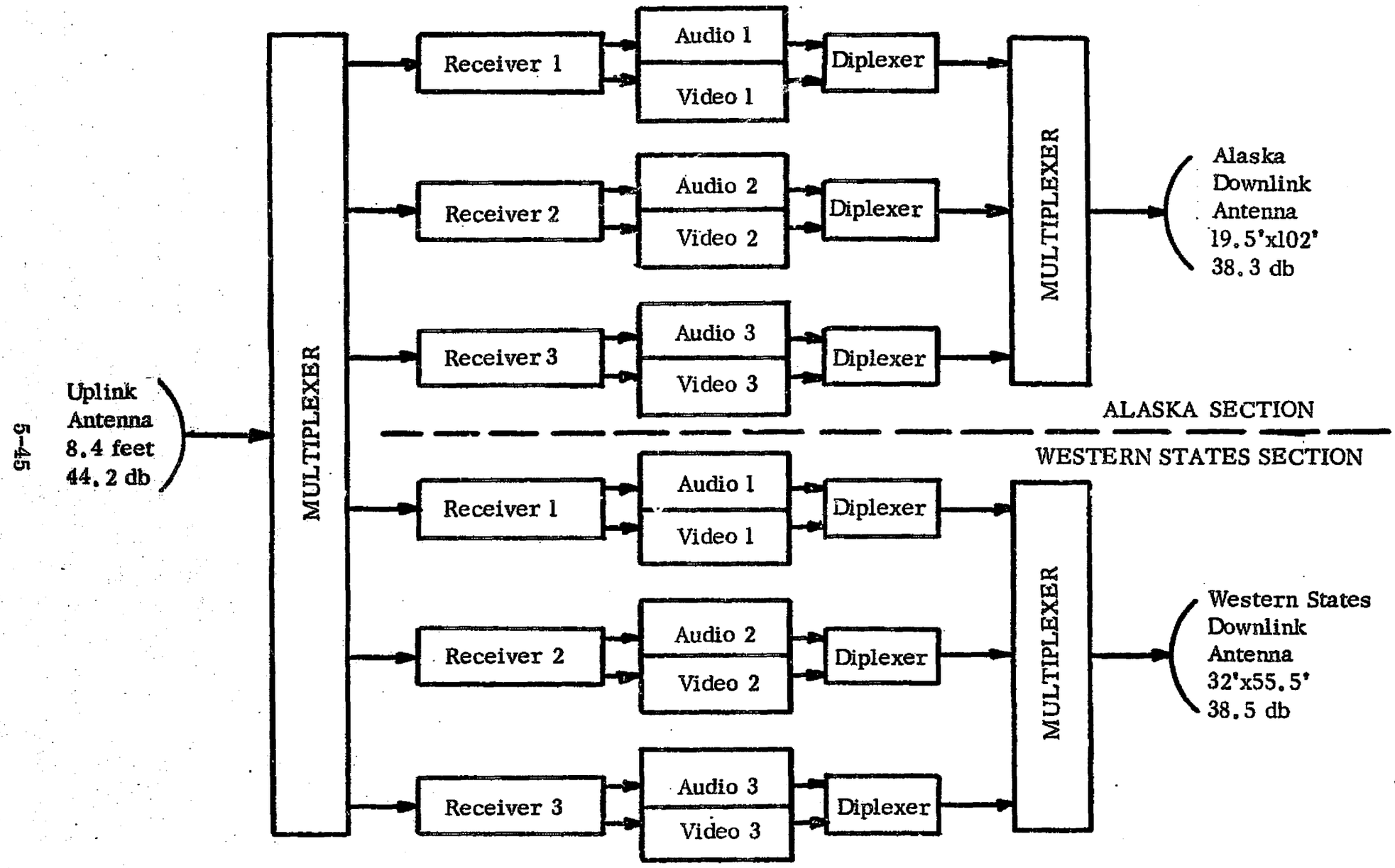


FIGURE 5-4. Communications System Block Diagram

TABLE 5-32.

GROUND UPLINK SUBSYSTEM TABULATION

	COST (MILLIONS)				
	ACQUISITION	R&D	OPS/YR	TOTAL	
Facilities	.061	.006	.001	.079	
Prog, Rec, & Contr Equip	.864	.000	.219	3.054	
Transmitter	.514	.000	.032	.835	50.5 watts
Antenna	.047	.000	.003	.078	52.4 db
Standby Power	.043	--	.002	.060	
Test Equipment	.200	--	--	.200	
Sys Des, Integ, & Mgmt	--	.531	--	.531	
Sys Oper Mgmt	--	--	.156	1.560	
Total/Facility	1.729	.537	.413	6.397	
Telemetry & Command	.290	.195	.183	2.318	
TOTAL FOR SYSTEM	2.019	.732	.597	8.715	

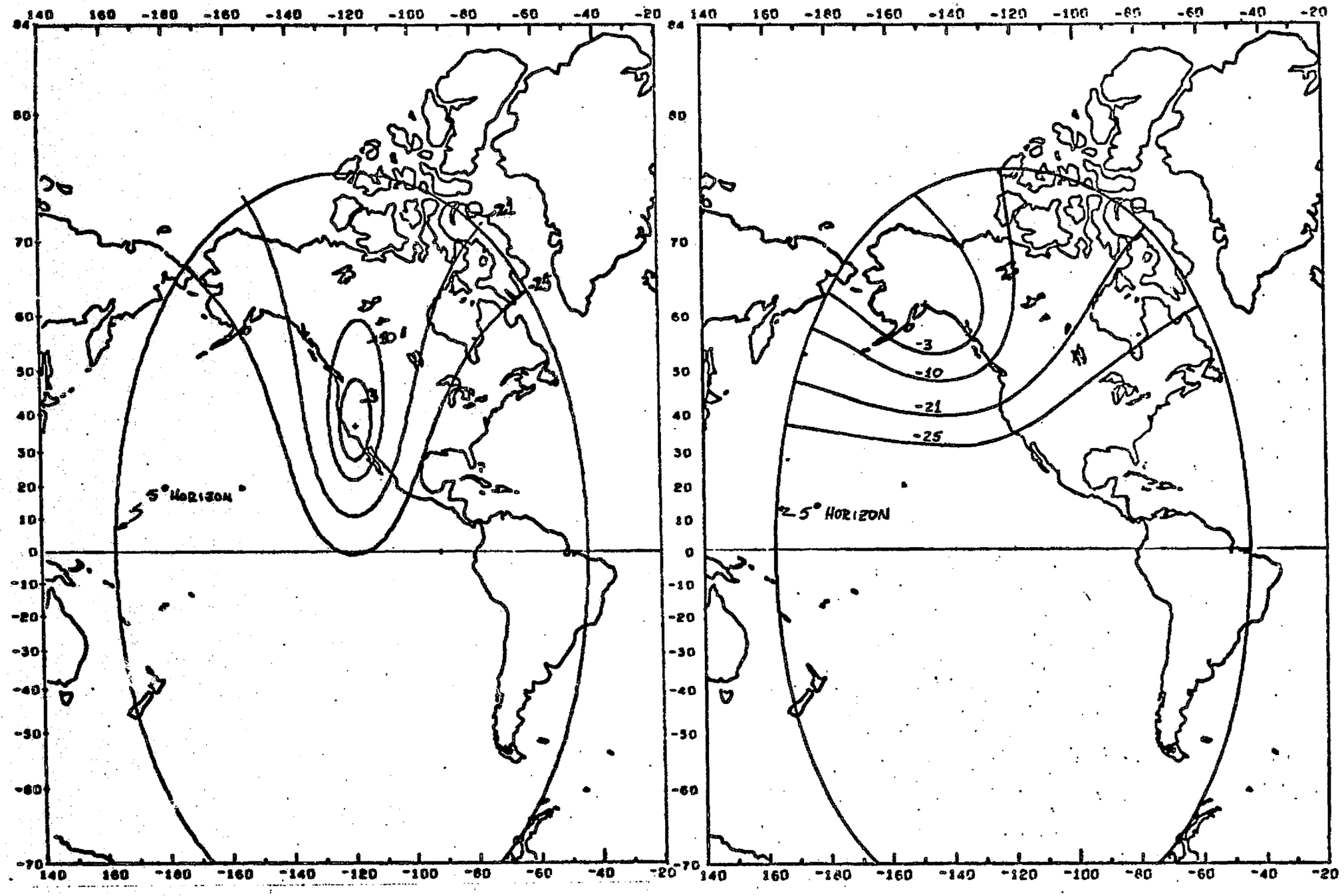


FIGURE 5-5. Antenna pattern projections for Alaska and the Western States.

5.3.4 RESULTS OF COST ANALYSIS. Receiver unit cost is often relatively low. However, in a service where there are a large number of receivers, this cost may become the predominant item. This makes for an advantage to increasing satellite power, for example, in order to permit higher noise figure, less expensive receivers. This, indeed proved to be the case for the Alaska and Western States Television System estimated to require 8.7 million receivers. The impact of the receiver cost forced the satellite weight to the boundary of 42,000 lbs. A satellite with a shorter lifetime would allow budgeting a larger weight to power generation thereby permitting higher rf power and a consequent reduction in receiver cost. This advantage proved to be more than offset by the added total launch vehicle and satellite costs to accomplish the ten year mission life. Some cost results from application of the TVBS synthesis program are given in the ensuing paragraphs. Certain costs in the associated tables have been circumscribed by a dottled line box to facilitate following the cost item through to the end conclusions.

5.3.4.1 Cost of Satellites. The satellite is analyzed as a complex structure containing power generation, electronic, station keeping and other equipment. Table 5-31 summarizes the satellite costs resulting from the total system cost minimization.

5.3.4.2 Cost of Ground Uplink Subsystem. This cost represents all aspects, except actual programming, of providing the uplink subsystem. Table 5-32 summarizes these costs.

5.3.4.3 Individual User's Receiving Costs. The individual user must procure or use his existing, conventional television set which is modified by addition of a preamplifier-converter. The user's costs, an antenna, the converter, installation and operation are given in Table 5-33.

5.3.4.4 Total System Cost. Itemization of the costs borne by the government and the individual consumers for this system is provided in Tables 5-34 and 5-33, respectively. The total cost for the system, including ground uplink, system, spacecraft, launch vehicles and ground receiving system augmentation is shown in Table 5-35. Specifically excluded is the actual TV set at each viewing site. The total system cost for the planned ten year program is $3.443 billion, including all R&D and two satellites (each with a five year life) and launch vehicles.

Table 5-35. Total System Cost.

	Government			
	Cost (Millions)	Consumer Cost Unit($)	Total (Millions)	Total System
Acquisition + R&D	839.0	90.66	788.7	
Installation	--	117.24	1020.0	
Operations and Maintenance	6.0	90.66	788.7	
Total System	845.0	298.56	2597.5	3442.5

*Based on a total receiver population of 8.7×10^6.

Table 5-33. Itemization of Individual Consumer Costs

	Acquisition Cost (Dollars)	Installation Cost (Dollars)	Total Initial Cost (Dollars)	Maintenance Cost/Year (Dollars)
Antenna (4.3 ft. UHF Parabola)	19.49	46.07	65.56	1.95
Receiver (2.5 db Noise Figure)	71.17	71.17	142.34	7.12
	90.66	117.24	207.90	9.07
				(90.66/10 Yrs)
TOTAL COST FOR 10YEAR SYSTEM =				$298.56

Table 5-34. Itemization of U.S. Government Costs

	Acquisition Cost (Millions)	R&D Cost (Millions)	Operations Cost/Year (Millions)	Total System (Millions)
Spacecraft	76.4	224.7	--	377.4
Launch Vehicle	211.1	36.7	--	458.9
Ground Uplink				
Program	1.73	0.54	0.41	6.40
Telemetry and Command	.29	.20	.18	2.32
				$845.00

As shown in Table 5-33, $2.6 billion of the total cost is borne by the general consumers at an individual cost of $299. The U.S. Government provides $845 million for the uplink system, launch vehicles and satellites.

6

LINK ANALYSIS

The television broadcast communications link consists of four major parts. These are:

1. Originating ground transmitting station.
2. Relay satellite consisting of antennas and transponders (receiver and transmitter for each channel).
3. Ground receiving station.
4. The propagation media between satellite and ground stations.

The following subsection gives a detailed description of the link, permitting determination of the radiated power level necessary to produce the signal-to-noise ratio required for high-quality data transmittal (or picture display) in the case of television.

6.1 DESCRIPTION OF THE LINK

The television broadcast communication link covers the portions of the system enclosed within the dotted line of Figure 6-1. All of the major portions of the link are treated in three "models" which permit the functional expression of the

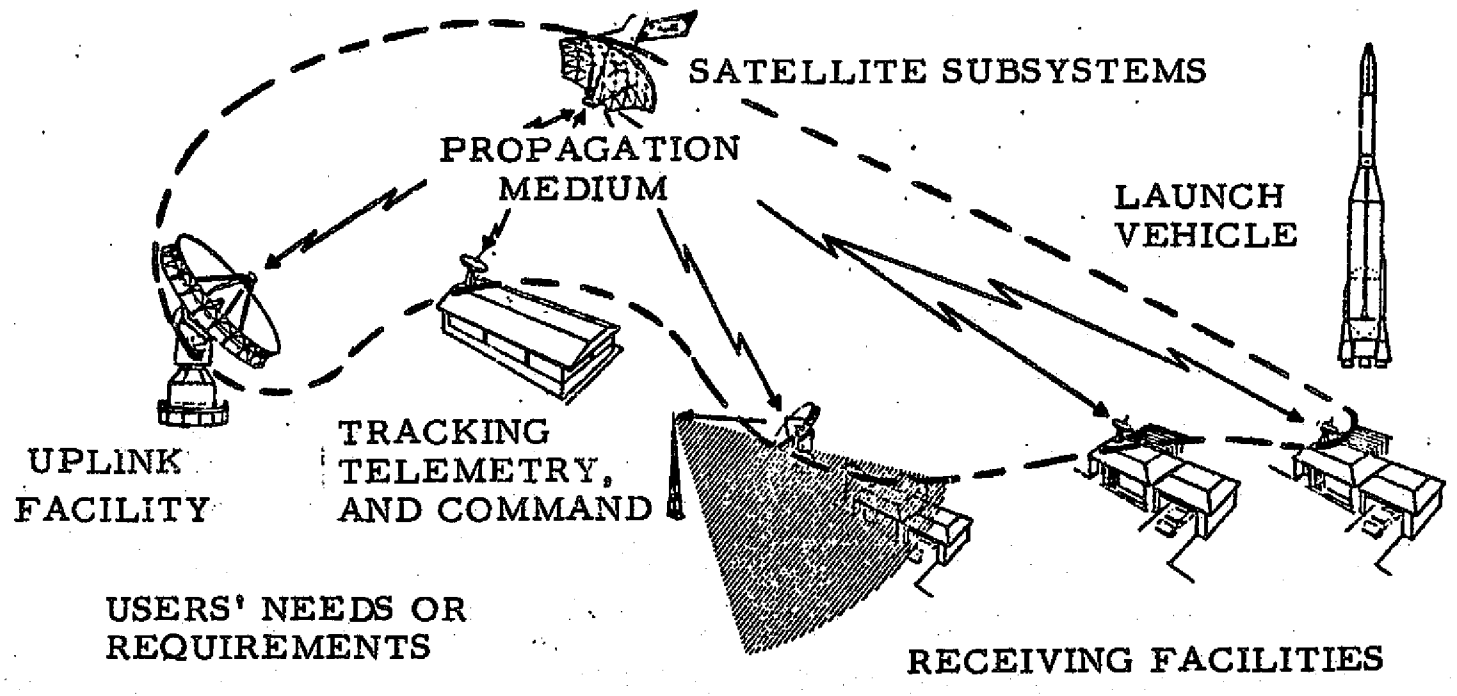


Figure 6-1. Total Communication System

communications link in terms of the system parameters:

1. Basic communications model (transmission, propogation medium and reception).
2. Orbit and antenna coverage model (allows relating satellite location, antenna gain functions and satellite pointing to the link performance).
3. Noise and propagation model (considers propagation loss and noise generation characteristics from transmitter output to receiver front input).

6.1.1 COMMUNICATION LINK ANALYSIS - The communication links are modelled using the relations shown in Figure 6-2, where:

G is antenna gain
P is transmitter power
L is system attenuation
N is system noise
C/N is carrier-to-noise ratio
A is satellite transponder gain

Subscripts:
U is uplink (at frequency f_U)
D is downlink (at frequency f_D)
G is ground based
S is satellite
1 is station 1
2 is station 2

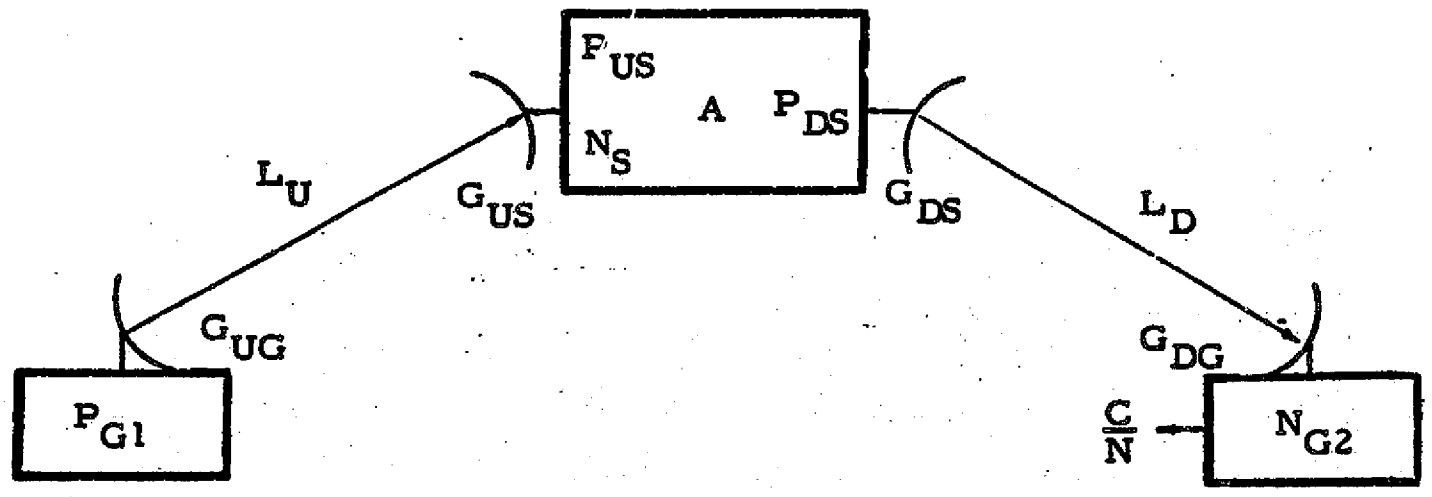


Figure 6-2. Communications Link Analysis

The fidelity of information transfer is determined by the user's needs (television image quality). Knowing the quality of reception and the modulation method, it is possible to specify the carrier-to-noise ratio at the receiver input, C/N_2.

The received carrier-to-noise ratio of the signal transmitted by the uplink, transponded by the satellite, and received by the downlink station for a constant gain transponder is:

$$C/N_2 = \frac{P_{G1}\, G_{UG1}\, L_U\, G_{US}\, AG_{DS}\, L_D\, G_{DG2}}{N_{G2} + N_S\, AG_{DS}\, L_D\, G_{DG2}} \qquad (6\text{-}1)$$

The total noise is composed of two terms:

1. Receiving system noise, N_{G2}.
2. Noise on the downlink due to the uplink, $N_S\, AG_{DS}\, L_D\, G_{DG2}$

   (i.e. noise input to transponder, N_S, amplified and transmitted to the ground receiving station).

For constant power output from the transponder, its gain, A, may be considered equal to $A' = (A - \xi)$, where ξ varies according to the power input (see Figure 6-3). The output power may be written as:

$$P_{DS} = (P_{US} + N_S)\,(A - \xi) = (P_{US}\quad N_S)\,A' = P_{US}\,A'\quad N_S\,A'. \qquad (6\text{-}2)$$

From equation (6-2):

$$P_{US}\,A' = P_{DS} - N_S\,A' \qquad (6\text{-}3)$$

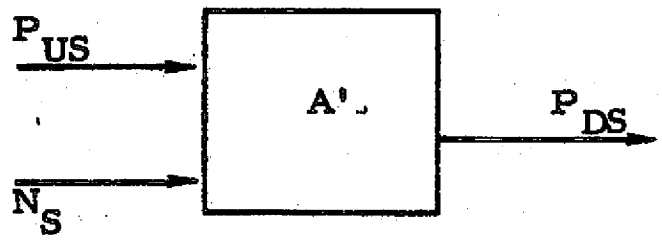


Figure 6-3. Constant Power Amplifier Model

The first four factors in the numerator of equation (6-1) are equal to P_{US}. P_{US} A' from equation (6-3) may be substituted for $P_{G1}\ G_{UG1}\ L_U\ G_{US}$ A in equation (6-1) giving the constant power transponder equation relating satellite transmitted power to carrier-to-noise ratio at the receiver input:

$$C/N_2 = \frac{(P_{DS} - N_S A')\ G_{DS}\ L_D\ G_{DG2}}{N_{G2} + N_S A'\ G_{DS}\ L_D\ G_{DG2}} \qquad (6\text{-}4)$$

The physical significance of the "effective gain", $A' = (A - \varepsilon)$, is that ε represents the phenomenon of "limiting" when the amplifier is driven into saturation. As the limiting point is approached, distortion results in case of amplifier modulation. In this application, FM distortion is not serious. If we were to go to an AM system we would have to back off on power to operate in a linear mode.

The technique of transmission of multiple carriers through a common satellite repeater is a common practice in telephony transmission. Due to the non-linear amplification of the fluctuations in the envelope of the combined wave, intermodulation distortion is produced in the transponded signals. One method for reducing this noise is to operate the repeater below saturation and at a lower DC to RF efficiency. In the case of television broadcast, however, the RF bandwidths are on the order of 30 megahertz at kilowatt power levels. The reduction in bandwidth with the attendant loss in FM improvement to allow two carriers to use the same transponder makes this technique unattractive for TVBS.

6.1.2 ORBIT & COVERAGE MODEL - This consists of two parts; the first is a separate program and the second is a subroutine of the synthesis program.

a. Antenna Pattern Coverage. The first program accepts as inputs (See Figure 6-4):

1. Satellite position (longitude of the sub-point).
2. The coordinates of the antenna beam center (latitude and longitude of the center of the desired coverage).
3. The orthogonal beamwidths for a pattern function resulting from a uniform phase distribution and an amplitude tapered distribution $(1-r^2)$ of 10 dB[1].
4. Relative angular position of desired radiation level contours (i.e., -2dB, -10dB, first sidelobe, etc.; to ten levels may be used).
5. The azimuth angle of the satellite antenna (to position the antenna axes compatible with the coverage ellipse on earth).

This program permits computing the power level contours on the surface of the earth. The SC4020 plotter plots these contours superimposed upon a Mercator projection of the earth as in Figure 6-5. These contours are useful in determining the effectiveness of the coverage and the flux density at any point in the area covered.

b. Range, Elevation Subroutine. This program accepts the same input parameters as the coverage program but computes the slant range to the "most distant" point on the 0.63 power (-2dB) contour (point nearest horizon as viewed from the satellite) and the elevation angle of the satellite from the -2dB point above. These parameters are used in the propagation and noise models to be described. In addition the major and minor axes of the one-half power coverage ellipse and its approximate area are computed.

If the elevation angle of the -2dB point above is less than 5 degrees, the point is shifted to 5 degrees, and the associated slant range and power level contour are

[1] S. Silver, "Microwave Antenna Theory and Design," Radiation Laboratory Series, Volume 12, Table 6.2.

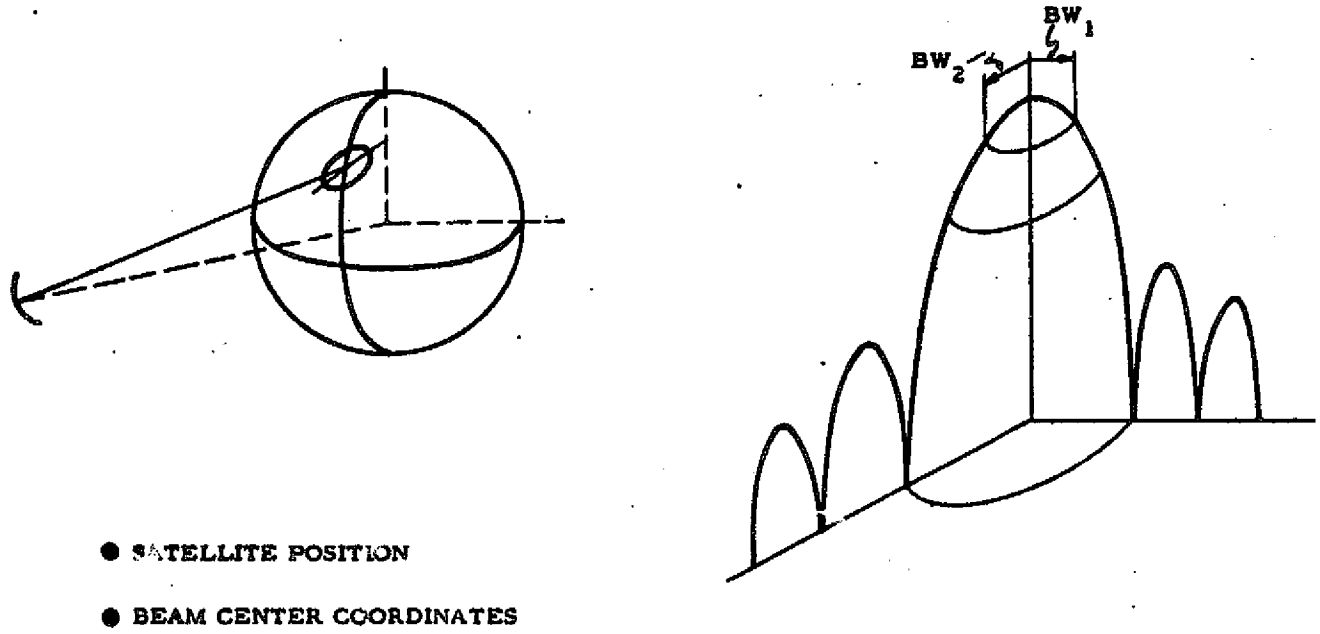


Figure 6-4. Antenna Pattern Model

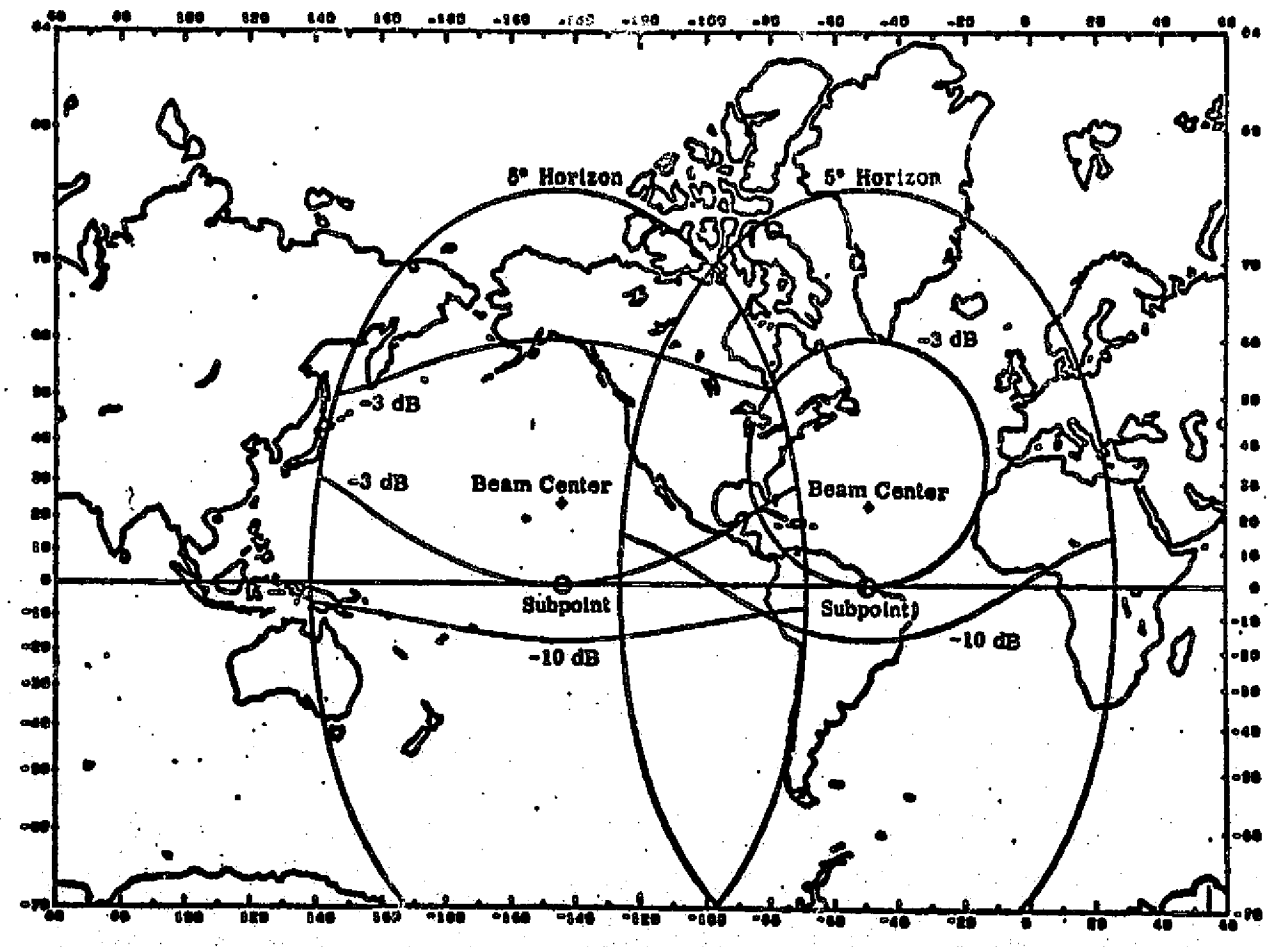


Figure 6-5. Antenna Projections

computed. The -2dB contour is taken as the typical "location loss" for the ground station.

6.1.3 NOISE & PROPAGATION MODELS - The basic models are shown in Figure 6-6. Given the elevation angles and the slant ranges for each satellite antenna beam, the attenuations due to clouds, rain, water vapor and oxygen, and the ionosphere, as well as circuit losses are determined.

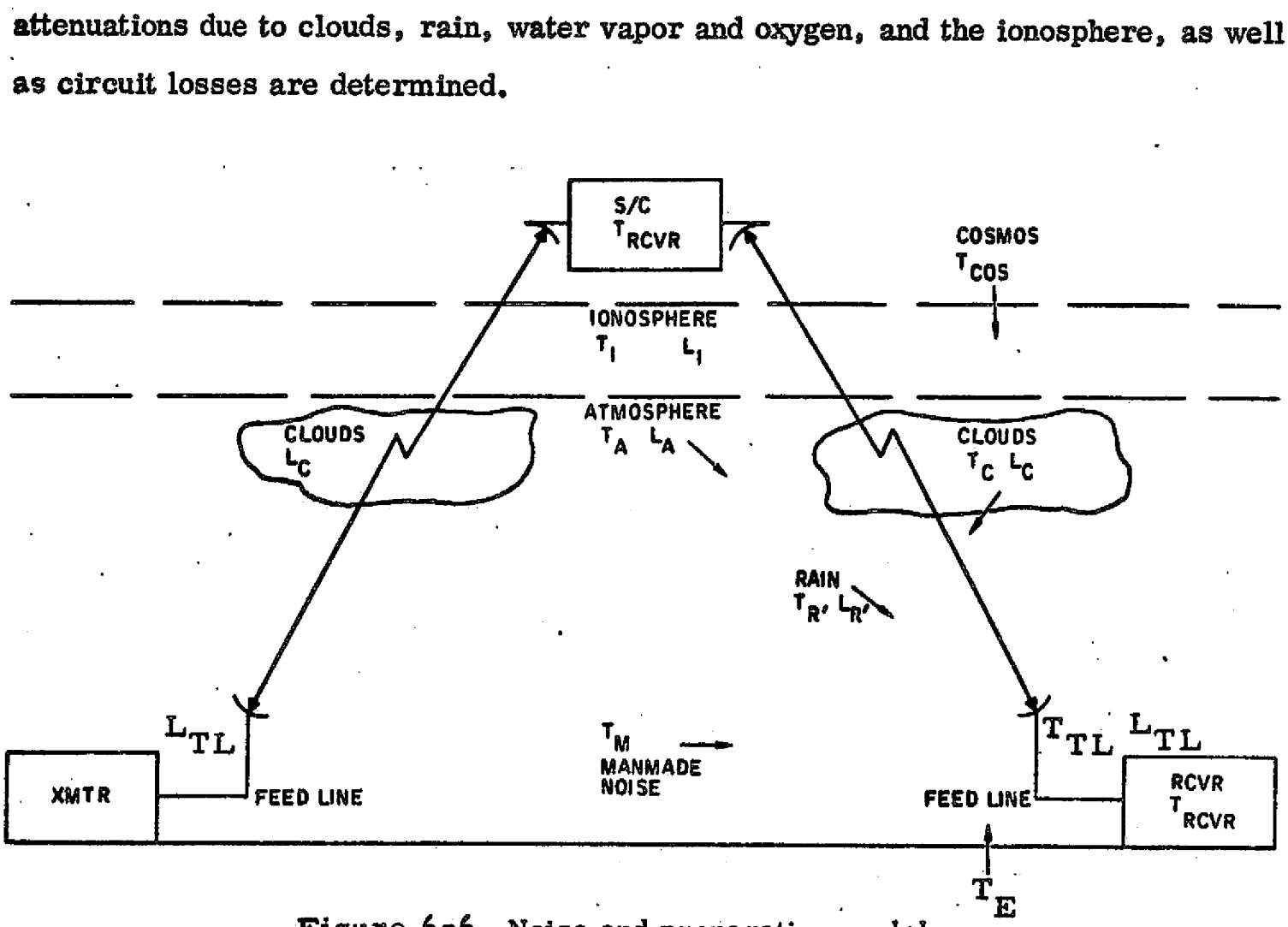


Figure 6-6. Noise and propagation models.

Additionally, the noise contributions due to these elements are calculated. Table 6-1 itemizes the terms and equations used in this model. The effective noise seen by the receiver is then

$$T_G = L_{TL} T_{ANT} + T_T + T_R \qquad (6\text{-}5)$$

where

Table 6-1. Terms and Equations of Propagation and Noise Model

Region	Attenuation	Absorption	Ambient Temperature	Effective Temperature at Receiver
COSMOS	--	--	T_{COSMIC}	$T_{COS} = L_I L_A L_C L_R T_{COSMIC}$
IONOSPHERE	L_I	$1 - L_I$	T_{ION}	$T_I = L_A L_C L_R (1-L_I) T_{ION}$
ATMOSPHERE	L_A	$1 - L_A$	T_{ATM}	$T_A = L_C L_R (1-L_A) T_{ATM}$
CLOUDS	L_C	$1 - L_C$	T_{CLOUD}	$T_C = L_R (1-L_C) T_{CLOUD}$
RAIN - TO SATELLITE	$L_{R'}$	$1 - L_{R'}$	T_{RAIN}	$T_{R'} = (1-L_{R'}) T_{RAIN}$
HORIZONTAL PATH	L_{RH}	$1 - L_{R'H}$	T_{RAIN}	
ENVIRONMENTAL	--	--	T_{MAN}	$T_M = L_{R'H} T_{MAN}$
EARTH	--	--	T_{EARTH}	$T_E = T_{EARTH}$
TRANSMISSION LINE	L_{TL}	$1 - L_{TL}$	T_{TL}	$T_T = (1-L_{TL}) T_{TL}$
RECEIVER	--	--	T_{RCVR}	$T_R = T_{RCVR}$

$$T_{ANT} = \left[(T_{COS} + T_I + T_A + T_C + T_{R'})\ \bar{G}_S + T_M\bar{G}_M + T_E\bar{G}_E\right] \qquad (6\text{-}6)$$

$\bar{G}_S$, $\bar{G}_M$, $\bar{G}_E$ are relative antenna gains over the three regions - sky, man-made noise, and earth. It is helpful to explain further some of the terms in equations (6-5) and (6-6). See Table 6-1.

a. T_{ANT} includes the sum of all external noise entering the system via the receiving antenna.

b. $L_{TL}\ T_{ANT}$ is the external noise attenuated (L_{TL}) by the transmission line to the receiver input.

c. $T_{COS} = L_{R'}\ L_C\ L_A\ L_I\ T_{COSMIC}$ → Exoatmospheric cosmic noise temp.

- → T_{COSMIC} attenuated by ionosphere.
- → T_{COSMIC} attenuated by ionosphere and atmosphere (oxygen and uncondensed water vapor).
- → T_{COSMIC} attenuated by ionosphere, atmosphere, and clouds.
- → T_{COSMIC} attenuated by ionosphere, atmosphere, clouds and rain.

d. $T_I = L_{R'}\ L_C\ L_A\ (1-L_I)\ T_{ION}$ → Ionosphere ambient noise.

- → Fraction of signal energy absorbed in ionosphere.
- → Communications signal excited ionospheric noise generator.
- → Ionospheric noise temperature successively attenuated by atmosphere, clouds and rain.

e. T_A and T_C follow model of c. and d. above (See Table 6-1).

f. $\overline{G}_S$, $\overline{G}_M$ and $\overline{G}_E$ are expressed as the (integral of the antenna pattern function)/ 4π (i.e., per steradian). The limits of integration divide the antenna's surrounding environment into the three regions, sky, surface and earth.

Figures 6-7, through 6-14 give, respectively, the antenna "regional" noise gains, the equivalent noise temperature for man-made noise, attenuation due to rain, clouds and the atmosphere, and the atmospheric and cloud contributions to noise temperature.

6.2 EXAMPLE OF SYNTHESIS PROGRAM PRINTOUT OF LINK PARAMETERS

The development and use of the communication system synthesis computer program is treated in detail in Chapter 3. When a network description results from use of the program, the printout permits reading not only the major system characteristics but also all essential parameters describing the link.

Table 6-2 presents the results of the link analysis performed for the U.S. ETV Direct case. In this case high-quality (TASO 1) color television programming is broadcast directly to modified conventional television receivers. This table shows the level of detail considered in the program and identifies the elements that are inputs to the program, derived within the program and printed in the program output — sufficient to describe the RF link(s) in detail.

Table 6-2. U. S. ETV Direct

Uplink Power Budget, [0.85] Hz*

a.	Transmitter power ([6] W)		+ 7.8 dB W
b.	Trans. antenna gain ([39.7] ft. diam.)		+ [38.1] dB
c.	Trans. circuit losses		- [3.0] dB
d.	EIRP		42.9 dB W
e.	Total propagation losses		- 185.3 dB
	1) Free space (23,800 Stat. Mi),	- [182.7] dB	
	2) Atmosphere and rain([33.3] ° elev,)	- [0.1] dB	
	3) Location and pointing,	- [2.5] dB	
f.	Sat. receiving ant. gain([28.7] ft. x [57.3] ft.)		+ [38.2] dB
g.	Receiver circuit losses,		- [1.0] dB
h.	Available carrier power		- 105.2 dB W

Table 6-2. U. S. ETV Direct (Continued)

i.	Total system noise power (kTB),			- 125.9 dB W
	1) Receiver([3.0] dB N.F.)	[290.0]	° K	
	2) Receiver input circuitry	[59.6]	° K	
	3) Antenna (- [1.0] dB, item g),	230.0	° K	
	4) Effective system temperature,	579.6	° K	
	5) Noise bandwidth,	[32.63]	MHz	
j.	Available carrier-to-noise ratio			+ 20.7 dB

Downlink Power Budget, [0.8] GHz*

a.	Transponder output power ([2.49] k W),			+ 34.0 dB W
b.	Trans. ant. gain ([28.7] ft. x [57.3] ft),			+ [37.7] dB
c.	Trans. circuit loss,			- [1.4] dB
d.	EIRP			70.3 dB W
e.	Total propagation losses			- 187.7 dB
	1) Free space (24,000 Stat. Mi),	- [182.4]	dB	
	2) Atmosphere and rain ([23.1] ° elev.)	- [0.1]	dB	
	3) Location and pointing	- [2.2]	dB	
	4) Polarization (circ. to lin),	- [3.0]	dB*	
f.	Direct receiving ant. gain ([1.9] ft. diam equiv.)			+ [11.0] dB
g.	Dir. rcvr. circ. loss,			- [2.0] dB*
h.	Total available carrier power,			108.4 dB
i.	Total system noise power (kTB),			- 118.6 dB W
	1) Receiver ([11.0] dB N.F.),	[2610.0]	° K	
	2) Receiver input circuitry	[107.0]	° K	
	3) Antenna (- [2.0] dB, item g),	116.2	° K	
	sky, [0.537] x [54.2] = 29.1 °K			
	envir, [0.036] x [1846.5] = 66.5 °K			
	earth, [0.305] x [290.0] = 88.5 °K			
	184.1 °K			
	4) Uplink contribution	[283.3]	° K	
	5) Effective system temperature,	3116.5	° K	
	6) Noise bandwidth,	[32.63]	MHz	
j.	Available carrier-to-noise ratio			+ 10.2 dB
k.	Total improvement factors			+ 34.5 dB
	1) Weighting (EIA/BELL)	+ 7.0	dB*	
	2) Peaking & TASO conversion	+ 7.6	dB*	
	3) FM, $3m^2(m+1)$, m = [2.88],	+ 19.9	dB	
l.	Available signal-to-noise ratio			+ [44.7] dB*

* = inputs

[ ] = on printout

ANTENNA DISCRIMINATION TO NOISES

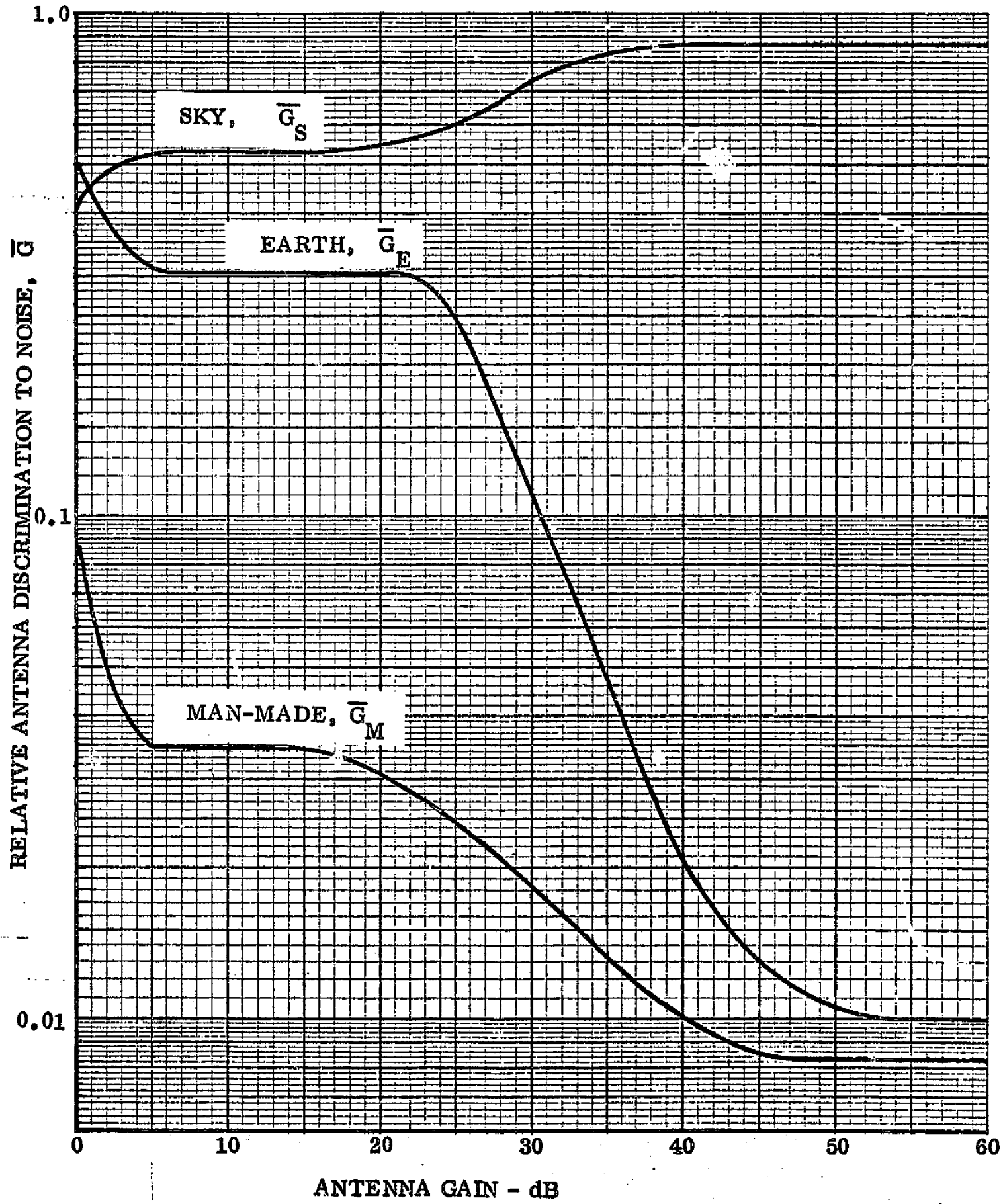


Figure 6-7. Main Lobe Gain - dB

EQUIVALENT NOISE TEMPERATURES

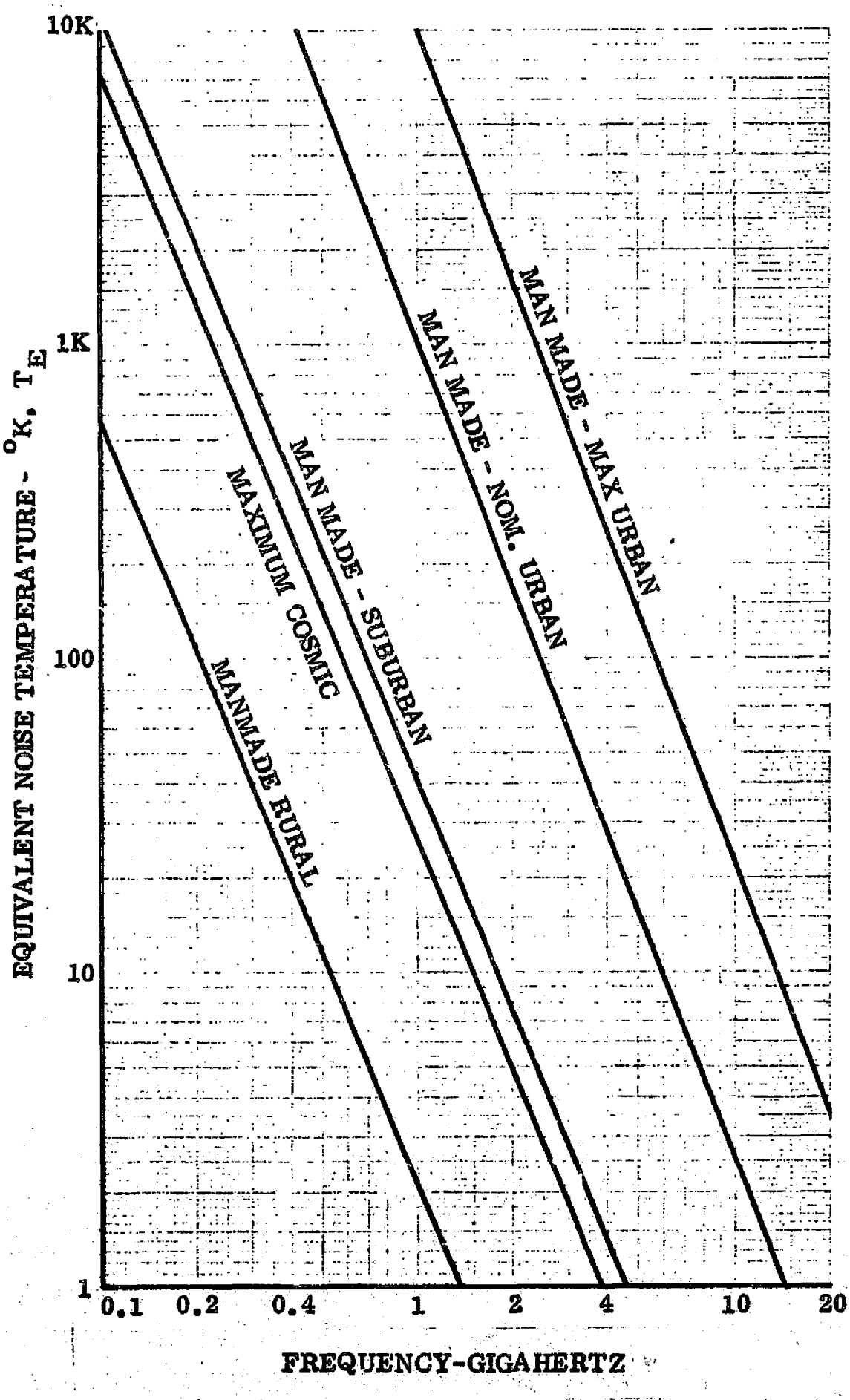


Figure 6-8. Man-Made Noise

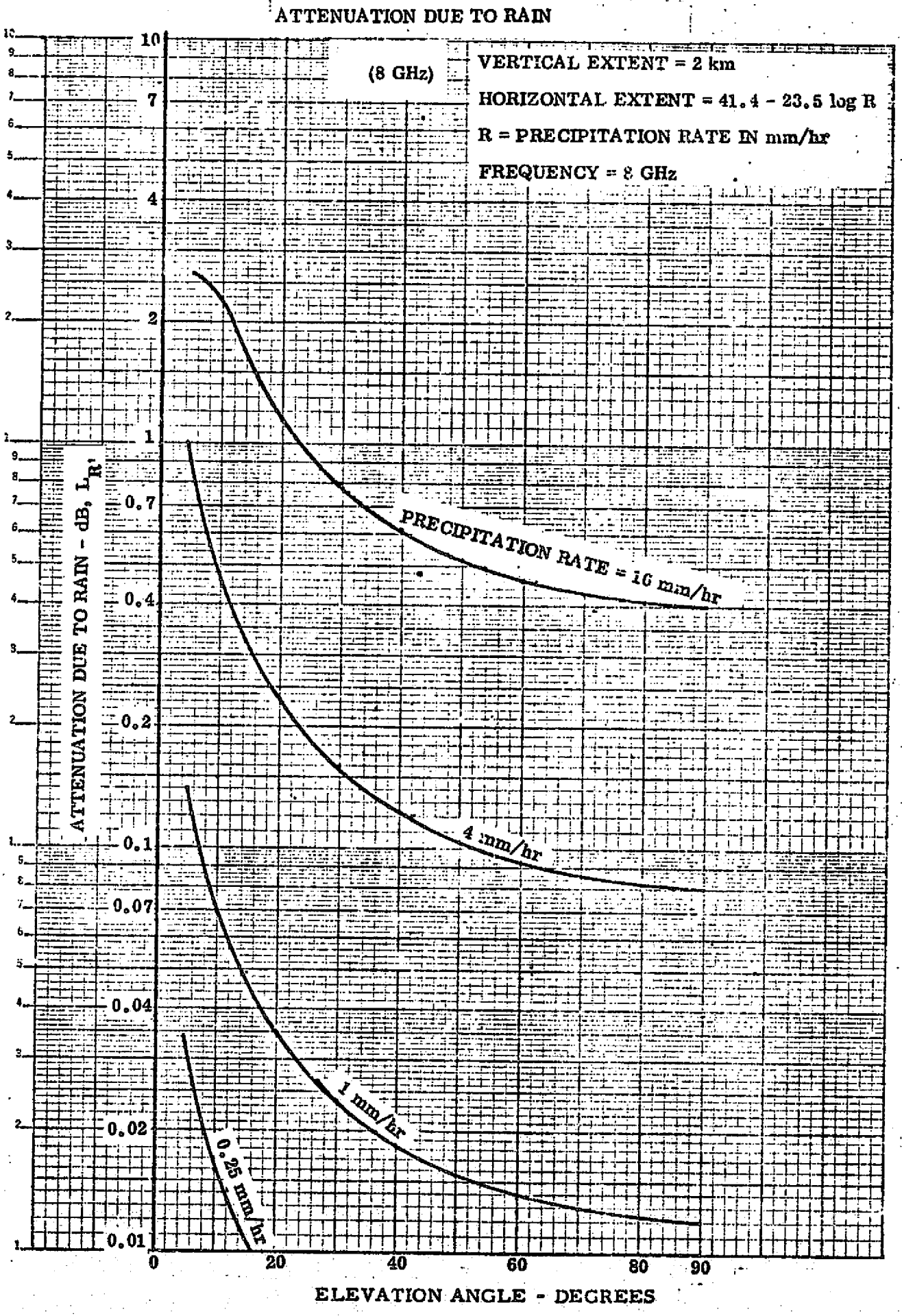


Figure 6-9. Attenuation Due To Rain

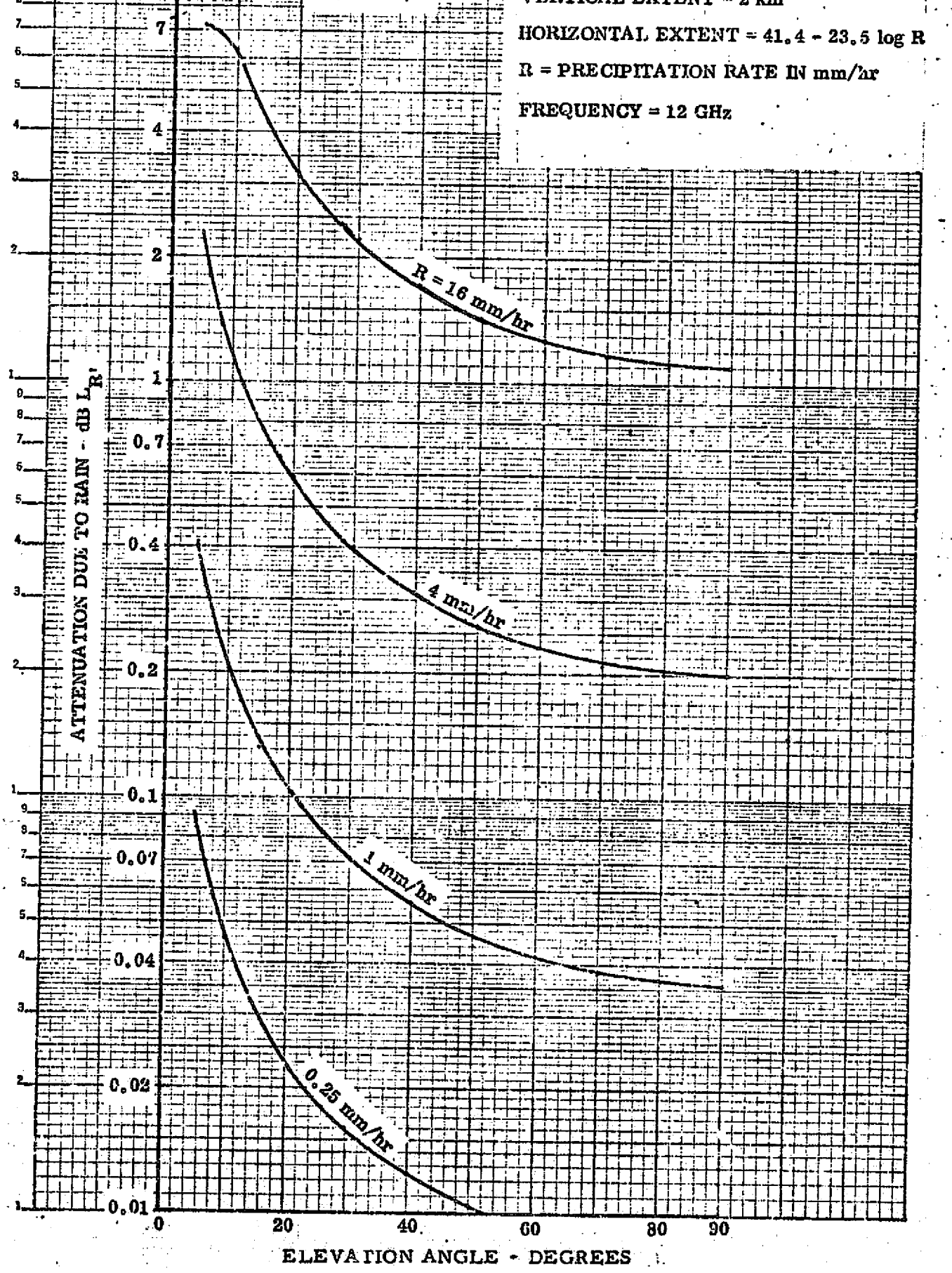


Figure 6-10. Attenuation Due To Rain

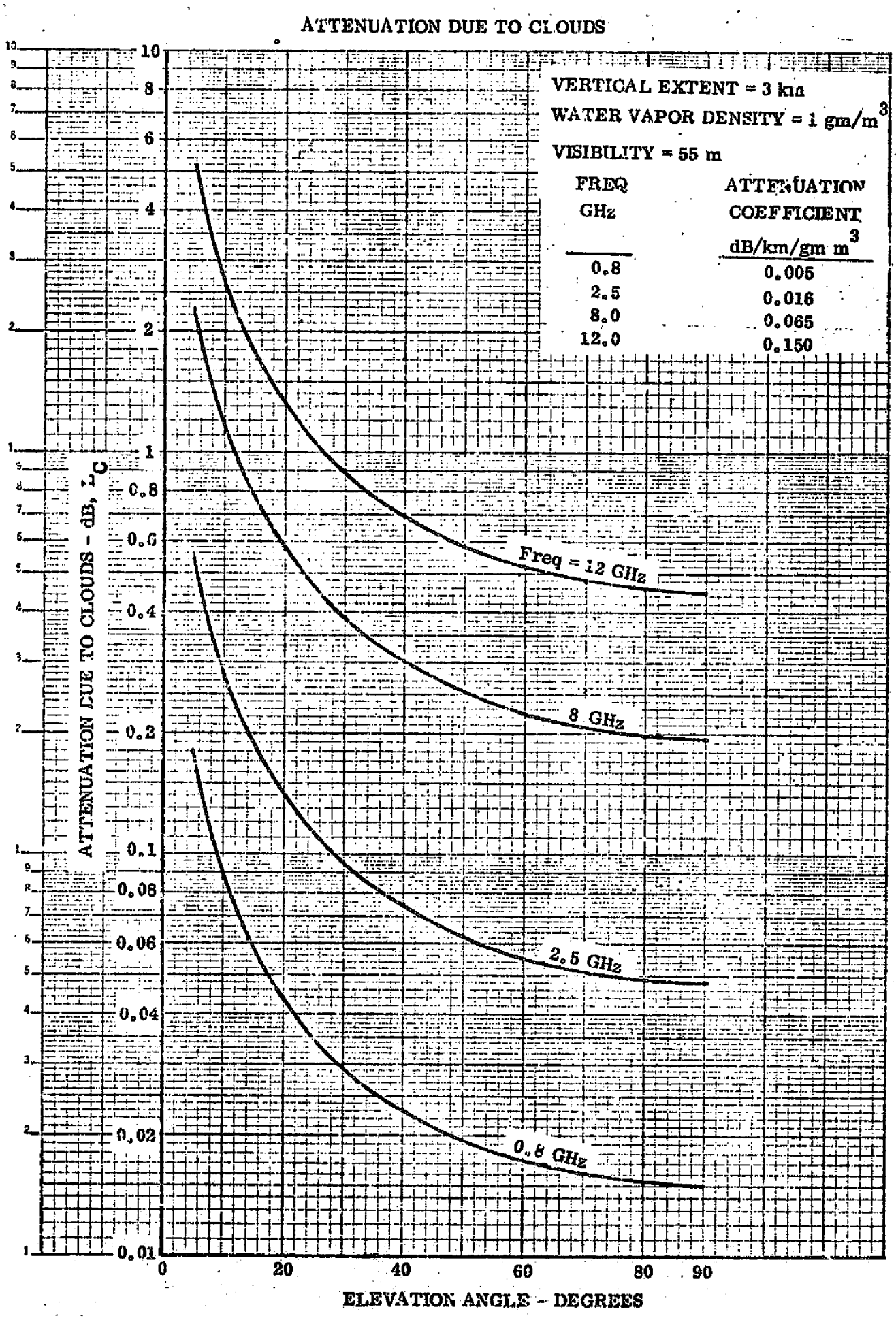


Figure 6-11. Attenuation Due To Clouds

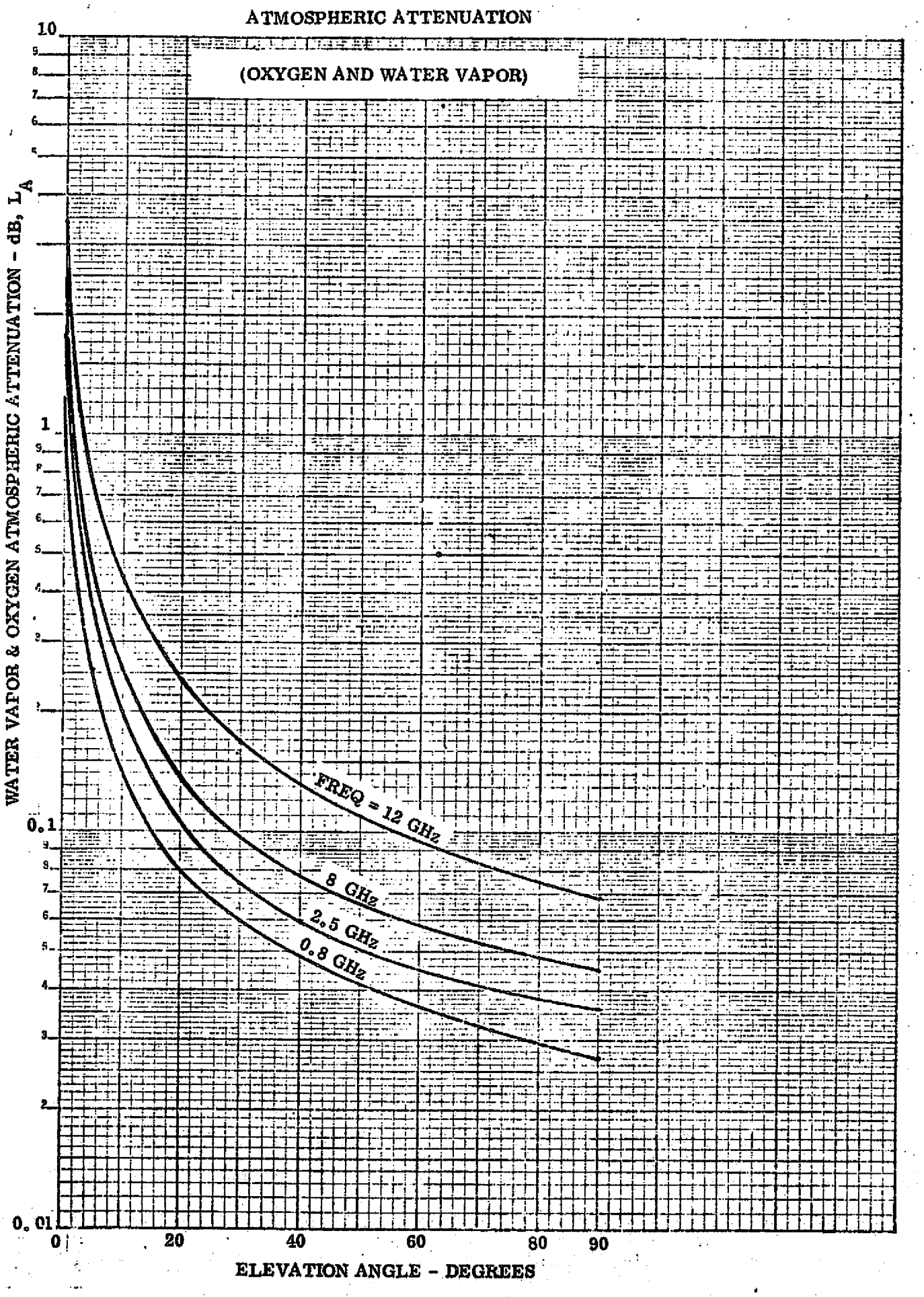


Figure 6-12. Atmospheric Attenuation

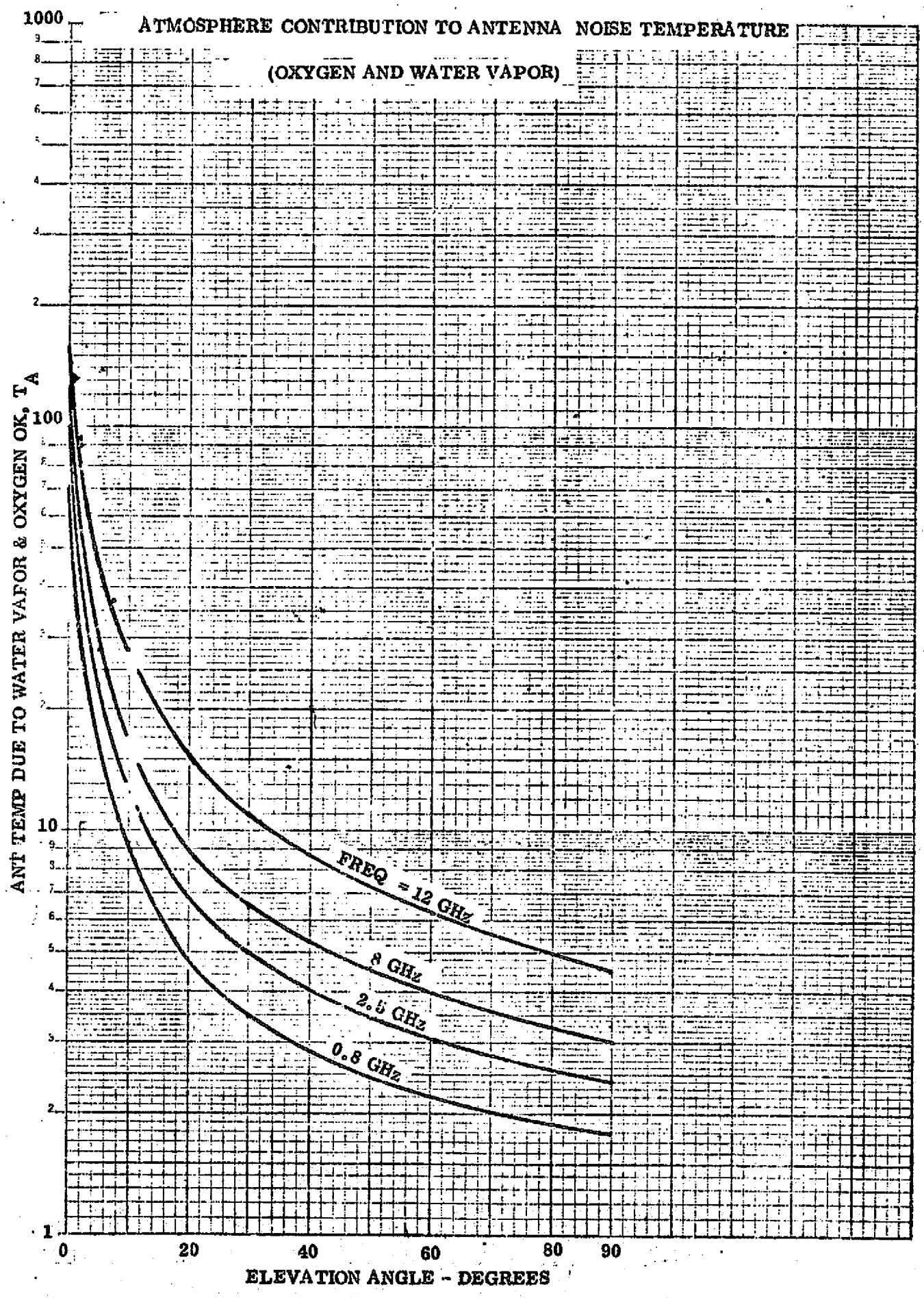


Figure 6-13. Atmosphere Contribution to Antenna Noise

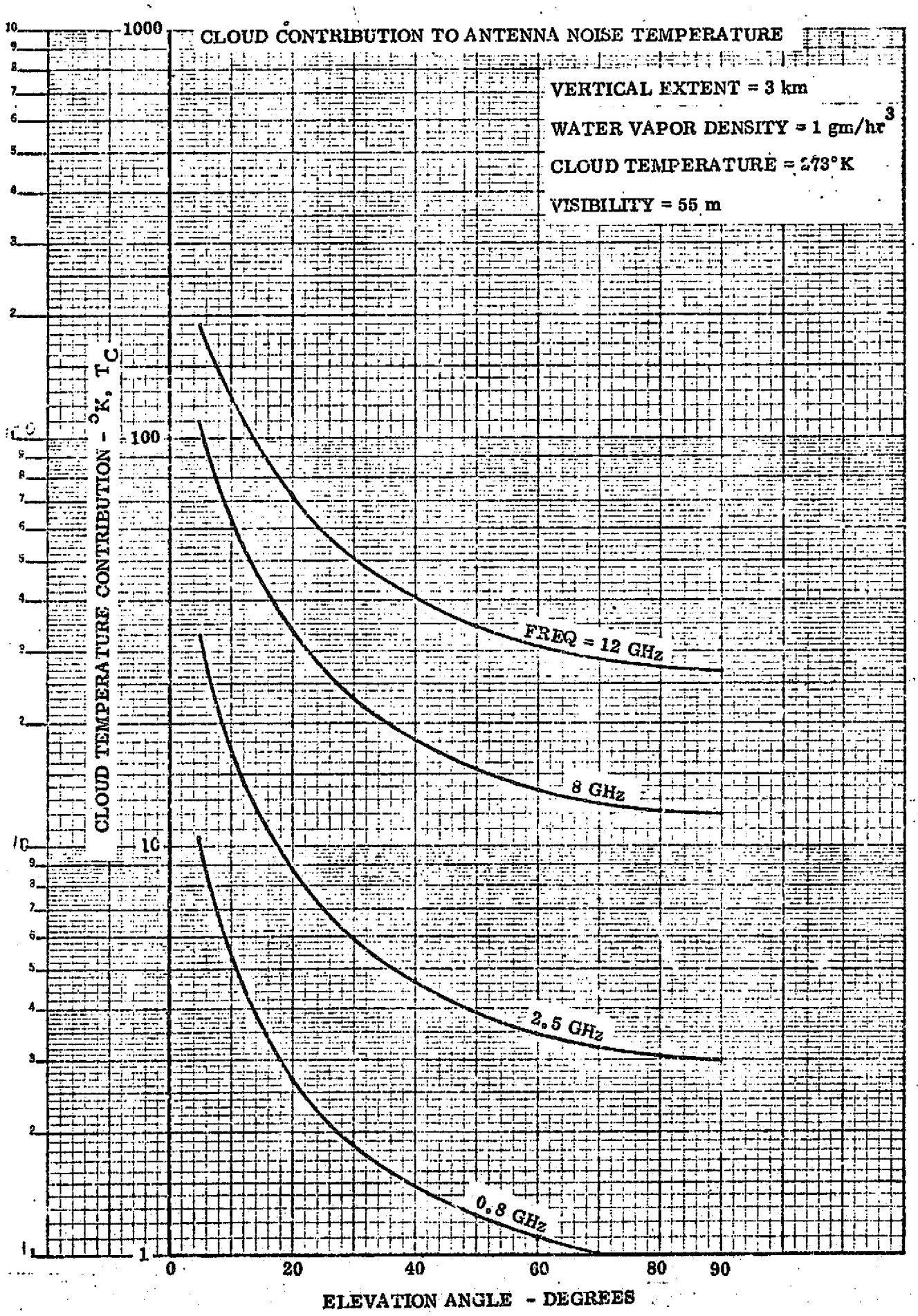


Figure 6-14. Cloud Contribution To Antenna Noise

7

MANNED SUPPORT

7.1 INTRODUCTION

The study has shown the practicability of TV broadcast satellites in synchronous orbit. Unfortunately, the radiation problem is significant at synchronous altitude and solar flare protection would require a high weight penalty for a continuously manned synchronous broadcast relay station. Use of man for short-term support is more reasonable. With the prospect of extensive use of man in the Shuttle and low orbit space base operations, two basic approaches are practical:

1. Design the satellite with a fully automated capability — with provisions for docking, environmental hookups, easy access, and removal of key modules for repair or update.

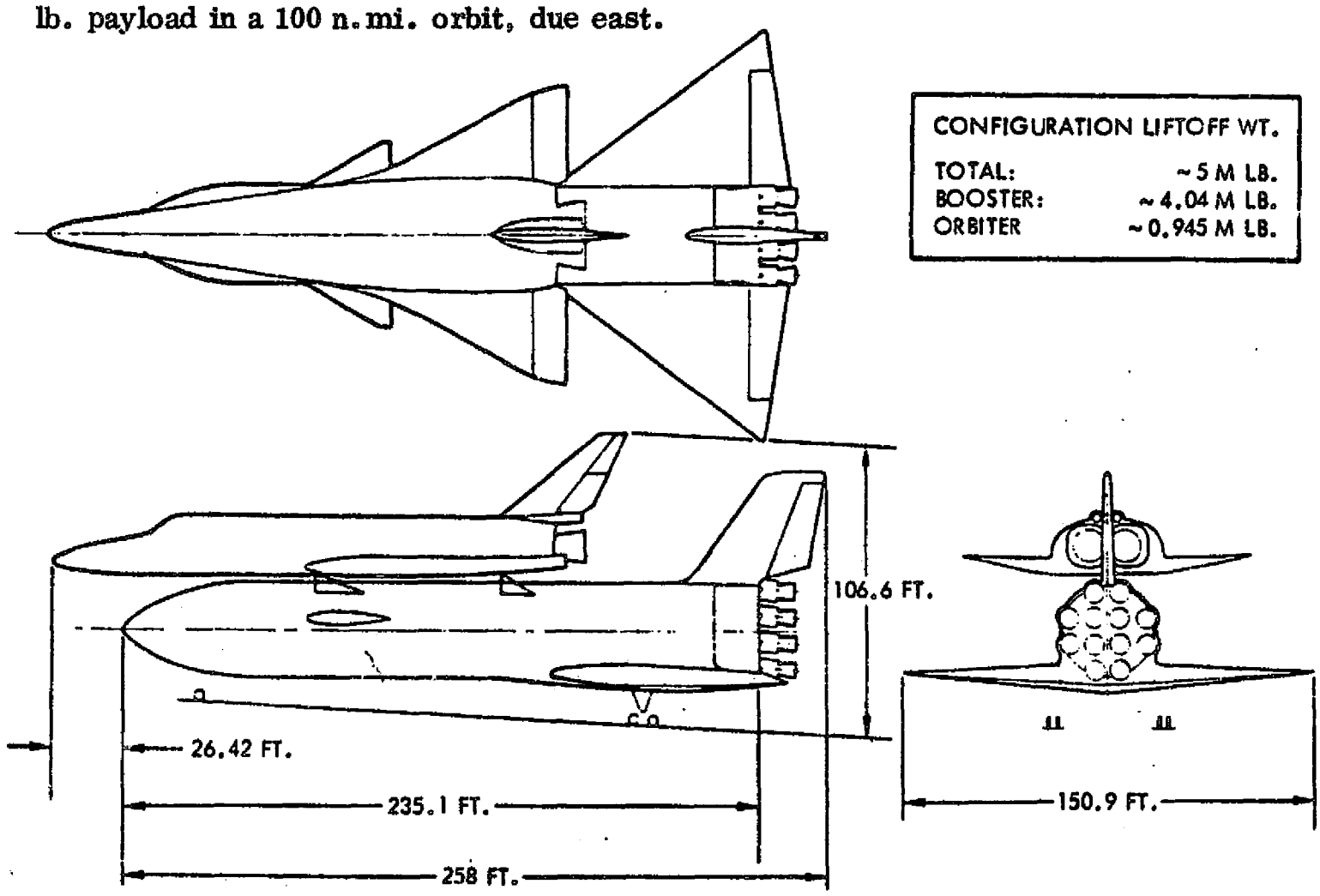
2. Use man for the critical startup period with EVA capabilities to support deployable systems, solar cell panels, multiple antennas, and possibly nuclear reactor booms.

In the first case, the satellite would be capable of initial fully automatic operation. If a problem occurred such as has happened on OAO, Intelsat III or ATS; a manned craft from the shuttle-supported low orbit space base could be sent to effect a repair. In the second case, manned application could be to replace the critical high power transmitters or possibly supplement the degrading power supply system. Long life assurance practices would still be applied with selective redundancy, screened or burned-in parts supported by the ability to be maintained by man.

These approaches require a space tug to transfer crew and equipment from low orbit to synchronous orbit and return. The velocity requirements for transfer to synchronour and rendezvous with the TVBS are in excess of 14,000 fps. Return velocity requirements are equivalent, resulting in a required propellant fraction in excess of 0.91. This requirement is not readily satisfied by a single stage, reusable vehicle of the present space tug concepts. It is more compatible with the continuous burn nuclear vehicle being proposed for the translunar shuttle (1982 approx.).

The space shuttle is the key element for future space operations in low earth orbit. In the post-1977 period, the shuttle will provide economical transportation for unmanned and manned payloads for both NASA and DOD. The shuttle will also provide the ability to accomplish substantial reductions in payload costs through the relaxation of payload weight requirements, the more benign payload environment, the ability to

return payloads for repair or refurbishment prior to redeployment, and the provision of intact abort capability, which precludes the loss of payloads due to malfunction of the launch vehicle. The vehicle will be a two-stage, vertical takeoff, horizontal landing, fully reusable system in which maximum use will be made of aircraft design and operations procedures. The first stage is referred to as the booster and the second stage as the orbiter (Figure 7-1). Booster propulsion is supplied by 12 main rocket engines with a thrust of 550,000 pounds at sea level. The orbiter uses two similar engines modified for greater expansion ratio nozzles. Each stage is manned by a crew of two. In addition, the orbiter may carry two cargo masters and eight passengers. Recent NASA direction has changed the primary design mission from space station resupply (25,000 lb. payload to 270 n.mi. at 55° inclination) to a requirement of 65,000 lb. payload in a 100 n.mi. orbit, due east.



CONFIGURATION LIFTOFF WT.	
TOTAL:	~5 M LB.
BOOSTER:	~4.04 M LB.
ORBITER	~0.945 M LB.

Figure 7-1. Space Shuttle Booster and Orbiter.

7.2 ROLE OF MAN IN THE MISSION

The astronauts may participate in the TVBS program as observers and experimenters in the synchronous orbit environment. They may take an active role in the initial assembly and checkout of the satellite structures and systems. During the lifetime of the satellite, they may perform routine maintenance, may repair and replace modules after failure, install new equipment to improve or expand service provided, and adjust or realign satellite systems. While docked to the satellite, the propulsion capacity

of the manned vehicle can be used to effect stationkeeping maneuvers or the relocation of the satellite. Because of the routine nature of the function of the TVBS, normal operation of the satellite by the astronaut is not predicted, but short-term operation can be necessary for checkout and experiment activities.

7.2.1 DEPLOYMENT AND CHECKOUT — All concepts of the TVBS used in the study are based on automatic deployment sequences initiated by ground control after the satellite has been placed in synchronous orbit. With the use of the Saturn V launch vehicle, the need for assembly in orbit is precluded, although major structures must deploy from the stowed configuration to achieve the orbital configuration of the satellites. Warmup of the satellite systems, stabilization and orientation, and checkout are also initiated and controlled from the ground. If man is available in the synchronous orbit environment, he can be used to improve the probability of successful deployment and entry of the satellite into service in the communication system. Table 7-1 lists tasks which may be accomplished by the astronaut team during deployment and checkout of the satellite. A large (configuration F) satellite is used for illustration.

7.2.2 MAINTENANCE AND REPAIR -- The TVBS satellite concepts are set to provide a 5 or a 10 year service life. Provision of redundant systems and switching, where necessary to compensate for insufficient individual component life, is made. For this reason, routine maintenance is not anticipated as a requirement of the system. There are, however, maintenance tasks which could be considered in conjunction with repair, replacement, system updating activities which justified the rendezvous with the satellite after it had been in service for some time. A list of maintenance and repair tasks which could be performed by astronauts is provided in Tables 7-2 and 7-3.

7.2.3 HAZARDS TO EVA AND MANNED ASSIST — The inclusion of manned assist or backup in the satellite system, immediately imposes the requirement for manned rating of all components, also thorough testing and simulation to establish very high reliability standards for performance in the space environment. As a consequence, any deviation possible in the planned chain of events constitutes a potential hazard, unless it has been subjected to prior analysis and accepted as satisfactory. The degree of the hazard should be understood, to enable certain courses of action or correction to be defined as acceptable or unacceptable and also to help define the astronaut constraints and limitations. The general hazard problems can be listed as follows:

a. Unfired pyrotechnic devices.
b. Approaching undeployed structure or components.
c. Collisions with structure.
d. Electric shock or electrostatic discharges.
e. Vision fogging, sun blindness.
f. Suit damage.
g. Heat
h. Life support systems failures.
i. AMU malfunction.
j. Tether entanglement problems, cutting of tether, or drifting.
k. Communications breakdown.
l. Ionizing radiation.
m. Micrometeoroid puncture.
n. Microwave radiation.

An expansion of these hazards is presented in Table 7-4.

Table 7-1. Deployment and Checkout Tasks.

	TASK DESCRIPTION	TIME (HR:MIN)	EQUIPMENT REQUIRED
1.	Observe and photograph deployment of structures spacecraft	0:40	Still and movie cameras
2.	Verify final stage separation, inspect	0:20	Still camera
3.	Dock to MDA, open hatch, and enter MDA spacecraft	0:40	
4.	Checkout environmental control system.	0:30 IVA	
5.	Suit up, checkout EVA equipment and depressurize MDA.	0:40 IVA	
6.	EVA inspection of reflector, solar cell panels, and ATC thrusters and supports.	2:00 EVA	
7.	EVA correction of faulty deployment of structures. Lock up truss elements. Replace structural elements. Fire pyrotechnics, or manually release faulty actuators.	A/R EVA	Power screw driver, hammer, battery and cable, spare truss elements, C-clamps.
8.	EVA repair or replacement of faulty ATC thrusters or supports.	A/R EVA	Spare thrusters, supports, C-clamps.
9.	Checkout primary and secondary power systems, adjust for peak performance.	5:00 IVA	Electrical power test set.
10.	Warm up, align and verify operation of satellite stabilization systems.	2:00 IVA	
11.	Set communications subsystems to standby conditions and checkout.	1:00 IVA	
12.	Checkout transmitters at full power, check carrier frequencies & adjust.	2:00 IVA	
13.	Monitor thermal control system operation, verify MDA pressure integrity, monitor life support system performance.	A/R IVA	

Table 7-2. Increased Life by Manned Support.

SYSTEM	TYPICAL LIFE RANGE	MANNED TASK
High power transmitters	3-5 Yr	Replace, startup, checkout
Receiver & replay network	5-7 Yr	Replace, update
Electrical power	5-10 Yr	Supplement as system degrades, aid in deployment
Sensor (attitude & navigation)	7 Yr	Replace unit, provide initial pointing
Thermal control	7 Yr	Replace radiations, replace degraded insulation
Stationkeeping & attitude control	7 Yr	Replace propellants, gyros, jets
Telemetry & command	7 Yr	Replace unit
Antenna	>15 Yr	Repoint, change feeds for frequency changes
Structure	>20 Yr	Repair meteoroid damage in rare cases

Table 7-3. Potential Unscheduled Repair Tasks.

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
Separation	Failure to separate: a) Petals b) Experiment to pallet c) Feed deployment d) Reflector deployment e) Solar cell release Perform separation	1) Protective cover 2) Power saw 3) Portable shape charge 4) Battery 5) Volt-ohmmeter 6) Low reaction torque tool	3-9 EVA	1) Potentially hazardous unless design includes protected EVA disassembly. 2) Two-vehicle dynamics is a problem unless section can be cut automatically.
Truss Member Lock Down	Lock tubular truss members — feed and reflector	1) Reaction torque tool (apply moment at joint) 2) Two bar extension with power driven screw jack (reach to adjacent spider adjustable) 3) Flexible split sleeve	0.5-3.0 EVA	Store in feed compartment. Sleeve fits mast type joints, aligns them, and carries load.
Antenna	Repair damaged member that is preventing full deployment.	1) Power saw 2) Expandable tube 3) Split sleeve splice	0.5-3.0 EVA	1) Store on side of feed compartment. 2) Redundance of truss will allow member to be cut out without impairing total structure.
	1) Adjust tolerance 2) Repair tear 3) Gross tolerance correction	Los reaction torque tool and adjustable turn capability e.g.) set at 2 turns VELCRO tape VELCRO tape adjustable cable	10 min/ adjust 0.5 1.0	Laser measuring unit is required to determine which member to adjust and substantiate adjustment.

Table 7-3. Potential Unscheduled Repair Tasks (continued).

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
Solar Cell System, Solar Array	Mechanical extension of segment.	Wrench, pliers	0.5 per segment	Accomplished in the event of malfunction of automatic system.
	Array orientation.	Powered monitor panel; attitude control monitor panel.	0.5	Where vehicle orientation is compatible with solar array orientation.
	Power monitoring.	Power monitor panel.	0.5	Routine within S/C.
	Fault location.	Power monitor panel; test meters; hand tools; spare parts of maintenance type-fuses; circuit breakers; harnesses; etc.	0.5 +	Trouble shooting per test procedures inside S/C.
	Maintenance inspection.	Power monitoring panel; AMU; hand tools & meters.	1.0 inside S/C	Periodic inspection of status of all elec. equip. - fuses, meters, light bulks, harness connections, etc. Visual and electrical.
Battery System	Maintenance inspection	Power monitoring panel.	1/2	Routine visual & electrical inspection of the battery.
	Repair/replacement.	Power monitoring panel; hand tools.	1-2	Repair by replacing "bad cells" and/or interconnection links or by use of overlays.
	Charge monitoring.	Power monitoring panel.	1/2	Routine spot check of state of charge and charging process.

Table 7-3. Potential Unscheduled Repair Tasks (continued).

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
Power Conditioning	Maintenance inspection.	Power monitoring panel; hand tools & meters.	2	Periodic inspection of status of power conditioning equip. on a point-point check basis.
	Repair/replacement.	Power monitoring panel; hand tools.	1-2	Repair by replacing bad components & clearing line fault indicators-fuses, etc.
Standard Gain	1) Extend & adjust into correct position.	1) Screw driver 2) Low torque tool 3) Replacement antenna		Extra antenna elements may be stored on side of feed compartment or in Apollo pallet area.
	2) Splice or replace coax line.	1) COAX splicer 2) Insulator		
Feed Adjustment	1) Rotate feed into place	1) Torque tool 2) Lubricator 3) Hammer	0.5	Hinge joint lockup
	2) Adjust to optimum focal point.	1) Torque tool 2) Lubricator	1.0	
	3) Lock feed	1) "C" clamp	0.3	
	4) Optical alignment	Transit with Stadia crosshair.	0.5	Backup to laser system.
	5) Replace laser unit	1) Screwdriver	1.5	Store replacement in pressurized feed compartment.
	6) Install conductor in low frequency feed	1) Pull through cable & hand wrench	1.5	Possible to use power torque wrench to raise conductor.
Thermal Coating (Passive)	Repair damage to thermal coatings.	1) Coated sticky tape with various ratios, for hard surfaces. 2) Spray gun for mesh on large area requirements.	0.5-3.0	

Table 7-3. Potential Unscheduled Repair Tasks (continued).

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
Attitude Sensor System	a) Align vehicle to local vertical and zero and calibrate horizontal scanner.	Telescope Wrench & screwdriver	5.0	
	b) Acquire & track Polaris-achieve star tracker lock on - zero & calibrate tracker.	Ditto	5.0	
	Repeat (a) and (b) periodically.	Ditto	4.0 ea.	
	c) Measure & compensate gyro drift rate.	Ditto & computer or data link to ground station.	2.0	
	d) Align & calibrate solar aspect sensor.	Telescope Screwdriver	2.0	
	Repeat (c) and (d) periodically.	Screwdrivers	1.0	
CMG or Inertia Wheel (Does not apply with active control)	Inspect	Lubricator	1.0	Deterioration or noise problem.
	Replace bearings.	Wrench		
	Remove or replace torque motor.	Wrenches Screwdrivers	2.0	
	Repair vacuum leak in wheel housing.	Leak detector Epoxy Files, wrench Cleaning material	1.0	
	Remove & replace faulty electronics inside of space station.	Wrenches Screwdrivers	1.0	

Table 7-3. Potential Unscheduled Repair Tasks (continued).

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
CMG or Inertia Wheel (Does not apply with active control)	Repair electronic units at bench.	Wrenches, screwdrivers Pliers. Electrical connection equipment.	 1.0	This work depends upon the modular type build-up employed.
	Electronics troubleshooting & maintenance.	Test instruments. Screwdrivers	4.0	This work also depends upamount of built-in checking feature.
Reaction Control System	Remove & replace nozzle and test.	Wrenches, screwdrivers.	0.5	
	Remove & replace valve & test.	Wrenches, screwdrivers.	1.0	
	Fit new cable to ATC.	Wrenches, screwdriver. Pliers & cutters.	3.0	Assume damage to cable broken connections.
	Electronics troubleshooting & maintenance.	Test instruments. Screwdrivers	4.0	Depends upon built-in checking features. Modular construction.
Control Logic	Maintain attitude during system repair or mainten.	Hand controls	1.0	
	Optimize control system parameters for minimum energy expenditure.	Fuel & watt/hr usage vs. time for required pointing accuracy.	10.0	This time spread over several weeks.
Spinning Joint	Maintenance and lubrication.	Wrenches, lube, screw-screwdrivers.	2.0	
RF Antenna	Complete all electrical connections.	Clamps, screwdrivers, wrench, adhesive tape.	2.0	Generally this applies to disconnected cables for convenience of packaging.
	Broken connection or cables.	Spare cables, and as above.	2.0	Could happen on deployment.
	Switch on power.	Manual		

Table 7-3. Potential Unscheduled Repair Tasks (continued).

SYSTEM	TASK	EQUIPMENT	HOURS	REMARKS
RF Antenna	Check output levels.	Volt-ohmmeter, fuses, screwdrivers.	1.0	
	Faulty units (electronic).	Replacement modules meters. Screwdrivers	2.0	Equip. design based on simple unit replacement and connections.
	Connect transmission line feed to receiver.	Signal generator, reflecto-meter.	0.5	
	Connect feed to transmitters.	Ditto	0.5	
Communication System	Monitor & adjust transmit-ter/receiver frequency/ stability.	Test equip. Noise oscillo-scope, frequency sig. gen., volt/amp meters.	1.0	Check instrument system could be built into modules.
Communications	Troubleshooting & repairs.	Replacement modules or switching. Fuses, wire. Hand crimping tools. Pliers.	1 to 8	Inventory of replacement units would be based on reliability figures.
RF System Pattern Tests	Focus feed. Point to radio star or sun.	Manual	2.0	Could be performed from airlock at feed.
	Adjust feed & monitor out-put. Adjust for max. response.	Monitor panels, instruments.		
	Boresight measurement of antenna/mechanical axis. Compare RF lobe axis with sight on radio star.	Recording equipment.	2 to 6	Compare great circle cut pattern in orthogonal planes along axis.
	Measure beamwidth and sidelobe data.	Recording equipment, to measure principal plane and sidelobe data.	2 to 8	

Table 7-4. Effect of Basic Hazards on the Concept.

HAZARDS	MAJOR CREW LIMITATIONS	EFFECT ON MISSION/SYSTEMS
Environmental (External) Ionizing Radiation	Max. allowable dose: 32 rad/120 hr. (~0.3 rad/hr.) to blood forming organs of body. Proton damage to eyes critical in altitudes 400-15,000 n.mi. (also in event of solar flares).	Req'd. S/C shielding increases from 1 in. to 13 in. Al. between 400-15,000 n.mi. altitudes for prolonged stay. Periodic EVA "safe" below and above these altitudes or in polar orbits (assuming no solar flare "storm").
Solar Radiation (Non-ionizing)	Visual capability reduced by glare, sharp contrasts created by direct and reflected light. Sun visors and portable light sources required. Time required for eye adaptation to light/dark changes is reduced by use of visors and proper light sources.	Scheduling of certain EVA tasks for "darkside" operations. Sufficient floodlighting to "fill in" shadows imposes power penalty to system.
Microwave Radiation	Major Crew Limitations. Chief effect on man is heating. 200-900 MHz region - deep penetration. 1.5 - 11.0 GHz region - heating at or near surface of body. Most susceptible tissues - brain, testes, hollow viscera, eyes. 1 to 10 MW/cm^2 - safe for occasional exposures. 1 MW/cm^2 - safe for indefinitely prolonged exposures.	The heating effect is a function of the strength of the microwave field, time, and frequency. Initial calculations of field strength for 100 ft. dish antenna indicate no microwave radiation danger to crew.
Pyrotechnic Misfire	Crew must be protected from shrapnel by built-in cover. Stability of component to be separated and approach position must be considered. NOTE: First check battery, lines, and connection. Deactivate power and remove bolts with torque gun. Tether must be clear and in position to extract astronaut with spacecraft. Alternate is to place cutting charge and fire from safety of spacecraft.	Failure of pyrotechnic will abort mission if EVA not feasible. (High reliability makes this unlikely but should be considered in design).

Table 7-4. Effect of Basic Hazards on the Concept (continued).

HAZARDS	MAJOR CREW LIMITATIONS	EFFECT ON MISSION/SYSTEMS
Meteoroids	Thermal-meteoroid protection garment for Apollo A6L suit necessary for the longer EVA tasks, and may be required for all EVA.	Additional limitation on EVA astronaut mobility and manual dexterity.
Vacuum	Possibility of cold-welding or other unexpected interaction of materials in EVA cannot be excluded. (Earth-laboratory pretesting of materials in astronaut's EVA equipment to assure thermal-vacuum compatibility assumed).	Materials problem indirectly related to EVA, and mission/system effects.
Operational Damage to space suit and loss of LSS.	Extreme caution by EV astronaut to avoid snagging on projections. TMG coverall will tend to protect pressure envelope but punctures may cause localized "hot spots".	Sharp projections to be avoided in antenna designed for EVO.
Loss of visual contact with spacecraft.	Frequent 2 min. rest periods must be scheduled during peak activity to reduce metabolic load and possible fogging of faceplate. UV/light visor will reduce risk of blindness but emergency rescue/retrieval procedures must be considered.	Adequate PLSS capability to handle peak metabolic loads required. Also, S/C illumination during darkside operations. Rescue/retrieval by safety line, S/C maneuver, or manned/unmanned SMU depending on distance and available equipment.
Malfunction of HHMU PLSS.	Assume HHMU disconnected from S/C, astronaut must activate emergency backup system and return to S/C.	Spacecraft may be required to maneuver to striken astronaut when HHMU fails.
	Manual/automatic activation of emergency ECS, with return to S/C.	Emergency PLSS capability required to support astronaut for 1 hour.
Impact Against Structures.	Control of body orientation, and avoidance of rapid movements required.	Damage to antenna structures possible.
Entanglement	Long tetherlines, umbilical considered undesirable hazards for EVA tasks around antennas. Short, rigidized tethers will reduce hazard.	Assistance of second EV astronaut may be necessary.
Rocket Plume Impingement (RCS)	Protection against damage to spacesuit, tethers, umbilicals required.	RCS shut down when any danger of plume impingement on astronaut or safety lines.

7.2.4 COMMUNICATION EXPERIMENTS — Concept F is a very large, stable space platform. If not in regular service, and probably for short periods during regular service, it could provide power, telemetry support, control, and a suitable environment for space experiments. As an adjunct to a rendezvous, for example, for satellite repair, provision could be made for the conduct of space experiments. There are many experiments having objectives which illustrate the possible usefulness of the TVBS as an experiment platform and the role of the astronaut as an experimenter in conjunction with the TVBS program. The following paragraphs list two experiments and indicate possible application of a typical concept F TVBS. The experiments are derived from the NASA "Blue Book", Volume V, Communications/Navigation Experiments.

7.2.4.1 Optical Frequency Demonstration — The purpose of this experiment is to investigate optical frequencies for space-to-ground and space-to-space communication applications. Transmitting and receiving optical systems no greater than 30 to 60 cm in diameter are envisioned. This package size could easily be accommodated in the MDA compartment or outside on the antenna major axis, without interfering with the satellite antenna beams. The pointing tolerance of 0.1 degree for the large satellite provides a stable base for alignment of the laser beam with a ground station, another satellite, or the maneuvering manned vehicle. If protection from solar flux is required, long periods of time exist during which an optical system directed toward middle north latitude will not point within 30 degrees of the sun.

The astronaut would play an important role in the experiment in the delivery, installation, alignment and operation of the optical systems. He will be able to make optical and electronic component changes, and observe the experiment.

7.2.4.2 Millimeter Wave Communication System and Propagation Demonstration — This experiment will investigate the utility of millimeter waves in space communications applications. Data will be collected on propagation between space vehicles and from space vehicles to ground terminals.

Size (2-3 ft. diam. antennas, 0.1 cu. ft. receivers and transmitters), weight (10 - 20 lb.), and power required (less than 500 watts) are modest for millimeter wave experiments. The large, stable platform of TVBS is an ideal vehicle for support of experiments of this nature.

7.3 TYPICAL MANNED MISSION

The use of man in a TVBS mission in a cost-effective manner is marginal within the scope of the missions considered in the study. Other factors, such as the manned support to TVBS being only part of a more complex manned mission, could justify the use of man. Man's usefulness increases when the cost and complexity of the satellite is great — and the payoff resulting from the manned task, (e.g. the restoration of a satellite to service) is great. Therefore, the manned mission selected involves the

satellite configuration of those considered in the study, having the largest antenna, most individual radiated beams, largest solar array, and (typically) the greatest replacement cost. This is configuration F, and the specific application used in the following typical mission description is the U.S. ETV/ITV mission.

While not necessarily a requirement for the performance of this mission, it is assumed that the satellite system is designed for a 10-year service life. This would tend to yield the satellite with the largest replacement cost. The satellite, it is assumed, has failed to deploy properly, or failed for other reasons to perform its mission shortly after deployment. The satellite in configuration F has a manned docking adapter on the antenna feed module, and provisions for short manned stay (up to 14 days) are provided. The telemetry and instrumentation system has provided data so that the cause of failure in the equipment has been diagnosed from the ground. The tools and equipment necessary to effect the repair can be transported in the manned vehicle. All elements are available for a demonstration of use of man for the restoration of service by the otherwise valueless satellite.

7.3.1 SATELLITE CONFIGURATION — An external view of the satellite is shown in Figure 7-1. Four rollout solar arrays extend from two booms mounted on the rim of the antenna structure. This structure, which may be as large as 100 feet in diameter, is an expandable truss structure having six parabolic antenna surfaces corresponding to the six antenna beams. Feeds for the individual beams are located around the feed compartment. The feed compartment is designed to facilitate manned support. During studies of large antenna configurations, it became evident that most of the activities related to deployment, checkout, calibration, maintenance and repair centered about the feed focal point of the antenna. Therefore, most of the electronics equipment is enclosed in the feed module. Docking equipment (MDA — Multiple Docking Adapter) and life support systems are incorporated into this assembly. Hatches and EVA aids are arranged so that the astronaut can readily move from the feed module to the antenna structure and solar arrays. The provision of suit umbilical outlets in the feed compartment allows the use of the feed compartment as an airlock, allowing crew in the command module to remain in a pressurized environment during EVA. For astronaut tasks within the feed compartment, pressurization is maintained compatible with the shirt-sleeved environment of the command module. The weight and cost penalties of providing these provisions in an otherwise unmanned satellite configuration are summarized in Table 7-5. Recurring cost for the manned support provisions is approximately 5 per cent of total satellite cost.

7.3.2 FAILURE DETECTION — It is assumed that a satellite failure is detected. Telemetry data indicates a failure in the battery charging circuit. Broadcast service is interrupted and transmitters operated at standby power during subsequent eclipse periods.

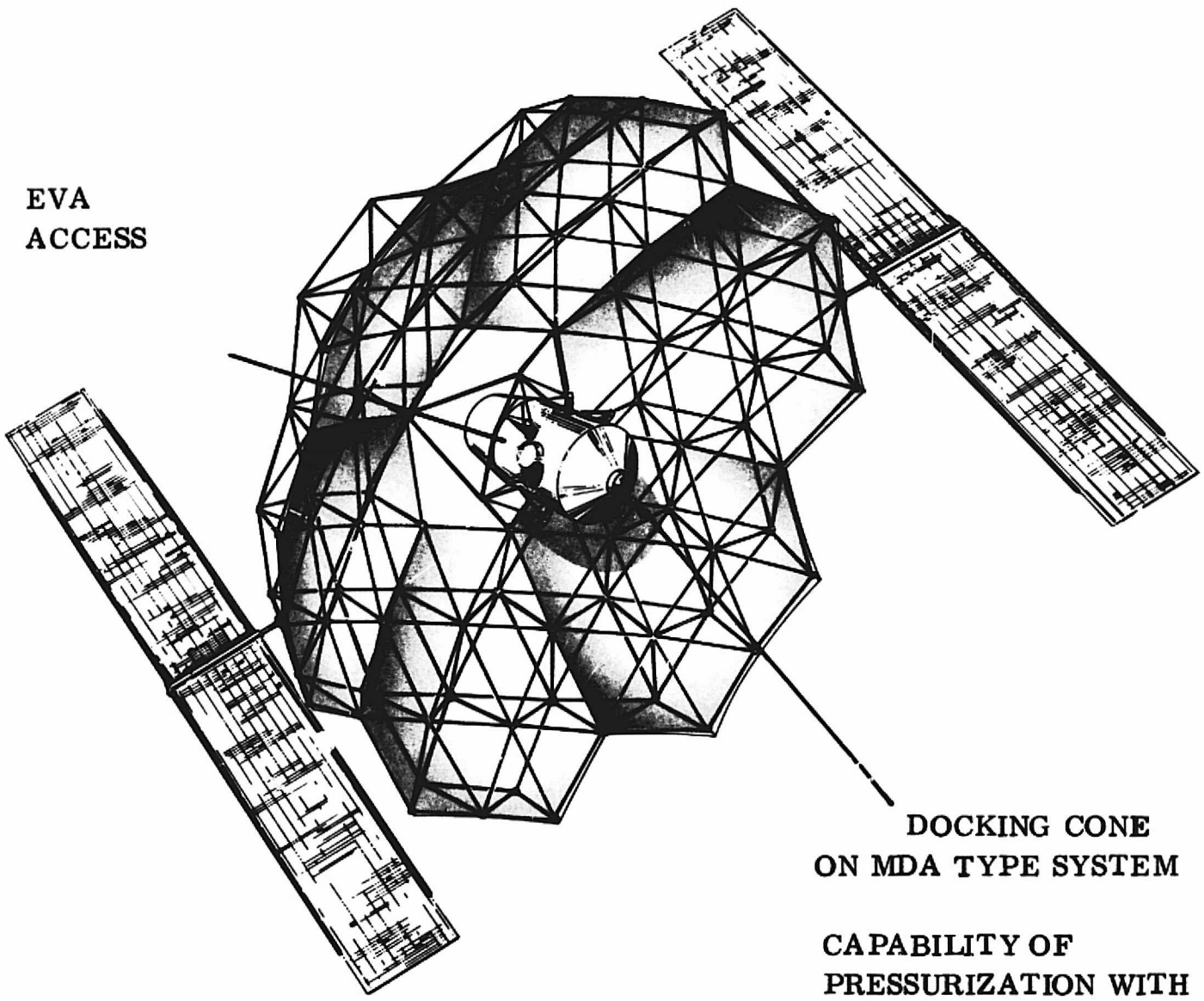


Figure 7-1. Concept F.

Table 7-5. Weight and Cost Penalties for Manned Support Provisions.

SPACECRAFT ELEMENT	WEIGHT PENALTY (LB.)	RECURRING COST ($ K)	NON-RECURRING COST ($ K)
MULTIPLE DOCKING ADAPTER[1]	6,000	1,630	7,000
MANNED PROVISIONS	3,200	1,800	24,900
POWER SYSTEM[2]	500	470	
REPAIR PROVISIONS[3]	500	300	
TOTALS	10,200	4,200	31,900

[1] Weight estimated in excess of typical non-man-rated compartment.

[2] Provision made for 3 kilowatt additional power for life support system.

[3] Design of equipment modules to facilitate repair and replacement.

After the semi-annual periods of daily eclipse, the satellite is returned to normal status, however, the risk of loss of control of the satellite during stationkeeping maneuvers or later eclipse periods warrants consideration of a manned repair mission.

7.3.3 MANNED SUPPORT MISSION OBJECTIVES — The primary objectives of the manned support mission are:

1. Rendezvous with the TVBS and perform visual inspection of the satellite structures.
2. Dock with the MDA.
3. Enter the MDA and perform visual inspection for damage.
4. Test and determine failure mode of charge systems.
5. Replace charge system modules.
6. Undock and continue manned mission.

Secondary objectives of the manned support mission are:

1. Perform formation cycles and verify reconditioning of battery systems.
2. Adjust dummy load for operation of the solar array at maximum power point.
3. Adjust voltage regulation system, if necessary, for operation within design limits.
4. Check transmitter carrier frequencies and adjust if necessary.
5. Perform overall system check.

7.3.4 SUPPORT EQUIPMENT REQUIREMENTS — Equipment required to be carried in the manned support vehicle peculiar to meeting the objectives of this mission are the replacement modules for the satellite charging systems and special test equipment. The latter is estimated to be a single suitcase sized electrical power test set. It is

used to perform primary objective No. 4, and secondary mission objectives 1, 2, and 3. It will remain in the MDA after the tests are completed. If it is compatible with other mission objectives, the satellite modules that require replacement during the IVA will be returned to earth for further testing. Characteristics of the equipment required for delivery by the manned support vehicle are:

ITEM	VOLUME (Cu. Ft.)	WEIGHT (Lb.)	COST ($ K)
Charge Control Modules (2)	2.0	120	90
Charge Switching Module	0.5	5	12
Charge Control Harness	0.5	12	1
Electrical Power Test Set	3.0	80	25

60

8

TECHNOLOGY EVALUATION

8.1 SATELLITE SUBSYSTEM DESIGN REQUIREMENTS

The subsystems include those whose characteristics are major determinants of the feasible radio frequency output power and the beam size and beam pointing accuracy. A prime design objective for a TV broadcast satellite system is to provide the required signal by the most economical method in both dollar cost and frequency spectrum conservation. High power broadcast satellites are feasible in the 1970 - 1980 time period if current technology and subsystem developments are continued.

Development of some key elements for high powered satellites is in process. Low cost ground converters are being developed, and solar array design and development has been under way for many years. High power transmitter, high voltage power conditioners, and special antennas are being designed for broadcast satellites.

Experience gained on current space programs is being applied to develop high voltage and high power components, and to attain long-life endurance in space.

8.2 HIGH POWER SPACEBORNE TRANSMITTER TECHNOLOGY

Since both FM and AM must be considered for space TV broadcasting it is necessary to determine suitable techniques for obtaining high overall efficiency in conjunction with each type of modulation. With FM, the power amplifier may be operated at saturation. This type of operation allows the highest efficiency to be attained. With AM, the output amplifier must have sufficient dynamic range to handle the peak sync level. Attainment of high efficiency is more critical for AM transmitters since no modulation improvement factor may be used to reduce the power requirement as may be accomplished with an FM system. Both the efficiency and life of the final power amplifiers affect the feasibility and cost of a given mission, since they are so closely coupled to such factors as the weight, size and cost of solar panels and heat radiators.

Microwave tubes generally operate at reduced efficiency when the output is modulated downward from saturation. Conventional microwave amplifiers must be operated well below saturation to avoid distortions and to achieve the required phase and amplitude linearity. At low AM modulation levels this type of amplifier is very inefficient.

The conventional terrestrial broadcast television transmitter system is usually composed of two separate transmitters operating into a common antenna system. The video signal is transmitted as a vestigial sideband signal. Upper sideband signals up to a frequency of 4.2 MHz are transmitted at full amplitude while lower sideband frequencies to 0.75 MHz are transmitted. Lower sideband frequencies removed from the carrier by 1.25 MHz or more are required to be down by 20 db.

In some commercial broadcast transmitter complexes the vestigial sideband filter and the video-aural diplexer are combined into one unit. The unit is inserted at a high RF level point between the power amplifiers and the antenna. The filter unit required to do this job in the UHF TV band typically weighs over 1000 pounds and occupies a volume of 100 to 200 cubic feet. In more recent designs low level modulation is employed, and the vestigial sideband filter is inserted prior to the power amplifier.

HIGH POWER RF BREAKDOWN TECHNOLOGY IN A SPACE ENVIRONMENT

RF breakdown problems have been reviewed and studied by NASA (References 8-1, 8-2, 8-3). Failures due to corona and glow, arc-over and multipacting were determined. Only one failure was deemed due to multipacting, probably because of the low RF power operation associated with satellite history. Among the causes of failure listed were:

a. Outgassing
b. Insulation breakdown
c. Circuit configuration
d. Entrapped gas
e. Contamination
f. Pressure leaks
g. Environment plasma

Among significant parameters involved in breakdown are:

a. Electrode geometry
b. Pressure
c. Temperature
d. Electric field strength
e. Type of gas
f. Frequency
g. Radiation environment
h. Plasma in space
i. Type of dielectric
j. Type of conductor
k. Electrode history

The power handling capacity of transmission lines propagating pulsed signals is usually limited by breakdown due to ionization of the gas that fills the line. A minimum value of breakdown field occurs at a pressure (approximately 1 mm Hg) where the radio frequency is equal to the gas collision frequency. At lower pressure, the breakdown field strength increases rapidly. At pressures on the order of 10^{-6} mm Hg, breakdown is no longer due to ionization of the remaining gas molecules, but to other mechanisms. It seems likely that the most important process that occurs is field emission whereby electrons are pulled loose from metal surfaces by electric fields having strengths on the order of megavolts per centimeter. Such field strengths can arise from minute irregularities on the propagating surface even when the average field strength over the surface is much lower. Thus, it is very important in evacuated high-power filters and transmission lines that the inside surfaces be quite smooth.

Another phenomenon that occurs in a vacuum is called multipactor. This is a resonant secondary-emission phenomenon that occurs when an electron under the action of an electric field has a transit time between opposite electrodes equal to one-half the period of an RF cycle. Multipacting can occur in the space environment if the proper relationships between RF voltage, frequency, and electrode geometry exist.

All of the following conditions must exist to establish a multipactor discharge:

a. The mean-free-path of the electrons must permit an electron to be accelerated between the emitting surfaces with low probability of collision with ambient atoms or molecules.
b. The arrival energy of the incident electrons must produce a net secondary emission ratio greater than one.
c. The electron transit time must be in resonance with the applied frequency.
d. In order to maintain a multipactor discharge the applied voltage, ambient pressure, and emitting surface must not change. (The applied voltage may be altered because of detuning and variation in load impedance due to the detuning.)

Methods of eliminating the possibility of multipactor breakdown are:

a. Reduce the mean free-electron path length by means of pressurization or by utilizing foam or solid dielectrics.
b. Reduce secondary emission ratio of the electrode surfaces by using coatings or selecting low-emission-ratio materials.
c. "Detune" electrode geometry by proper choice of configuration and amplitude of RF signal. DC bias might also be used to alter resonance effects.

Experimental data on the relationship of RF voltage to the frequency-gap product is shown in Figure 8-1 for beryllium, copper, epoxy, teflon, tin and aluminum (References 8-4). An important point to be observed here is that insulators will multipact as well as metals.

The peak RF voltage necessary for a multipacting discharge to occur between parallel plates with a uniform applied electric field is given approximately by (Reference 8-4):

$$V_o = \frac{\omega^2 m d^2}{e} \cdot \frac{1}{\frac{K-1}{K+1}\,(2n-1)\,(\pi\,\omega s\,\phi) + 2\sin\phi}$$

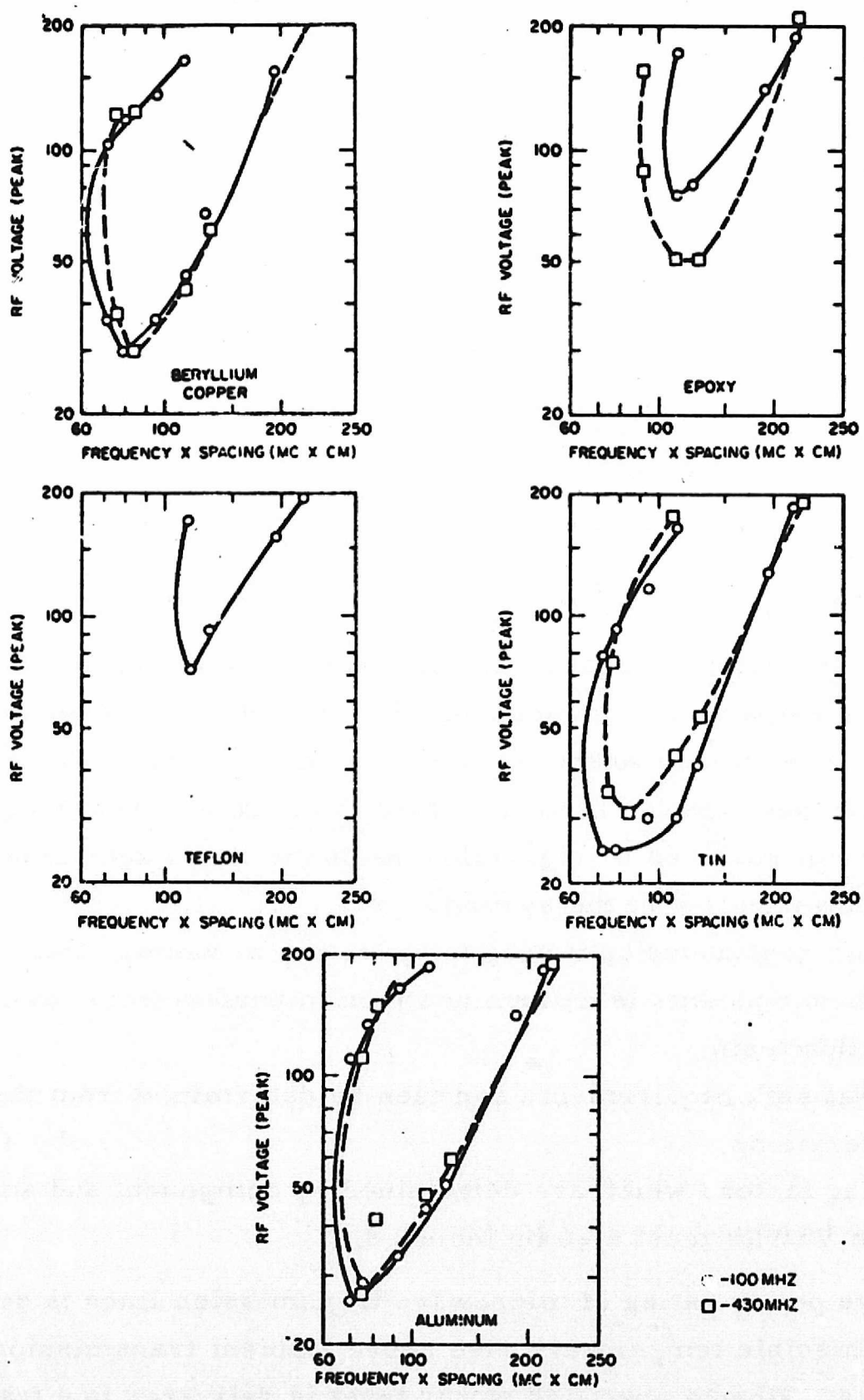


Figure 8-1. Relationship of RF Voltage to Frequency-Gap Product for Various Materials (Reference 8-4)

where

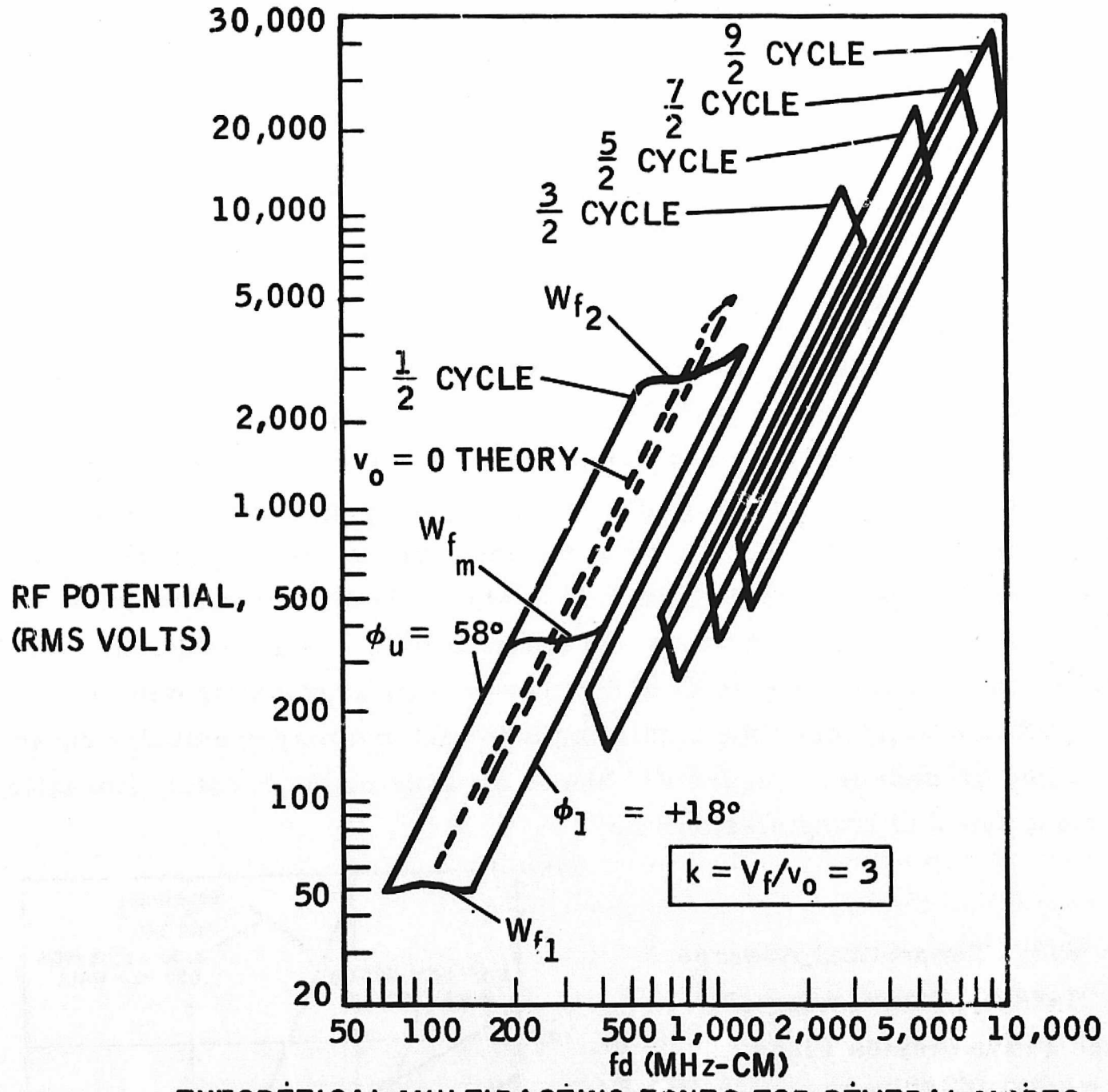
m	= electron mass
e	= charge on an electron in a sinusoidal field of peak strength E and frequency $f=\omega/2\pi$
d	= electrode spacing
$(2n-1)\pi$	= multipacting mode where n = 1, 2, 3, . . .
ϕ	= phase angle at which secondary electrons are emitted
K	= V_f/V_o is the assumed constant ratio of electron arrival velocity to emission velocity.

Good agreement with test data has been observed with K = 3. The values of breakdown voltage are plotted versus the frequency-spacing product in Figure 8-2. The multipacting regions for parallel electrodes shown in Figure 8-1 are based on experimental measurements.

CW power rating is calculated by the following procedure:

a. From the known attenuation factor or attenuation per unit length, the power dissipated in a component or in the walls of a transmission line may be determined where a given incident and load VSWR is specified.
b. The dissipated power is then related to the rate of heat transfer from component surfaces or transmission line walls to determine the operating power rating of the system.
c. The safe continuous operating temperature of various transmission system components is determined from manufacturers' data or from evaluation tests.
d. The heat sink requirements can then be determined from the foregoing considerations.
e. Derating factors which are determined by component and antenna feed system VSWRs must also be included.

The average power rating of microwave transmission lines is determined by the permissible temperature rise above ambient transmission-line wall temperature. When a specified power level is delivered to a transmission line with a specified termination VSWR, the transmission-line wall temperature rise and distribution can be determined.



THEORETICAL MULTIPACTING ZONES FOR SEVERAL MODES; W_{f1} = 50 V AND W_{f2} = 3000 V

Figure 8-2. Illustration of Multipactor Prediction by Method of Hatch

In general, transmission line components such as circulators, filters, and hybrids do not operate satisfactorily at high temperatures. Thus, the problem of heat transport and radiation require careful consideration. The amount of heat generated is not negligible: For example, a circulator with matched terminations and 0.3 db loss will dissipate about 66 watts with a 1kW incident signal. The maximum design objective of 1 db requires a thermal system capability of dissipating 205 watts. Heat-sinking the center conductor of coaxial cable represents a primary problem in a high power RF system design and requires a tradeoff investigation during the design phase.

The larger, rigid forms of coaxial cable usually use dry air as a dielectric with occasional insulators for mechanical support. The supporting insulators of such lines are the major loss-determining elements. Breakdown will usually occur in the vicinity of the supporting elements. Another factor that requires careful attention in designing high average power coaxial transmission lines is the occurrence of voids. Voids are caused by mechanical imperfections in the dielectric insulators which allow small gaps to form between the conducting walls and the dielectric. High field concentrations can occur at these voids and cause gradual degradation due to heating effects which char the insulating material and may eventually cause catastropic breakdown. Figure 8-3 shows average power handling limitations of various types of transmission line.

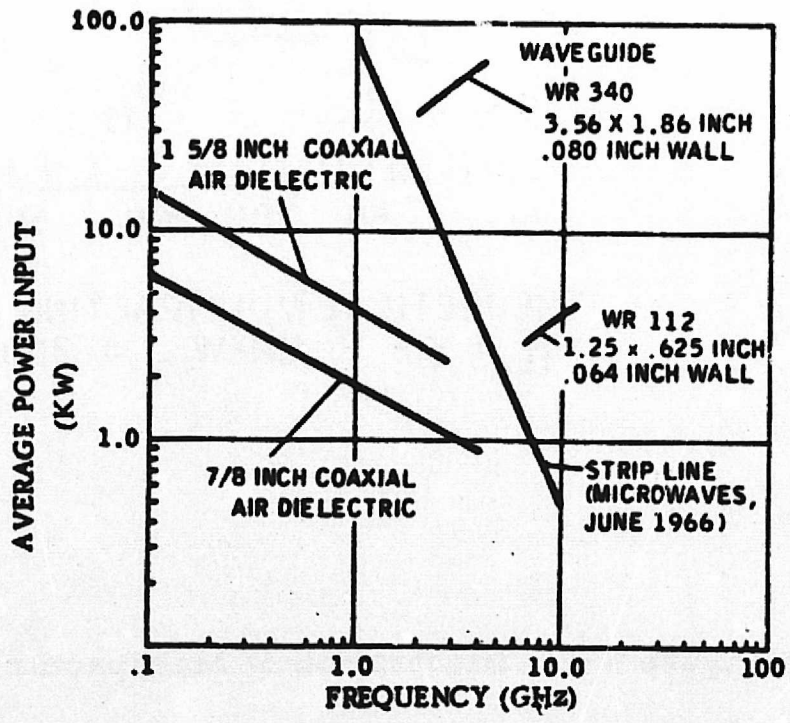


Figure 8-3. Theoretical Average Power Handling Limitations of Matched Transmission Lines (60°C Center Conductor or Waveguide Temperature Rise)

8.3 HIGH POWER OUTPUT AMPLIFIERS

8.3.1 VACUUM TUBE AMPLIFIERS. Analytical designs of spaceborne RF amplifiers have been developed under NASA/Lewis Research Center contracts (References 8-5 through 8-8), and also under a NASA/Huntsville contract. Emphasis in these studies was placed on achieving high overall efficiency. Frequencies of operation, power levels, and the types of modulation considered in conjunction with those designs are listed in Table 8-1. Based on immediate implementation of design and development efforts, the availability of these tubes are projected for the 1975 - 1980 time period. Traveling wave amplifiers, klystrons and cross-field amplifiers were the primary types of devices considered in the Lewis studies. Multistage collector depression was incorporated in all of those designs. (Electrons are decelerated before collection in order to minimize the energy lost as heat due to electron impact upon the collector.) These studies were required to consider tube designs with a minimum lifetime of 20,000 hours. The Hughes TWT study predicted a lifetime of 50,000 hours.

Table 8-1. RF Amplifier Study Summary

Modulation Type		AM-VSB		FM		
Frequency (GHz)		0.850	2.0	2.0	8.0	11.0
RF Power Output (kW)		7.5	5.0	5.0	5.0	5.0
Amplifier Type	Study Contractor					
Gridded Tube	GE	X				
CFA	SFD	X	X			
CFA	Litton			X		
EMFK	GE	X	X	X	X	X
ESFK	Litton	X	X	X	X	X
TWT	Hughes	X	X	X	X	X

CFA — Crossed-field amplifier
TWT — Traveling Wave Tube
EMFK — Electromagnetically Focused Klystron
ESFK — Electrostatically Focused Klystron

Efficiency of conventional microwave tubes can be significantly improved by utilizing collector depression. The collector is electrically insulated from the circuit or body of the tube and is operated at a positive potential less than that of the tube body. Spent beam electrons are decelerated because of this depression and the kinetic energy of the beam is reduced at the collector, resulting in greater overall efficiency. Part of the kinetic beam energy serves as the energy source for the generation of RF power in the tube's interaction region. Because of this energy conversion, the spent electron beam will have a velocity spread and the average beam velocity will be reduced. If the collector potential is depressed to a greater degree than he corresponding velocity of the slowest spent beam electrons then the direction of flow of these electrons will be reversed, resulting in what is termed "backstreaming" (Reference 8-3). The velocity spread of the beam electrons increases with the power capability of the tube; thus, multistage collectors allow a larger electron energy recovery than a single collector.

The multistage collector designs involve new concepts such as magnetic refocusing of the spent beam, and transverse magnetic and electric beam deflection for improved velocity sorting of the spent beam. Implementation of multistage collector techniques is expected to be a difficult task in view of limited success in the past (Reference 8-3). Thus it may be concluded that the overall efficiencies shown in Tables 8-2 and 8-3 will not be attained unless sufficient development funding is provided for the design, development, and testing of high power tubes, in conjunction with either NASA or military space programs.

Tables 8-2 and 8-3 list predicted characteristics of vacuum tube amplifiers analyzed in the referenced studies. The data listed in the tables was taken from the study reports according to the following listing:

TWT	Traveling wave tube (Hughes) NAS 3-9719
EMFK	Electromagnetically focused klystron (General Electric) NAS 3-11514
ESFK(1)	Electrostatically focused klystron with a three-stage conventional depressed collector (Litton) NAS 3-11515

Table 8-2. Summary of Predicted Spaceborne Amplifier Characteristics for AM-VSB Television Transmission

Frequency (MHz)	RF Power Output (kW) (Sync Peak)	Tube Type	Overall Saturated Efficiency (%)	Overall* Average Efficiency (%)	Gain (db)	Largest Dimension (in.)	Weight (lb)	Cathode Loading (mA/cm^2)	Focusing*** Technique	Life Expectancy (hr)	Bandwidth (MHz)
850	7.5	TWT	66**		20	67	324	78	PPM	50,000	6
		CFA	84	70	20	11	67	500	PM	>20,000	
		EMFK	77		40	58	125	100	EM	50,000	
		ESFK(1)	72	27	40	42	125	35	ES	50,000	
		ESFK(2)	81	81	40	42+	125+	35	ES	50,000	
2000	5.0	TWT	69		20	26	54	142	PPM	50,000	6
		CFA	80	65	20	11	24	200	PM	>20,000	
		EMFK	77		50	30	57	300	EM	>20,000	
		ESFK(1)	70	26	40	20	29	197	ES	50,000	
		ESFK(2)	78	78	40	20+	29+	197	ES	50,000	

* Based on average picture power of 0.32 peak sync

** Including AM-VSB driver stage and separate amplifier for FM audio carrier

*** PPM - Periodic permanent magnet
PM - Permanent magnet
EM - Electromagnet (solenoid)
ES - Electrostatic

Table 8-3. Summary of Predicted Spaceborne Amplifier Characteristics for FB Television Transmission

Frequency (MHz)	RF Power Output (kW)	Tube Type	Overall Saturated Efficiency (%)	Gain (db)	Largest Dimension (in.)	Weight (lb)	Cathode Loading (mA/cm^2)	Focusing Technique	Life Expectancy (hr)	Bandwidth (MHz)
2,000	5.0	TWT	79	40	35	70	142	PPM	50,000	30
		CFA	81	16	9	46		PM	>20,000	
		EMFK	80	47	34	74	300	EM	>20,000	
		ESFK(1)	70	40	21	31	197	ES	50,000	
		ESFK(2)	79	40	21+	31+	197	ES	50,000	
8,000	5.0	TWT	74	40	12	34	470	EM	50,000	30
		EMFK	75	40	18	30	1400	EM	>20,000	
		ESFK(1)	68	40	13	17	1010	ES	50,000	
		ESFK(2)	78	40	13+	17+	1010	ES	50,000	
11,000	5.0	TWT	71	40	9	29	490	EM	50,000	30
		EMFK	67	38	18	35	2700	EM	>20,000	
		ESFK(1)	65	40	13	16	1340	ES	50,000	
		ESFK(2)	74	40	13+	16+	1340	ES	50,000	

ESFK(2)	Electrostatically focused klystron with a five-stage depressed collector and transverse magnetic field (Litton) NAS 3-11515
CFA(1)	Crossed-field amplifier (SFD) AM-VSB NAS 3-11516
CFA(2)	Crossed-field amplifier (Litton) FM NAS 3-11513

Analysis of gridded-tube circuits conducted by G.E. under the NASA Huntsville contract showed that efficiencies of about 60 percent at peak synchronous and 40 percent at 0.32 peak synchronous level could be obtained with the G.E. L164S tube operating in a Class B linear mode. It was estimated that efficiencies approaching 70 percent peak and 46 percent average could be attained with planned tube developments.

Above 1 GHz, transit time becomes a major problem in conjunction with gridded tubes. The cathode-grid spacing becomes small, on the order of 1 mm or less, and therefore the power handling capability is limited because of the possibility of grid-cathode arcing. Thus, at the higher frequencies, gridded tubes must be paralleled in order to obtain high power levels.

The small size and high efficiency of the CFA makes it attractive for use at UHF, although the small size of the RF structure becomes a detriment at higher frequencies. The small size makes it difficult to dispose of heat generated in the tube.

8.3.2 SOLID STATE AMPLIFIERS. In comparison to tubes, the output power levels of transistor amplifiers are low. Presently available transistors will produce power levels of 10 watts at 2 GHz. The power gain of such an amplifier is approximately 5 db and the efficiency while operating as a common-base Class C amplifier is 40 percent. In general, transistor amplifiers are characterized by relatively low power output for a single transistor, thus requiring the paralleling of several units to obtain higher power levels. Also, most applications of transistors in RF power amplifiers have been as Class C amplifiers. In utilizing the transistor as a linear power amplifier in AM-VSB television transmission, the efficiency would be relatively low and the power dissipation would be high. Therefore,

investigation of special linear amplifier circuits would be required to develop high efficiency AM-VSB solid state power amplifiers.

The history, present state-of-the-art, and projections of future capabilities of semi-conductor power amplifiers are shown in Figure 8-4.

8.3.3 AM-VSB TRANSMISSION

High power amplifiers for AM-VSB signals must provide linear amplification with very high efficiency. Conventional microwave amplifiers must be operated well below saturation in order to avoid signal distortion and also to achieve the required phase linearity. Conventional amplifiers would be very inefficient at low modulation levels.

Special circuits were considered for use in conjunction with gridded tubes (primarily the G.E. L-64S) by the General Electric Co., under the NASA/ Huntsville Multikilowatt Transmitter Study (NAS 8-21886). These special circuits generally use two amplifiers whose inputs and outputs are connected by quarter-wave networks. Their operating parameters are adjusted so that all values up to one-half the amplitude of the input signal voltage are amplified by one amplifier; at one-half the maximum input level, the first amplifier starts to saturate and the second amplifier goes into operation. At the maximum signal input level, both amplifiers operate at peak efficiency and each delivers one-half the power developed in the load.

The primary circuits of consideration in conjunction with gridded tubes were the Termon-Woodyard and Doherty circuits. Other circuits considered by G.E. were the Dome, Chireix outphasing, and Fisher circuits. It was determined that the latter three circuits were not suitable for the TV application. A drawing of the Doherty configuration is shown in Figure 8-5.

A primary advantage in using gridded tubes is their present development status. Less development work would be required in conjunction with a spaceborne UHF satellite transmitter development program.

The referenced Hughes TWT study considered a concept where the final TWT amplifier stage operated with constant drive power and grid-controlled gain. This concept allows high-efficiency operation over the dynamic range

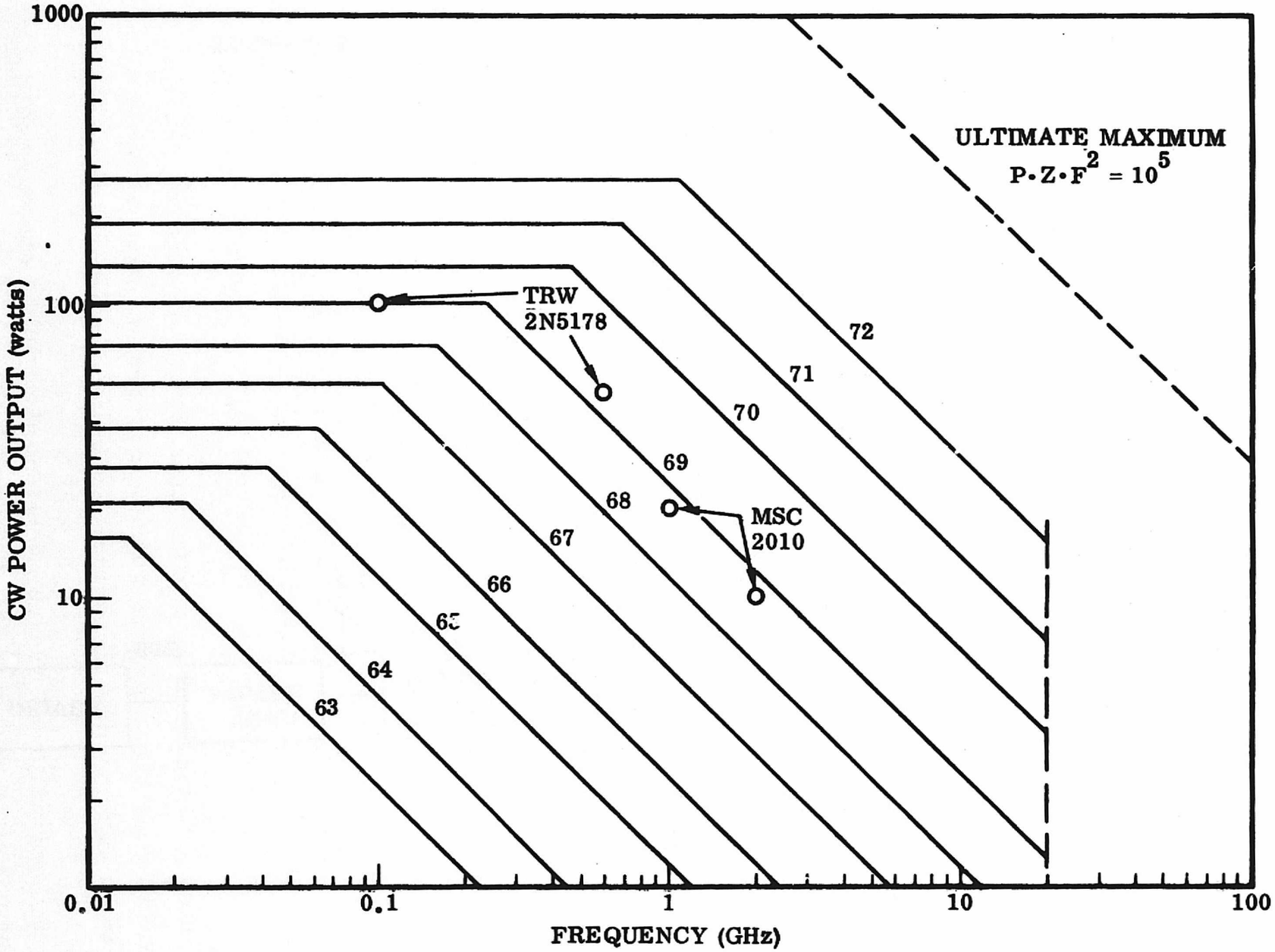


Figure 8-4. Transistor Capability - History and Projections

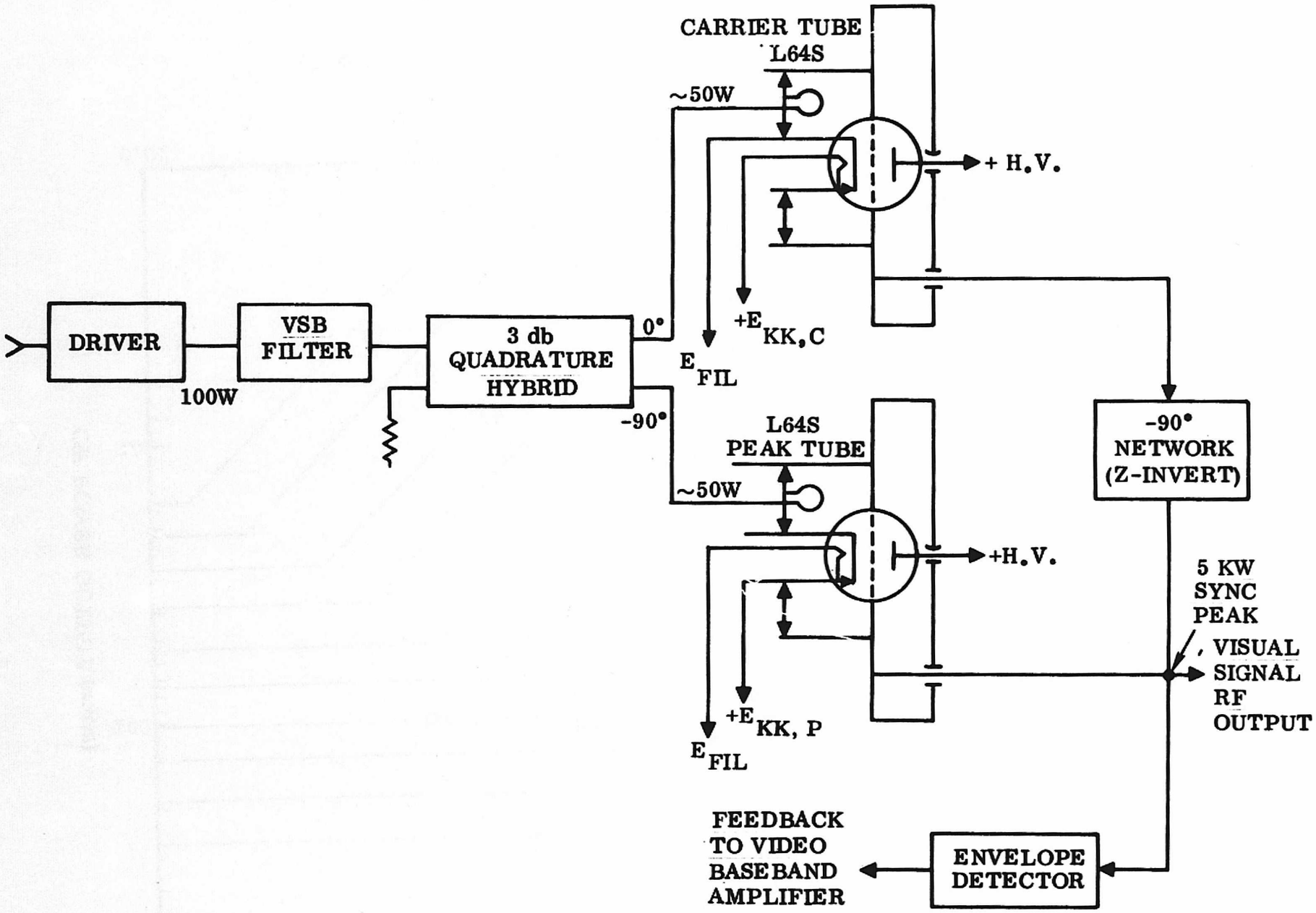


Figure 8-5. Doherty Linear UHF Amplifier Circuit (Ref 8-9)

of the AM-VSB signal (approximately 20 db). Constant drive power and a varying grid voltage are obtained from a limiter-driver chain and an envelope detector. The gain of the output amplifier is controlled by near saturation over the dynamic range of the AM-VSB signal. A block diagram of the Hughes scheme is shown in Figure 8-6.

AM-VSB signal phase characteristics must be preserved in the amplification process; therefore, the concept shown in Figure 8-6 must include circuitry for phase linearization. Both phase compensation and automatic control were discussed in the NASA 3-9719 final report.

The crossed-field amplifier design conducted under the NASA/Lewis studies for the AM-VSB transmission utilized a circular slow-wave structure and circular sole. A depressed collector with 19 electrodes at 850 MHz and 13 electrodes at 2 GHz was analyzed. When available this transmitter would be preferable.

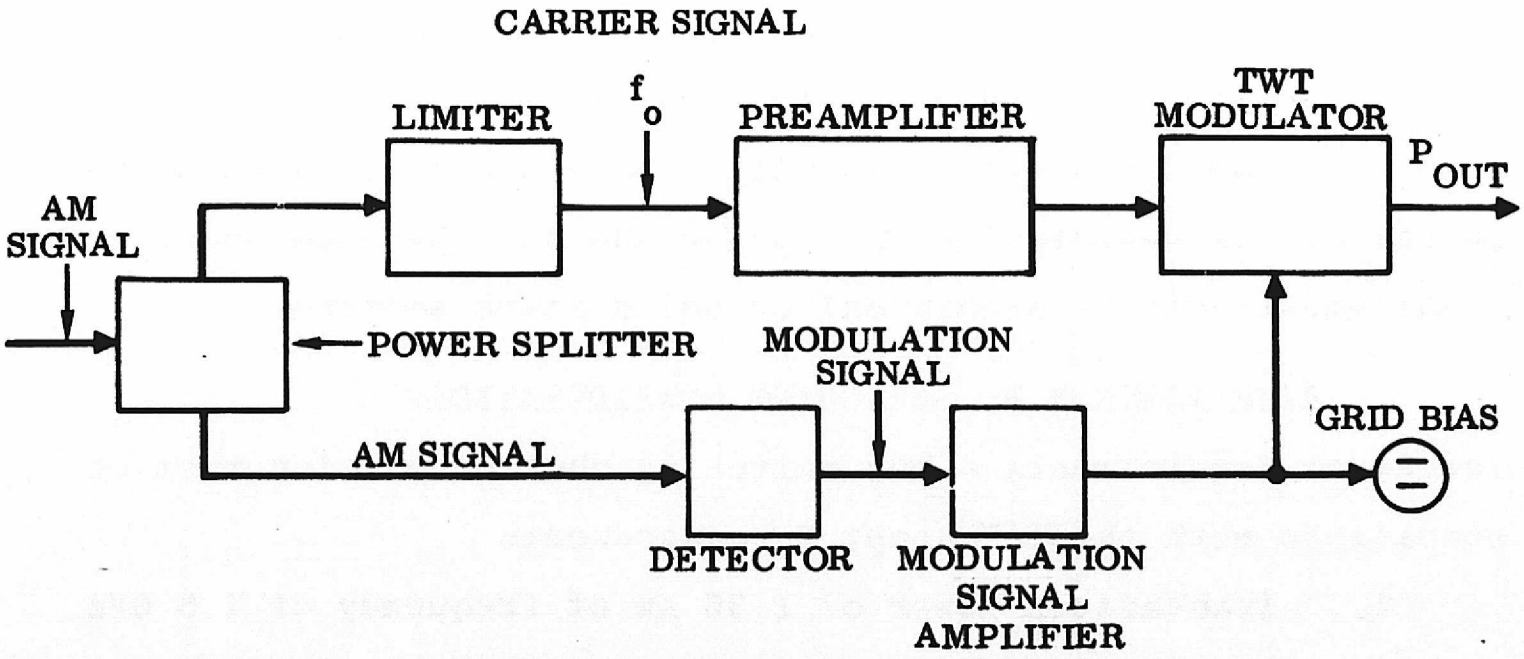


Figure 8-6. AM Amplifier Chain with Traveling-Wave Tube Modulator (from NAS 3-9719)

8.3.4 FM TRANSMISSION

Repeaters for FM transmission to low-cost ground stations will have an overall repeater gain that is considerably higher than present-day communication satellites. Overall repeater gains on the order of 130 to 150 db may be anticipated, depending upon the particular application. The high gain requirement generates potential problems in such areas as receiver-transmitter isolation and instabilities due to feedback. In FM-to-FM frequency translation repeaters, multiple frequency techniques may be used. This allows the overall gain to be achieved at different frequencies and considerably reduces the possibility of unwanted feedback.

8.3.5 TRANSMITTER INTERCONNECTION AND SWITCHING

To provide a satellite system with a five year lifetime made up of elements with less than five year lifetimes it is necessary to add redundant components to the system. High power CFA transmitters are characterized by lifetimes of two years so that for a five year lifetime TV broadcast satellite redundant transmitters must be capable of being switched into the system. Switching requirements consist of low power video, d.c. power and high power r.f. Applicable switches are solid state for video applications, mechanical or solid-state for d.c. power and for the high power r.f. requirements either mechanical or solid state switches.

HIGH POWER R.F. SWITCHING CONSIDERATIONS

Technical Requirements - The switching characteristics must be compatible with these Concept F requirements:

1. Transmitter power of 1.35 Kw at frequency of 2.5 GHz
2. Capable of selecting the output of any one of three transmitters.
3. Minimize insertion loss, size, weight and input power.
4. Provision for heat sinking.

5. Five year minimum transmitter lifetime (Ten year switch lifetime).

6. Minimize development costs.

Design Approach -

1. Mechanical - To switch the outputs of one of three transmitters to the input of a multiplexer, two three-port wave-guide switches might be used as shown in Figure 8-7. Assume both switches are de-energized. The output of transmitter No. 1 is now fed to the antenna multiplexer. Energizing switch No. 1 switches the output of transmitter No. 2 to the multiplexer and energizing both switches feeds the output of transmitter No. 3 to the multiplexer. Implementation using waveguide switches such as shown in Figure 8-7 can be accomplished using discrete vendor supplied switches and waveguide sections or designing an assembly in which the switches and waveguides are integral with the transmitter assembly. The latter approach would result in a savings in weight and size but would involve considerable R&D effort. To conserve power the switches might be of the latching type so that the only time power need be applied to the switches would be when the switches change state.

Mechanical switching utilizing coaxial switches and transmission lines must also be considered. The tradeoffs to be considered in comparison to using waveguides are insertion loss, size, weight, heat sinking and R&D required. The maximum insertion loss of off-the-shelf waveguide switches is 0.2 db over the operating band.

2. Solid State Switching - Solid state switching can be performed either with P-I-N diodes or ferrite devices. Both waveguide and coaxial transmission lines should be considered.

a. P-I-N Diode Switching

Because of heat sinking requirements for high power switching, the diodes are preferably used in shunt rather than in series. A possible configuration using diode switching might be as shown in Figure 8-8. With the diodes biased as shown, transmitter 1 is switched to the output load. Any one of the three transmitters may be switched to the output load by properly biasing each of the four diodes. The Unitrode UM4910 is proposed as the diode for this application. This diode is characterized as follows:

Forward series resistance	0.15 ohms
Cutoff frequency	200 GH_z typ
Capacitance	3.0 pf max

With the diodes biased as shown in Figure 8-8 the VSWR of the quarter wave sections terminated by D1 and D4 is 50/.15 assuming a Zo of 50 ohms for the transmission line. The reflection coefficient is

$$\frac{VSWR-1}{VSWR+1}$$

$$\cong \frac{333-1}{333+1}$$

The percent of power dissipated in the diode is

$$100 - \left[\left(\frac{333-1}{333+1}\right)^2 \times 100\right]$$

1.3%. Assuming an RMS R.F. power level of 1.35 KW thediode loss is 17.5 watts r.m.s. and the diode current is $\sqrt{\frac{17.5}{.15}}$ = 10.8 amperes. The heat rise would be 10.8 x 2 = 21.6°C.

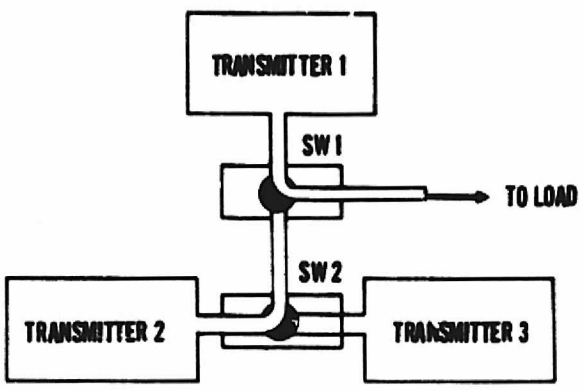


Figure 8-7. Waveguide Switch Configuration

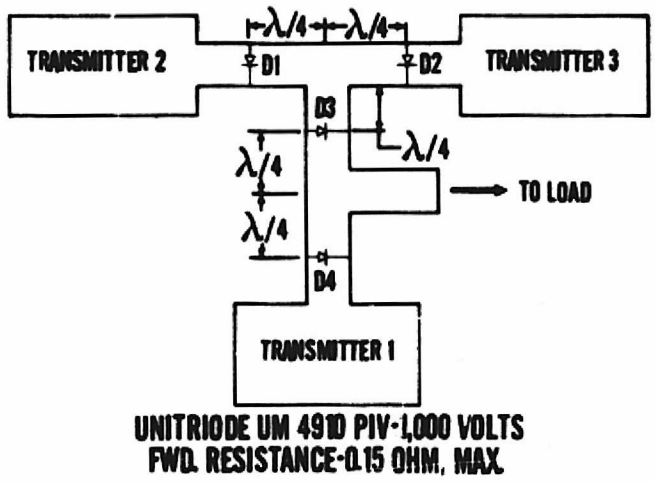


Figure 8-8. P.I.N. Diode Switch Configuration

Table 8-4. High-Power RF Switching

PARAMETERS	MECHANICAL	SOLID STATE
POWER HANDLING	50 KW-LIMITED BY WAVEGUIDE BREAKDOWN	2.5 KW- LIMITED BY DIODE PIV
VSWR	1.10	1.20
INSERTION LOSS	0.4 DB	0.75 DB
BANDWIDTH	FULL WAVEGUIDE	10 % OF f_0
SIZE & WEIGHT	—	✓
RELIABILITY	—	✓
ENERGIZING POWER	PULSE ONLY-NEGLIGIBLE	SUSTAINED BIAS-1.5 W/DIODE
COST	—	✓

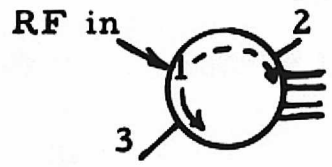
RECOMMENDED DESIGN APPROACH
INTEGRAL SYSTEM INCORPORATING SOLID-STATE SWITCHES IN TRANSMISSION LINES

In the configuration of Figure 8-8 the total insertion loss for all four diodes is about 0.15 db at 2.5 GHz including the power supplied to forward bias two of the diodes. Considering the bandwidth of operation and miscellaneous waveguide losses the loss of the switch is calculated as 0.75 db.

Peak power in a TV signal is approximately equal to 3 Prms. Based on a VSWR of 1.5 and an rms power level of 1.35 KW, voltage peaks at the reverse biased diodes would be E peak = $\sqrt{(1350)\ (3)\ (5)}$ x 1.5 volts = 670 volts which is well within the PIV rating of the UM 4910 diode.

b. Latching Wave Guide Circulators

The ferrite latching circulator is basically a non-reciprocal latching SPDT switch that transmits microwave energy with low loss between points in the direction of the solid arrow for one switch state and in the direction of the dotted arrow for the other switch state.



D.C. Power &
Trigger Terminals

To switch the circulator a trigger pulse is applied to one of two input terminals. The circulator is also connected to a DC power supply capable of providing the average power drain required for the desired number of switching operations per second. This type of device requires no holding power - it latches into the state to which it is switched and remains there with zero power drain until it is switched to the other state.

Characteristics of a commercially available X-band unit are:

Frequency range	8 - 12.4 GHz
Bandwidth (%)	15
Isolation (min.)	20 db
Insertion loss (max)	.3 db
VSWR (max)	1.25
RF Switching time (nominal)	1 μ sec
Switching events per sec. (max)	20,000
Approximate switching energy	200 μ joules
Size (L x W x H inches)	2.5 x 2.5 x 2

other units with similar characteristics are presently available throughout the microwave spectrum. (Reference 8-12)

8.3.6 RECOMMENDED DESIGN APPROACH - A preliminary design of a complete subsystem including transmission lines, filters, isolators, multiplexers, switches, bias supplies, fault detection and control devices should be considered. Ferrite latching circulators appear to be the optimum device for the switching application due to their low insertion loss and zero power drain in the latched position. The ultimate power limitations of the ferrite switch has not been determined, thus the PIN diode could be competitive at the higher power levels. The ferrite switch would tend to be a more reliable unit than the mechanical switch since the switching action is all electronic in nature.

8.4 ANTENNA TECHNOLOGY

8.4.1

ANTENNA CONSIDERATIONS. The broadcast satellite transmitting antenna can be divided into two categories: small antennas which can be launched in operating position; and large antennas which due to shroud limitations must be folded for launch and then deployed in space. An antenna diameter of approximately 10 feet divides the two classes. A variety of small antennas have been used in space and pose no major technological problems for the broadcast satellite.

Large Antennas - Space erectable antennas to diameters of approximately 40 feet can be packaged in a petal or flexible rib configuration. Antennas of this type have been considered and a selection made for launch on the ATS-F technology satellite in the early 1970's.

A prototype 10-foot diameter petal-type spacecraft antenna has been fabricated and tested. An antenna of this type was used in the Apollo mission.

Extremely large antennas can be fabricated using the deep truss concept with hinged tubular struts that has been developed by General Dynamics Convair Aerospace for NASA/MSFC. Conceptual designs have been completed for diameters of 140 feet. Units have been fabricated and tested in sizes of 6, 10, and 15 feet. Figure 8-9 is the 15-foot erectable antenna that was built for NASA-Goddard under contract NAS 5-21133. The RF reflective surface is a lightweight flexible mesh which is supported and its shape defined by a subsystem of tension lines located immediately behind the mesh. Typical measured aperture efficiency at 8 GHz was 50% with simple waveguide feed.

The deployable truss parabola affords excellent packaging characteristics, structural rigidity, resistance to thermal distortion, and high natural frequency that is necessary for compatibility with attitude control systems of satellites. Figures 8-10 through 8-13 show antenna packaging parameters, weight as a function of size, thermal characteristics, and RF performance characteristics of the truss antenna.

Beam Shaping - The high powers associated with the broadcast satellite make it desirable to keep the power radiated outside the area of interest to a minimum. This can be done by suppressing the side lobes adjacent to the main beam as low as possible. The results of a NASA/LeRC program to suppress the side lobes has shown that levels of -40 db below the main lobe power level out to angles of 15 degrees are possible.

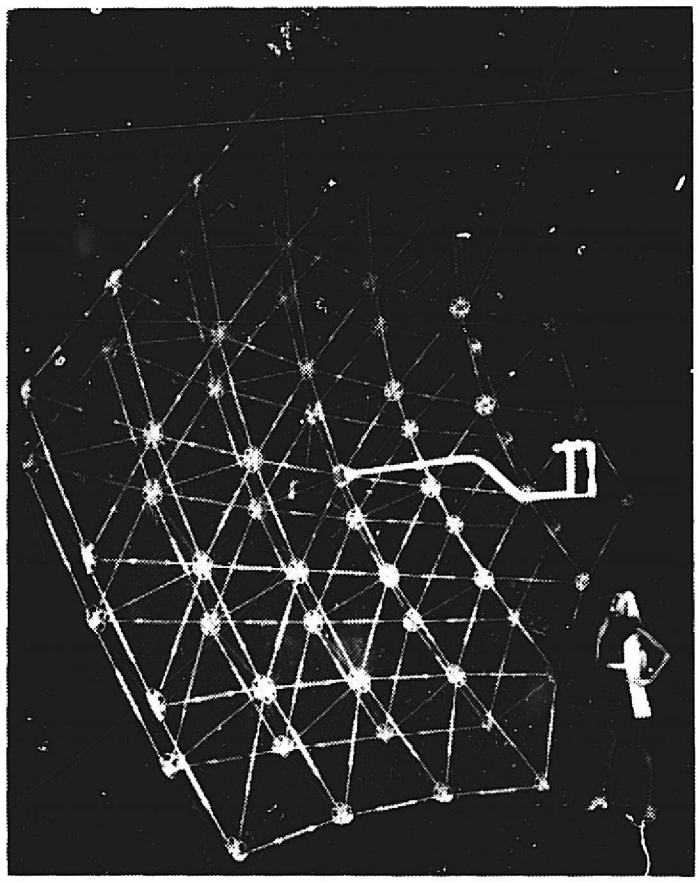


Figure 8-9. 15 Foot Erectable Truss Antenna

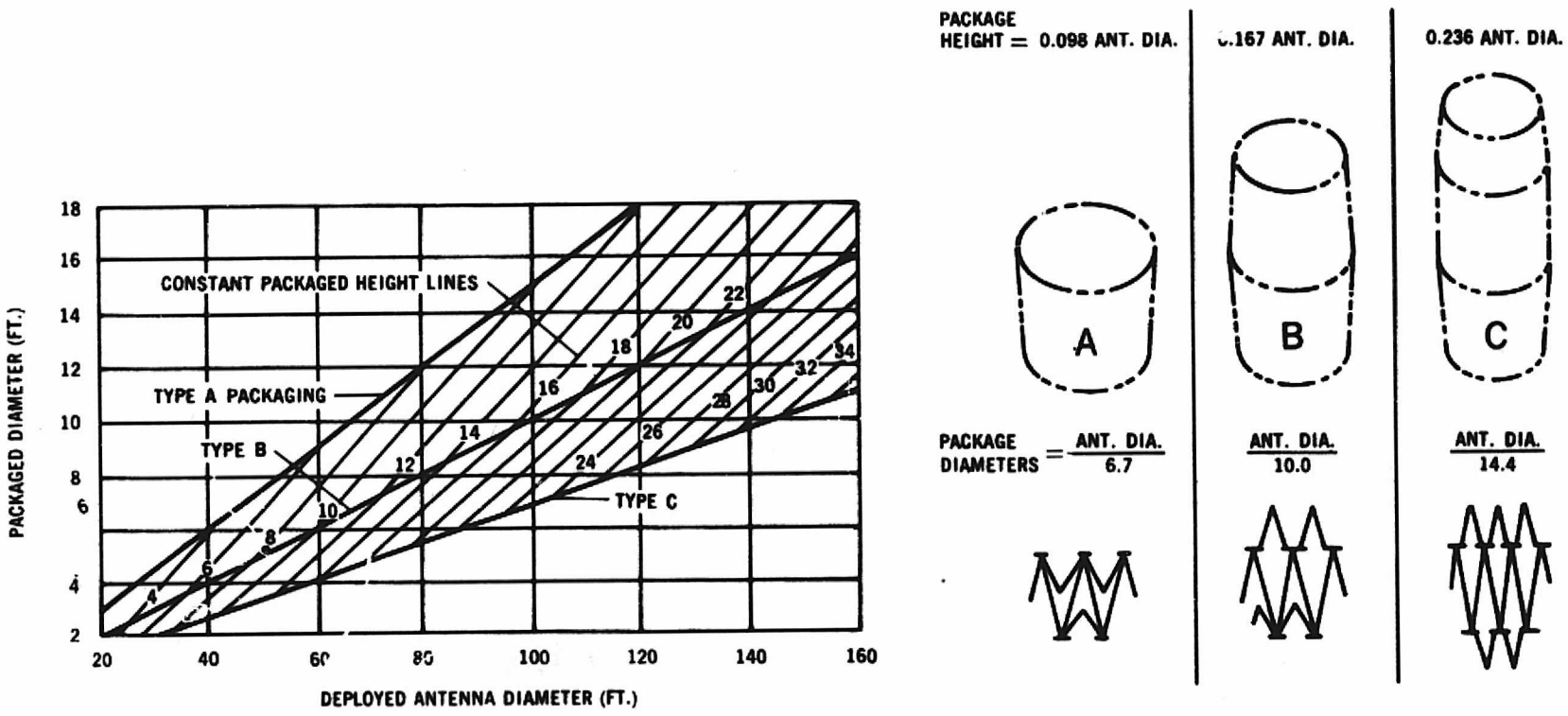


Figure 8-10. Antenna Packaging Parameters

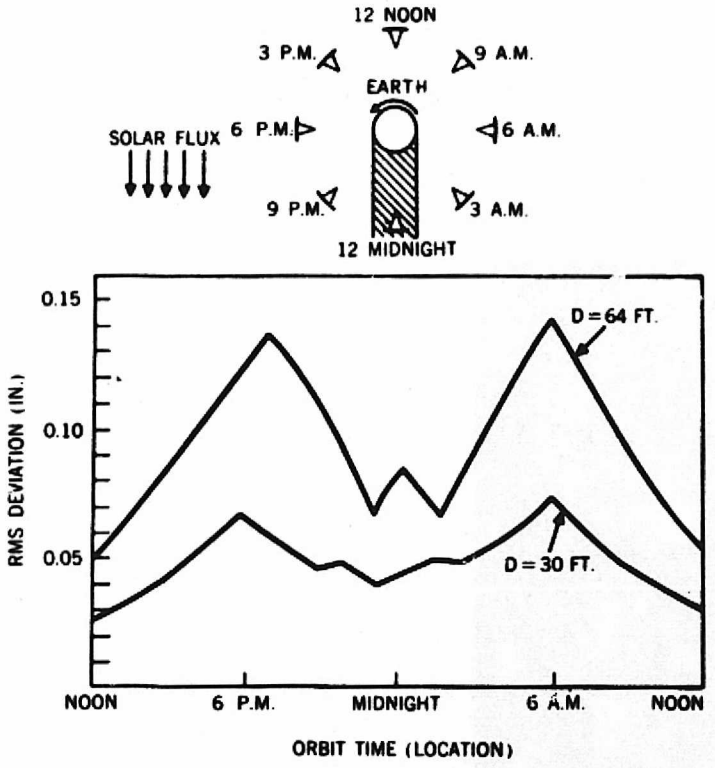


Figure 8-11. Total Reflector RMS Deviation for 30- and 64-Ft., 8-Bay Titanium Antennas in Synchronous Orbit

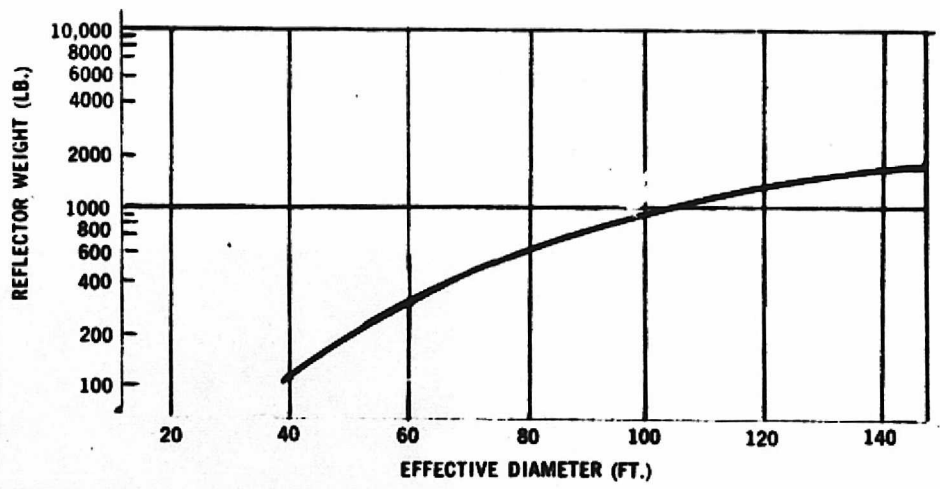


Figure 8-12. Weight as a Function Of Size

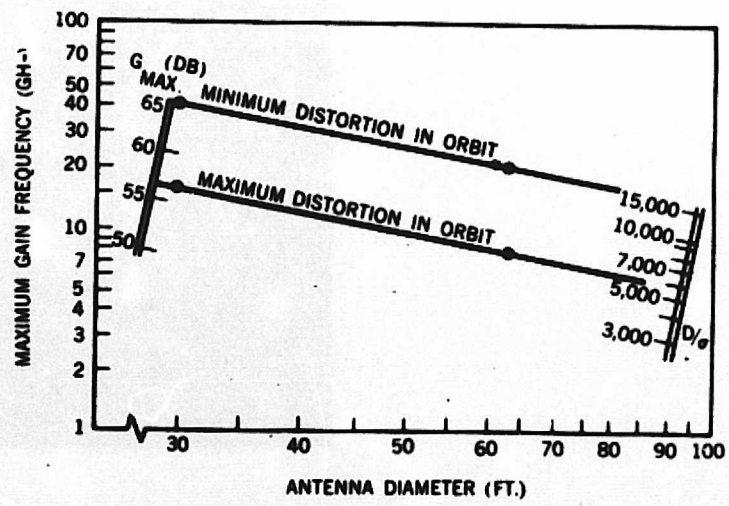


Figure 8-13. Maximum Gain and Maximum Usable Frequency Capability of the Truss Antenna in Synchronous Orbit

Side lobe supression by heavy taper and increasing antenna size results in decrease in antenna efficiency and some increase in half power beamwidth. This characteristic results when the first null is held constant. Figure 8-14 illustrates the secondary beam characteristics when these sidelobe supression techniques are employed. Side lobe levels are also affected by RMS surface error and operative blockage, therefore stringent control on surface tolerance and minimization of feed and feed support blockage within the antenna operature is required.

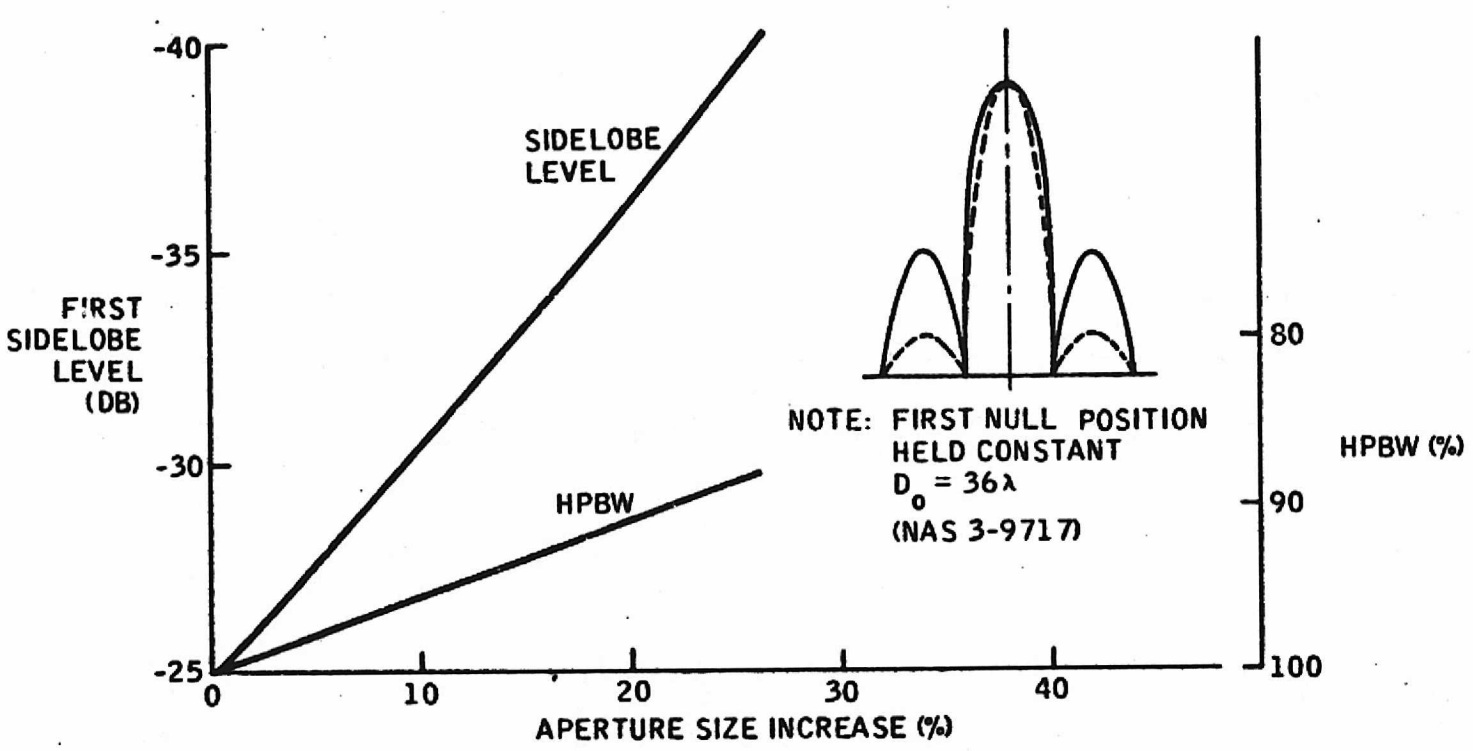


Figure 8-14. Sidelobe Suppression by Heavy Taper and Increasing Antenna Size

Antenna Beam Pointing Figure 8-15 shows the reduction of gain at the 3 db beam edge caused by pointing errors (expressed as a fraction of the half power beam width) for different aperture illuminations.

The pointing accuracy depends on the satellite structural flexibility. For small, rigid satellites the accruacy is limited by sensor performance. The capabilities of typical attitude sensors are shown in Table 8-5. It is anticipated that in 1975 an accuracy better than 0.2 degrees can be attained for the large structure satellites.

Summary of Transmitting Antenna Gain Limits

The gain limits set for 1975 may be summerized as follows:

At low frequencies a gain limit is set by the maximum antenna size.

At higher frequencies the gain limit is set by beam pointing accuracies. These are .05 degrees for antennas less than 10 feet diameter and .2 degrees for a 30 foot diameter antenna.

Beam steering by scanning the primary illumination pattern in a parabolic antenna can be achieved with resulting loss in efficiency, increase in side lobe levels, and gain loss. Figure 8-16 shows results of scanning via off axis feed positioning.

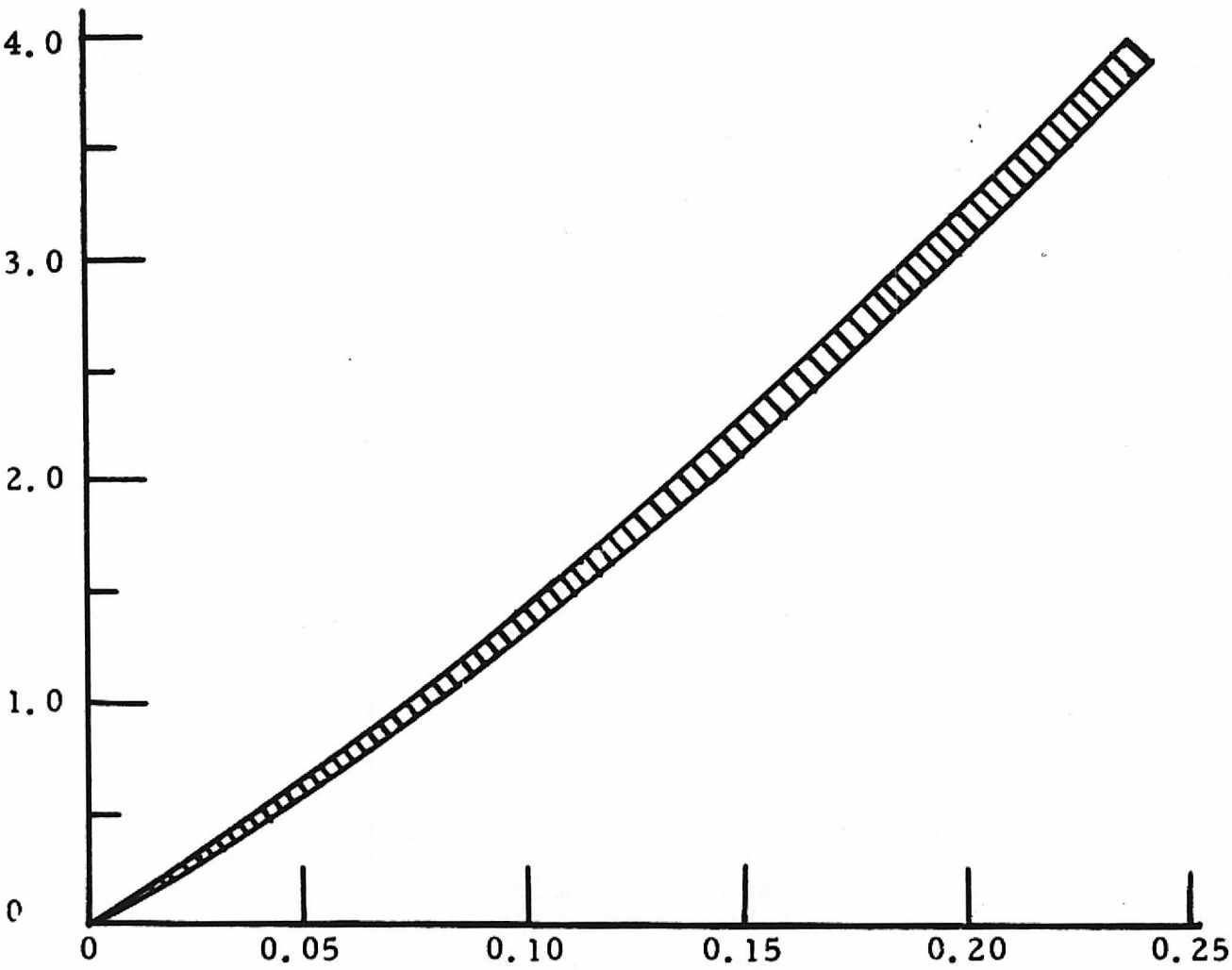


Figure 8-15. Degradation of Beam Edge Power Level as a Function of Pointing Error

Table 8-5. Attitude Accuracies of Spacecraft Sensors

Sensor	Accuracy	Remarks
Earth-Horizon	0.1° - 1°	Many Satellite Applications
Sun	0.1°	Many Satellite Applications
Star	.01°	Used in OAO (1968)
Interferometer	.03°	Will be used on ATS-F
Monopulse	0.1°	Will be used on ATS-F

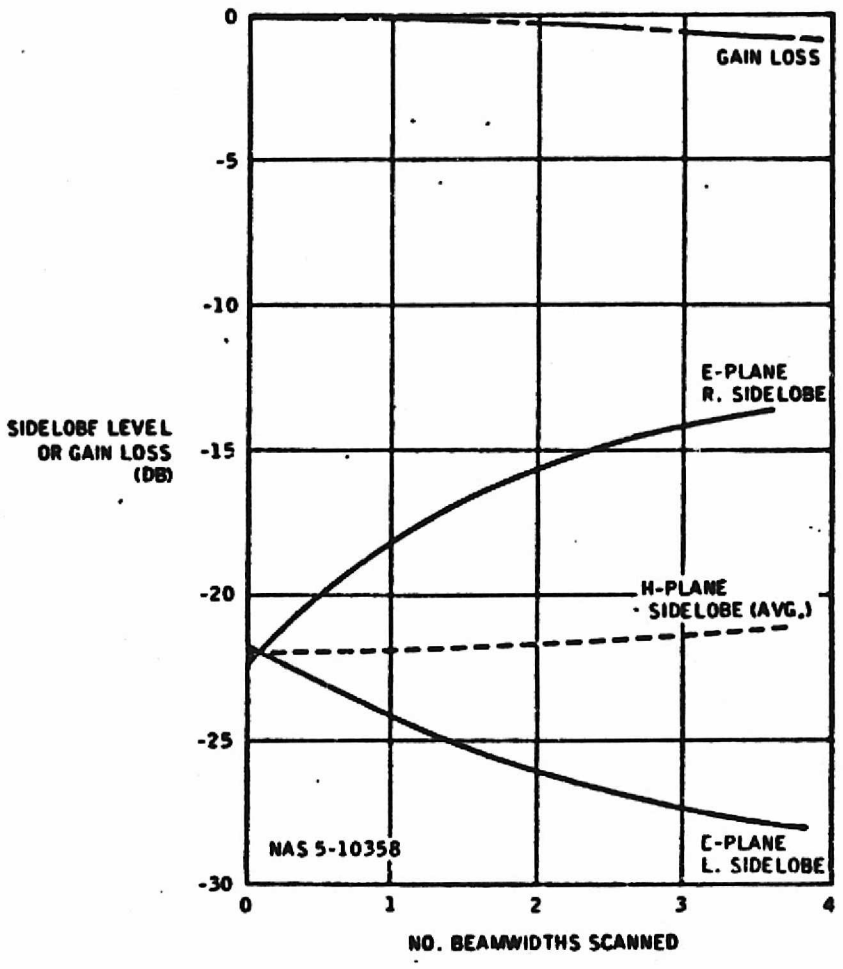


Figure 8-16. Measured Values of Gain Loss and Sidelobe Level vs. Off-Axis Feed Position

Electronically Steerable Array - Steerable arrays are far more complicated and heavier than conventional multiple aperture antennas. Since very large spacecraft (within limitations of current boosters) are feasible, steerable array configurations need to be re-appraised because weight of the antenna may be less decisive.

The use of rapid, intertialess, beam pointing is not required when broadcasting from geo-stationary satellites. Steerable arrays can be justified when multiple or shared apertures become more attractive than a single aperture. At lower frequencies, apertures having high gain are so large that an electronically steerable array becomes more applicable. In addition, distribution of

transmitter power over many modules reduces requirement of a single point requirement for RF power and termal loads. Results of the reduction in high power concentration at a single point is an increase in life and reliability of associated components. An array also provides redundancy in its basic design. Problem areas associated with steerable array is phase tracking between signals and associated pilots and the need for lower side lobe to reduce interference.

Typical array configurations are shown in Table 8-6.

Table 8-6. Typical Array Configurations

HUGHES

SCANWIDTH / BEAMWIDTH	NO. OF ELEMENTS	ELEMENT GAIN MIN.	ARRAY GAIN MIN.	WORST SL
$16^0/4^0$ *4	32	12 DB	27 DB	<-15 DB ESTIMATED
$15^0/3^0$ *5	32	15	30	<-15 DB ESTIMATED
*$30^0/3^0$ * 10	64	12	30	-15 DB MEASURED
$16^0/2^0$ * 8	64	15	33	<-15 DB ESTIMATED

* REFERENCE:
KUMMER & BIRGENHEIER, PROC. IEEE, NOV. '68.

Figure 8-17 illustrates a possible version of an electronically steerable array with elements of backfire dielectric rods for x-band, and short-back fire elements for UHF (Reference 8-14, 8-15, 8-16). Array diameter will depend on the allowable side lobe level. Table 8-7 is weight and volume breakdown for the array.

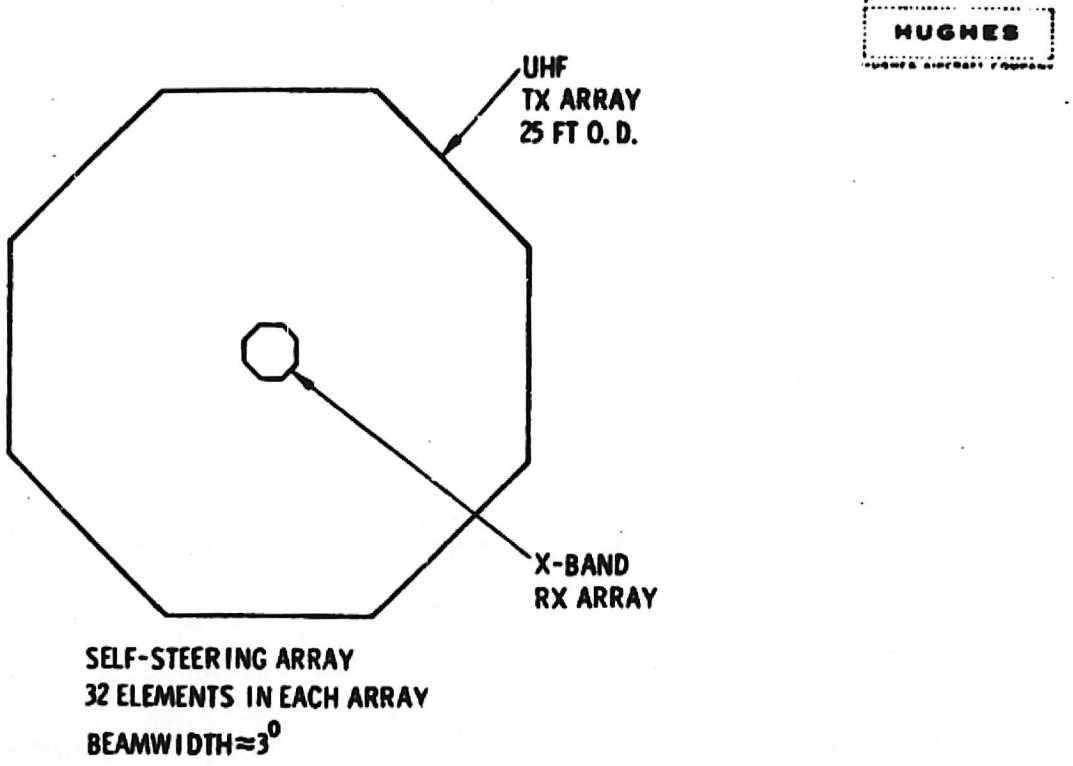


Figure 8-17. Multi-Beam Satellite - A Possible Concept

Table 8-7. Estimated Weight and Volume Breakdown For Self-Steering Array

ASSUMPTIONS IN THIS CASE:

2 channels
32 elements
Total r-f power = 3.2 kw

		Transmitt at 800 MHz (concentric with X-band receive array)	Transmitt at 12 GHz (side-by-side with X-band receive array)
Radiating Element, TRANSMIT Array, incl. pro-rated ground plane and structure	type	short-backfire element	backfire dielectric rod
	length	8 inches	4 inches
	weight	0.6 lbs	0.2 lbs
Radiating Element RECEIVE Array, incl. pro-rated ground plane and structure (X-band in both cases)	weight	0.2 lbs	0.2 lbs
Receiver, per element, less pwr amplifier (1 for 2 channels)	weight	2.5 lbs	2.5 lbs
	volume	4x2x12 = 96 in^3	
Transmit Power Amplifier, per element, type		transistor matrix	TWTA
Transmit P.A., per element (1 ea. at 100w/element/channel) i.e., 2 for 2 channels, including driver ampls	weight	2x10 = 20 lbs	2x3 = 6 lbs
	volume	(2x100 in^3)	(2x125 in^3)
P.C. and protective cktry associated with each P.A. element	type	low-V DC regulator	hi-V DC-DC converter
	weight	2x8 = 16 lbs	2x15 = 30 lbs
	volume	(2x50 in^3)	(2x200 in^3)
Total Weight/Element (w/2 channels)		39 lbs	39 lbs
Total Weight for 32-element array (w/2 channels)		1250 lbs	1250 lbs

8.4.2 COVERAGE AREA

As noted in Figure 8-18, the smaller the area of coverage to which a broadcast is to be directed, the greater the satellite antenna gain required (Reference 8-17). Thus, for smaller coverage areas less transmitter power is required to provide a given power density or signal strength on the ground. Therefore, assuming a satellite antenna size limitation has not been reached, minimum coverage should be provided in order to minimize the satellite primary power requirements.

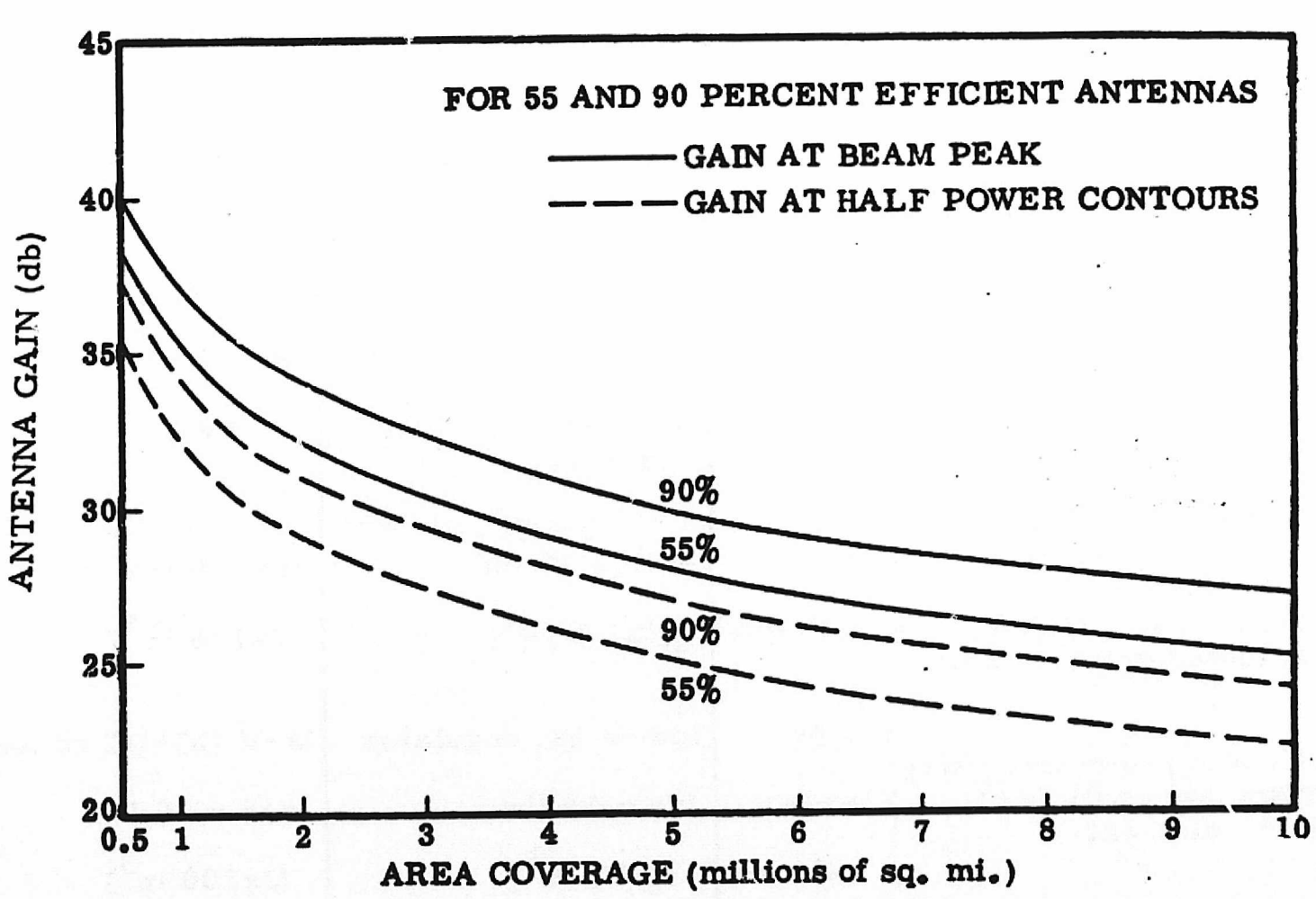


Figure 8-18. Antenna Gain Assoicated with Area Coverage Requirements

Figure 8-19 illustrates the increased coverage obtainable from a synchronous-orbit satellite for a given beamwidth as the elevation (or azimuth) look angle is varied (Reference 8-18). Atmospheric variation in path attenuation is also illustrated in the graph. It may be observed that optimal location of the satellite can permit halving the beamwidth thus permitting an antenna gain increase of 6 db.

8.4.3 EFFECTIVE RADIATED POWER CONSTRAINTS FOR THE SYNCHRONOUS ORBIT CASE PER CCIR RECOMMENDATION 358-1

The flux density produced at the surface of the earth by emission from a satellite is given by

$$P = \frac{G_t P_t}{4\pi R^2} = \frac{ERP}{4\pi R^2}$$

where

G_t = satellite antenna gain

P_t = satellite transmitter output power

R = 35,700 km (synchronous orbit to subsatellite point)

P = power density

ERP = effective radiated power = $G_t P_t$

In db,

$$P\left(\frac{dbw}{m^2}\right) = ERP\ (dbw) - 162.$$

According to Recommendation 358-1 (Oslo, 1966) the maximum flux density produced at the surface of earth by emissions from a space station for all conditions and methods of modulation shall not exceed

$$\left(-152 + \frac{\theta}{15}\right)\ dbw/m^2/4\ kHz\ band$$

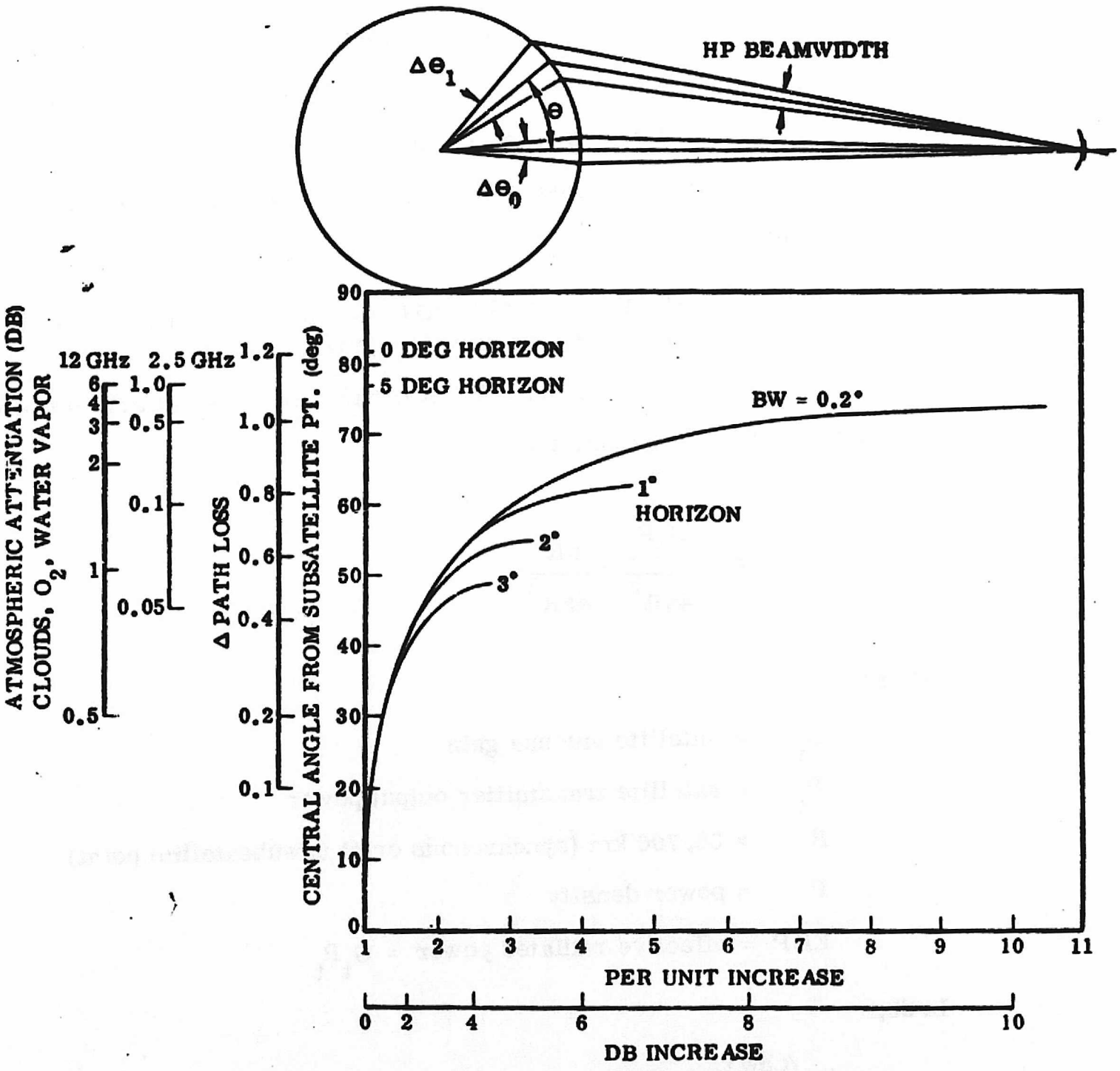


Figure 8-19. Satellite Coverage Parameters

where θ is the angle of arrival of the wave in degrees above the horizon. Equating (2-2) and (2-3) gives, for the synchronous orbit case,

$$\text{ERP (dbw)}\Big|_{max} = \left[162 + \left(-152 + \frac{\theta}{15}\right)\right]\text{(dbw)} + BW_r$$

where

BW_r = ratio of operating bandwidth to 4 kHz in db

$$\text{ERP (dbw)}\Big|_{max} = 10 + \frac{\theta}{15} + 10 \log_{10} \frac{BW}{4\ \text{kHz}}$$

For example,

if $BW = 6$ MHz
and $\theta = 45^\circ$

$$\text{ERP}\Big|_{max} = 10 + 3 + 10 \log_{10} (1.5)\,(10^3) = 44.8 \text{ dbw.}$$

Therefore, according to Recommendation 358-1, the maximum ERP that may be considered, where the frequency allocations are shared between satellite and terrestrial systems, is 44.8 dbw over the frequency range extending from 1 to 10 GHz for 6 MHz AM VSB systems with the bandwidth and angle specified above.

8.5 POWER SYSTEM

As projected power requirements have increased a review of space power system is in order. Most of the systems (with the exception of solar cells, batteries, and fuel cells) operate on thermodynamic cycles or temperature differentials. The application regimes for typical space power systems is shown in Figure 8-20. From this figure it can be seen that, for mission life-times in excess of one year, solar cell, isotope and reactor systems are applicable. A comparison of these three power sources are tabulated in Table 8-8.

The technology of solar cell systems is well in hand, primarily because of their continued use throughout the domestic and foreign space programs. Table 8-9 summarizes the current state of the art in silicon solar cells with some projections for 1975 and 1980. Study programs of high-power arrays have been conducted by Hughes, Boeing (50 kw) and others. A 1.5 kw version of a rollout array will flown in late 1970. The data obtained from the flight would enable the verification and up grading of the existing dynamic computations allowing the design and fabrication of an optimized, reliable 12 kw (10 kw at the end of 5 years) rollout array for a 1975 satellite. Other types of solar cells -- thin film cadmium-sulphide, lithium-doped silicon, cascade, polycrystalline, etc. -- are being evaluated. Their main dificiencies lie in decreased efficiency and increased cost. Their acceptablility over the basic silicon cells is questionable.

Isotope thermoelectric generator (RTG) systems have been well-researched and several low-powered systems have been developed and flown. Table 8-10 summarizes the status of radioisotope thermoelectric generator. While their applicability up to 10 kw can be shown, no significant accomplishments have been achieved above 100 watts, with the possible exception of SNAP 29 now under development at 500 watts. Typical isotope characteristics are shown in Table 8-11. Availability of adequate quantities, cost, and radiation shielding requirements are their main problems, which are further aggravated by personnel hazards during ground handling and international agreements requiring safe abort and re-entry fuel package designs.

Nuclear reactor systems offer the greatest potential in terms of gross power capability. SNAP 10 A, flown in April 1965, demonstrated a reactor/thermo-electric 500-watt system SNAP 8, a reactor/Rankine system is under

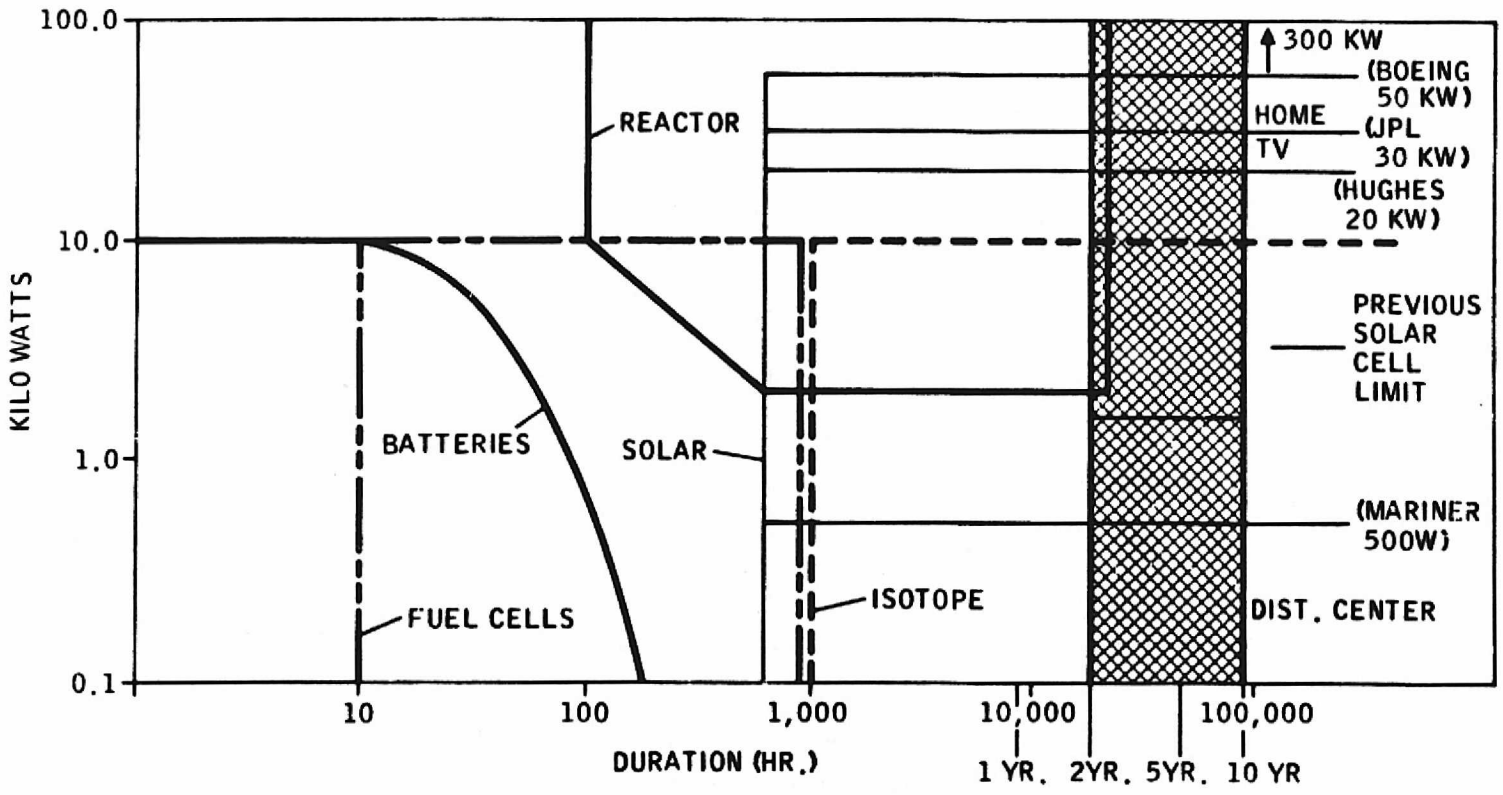


Figure 8-20. Power System Application

Table 8-8. Electrical Power Subsystem Power Source

POWER SOURCE	MAIN ADVANTAGES	MAIN DISADVANTAGES
1. SOLAR CELL ARRAY	1. STATIC SYSTEM. 2. STRONG TECHNOLOGY BASE. 3. ADAPTABLE TO A WIDE VARIETY OF CONFIGURATIONS. 4. LONG LIFE	1. SENSITIVITY TO SPACE ENVIRONMENT 2. NONOPERATIVE IN ORBITAL DARK PERIODS. 3. ASSEMBLY FROM LARGE NUMBER OF SMALL COMPONENTS. 4. FLEXIBILITY, DEPLOYMENT & ORIENTATION
2. NUCLEAR REACTOR	1. SEMI-STATIC SYSTEM 2. SNAP-2, -10A, -8 & SPUR-50 DEVELOPMENT PROGRAMS IN PROGRESS. 3. COMPACT SYSTEM.	1. LIMITED LIFE. 2. HEAVY SHIELDING REQUIREMENTS. 3. LOW EFFICIENCY.
3. RADIOISOTOPE THERMOELECTRIC GENERATOR	1. LONG LIFE 2. SEMI-STATIC OR STATIC SYSTEM. 3. COMPACT SYSTEM	1. SAFETY-RADIATION HAZARDS. 2. TECHNOLOGY BASE INADEQUATE AT POWER RANGE OF INTEREST. 3. ISOTOPE AVAILABILITY -QUANTITY & COST.

Table 8-9. Electrical Power Subsystem
Radioisotope Thermoelectric Generators

SNAP	POWER (W)	USE	FUEL	DESIGN LIFE (YR.)	STATUS
3	2.7	DOD NAVIGATION SATELLITE	Pu^{238}	5	IN ORBIT
9A	25	DOD NAVIGATION SATELLITE	Pu^{238}	5	IN ORBIT
11	25	SURVEYOR	Cu^{242}	0.25	TESTED
13	12.5	THERMIONIC DEMONSTRATION	Cu^{242}	0.25	TESTED
19	30	NIMBUS B	Pu^{238}	5	UNDER DEVELOPMENT
27	50	APOLLO LUNAR SURFACE EXPERIMENT PACKAGE	Pu^{238}	1	UNDER DEVELOPMENT
29	500	DOD APPLICATION	Po^{210}	0.25	UNDER DEVELOPMENT

Table 8-10. Electrical Power Subsystem
Solar Cell Arrays

PARAMETER	1970	1975	1980
SIZE/TYPE	2 x 2 CM N/P SILICON*	2 x 6 CM N/P SILICON	4 x 6 CM N/P SILICON
THICKNESS	8 TO 12 MILS	6 TO 8 MILS	4 MILS
CONTACTS	WRAP-AROUND	WRAP-AROUND	WRAP-AROUND
POWER/CELL	72.8 mW	225 mW	450 mW
EFFICIENCY	13%	12%	12%
COVERGLASS THICKNESS	4 MILS (MIN.)	6 MILS (MIN.)	6 MILS (MIN.)
AREA - THEORETICAL	13 TO 15 W/SQ.FT.	15 TO 20 W/SQ.FT.	15 TO 20 W/SQ.FT.
AREA - PRACTICAL	10.3 W/SQ.FT.	15 W/SQ.FT.	16 W/SQ.FT.
WEIGHT**	48 W/LB.	55 W/LB.	60 W/LB.

* 2x6 cm & 4x4 cm cells may develop sufficient usage to be available in large quantities at competitive prices.

** Not including substrate/structures

Table 8-11. Isotope Characteristics

ISOTOPE	HALF-LIFE (YR.)	1970 AVAILABILITY KWt/YR.	KWe/YR.	1970 COST ($/WATT)	RADIATION PRESENT	SHIELDING
Sr^{90}	27.7	170	13	19	β, Brem.	Heavy
$Cs\text{-}Ba^{135}$	30.0	140	10	21	β, γ	Heavy
Pu^{238}	87.6	50	4	535	η	Light
CM^{244}	18.4	50	4	480	α, neutron	Moderate
Co^{60}	5.24	100	8	10	β	Heavy

development at 30 kw. A growth potential for this system is projected to 300 kw. The main problems associated with these systems are limited lifetime due to generation of helium in the fuel casings, heavy shielding requirements, and development requirements in conversion equipment.

Approach to the problem of power transfer is presented in Figure 8-21. No immediate solution to this problem is available, but the contactless transfer method preferred because of simiplicity and flexibility.

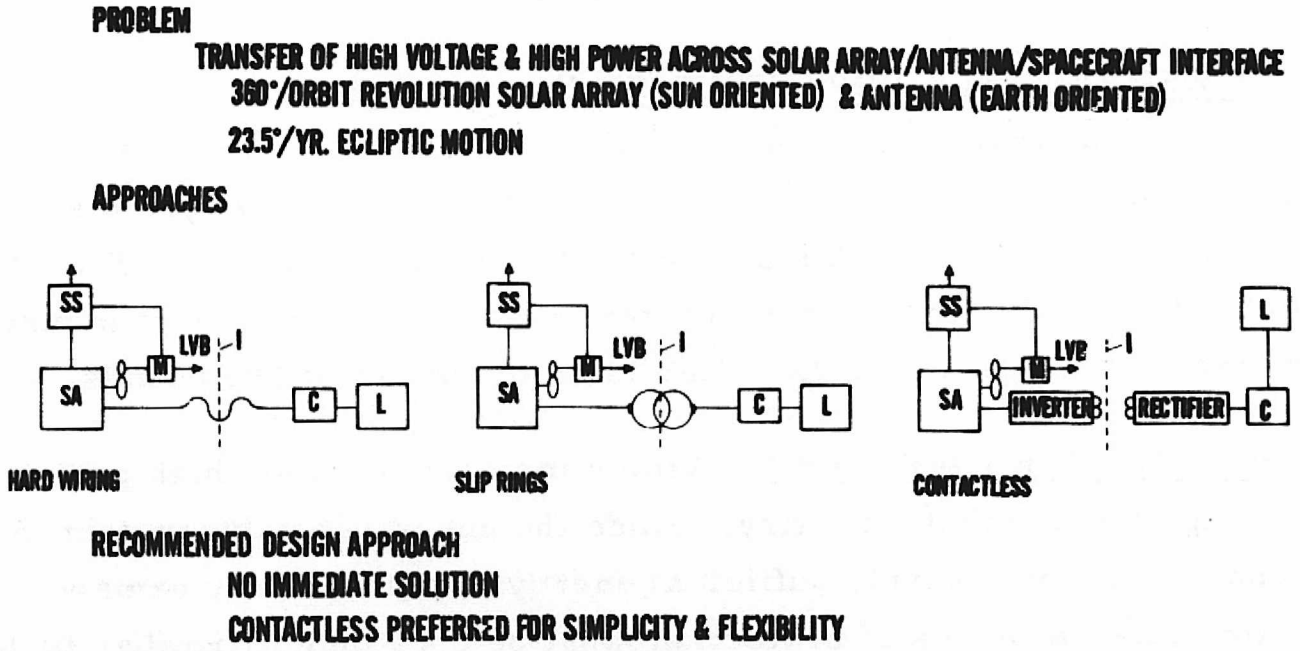


Figure 8-21. Power Transfer

8.5.1 POWER CONDITIONING. High voltages with adequate regulation must be provided to operate tubes such as those listed in Tables 8-2 and 8-3. The power conditioner must convert prime power, obtained from solar panels, batteries, or nuclear sources, to the proper levels. Storage at high efficiency, low ripple, high voltage breakdown, and excess heat dissipation are factors that must be considered in designing a spaceborne power supply.

Satellites presently in space using solid state transmitter modules have efficient low voltage power conditioning. The extension of these power conditioning units to higher power solid state modules appear feasible within present state-of-art.

Present power conditioning used in communication satellites having microwave tubes have outputs of 3.5 KV at power levels of less than 100 watts.

Broadcast satellites having microwave tubes will demand power at voltages as high as 15 KV at levels as high as 10 KW.

The projected high voltage, high power, power conditioning subsystems will take advantage of techniques currently being used in ion engine thruster power supplies for space applications. There are, at present, two such programs, one of which is for the SERT II satellite to be launched in late 1969. Extension of the approaches of these systems to higher voltages and higher power will assure power conditioning capable of fulfilling the requirements of the tubes that will be available for use in 1975.

8.5.2 POWER CONDITIONING EFFICIENCY. Table 8-12 is a summary of data from various sources on power conditioning efficiency (Reference 3-10). Energy storage must be provided from AM-VSB transmitting systems. LC filters may be employed for this purpose. For high power AM-VSB systems the weight of such a filter becomes appreciable; for a 10 kW average power transmitter, the weight of the LC filter is on the order of 700 pounds.

8.5.3 PROTECTIVE CIRCUITRY. Arcing may occur within high power tubes or in the high level output circuitry. Since the energy storage system in the power conditioner may supply sufficient energy to permanently damage a transmitter tube, a means of protection must be provided. Crowbar techniques are generally used for this purpose in conjunction with radar transmitters. Similar techniques may be used for spaceborne systems.

The electronic crowbar circuit protects the microwave tube by sensing the occurrence of an arc or high VSWR level. Within a few microseconds an electronic short circuit is placed across the power supply output. The power supply should be designed to de-energize upon crowbar initiation and should also be capable of withstanding a shorted load.

8.5.4 THERMAL DISSIPATION. Cooling of the RF power amplifier is difficult because of the high heat density typical of devices such as TWT's and klystrons. Heat pipes may be used to remove heat from a high density source and transfer this energy to a radiating surface.

In design of a radiation heat transfer system, the basic tradeoff encountered is that of determining the radiating surface temperature and surface area.

Table 8-12. Power Conditioning Efficiency Data Summary

DESIGN APPROACH	EFFICIENCY (PERCENT)	DATA SOURCE	COMMENTS
SCR Morgan type Pre-reg. (90) followed by DC-DC converter (90)	81	Hughes Air-borne/missile electronics technology	13 KV $\pm$ 1% at 1.65 amps
Transformer-Rectifier(98) followed by Vacuum-Tube switching regulator (98)	96	Hughes air-borne/missile electronics technology	13 KV $\pm$ 1% at 1.65 amps
SCR DC-DC Converter (90) followed by vacuum-tube switching	88	Hughes/air-borne/missile electronics technology	13 KV $\pm$ 1% at 1.65 amps
Transistor Inverters with pulse width modulated regulation	93	Hughes Ion Engine Technology	2 KV $\pm$ 1% at 1.0 amps, 8 inverters in series. (Efficiency applicable up to 2 KW/module)
Unknown	85 to 90	G.E.	Up to 5 KW total power
Unknown	80 to 83	G.E.	Above 5 KW total power

Numbers in parenthesis are efficiencies of devices in tandem.

Solid state devices such as transistors require low operating temperatures, on the order of 370°K, while amplifying devices such as gridded tubes and klystrons can operate at temperatures on the order of 470° to 500°K.

Heat pipes using water or organic fluids operate at low temperatures and require large radiating surfaces while liquid-metal heat pipes, operating at higher temperatures, require less radiator area. Low temperature operation is desirable from the standpoint of amplifying device reliability; however, the temperature must be selected by tradeoff between satellite size and weight.

Radiators provide the only practical means of dissipating excess heat in a spacecraft over a long time span. The maximum allowable size of the radiator determines the operating temperature of the high-power transmitting device.

The heat pipe is an active thermodynamic system involving the state-change of such fluids as sodium, potassium, or cesium. The fluid medium is circulated by capillary wicking. No external pumps or valves are required, so the life and reliability of the heat pipe is close to that of a passive radiator system. A significant problem with the heat pipe is that of incorporating it into the basic amplifier tube.

Heat pipes have operated from +200°C to +2000°C and can transport as much as 25 kw per inch square of heat flux. Two types of heat transfer devices have been devised which utilizes the effect of vapor heat transfer and capillary action. These are the "Transport" and the "Constant Temperature" type. (Reference 8-19).

The "transport" type is made up of a containment vessel made of copper, nickel, or stainless steel, and a porous wick structure made of wire mesh (copper or nickel) that line the vessel. A liquid of either water or methanol saturates the wick. At the one end of the heat pipe the liquid is vaporized and the the vapor propagates to the condenser section of the pipe where condensation of vapor and heat conduction out of the pipe is achieved. This action is derived from attractive forces between liquid and vessel in combination with surface tension.

The "Constant Temperature" type differs from the "Transport" type by utilization of a reservoir of non-condensable gas within the heat pipe such that a two section condenser results. This design results in temperature leveling. A typical version of this technology for thermal control of a spacecraft would be to form a ring which internally contains a heat pipe and attaching the condenser to a radiator that is mounted external to the satellite. An application of this technology is the system used to cool an electronic deck on Advance Technology Satellite implemented by McDonnell Douglas' Donald W. Douglas Laboratory in Richmond, Washington.

An evaluation of various liquid coolants, vessel and wick material has been consolidated by K. T. Feldman of Energy Conversion Systems. A tabulation summarizing operating values of heat pipes is shown in Table 8-13.

In the analytical design of high power tubes thermal temperature control devices (heat sinks and heat pipes) are internally designed into the tube or where design allow, the tubes are attached directly to thermally conductive heat sinks. Radiators are left out since its design consideration would be influenced by the associated spacecraft and equipment.

8.6 GROUND RECEIVING STATION CAPABILITY AND FREQUENCY OF TRANSMISSION

In direct-to-home broadcasting the minimum effective radiated power (ERP) required from a broadcast satellite is constrained by cost considerations. ERP levels on the order of 70 to 90 dbw are required for transmission to unaugmented receivers with indoor antennas. Use of an outdoor antenna and incorporation of a modulation converter reduces the ERP requirement to a range of 30 to 70 dbw.

8.6.1 RECEIVER CONFIGURATIONS. Several basic receiver configurations that must be considered for use in conjunction with a satellite broadcast transmitter are as follows:

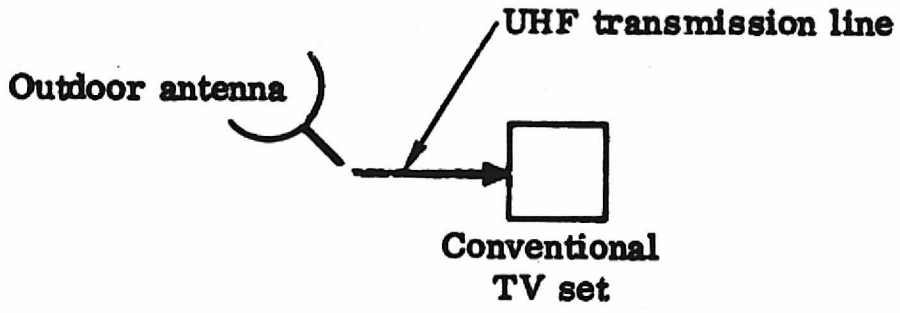
a. The satellite transmission frequency is in the UHF TV band and conventional AM-VSB format is used.

Table 8-13. Operating Values of Heat Pipes

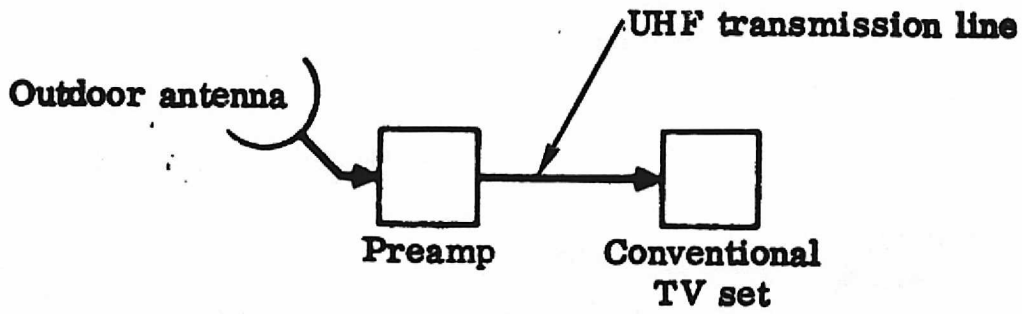
Temperature Range in °C	Working Fluid	Vessel Material	Measured Axial[1] Heat Flux in Kilowatts/ square inch	Measured Surface[1] Heat Flux in watts/square inch
-200 to -80	liquid nitrogen	stainless steel	0.431 @ -163°C	6.5 @ -163°C
-70 to +60	liquid ammonia	nickel, aluminum, stainless steel	1.9	19
-45 to +120	methanol	copper, nickel, stainless steel	2.9 @ 100°C[3]	487 @ 100°C
+5 to +230	water	copper, nickel	4.3 @ 200°C	942 @ 170°C
+190 to +550	mercury[2] +.02% magnesium +.001% tantalum	stainless steel	162 @ 360°C[4]	1,170 @ 360°C
+400 to +800	potassium[2]	nickel, stainless steel	36 @ 750°C	1,170 @ 750°C
+500 to +900	sodium[2]	nickel, stainless steel	60 @ 850°C	1,443 @ 760°C
+900 to +1,500	lithium[2]	niobium 1% zirconium	13 @ 1,250°C	1,334 @ 1,250°C
1,500 to +2,000	silver[2]	tantalum 5% tungsten	26	2,665

[1] Varies with temperature
[2] Tested at Los Almos Scientific Laboratory
[3] Using threaded artery wick
[4] Measured value based on reaching the sonic limit of mercury in the heat pipe

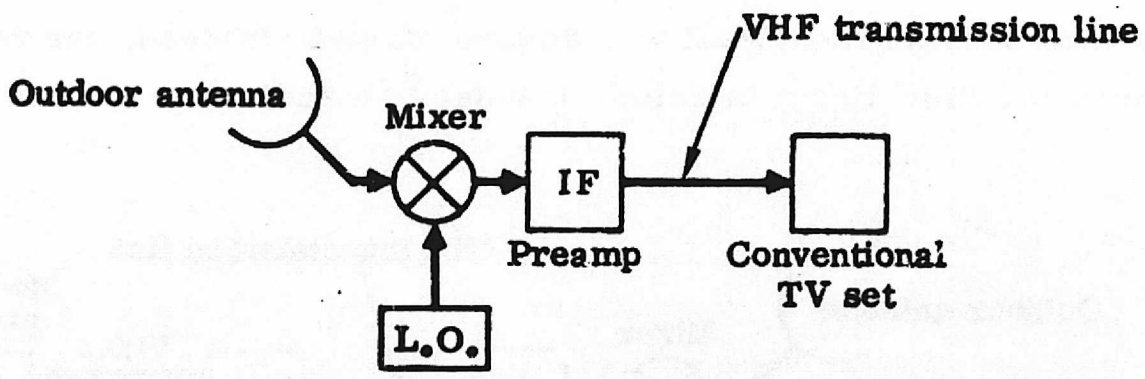
(a. configuration)



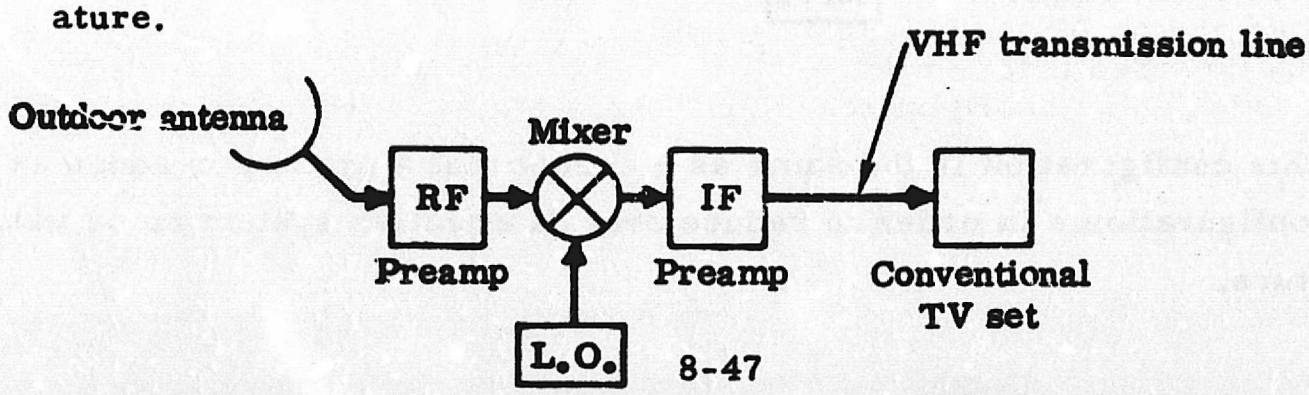
b. This configuration is the same as the first except that a preamp is mounted on or near the antenna to reduce the system effective noise temperature.



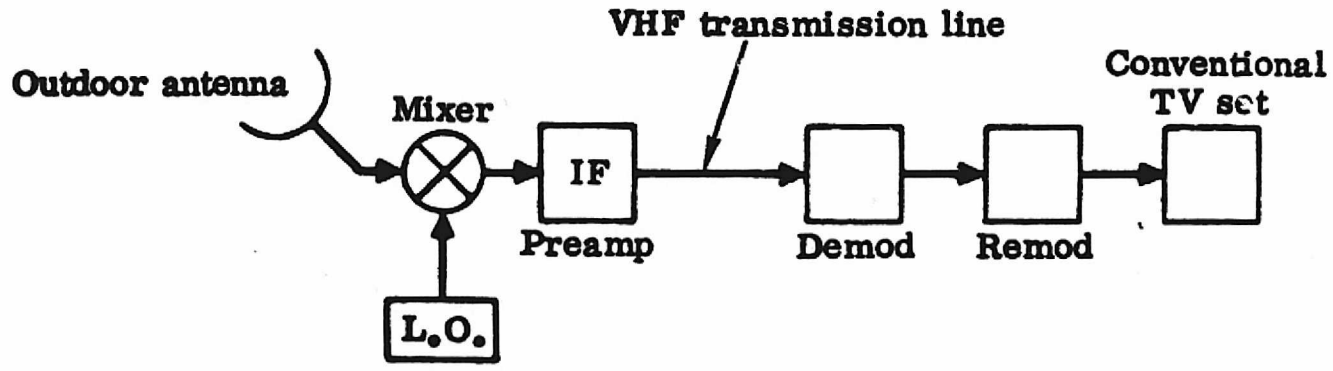
c. This configuration is the same as the first two except that the frequency of transmission is above the UHF band, requiring the addition of a frequency converter (balanced or single-ended mixer) on or near the antenna.



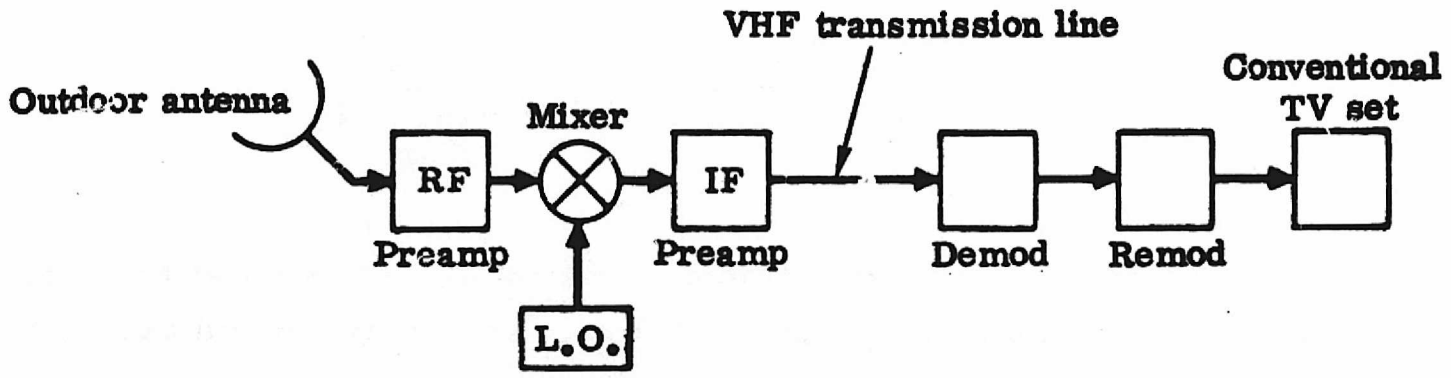
d. This configuration is similar to the third except that a preamplifier is mounted near or on the antenna to reduce effective system noise temperature.



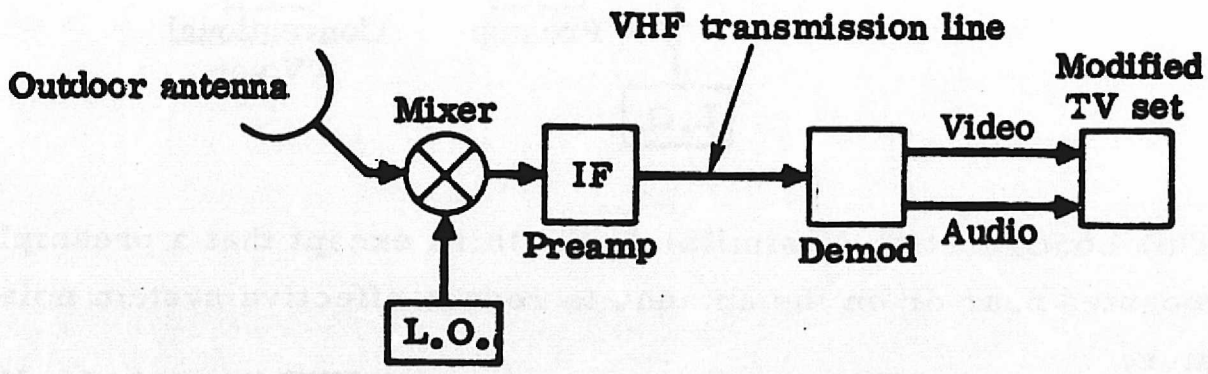
e. The satellite signal is frequency modulated; thus, the use of a modulation converter is required to transform the signal into standard AM-VSB format.



f. The configuration is the same as the fifth except that a preamp is mounted near the antenna to reduce the overall system noise temperature.

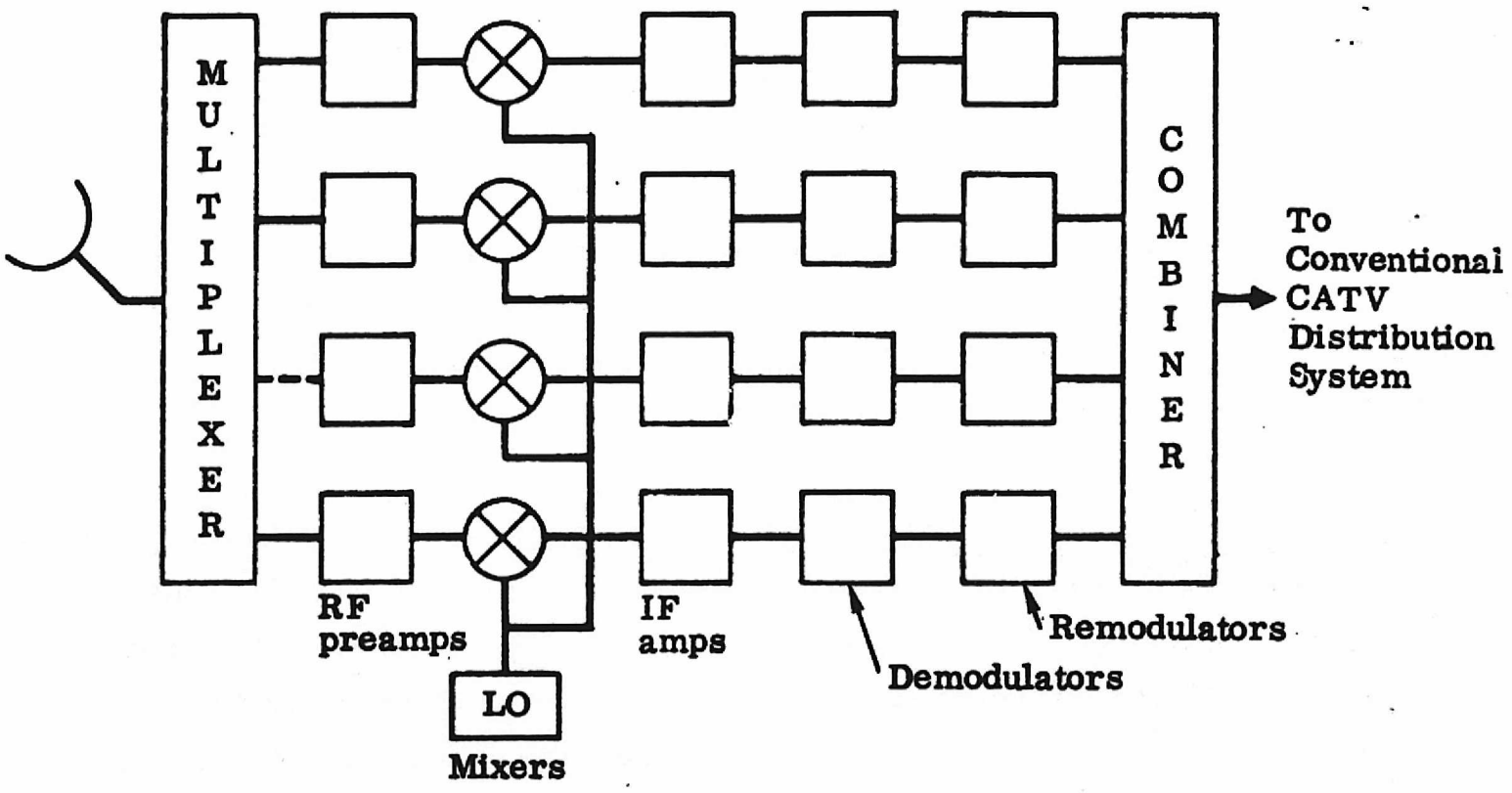


g. This configuration is the same as the sixth except that no remodulator is used to convert the signal to standard format. Instead, the receiver is wired to allow direct injection of video and audio into the set.



h. This configuration is the same as g except that a preamp is added as in configuration e in order to reduce overall effective system noise temperature.

i. The receiver configurations described above would be utilized in connection with a direct broadcast satellite. To provide a satellite broadcast service involving the distribution of programs through rebroadcast or cable networks a more complex receiving system would be required. A simplified block diagram of a redistribution type of receiving system is shown. Consideration of many variations of receiving systems in such an application is beyond the scope of this report, although future consideration of such systems appears to be mandatory, particularly in view of interference and sharing constraints.



8.6.2 RECEIVER COST. Mass-produced receiver cost data was obtained at a Phase I briefing of a NASA funded study performed by the General Electric Co. (Reference 8-20). The following material is based primarily upon data obtained at that review and also upon data listed in a report by the CCIR Study Group, USSG IV (Reference 8-13).

The GE study is a two year program in which the first phase has been completed and reported upon in a briefing held on 7 August 1969 at the NASA Lewis Research Center. The following tasks were accomplished during Phase I of the GE study:

Formulation of Candidate Systems

Cost Screening

Formulation of Conceptual Designs
Generation of Production Cost Estimates

During the second phase of the study a prototype design and evaluation will be conducted prior to the fabrication, test and delivery of 45 signal processing units. Fifteen of these units will be 2.25 GHz AM-VSB TV signal processors, 15 will be 2.25 GHz FM processors, and 15 will be 12.0 GHz FM processors.

In developing the processor designs it was determined that balanced mixers utilizing Schottky diodes would satisfy the contracted design specifications; thus, no consideration of using preamplifiers was found necessary to complete both phases of the study. Also, only single-channel processor designs were required; thus, no remote tuning or multiple-channel operation analysis was performed.

In order to "size" a spacecraft transmitter a wide range of receiver quality and cost data is required. Technical and cost data found in the referenced GE and CCIR reports has been utilized as a base to develop the range of ground receiver parametric data required.

Production cost estimates for direct-to-home receiver versus time for annual production volumes of one thousand and one million units were published in the Phase I briefing. This data was combined with the CCIR data to develop the data shown in Figures 8-22 through 8-26. Noise characteristics of typical receivers which may be available in 1975 are shown in Figure 8-27. Block diagrams of AM and FM receivers which illustrate the type of receiver that would be obtained for the indicated costs are shown in Figures 8-28 and 8-29.

It may be anticipated that a multiple-channel capability will be required for most satellite broadcast applications. In view of this requirement, multiple-channel AM and FM receiver cost estimates were made; these are shown in Figures 8-30 through 8-34. A general block diagram of the multiple-channel receiving system is shown in Figure 8-35. Figures 8-36, 8-37, and 8-38 illustrate the local oscillator multiplication scheme for UHF, S- and X-band.

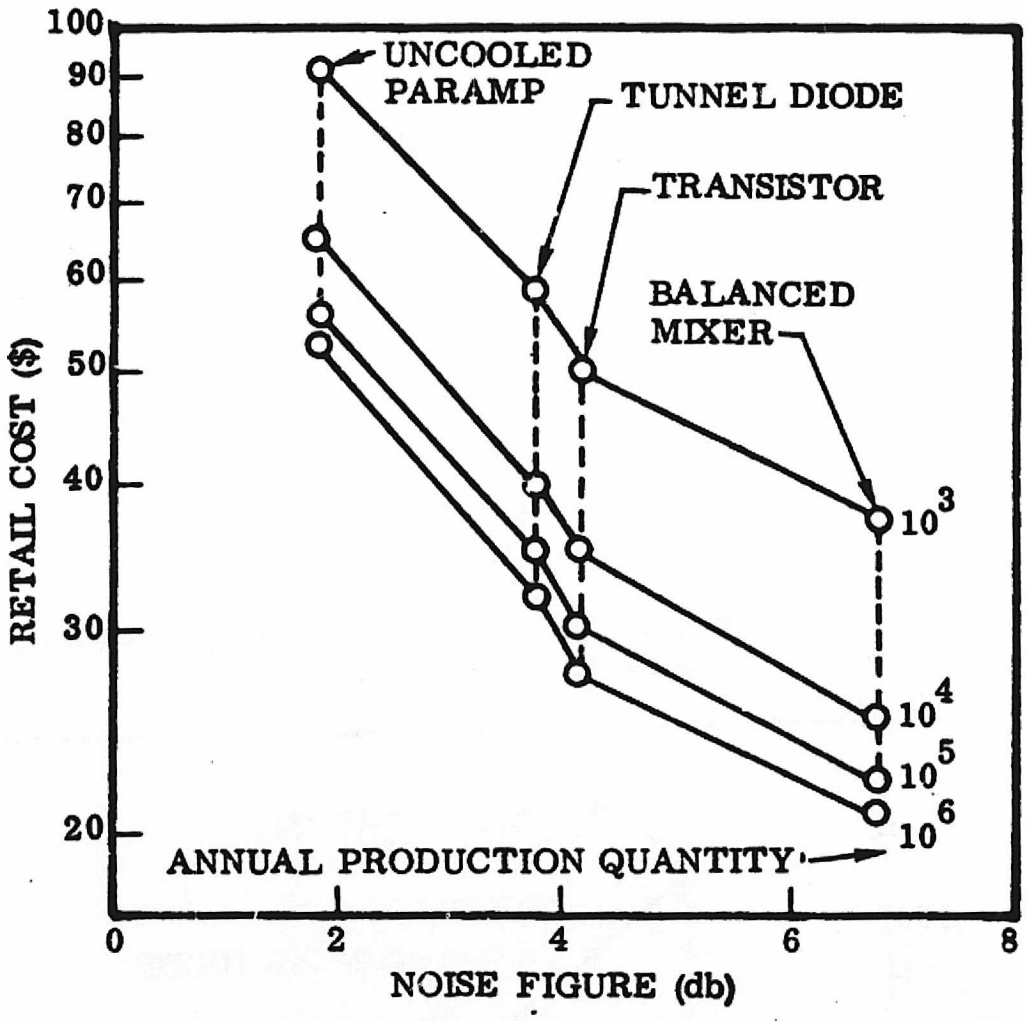


Figure 8-22. Satellite 0.8 GHz AM-VSB Signal Processor Retail Cost vs. Noise Figure -- 1969

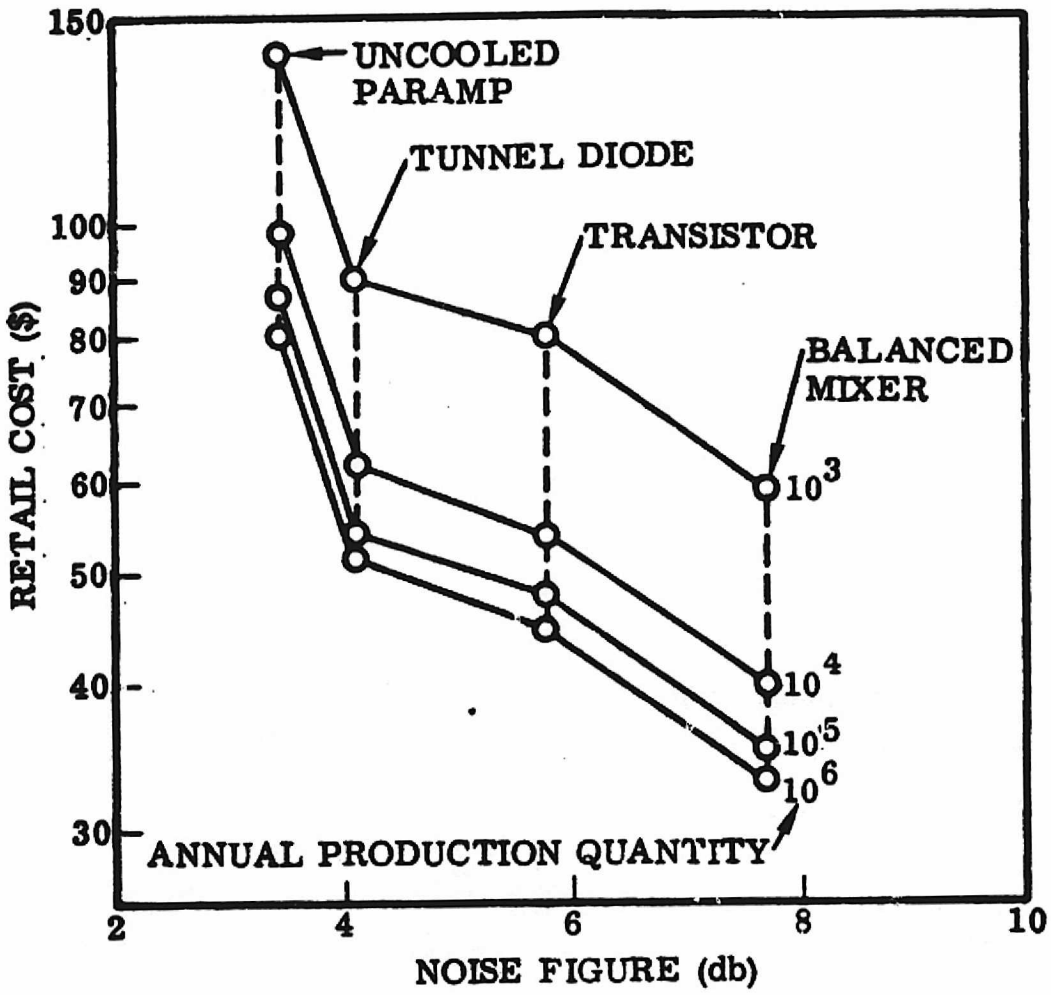


Figure 8-23. Satellite 2.25 GHz AM-VSB Signal Processor Retail Cost vs. Noise Figure — 1969

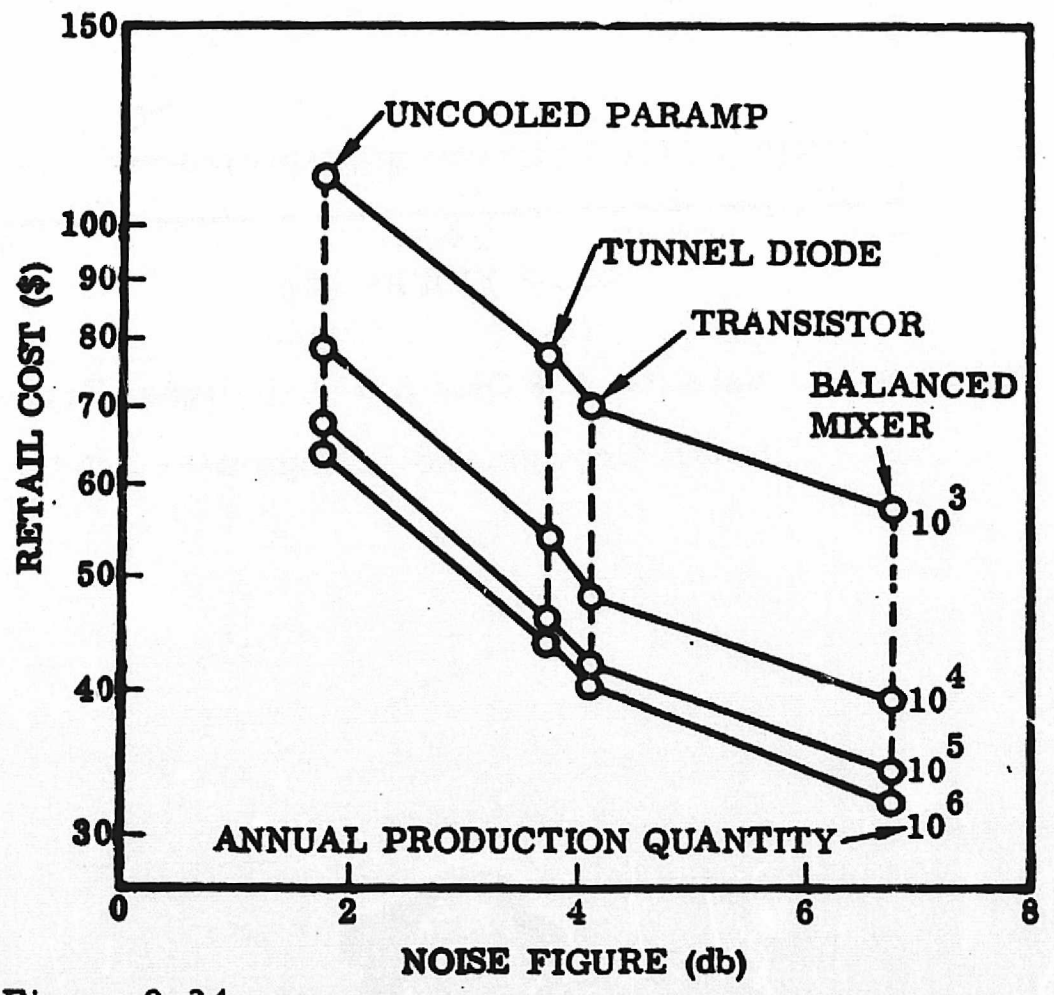


Figure 8-24. Satellite 0.8 GHz FM Signal Processor Retail Cost vs. Noise Figure — 1969

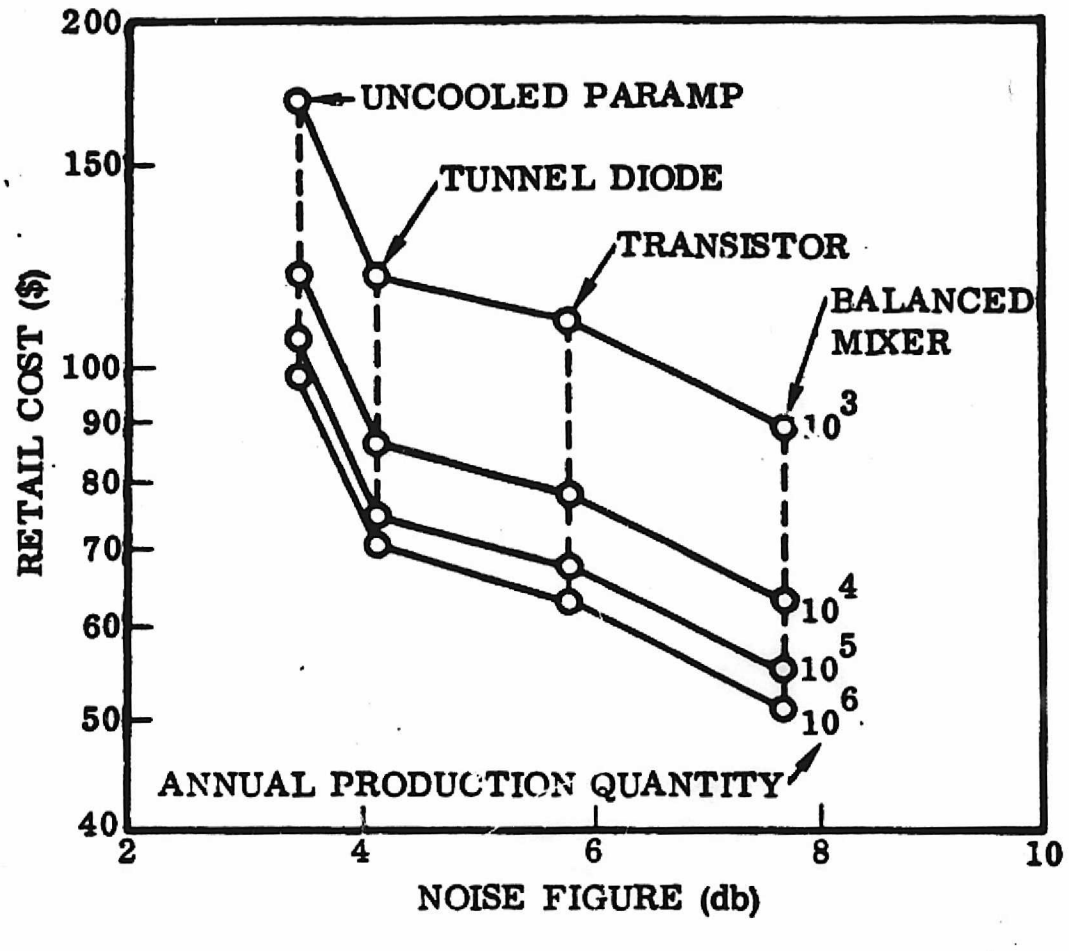


Figure 8-25. Satellite 2.25 GHz FM Signal Processor Retail Cost vs. Noise Figure — 1969

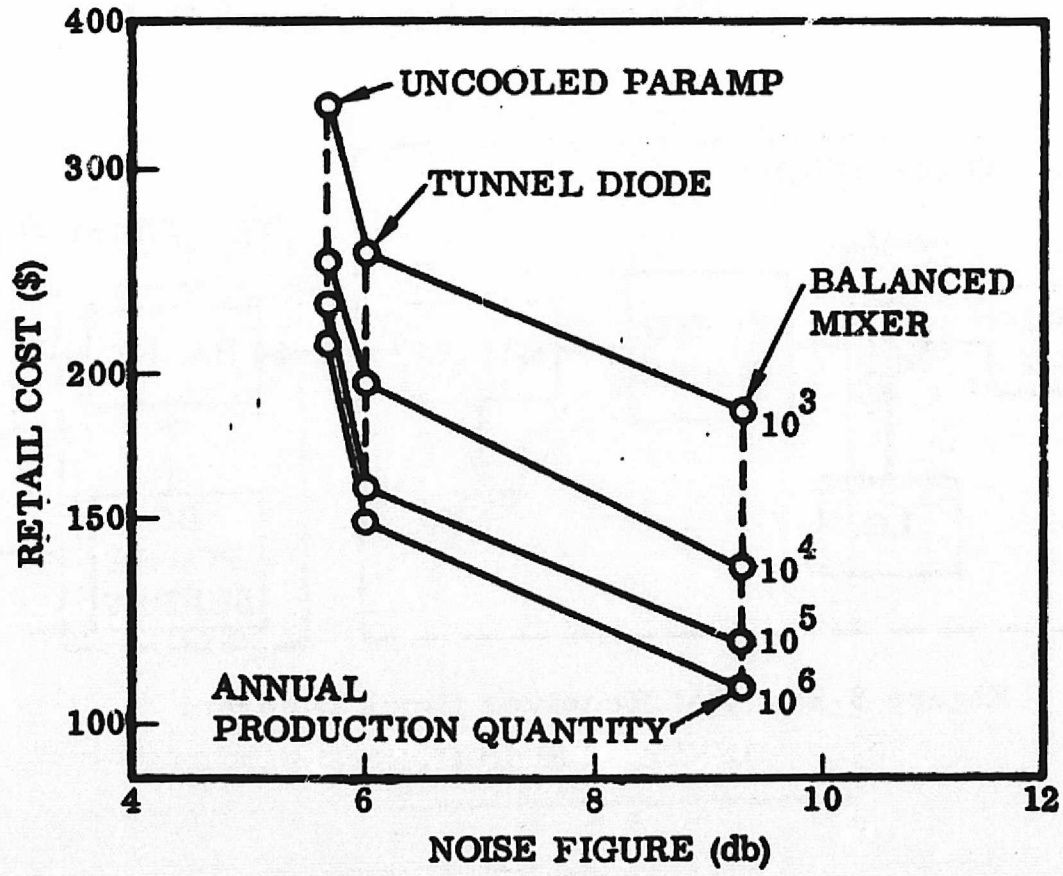


Figure 8-26. Satellite 12.0 GHz FM Signal Processor Retail Cost vs. Noise Figure — 1969

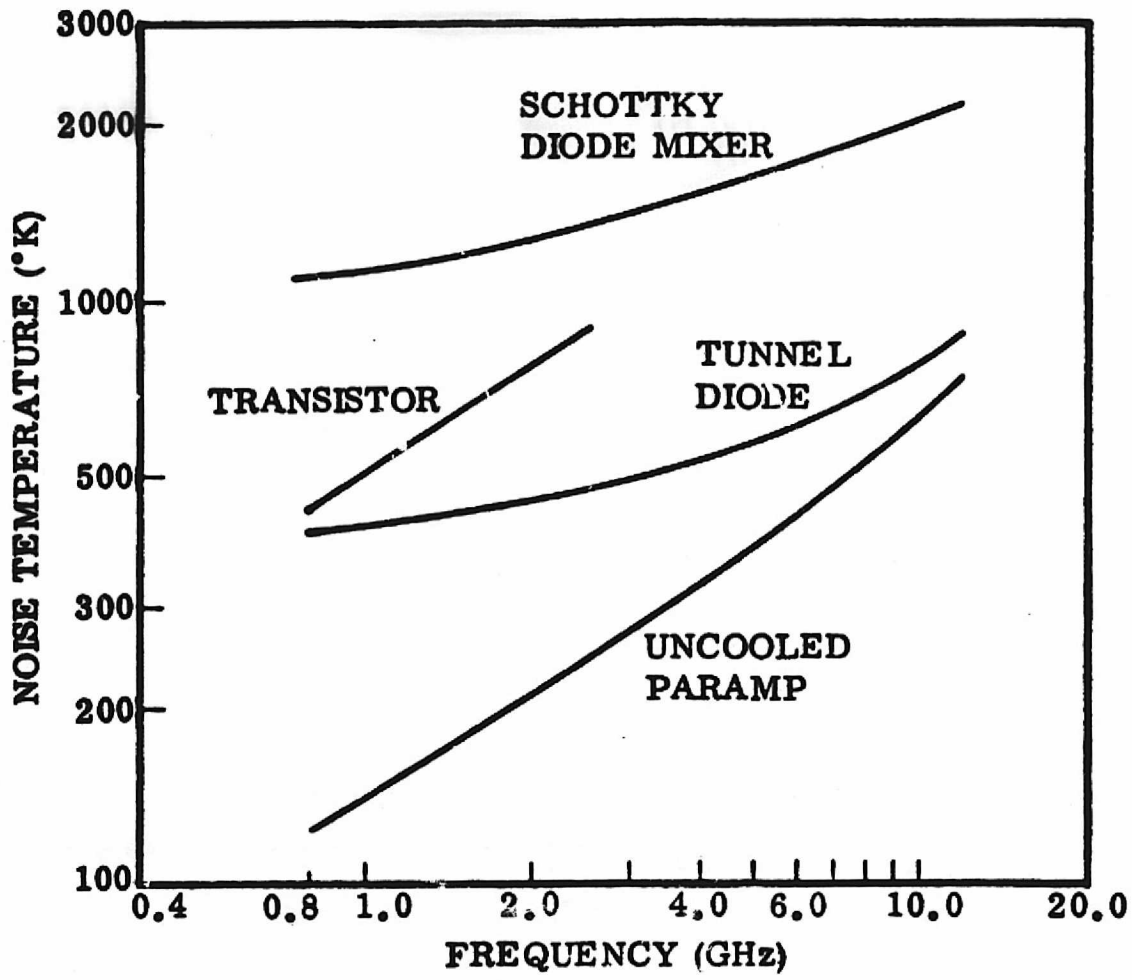


Figure 8-27. Noise Characteristics of Typical Receivers — 1975 (from CCIR Study Group IV Report)

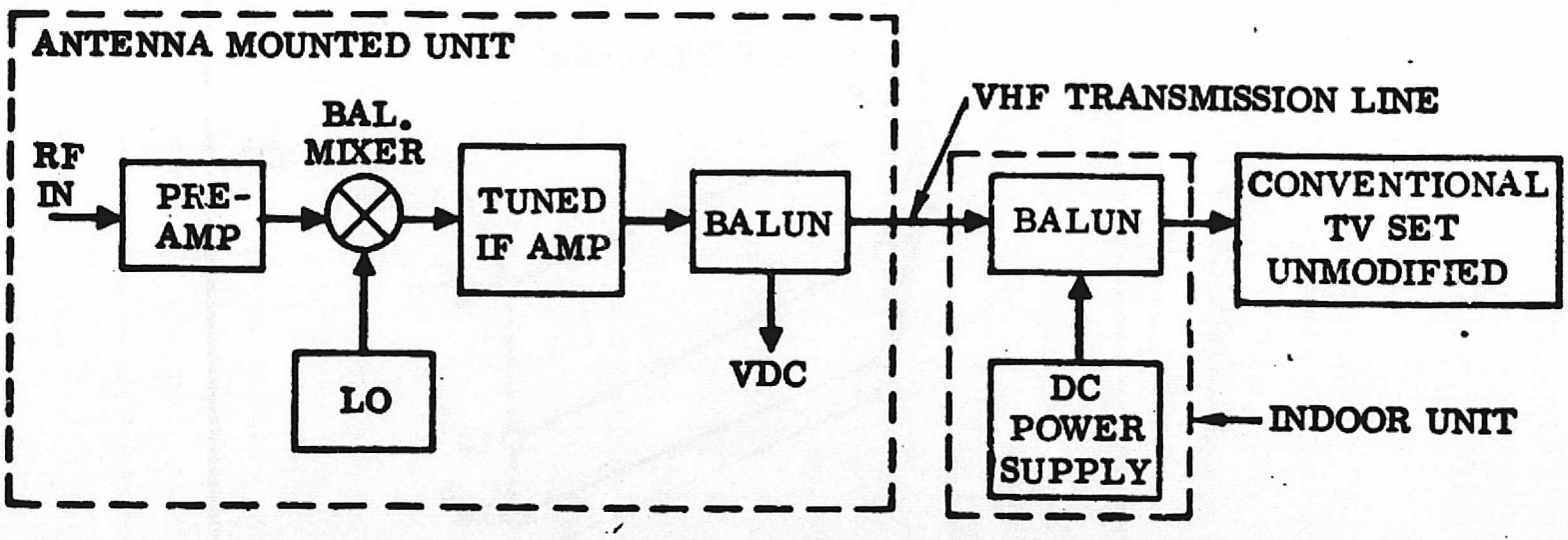


Figure 8-28. AM Receiver Block Diagram

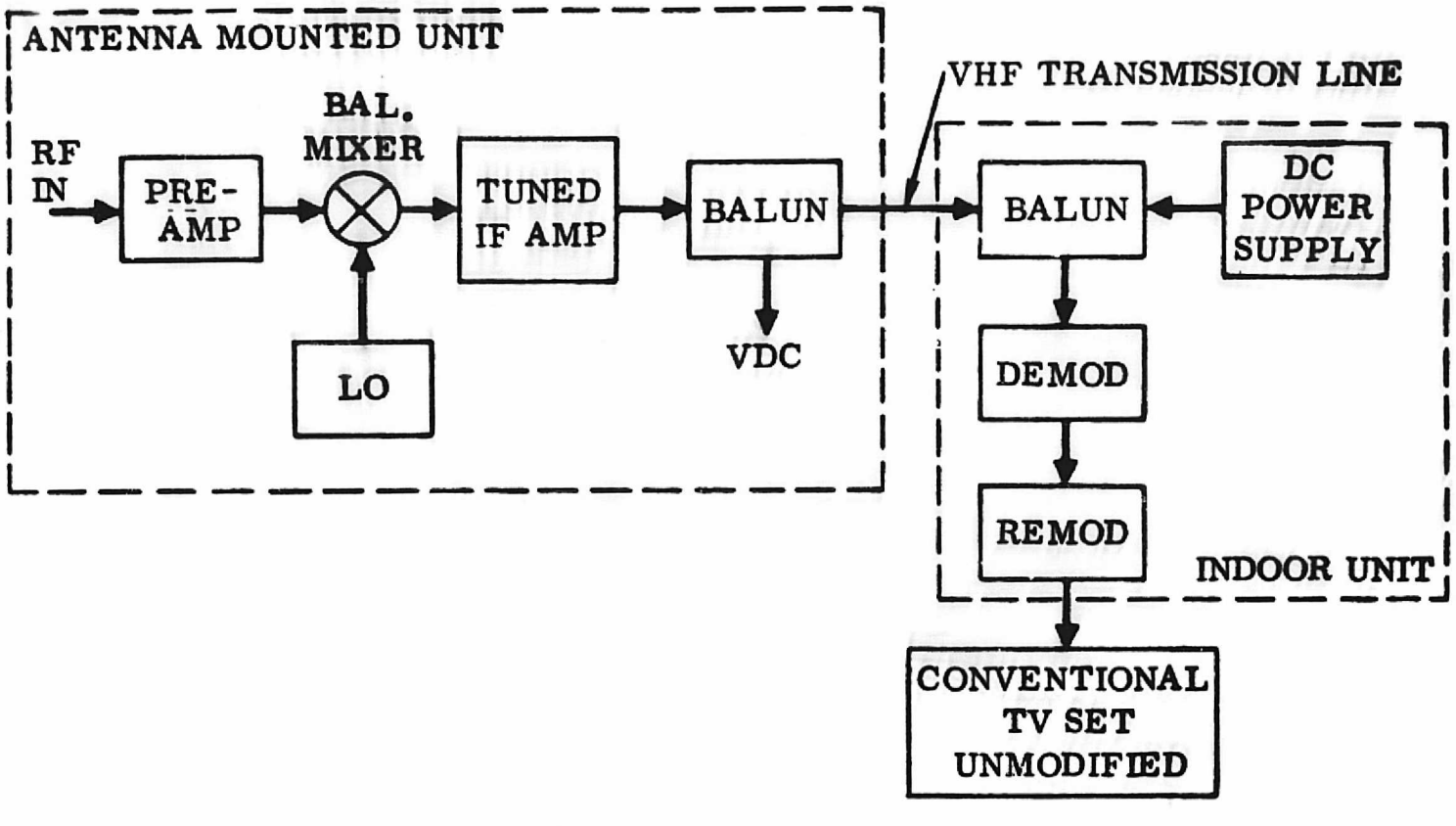


Figure 8-29. FM Receiver Block Diagram

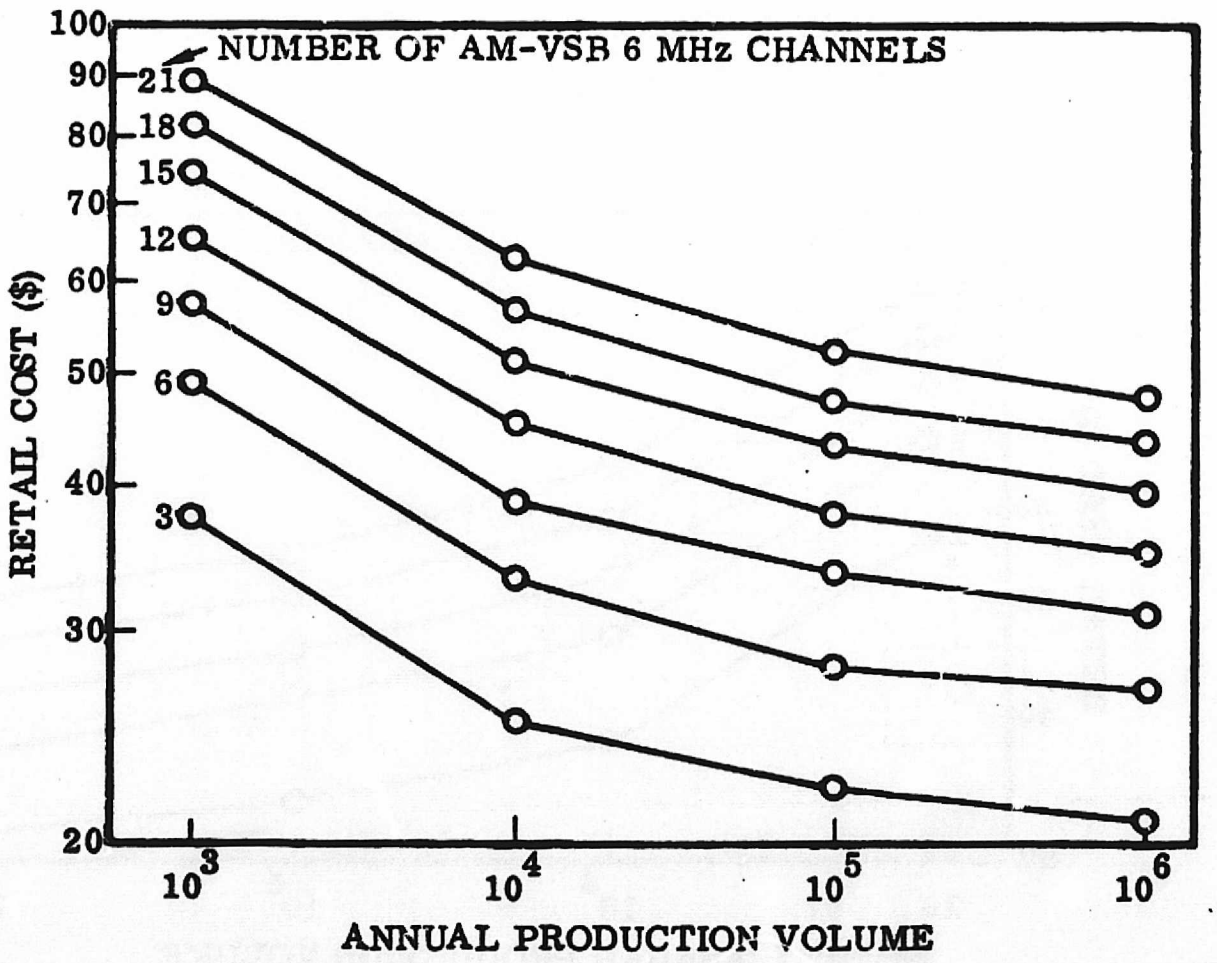


Figure 8-30. Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 0.8 GHz AM-VSB)

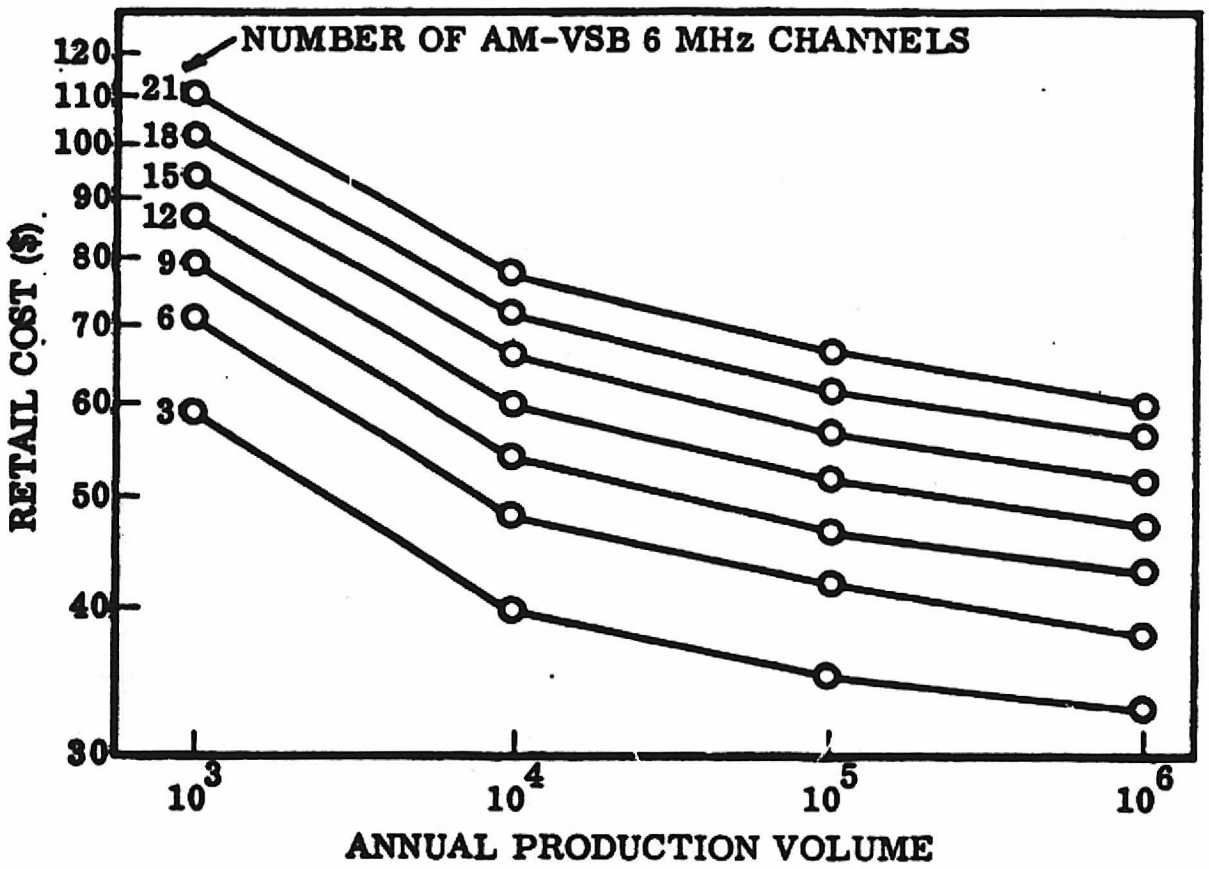


Figure 8-31. **Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 2.25 GHz AM-VSB)**

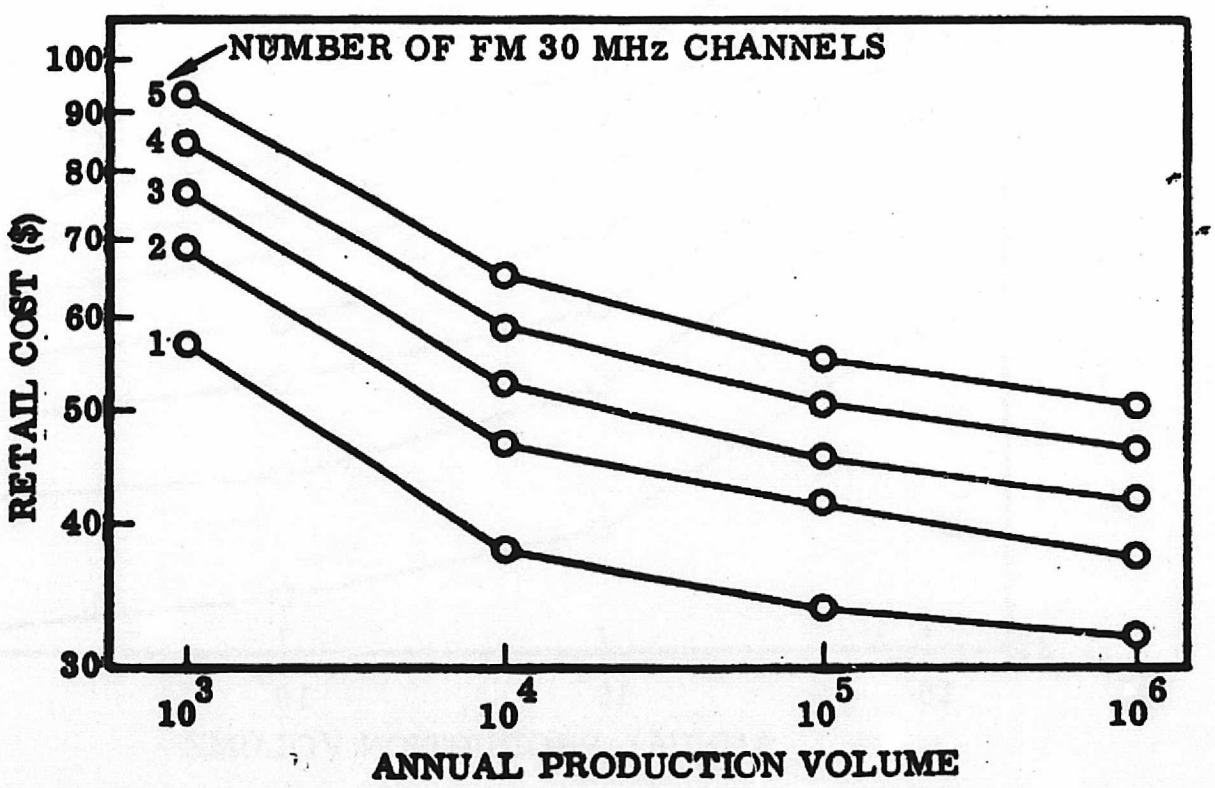


Figure 8-32. **Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 0.8 GHz FM)**

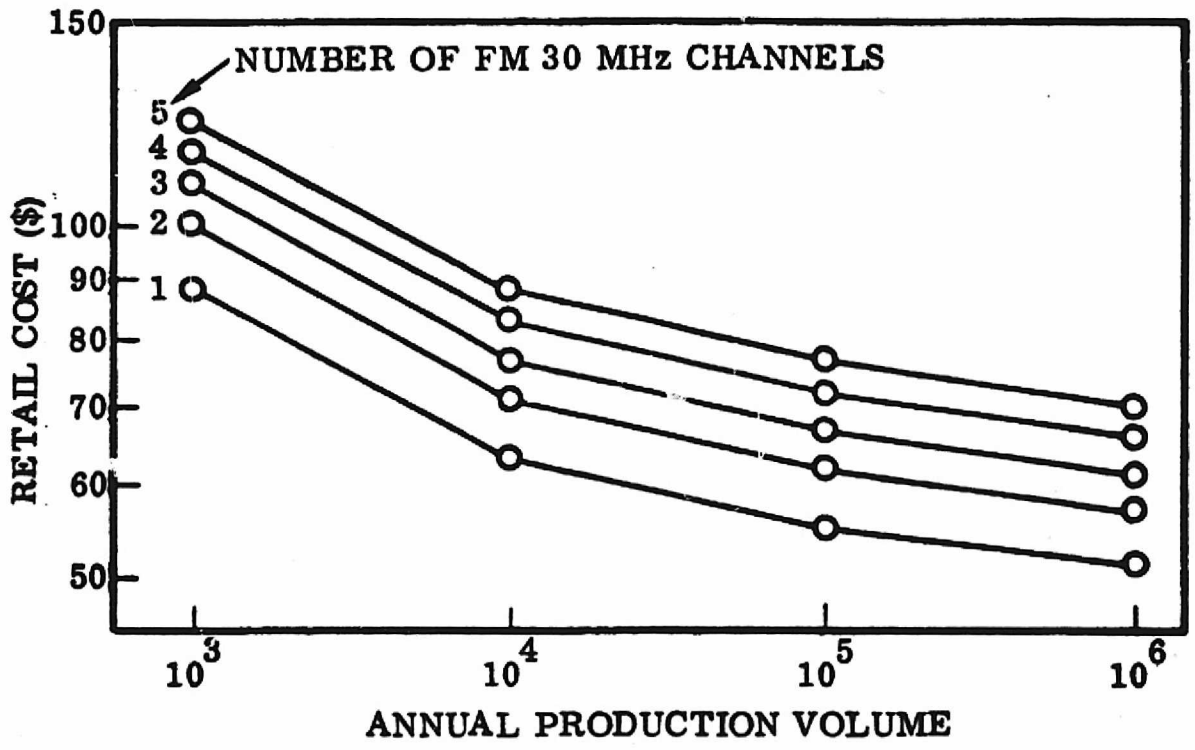


Figure 8-33. Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 2.25 GHz FM)

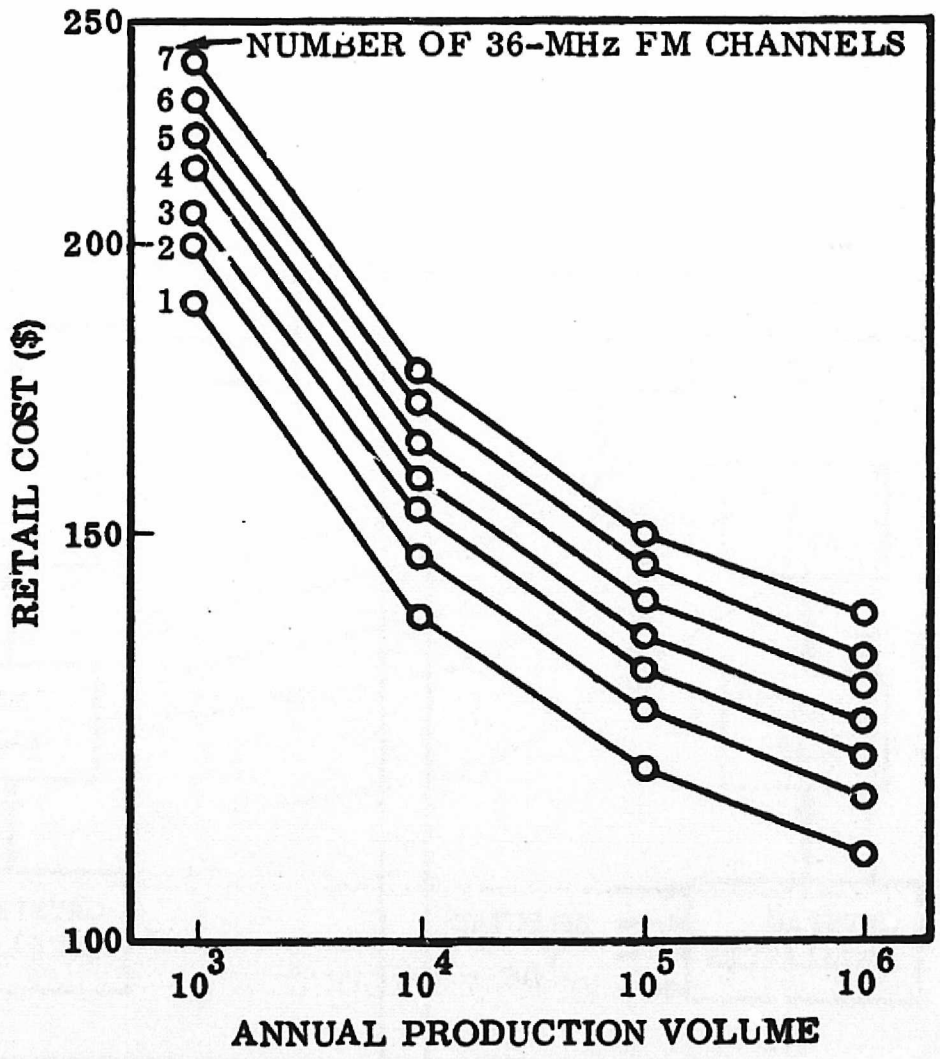


Figure 8-34. Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 12.0 GHz FM)

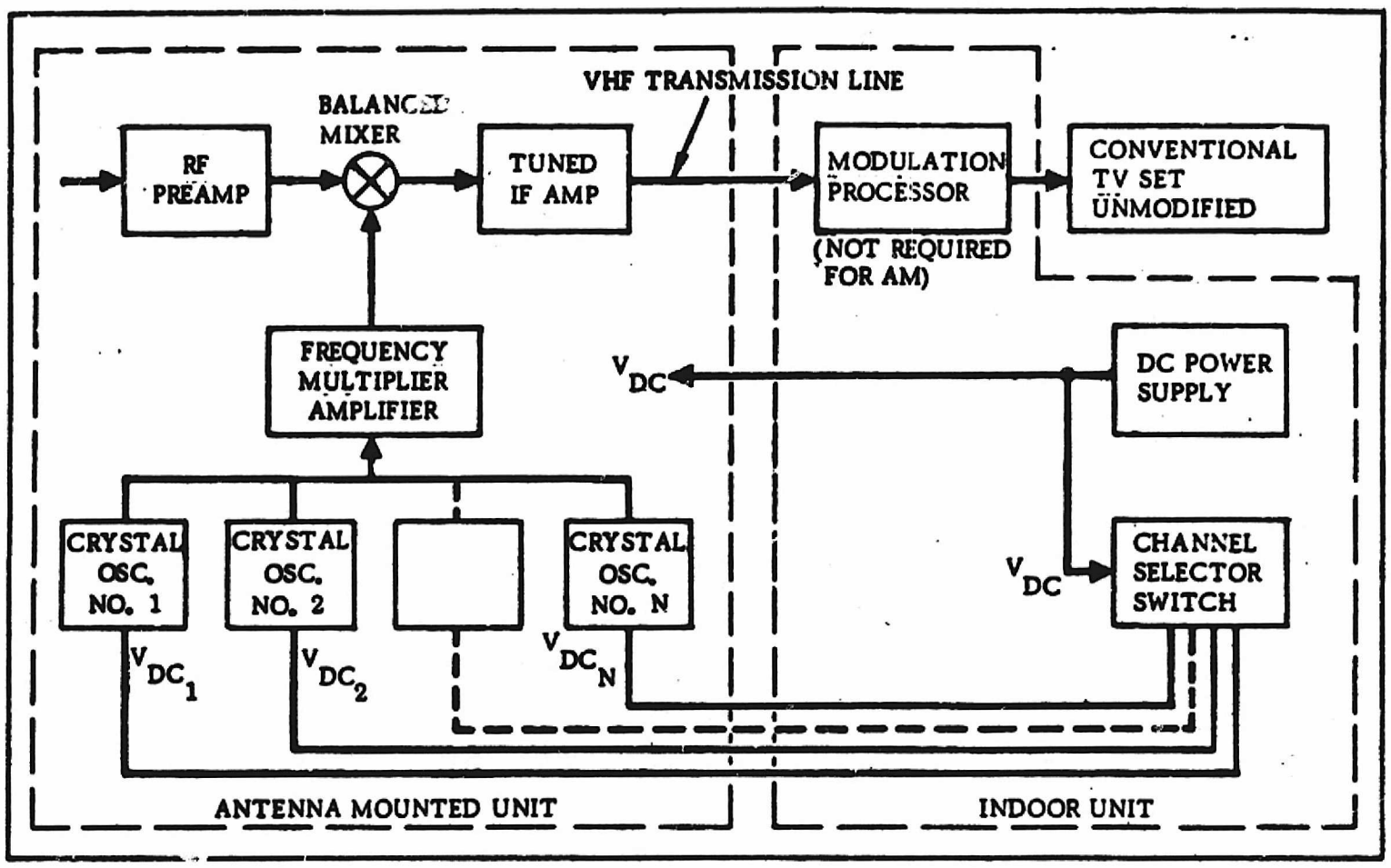


Figure 8-35. Multiple-Channel Receiving System

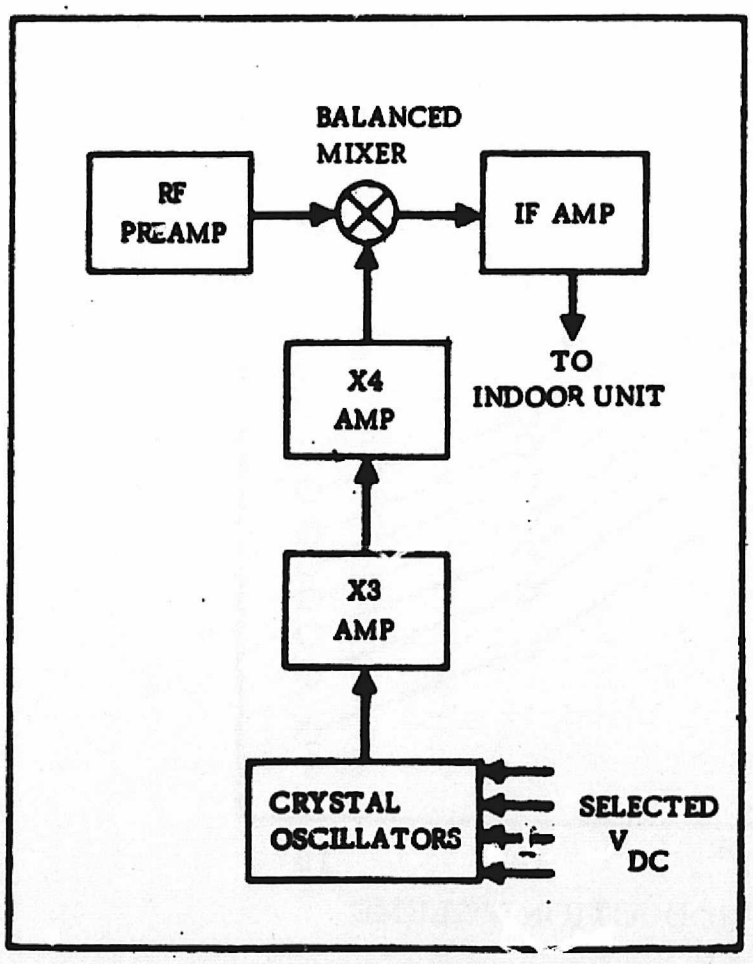


Figure 8-36. UHF Local Oscillator System

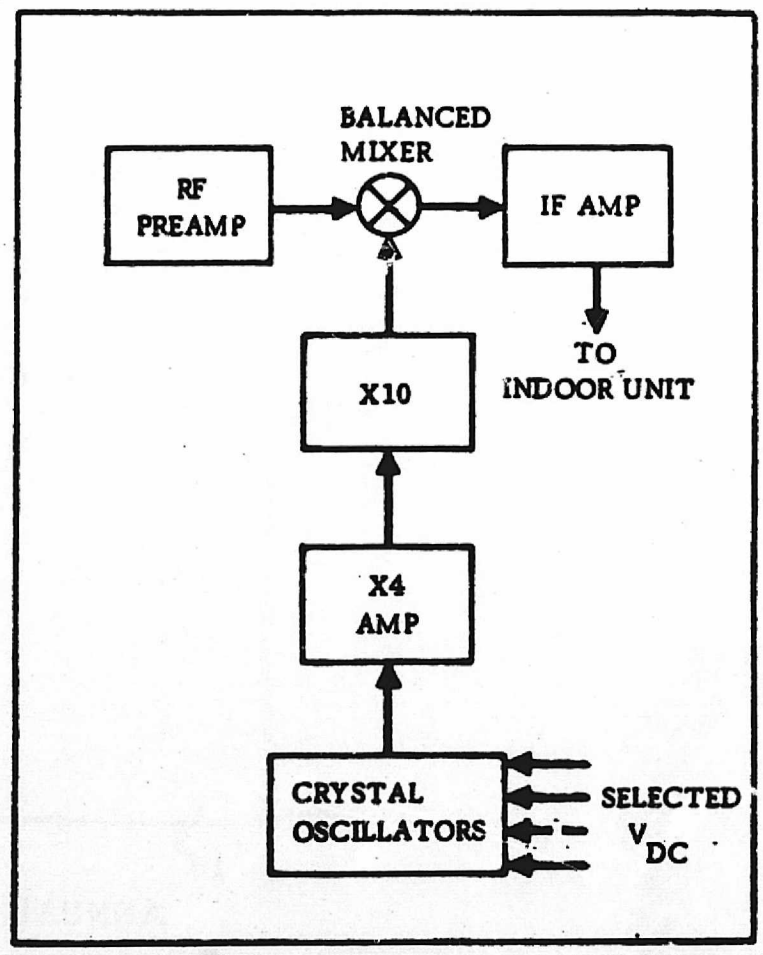


Figure 8-37. S-Band Local Oscillator System

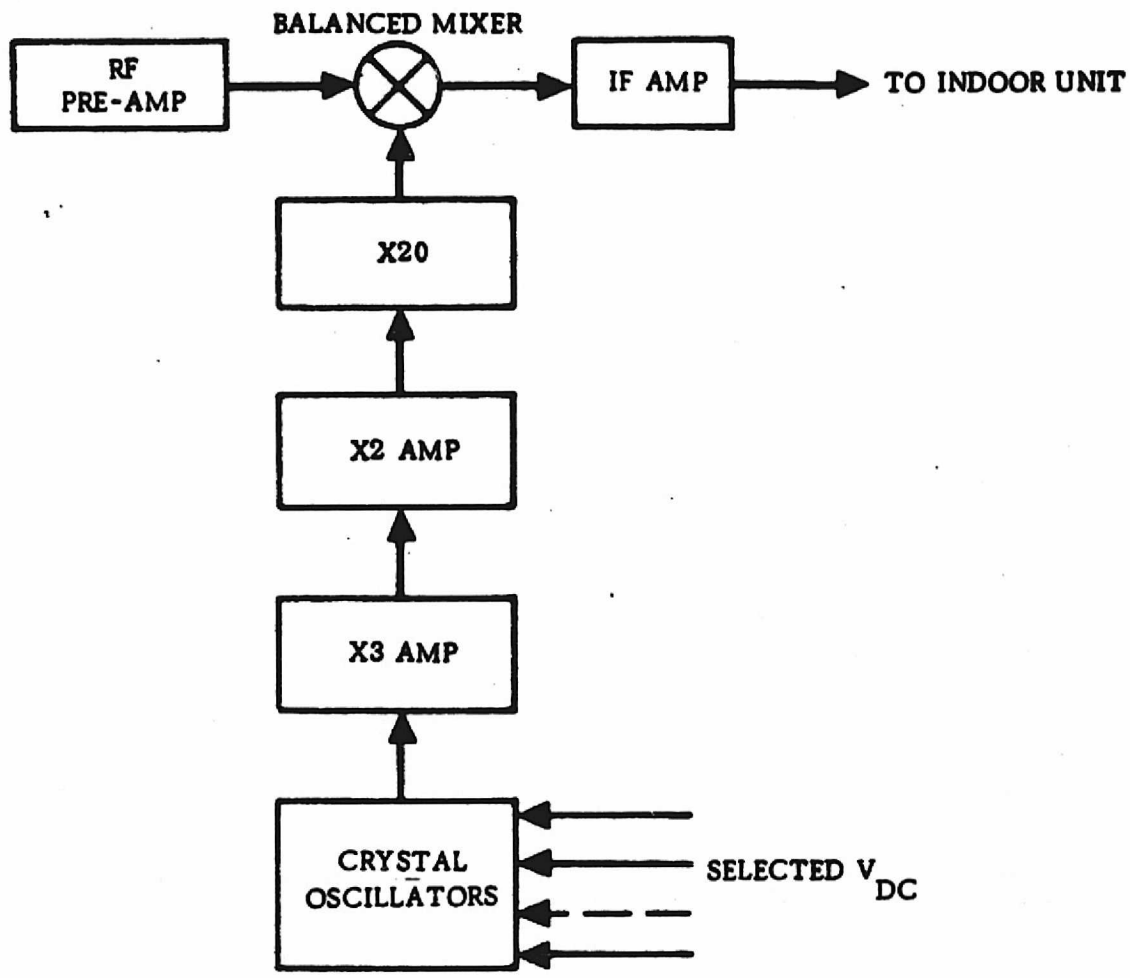


Figure 8-38. X-Band Local Oscillator System

8.7 ANTENNA COSTS

Costs of mass-produced antennas were obtained from antenna catalog data, NASA contracts NASw 1305 (Reference 8-21) and NAS3-9708 (Reference 8-22), and CCIR Study Group IV Annex II (Reference 8-23). Installation costs were taken from NAS3-9708. These costs are shown in Figures 8-39 through 8-43.

7

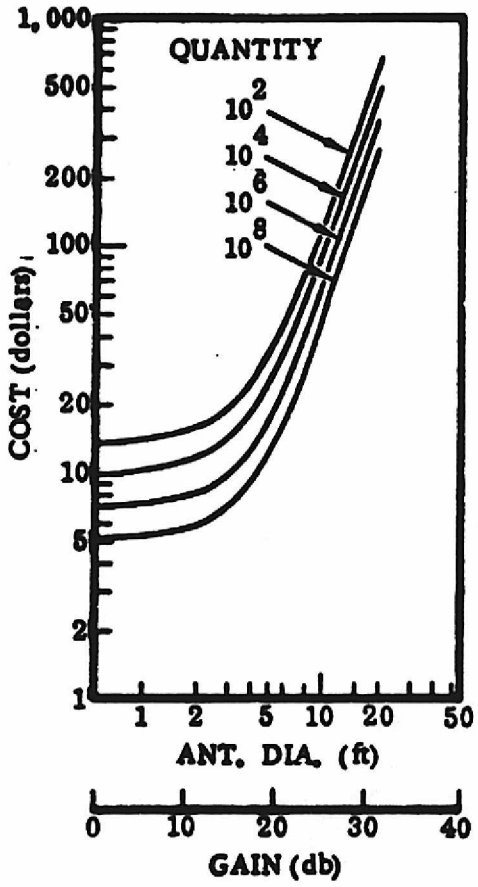


Figure 8-39. 0.8 GHz Antenna Cost

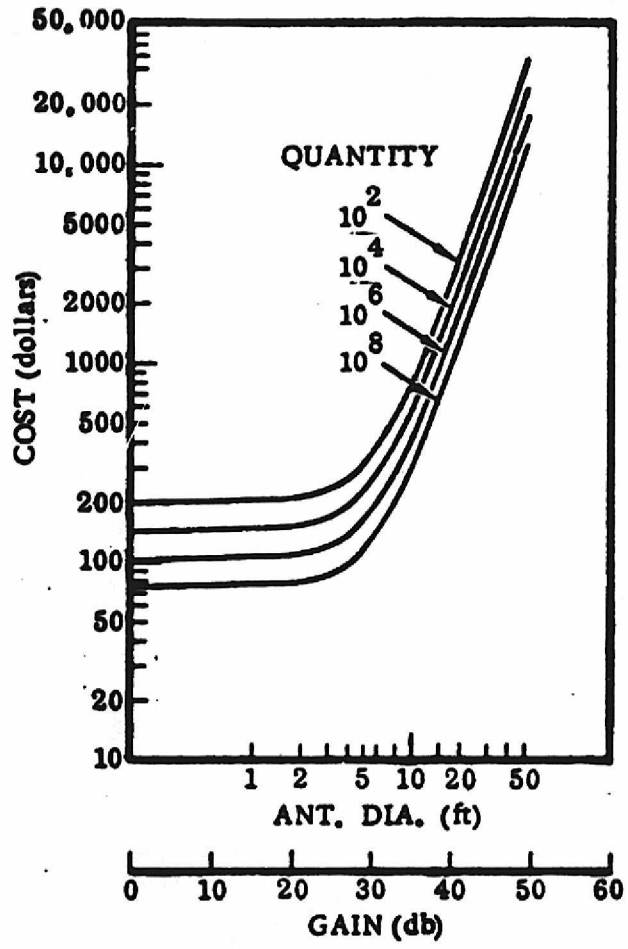


Figure 8-40. 2.5 GHz Antenna Cost

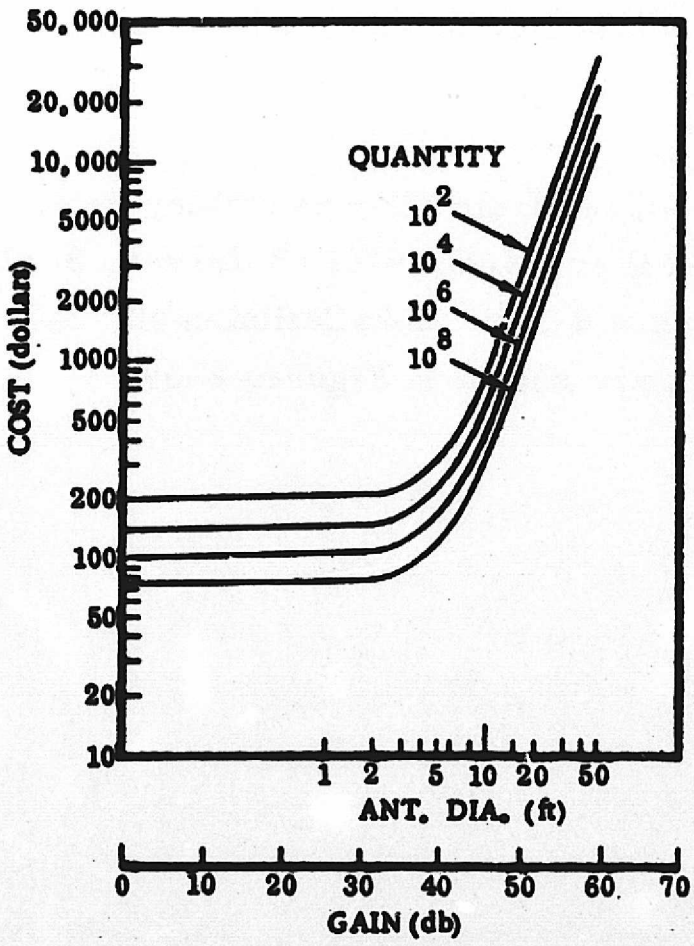


Figure 8-41. 8.4 GHz Antenna Cost

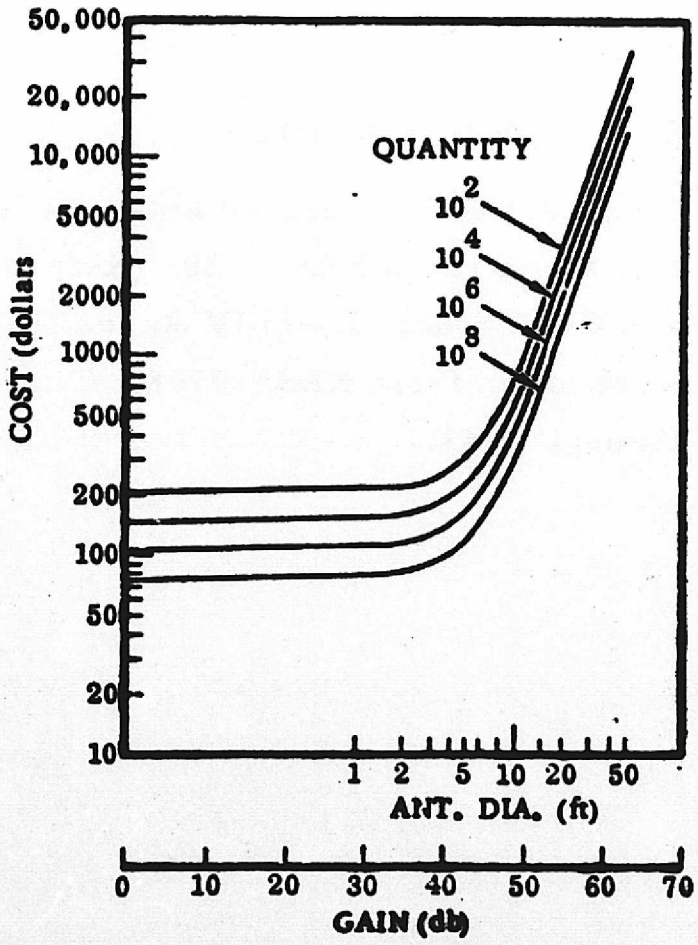


Figure 8-42. 12.2 GHz Antenna Cost

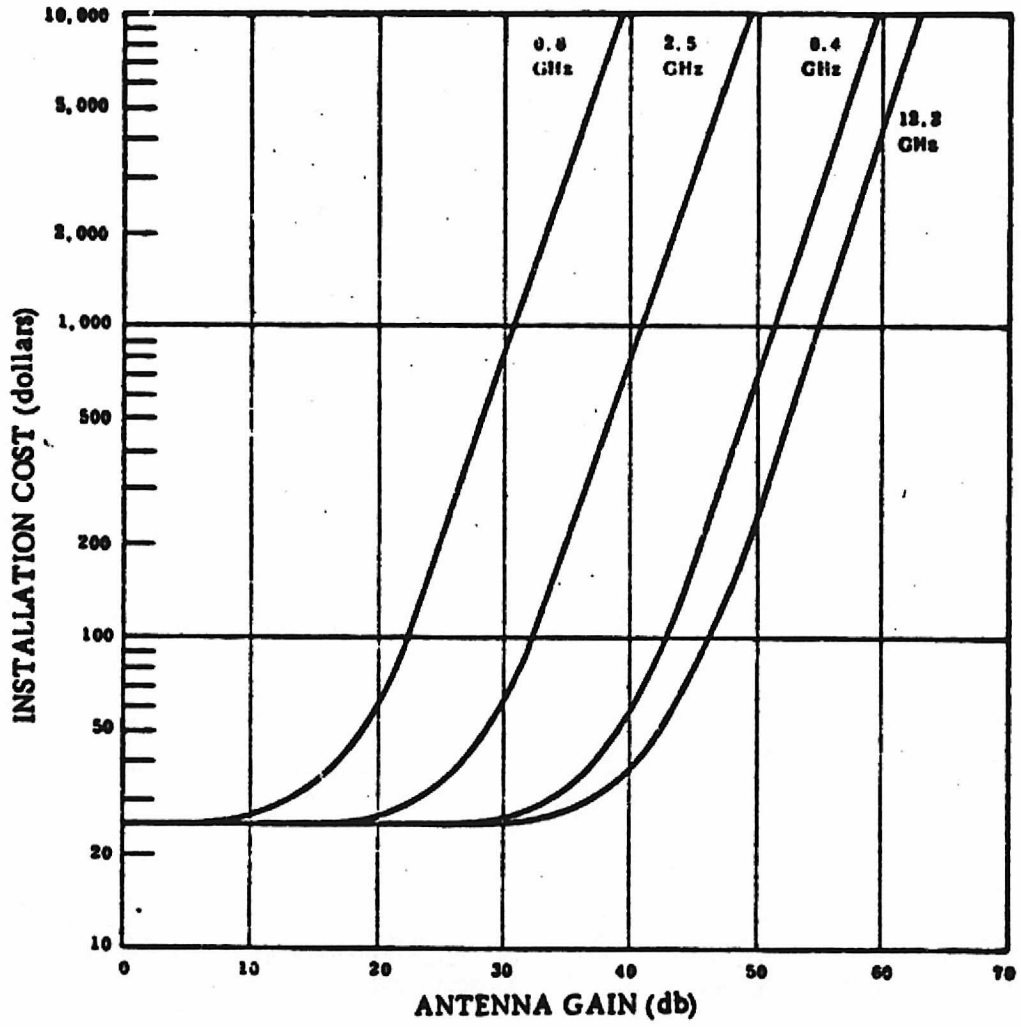


Figure 8-43. Antenna Installation Cost

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8-4 A. J. Hatch and H. B. Williams, "Multipacting Modes of High Frequency Gaseous Breakdown," The Physical Review, 1 November 1969.

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8-12 Microwaves, October 1970 Advertisement Page 25.

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9

CONCLUSIONS AND RECOMMENDATIONS

A review of the Television Broadcast Satellite Study, in terms of the study goals shown in Table 9-1, shows these have been met and, for the most part, exceeded.

Table 9-1. TVBS Study Goals

o Ascertain real TVBS user requirements.
o Develop systhesis computer program
— Minimum total costs
— System sensitivities
o Develop Saturn V class TVBS configurations.
o Determine critical technologies.
o Select "best" user/system application.
o Refine selected system(s).

9.1 CONCLUSIONS

User Requirements

A wide range of potential users was contacted. From these contacts the following general conclusions have been derived:

- o Ground facility coverage is not adequate for users in western areas, Alaska and U.S. Pacific territories.
- o Special interest groups, even in urban areas, are not adequately covered: AMA, institutional interconnections, parochial schools and others.
- o Interaction/2-way/talk-back, are prime objectives for most telecommunications systems.
- o International users are primarily in the classification of "underdeveloped" nations.
- o Consensus is that satellites have an important role to play in future telecommunications systems, particularly for education & low coverage areas.

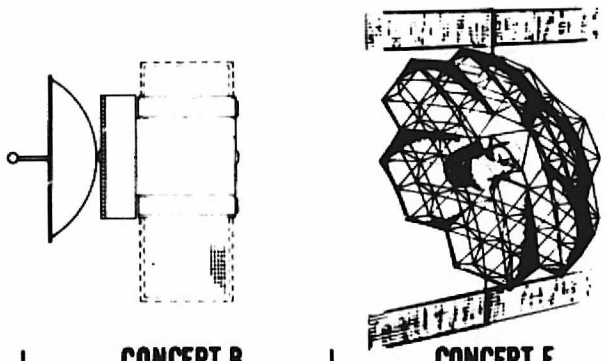
Synthesis Program

A most comprehensive synthesis program has been developed. It addresses the entire system — uplink systems, propagation characteristics, satellite and downlink systems (either Direct or Redistribution facilities) and derives a minimum total cost solution by performing the system and subsystem tradeoffs.

This same technique can be applied to any type of satellite payload if sufficient information can be derived to define the payload parametrically.

Saturn V Configurations

A series of 6 basic satellite configurations was derived to be compatible not only with the Saturn V in single and multiple payloads, but also with smaller launch vehicles as single payloads. Variations were introduced on two of these to provide a working group of 8 concepts. These were exercised through the synthesis program for each set of user requirements. The conclusion is that the 3 concepts shown in Figure 9-1 form the best foundation for continued analysis and definition.



	CONCEPT B	CONCEPT F	CONCEPT D
SIZE	TO 5,000 LB. 262 CU. FT.	42,000 LB. 6,000 CU. FT.	42,000 LB. 6,000 CU. FT.
BEAMS	1 OR 2 MAX.	6 TO 12 MAX.	4 TO 8 MAX.
POWER	5 KW MAX.	ABOUT 50 KW MAX.	ABOUT 100 KW MAX.
FREQUENCY	2.5 TO 12.7 GHz	800 MHz TO 12.7 GHz	2.5 GHz TO 12.7 GHz
MANNED	NO	YES	YES

Figure 9-1. Selected Concepts

Critical Technologies

Candidate missions and associated key satellite parameters are summarized in Table 9-2. The areas in which technology developments are required are also noted.

1. General. Some of the systems require wideband transmissions to accommodate multiple TV channels. The availability of spectrum space at the optimum frequencies is dubious. These systems may be forced to higher frequencies — e.g., 11.7 - 12.7 GHz or above.

Table 9-2. Mission Groups and Key Satellite Parameters.

Mission/User System	Satellite Parameters						Areas for Technology Development
	No. Beams (1)	No. Channels (2)	Prime Power (KW) (3)	RF Power* (W) (4)	Frequency Band (GHz) (5)	Antenna Size (Ft.) (6)	
1. U.S. Armed Forces Radio and Television	2	5	10	542	0.8	29.7	1,3,4,6
2. U.S. Parochial Schools	2	2	1.5	31	0.8	29 x 57	1,6
3. U.S. Biomedical Network	1	3	2	35	2.5	9 x 18	6
4. India ETV - Direct	1	1	7	1,512	0.8	27	3,4,6
5. U.S. ETV - Distribution	4	8	1.5	22	2.5	9 x 18	1,6
6. Mexican ETV - Direct	2	4-8	23	840	0.8	33.1	1,3,4,6
7. Mexican ITV - Direct	2	4-8	3	36	0.8	33.1	1,6
8. U.S. ITV - Distribution	8	4-24	87	1,380	2.5	11.4	1,3,4
9. U.S. ETV - Direct	6	2-12	100	2,490	0.8	29 x 57	1,3,4,6
10. U.S. ITV - Direct	8	4-32	5	256	2.5	9 x 18	1,6

*RF Power per TV Channel

Not specifically shown in Table 9-2, but of concern is the effect of the long life requirement of most systems on the attitude control and stationkeeping system. Ion propulsion is the most cost-effective system for these purposes at lifetimes greater than 5 years. This is particularly true when considering high-powered systems requiring tri-axial stabilization. Considerable effort beyond that so far expended on the SERT systems needs to be put into the development of a family of thrusters with an appropriate range of impulse.

2. Multiple Beams. Eight of the missions require multiple beams for providing coverage to specified geographic areas (e.g., 4 time zones in U.S.). The multiple beams can be implemented by means of multiple antennas, multiple feeds per antenna or phased arrays. Of these, only the multiple antenna approach has been considered for operation in space (Intelsat IV). Proposed phased array are for narrow-band systems. Their operation in wideband systems is questionable in terms of phasing characteristics and frequency response over the total bandwidth.

3. Prime Power. While solar array systems have been proposed for power levels up to 50 KW none have flown at power levels in excess of 5 KW. As noted in Table 9-2 seven of the systems require more than 5 KW and two of them require up to 100 KW. If solar arrays continue to be the workhorse for the earth orbiting missions advanced array, along with their system accessories (transfer mechanisms, control units, conditioning, etc.), must be developed. Alternatively, development must be initiated on appropriate SNAP isotope or reactor systems to provide this power.

4. RF Power Components. Considerable work has been undertaken by NASA in the development of "multi-kilowatt transmitters" at UHF. This needs to be extended to the higher frequency ranges to be compatible with future mission requirements.

5. Antenna Size. Development of erectable antennas has been underway for several years. The LMSC antenna, previously flown at approximately 20 ft. diameter on a USAF mission, has been selected for the ATS-F (30-ft. diameter). Present indications are that the diameter requirement has been reduced to be compatible with the previous flight unit. This requires further development to be undertaken to meet the large (and shaped) sizes shown in Table 9-2.

6. Ground Terminals. Most of the systems identified so far in the study have a large population of potential users. Furthermore, in most of these systems, more than 50% of the total system cost is attributable to the procurement, operation and maintenance of the ground terminals — uplink as well as downlink. This is an area that could benefit greatly by the development of low-cost, high-reliability and easily-operated ground terminals. A significant start has been made by NASA for low-cost direct receiving systems. Other options should be reviewed and accommodated.

9.2 RECOMMENDATIONS

1. Continue the planning and system development activities to establish a position of technological readiness for the implementation of the selected and similar missions.

2. Undertake detailed study of the selected missions:

   a. Armed Forces Radio and Television Services

   b. Combined Educational and Instructional TV Services for the U. S.

   c. Television Services for Alaska and the Western States

3. In recognition of the present plan to terminate production of the Saturn V launch vehicle, it is recommended that the alternative Space Shuttle/Orbit-Orbit Shuttle combination be investigated as the primary booster and final orbiter. This offers the further potential advantage of performing manned aspects of the missions at lower altitudes before final placement in the geostationary orbit.