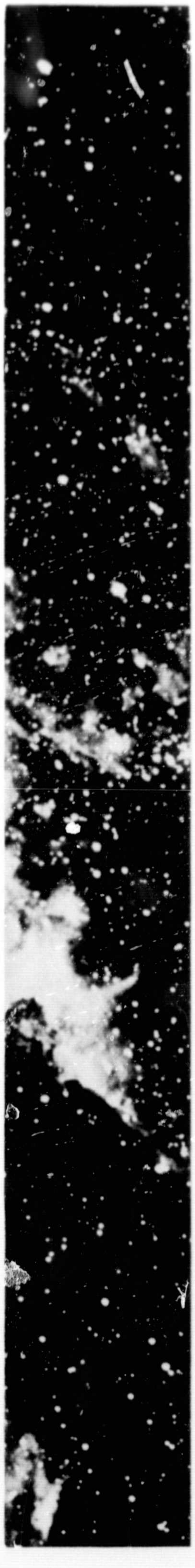
SPACE SYSTEMS

NASA CR-72578
1 August 1969



TELEVISION BROADCAST SATELLITE (TVBS) STUDY

TVBS SUMMARY REPORT

VOLUME I

Prepared For The

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-9708

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Contract No. NAS 3-9708

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PREFACE

The Television Broadcast Satellite (TVBS) study was performed, under NASA Contract NAS 3-9708, from August 1967 through January 1969 by the General Electric Company. The study results are presented in the following three volumes:

- Volume I - TVBS Summary Report
- Volume II - TVBS Research and Technology Implications Report
- Volume III - TVBS Technical Report

ABSTRACT

This report presents the results of a study of technological and cost factors associated with TV broadcast satellite systems. The cost and performance of the ground and space segments of the system are evaluated as a function of varying the parameters of transmission frequency, modulation, TV picture quality, audience size, size of coverage areas, indigenous noise, and ground receiving modification costs. Satellite conceptual designs are described based upon technology estimates for the early 1970's. Cost comparisons are made with terrestrial methods of delivering transmissions. Significant broadcast satellite technology items are identified and ranked in order of importance, and the following conclusions are made: broadcast satellites are feasible, cost effective, and capable of achieving turnkey operations sooner than terrestrial systems.

SUMMARY

This report encompasses a broad systems and satellite design study, performed under NASA contract NAS 3-9708, which investigated technical and economic factors associated with television broadcasting from space. Variables examined included signal quality, transmission frequency, indigenous noise, audience size, broadcast coverage area signal modulation, number of channels, and cost of ground receivers. Constraints or assumptions included a 1971 technology base, geostationary orbit, satellite life of two years, continuous payload operation (excluding eclipse), and propagation effects dependent upon latitude and tilt angle from satellite.

Services were divided into two major categories for this study. Direct Service is for use by the general public in the home. For this service the ground investment was restricted to less than $150 per receiver. Special Service is for special groups viewing at a smaller number of selected centers, and for inputs to terrestrial broadcast stations. Here, the range of ground investment was $1000 to $50,000 per receiver.

The costs of the ground and space segments of the system and the effects of variations in technical parameters on these system costs were estimated, resulting in data that permits evaluation of specific mission requirements.

Performance characteristics available in the early 1970's were estimated for satellite and ground system components and subsystems. This data permitted feasibility evaluation of synthesized systems and provided a basis for establishing technology development program recommendations. Significant system parameters (e.g., cost, weight, and varying geometry characteristics) are presented for all satellite and ground subsystems that vary as functions of identified critical design requirements.

Conceptual systems designs were developed for design requirements associated with four representative missions: (1) Community Distribution Services for India, (2) Direct Broadcast Service to Alaska, (3) Instructional TV Service to the U. S., and (4) TVBS Demonstration Mission to the U. S. These designs include link calculations to determine satellite design requirements at the operation point, which minimizes the pertinent system costs, preliminary definition of satellite and ground system components, development of feasible launch and orbital satellite configurations, launch vehicle selection, system cost estimation, and program plans and schedules.

The economics of terrestrial methods of providing a TV service were investigated. Different cost models were developed as a function of the type of ownership (commercial or government) and the type of service (broadcast, distribution, or educational). Models were developed for combinations of the above, which provide system costs per unit coverage area as a function of transmitter station spacing. Cost comparisons of satellite and terrestrial methods were made for the four selected systems.

Satellite broadcasting technology was investigated in order to determine those additional programs required to develop or advance the state of the art. Pertinent technologies were identified, their performance improvements with time predicted, and their impact on significant system parameters evaluated. Ranking criteria were established to permit listing the selected technologies in order of recommended priority of allocating development funding for varying satellite power level classifications. The most critical items (for high power TVBS applications) are high efficiency microwave and gridded tube transmitters, components for handling of high voltage and high power, interaction of flexible structures with control systems, deployment of large arrays of solar cells, low cost ground receiving systems, and thermal control of high-power transmitter components.

The study reached several important conclusions: (1) high power broadcast satellites are feasible in the next decade, if current technology and subsystem development is continued; (2) satellite systems are cost effective for large regions with no terrestrial broadcast stations (for regions having ground-based systems, the most cost-effective way of increasing capacity is to supplement the existing system with satellites); (3) turnkey operation can be achieved sooner by satellite than by ground-based systems if the objective is a service to the entire population of a region that possesses neither service.

SECTION 1

INTRODUCTION

The possibility of using space technology to provide television broadcast signals to large land areas of the earth has for some time been an extremely attractive prospect. Of all the applications of today's space program, the Television Broadcast Satellite (TVBS) probably has the greatest potential for directly helping the peoples of the world. In its various forms, the Television Broadcast Satellite can provide mass communication and education where there are none; it can extend and improve them where they exist; and it can accomplish these services more cheaply and quickly than any other means.

The overall purpose of this study is to determine the relationships among the parameters that affect the spacecraft so that NASA can use these results along with those of previous and concurrent studies to determine the technical requirements and assess feasible approaches to Television Broadcast Satellite Missions over the full range of possibilities.

The subject matter of this study is relevant to the growing awareness among peoples and national governments of the need to provide education to the large masses of the world population and of the need for better communications among the developed areas and nations. Much current interest in the ways and means of best providing these objectives has been expressed. This study investigated technical and economic factors of satellite systems and compared them to certain alternative terrestrial methods. Sociopolitical, programming, and educational effectiveness factors were not included in this study.

The specific data developed and the system analysis method used provide a workable tool for the cost-effectiveness evaluations. The information in this report has been organized to serve as a reference for government agencies or corporations having interest in television broadcasting or distribution.

Past and present television communication by satellites has been limited to relaying to large, complex ground receiving terminals. Satellites for this type of existing service operate at very low levels of RF power output and low transmitting antenna gain. The current technological state of the art is adequate for the small, low-cost satellite of this type, a fact which has been demonstrated. The earth terminals for this type of service must, however, be extremely complex and costly and require an extensive supporting distribution system on the ground. To achieve attractive costs for a system with a large number of receivers, it is necessary to reduce earth terminal costs by orders of magnitude.

One of the goals of the study was to define total systems that are optimized in terms of specific service needs and projected means of payment. Both the ground and space segments of the systems were examined to ensure that the economics would be evaluated in the proper perspective. Because the number of possible specific services was so large, a wide range of parameters had to be examined. The scope of the satellite design requirements was extended from the low Effective Radiated Power (ERP) levels of the distribution type of service to the maximum ERP values permitted by the range of boosters studied, and the associated payloads, and the desired broadcast coverage areas on the ground.

Specific study objectives were to (1) define and examine in detail the technological and cost factors affecting feasibility of a TVBS in the 1970-75 time period through the synthesis of feasible satellite configurations, (2) develop parametric data for spacecraft subsystems, and (3) develop conceptual system designs. The objectives and scope required development of a large number of satellite and ground system configurations. In order to accomplish the study, a three-phase program was defined: System Technical Analysis, System Protoconcept Design, and Satellite Conceptual Design.

The supporting mission analysis and system synthesis task consisted of mission definition to arrive at potential TV services of value, an audience analysis to define the range of audience size to consider for each type of service, and a cost comparison model to enable comparison of satellite broadcasting with alternative terrestrial methods. A simplified block diagram of the study plan is shown in Figure 1-1, followed by a more detailed discussion of each phase.

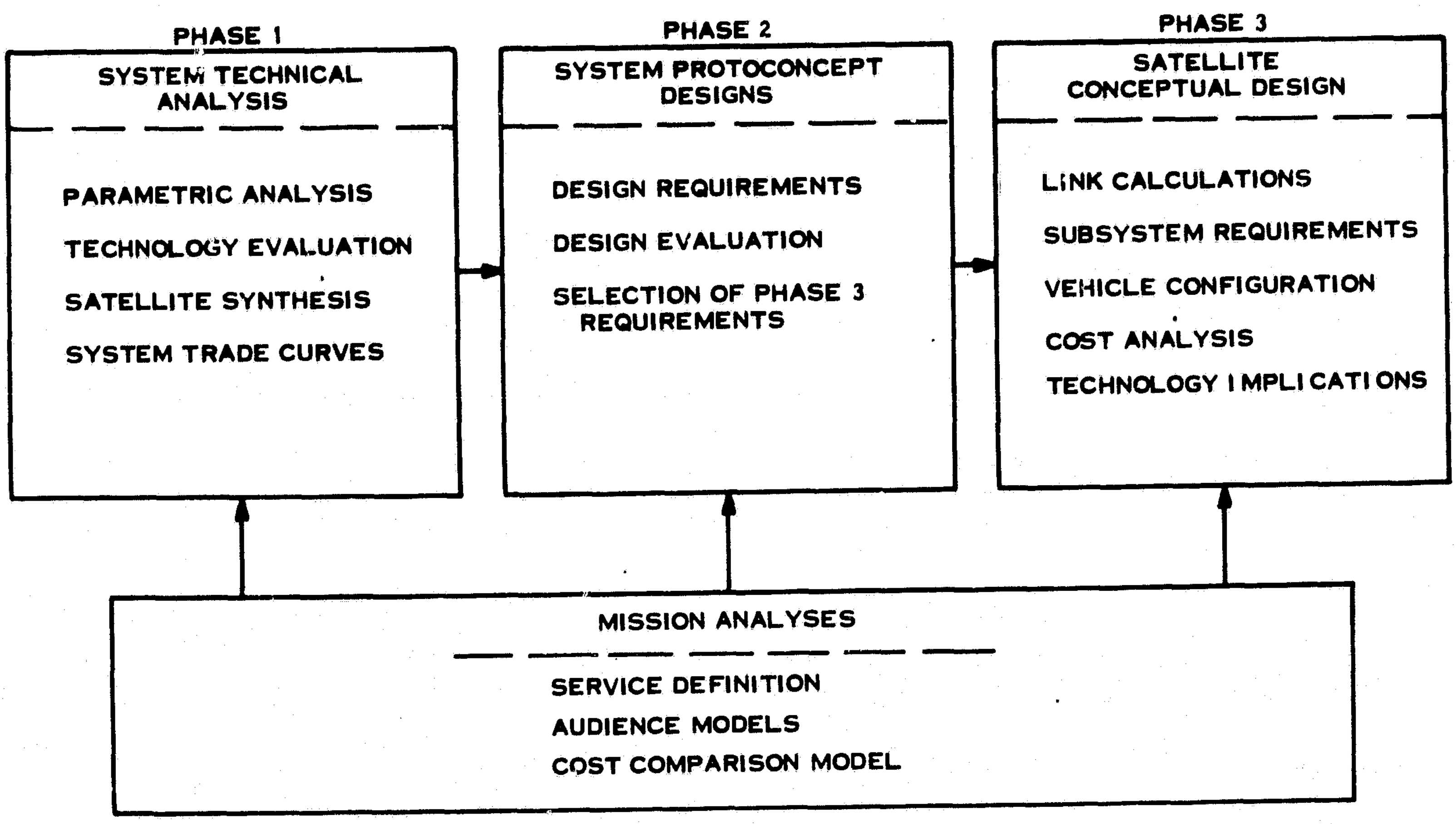


Figure 1-1. TVBS Program Plan

1.1 PHASE 1

Phase 1 was a system technical analysis that included parametric analysis of the ground and satellite subsystems, an evaluation of the current and anticipated state of the art in satellite subsystems, generation of system cost data for trade analysis, and definition of the design requirements for potential television satellite missions.

Phase 1 involved the generation of subsystem performance parameters of significance to the TVBS system (primarily, cost, weight, and power requirements) as a function of the critical design requirements. Where critical subsystem design requirements do not relate directly to broadcast parameters (e.g., structure, attitude control), subsystem design parameters were related to other significant satellite characteristics based on historical design information and engineering judgement. A GE system synthesis computer program was used to develop system cost data necessary for trade analysis.

1.2 PHASE 2

Phase 2 is a system protoconcept design for development of conceptual designs for a relatively large number of potential missions recommended by the GE Space Broadcast Advisory Board. The protoconcept design involved utilization of the results of the system synthesis computer program which generates satellite subsystem parameters and total satellite cost and weight factors. The computer results were modified to incorporate the results of the parametric analysis phase and were used to generate conceptual sketches of the orbital and launch configuration to preliminarily assess overall feasibility. These results were then evaluated by the Advisory Board, which recommended those configurations suitable for further study.

1.3 PHASE 3

Phase 3 is a satellite conceptual design to investigate the satellite aspects with four selected sets of mission requirements. Detailed link calculations were made to arrive at optimized satellite design criteria.

The Phase 3 designs were investigated to sufficient depth to assess design feasibility with respect to the orbital and launch configuration, to define critical technical problems and approaches to their solutions, to estimate development plans and schedules, and to make a detailed cost comparison with alternative methods.

SECTION 2

SUMMARY OF RESULTS

2.1 BOUNDARY CONDITIONS OF STUDY

A listing of the study scope of the contractual effort and of added constraints with respect to the range of parameters is presented in Table 2-1.

Table 2-1. TVBS Study Scope

Subject	Constraints
Launch vehicle	Atlas, Titan, and Saturn 1B class
Orbit	Geostationary
Earth coverage	1/2 to 10 million square miles (Center at subsatellite point)
Effective Radiated Power (ERP)	40 to 80 dBw
Repeater modulation	AM and FM
Transmitter frequency	470 to 890 MHz, 2 to 3 GHz, 8.3 to 8.5 GHz, and 11.7 to 12.7 GHz
Power sources	Any available by 1975
Duty cycle	One to 24 hours per day
Spacecraft life	Two-year minimum
Time period	1970-75
Technology base	1971 state of the art
Man-made noise levels	Urban, suburban, rural
Signal quality	TASO grades 1, 2, and 3 and CCIR relay quality
Audience size	$10\text{-}10^8$ receivers
Ground receiver cost	Direct = \$0-\$150 Special = \$1,000 to \$50,000

2.2 SCOPE OF THE STUDY

The scope and depth of the study is illustrated in Table 2-2. Listed are the types of data developed for the subject matter covered in each study phase. The balance of this report describes this data in detail.

Table 2-2. TVBS Study Results

Study Phase	Subject	Type of Data Outputs
Mission Analysis and Cost Models (Phases 1, 2, and 3)	TVBS services	Listing of candidate services
	TVBS audience	Potential receivers per service
	Terrestrial method costs	Cost models for alternative terrestrial methods
System Technical Analysis (Phase 1)	Parametric Data	Cost, weight, and size versus performance
	Ground receiver	Antenna, electronics, and line
	Satellite	Antenna, transmitter, power supply, thermal control, attidue control, propulsion, and structural subsystems.
	System Synthesis	Synthesis of Optimum System by Computer Program
	Ground signal model	Combination of electronics and antenna for given cost which produces minimum ERP requirement
	Satellite model	Synthesis of satellite subsystems requirements as function of ERP required
	System cost model	Satellite selection based on minimum satellite cost total system costs
	Technology Evaluation	State of the art, critical technology items, and ranking
	Ground system	(Modulation and frequency converters)
	Satellite system	Transmitters, antenna, power source, power conditioning, power transfer, thermal, attitude control/structure flexibility
Protoconcept (Phase 2)	Potential TVBS	13 conceptual designs with potential service description
System Conceptual Design (Phase 3)	Selected system conceptual design and description	Optimization analysis, link calculations, launch and orbital general arrangement drawings, satellite subsystem descriptions, program vosts and schedules for four selected systems.

2.3 MISSION ANALYSIS

2.3.1 POTENTIAL SERVICES

The services considered were characterized as being either "broadcasting" or "special service." Broadcasting is restricted to the meaning stated in the ITU/CCIR definition: "... a radio communication service in which the transmissions are intended for direct reception by the general public." Special service encompasses all other potential services that would not satisfy the above definition; it is defined by the ITU/CCIR as "... a radio communication service, not otherwise defined in this article, carried on exclusively for specific needs of general utility, and not open to public correspondence."

A large list of potential TV services with a wide range of transmission parameters was compiled and evaluated by the GE Space Broadcast Advisory Board. The Board is a panel of nine industry and university representatives who are nationally recognized authorities in their diverse fields of interest. Their fields of interest encompass the economic, technical, operational, financial, and educational considerations on an international level. The resultant list of potential (candidate) services is presented in Table 2-3.

2.3.2 AUDIENCE ANALYSIS

An audience analysis was performed to define the range of potential audiences in 1975 for each of the candidate services. Generic models were developed based on the type of service, economic levels, area sizes and population densities. Table 2-4 summarizes the range of results of the audience analysis for the service considered.

Table 2-3. Potential Space TV Services

NAME	GENERAL DESCRIPTION
	SPECIAL SERVICES
ITV	INSTRUCTIONAL TELEVISION FOR FORMAL CLASSROOM USE
"MEDICAL" TV	AN INSTRUCTIONAL SERVICE FOR MEDICAL OR OTHER POST-GRADUATE TRAINING
TV DISTRIBUTION	TO DISTRIBUTE TV SIGNALS FOR RETRANSMISSION BY TERRESTRIAL BROADCAST STATIONS
	BROADCASTING SERVICES
TV BROADCAST FOR THE AMERICAS	TO BROADCAST TV SIGNALS TO THE CONTINENTS OF NORTH AND SOUTH AMERICA
RTV	PROVIDE TV SERVICE TO RURAL, FRINGE AND LOW POPULATION DENSITY AREAS
GTV-D/E	GENERAL PURPOSE TELEVISION FOR DEVELOPING AND EMERGING NATIONS
CTV	CULTURAL TELEVISION FOR DEVELOPED AREAS
URBAN TV	TO PROVIDE TV SERVICE TO URBAN AREAS
UN-TV	WORLDWIDE SYSTEM OF DISSEMINATING UN, UNESCO, ETC

Table 2-4. Audience Analysis Results

SERVICE	NUMBER OF RECEIVERS		
	(MINIMUM)	(MAXIMUM)	
BROADCAST			
DIRECT BROADCAST	8500	51,000,000	RECEIVERS
SPECIAL			
INSTRUCTIONAL	3900	282,000	PRIMARY SCHOOLS
	235	42,000	SECONDARY SCHOOLS
	15	2,640	UNIVERSITIES
MEDICAL	60	20,700	HOSPITALS
DISTRIBUTION	5	14,100	TRANSMITTERS

2.3.3 TERRESTRIAL METHOD COSTS

The purpose of the terrestrial cost models was to define the system costs associated with transmitting a television signal from the originating source to the user by terrestrial means. This provided a basis for cost comparisons between terrestrial and satellite systems.

The cost models developed for comparison are based on certain assumptions made to permit modeling; however, the results are respresentative of realistic situations. The model assumes UHF stations transmitting at an ERP level of 1000 kw from antennas 1000 feet above ground. For these systems, the receiver is assumed to be a standard TV set with no preamplifiers; the antenna gain requirement is dependent upon distance from the station. Total system cost is a function of 2 elements: (1) the transmitting station installation and operation, and (2) the receiver installations. Since the receiving antenna installation cost is proportional to the distance from the station (and thereby inversely proportional to the number of transmitting stations and their total cost), there is an operating point for minimum cost dependent upon the number of receivers. In general, the minimum total cost occurs when the coverage radius is extended to a practical maximum by installation of high gain receiving antennas on towers at the fringe areas. Therefore, the coverage radii were established to be 52 miles for a direct service to a home or community receiver and 55 miles for special service receivers. This is based upon receiving antenna heights of 30 feet and 50 feet, respectively. In addition to the coverage radius, the second element determining the required number of stations is the desired portion of the area to be covered. Models chosen for comparison provide 85 percent for home/community coverage and 65 percent for instructional coverage. These values are comparable to existing terrestrial systems.

The initial investment and annual operating costs were determined by first establishing the costs of a single broadcast station and its share of the microwave link. The following variables were investigated in determining the system costs:

1. Type of Ownership. Commercial and governmental ownership was considered. These affect costs in that it is assumed that the government-owned system does not incur indirect costs, such as insurance and amortization of investment.

2. Type of Service. Direct broadcast or distribution services differ from educational services in that quoted microwave link rental rates are lower for educational services.

3. Percentage of Area to be Covered. This directly affects transmitter spacing and number of transmitters required.

4. Number of Channels.

5. Receiving Antenna Height. This also directly affects transmitter spacing.

For the purpose of this study, five unique sets of circumstances that would influence the costs were postulated. These considerations lead to the following models.

Model I: Commercial network with independently owned facilities and rented microwave link

Model II: Government ownership of stations and microwave links

Model III: Government ownership of stations with rental of microwave link at commercial rates

Model IV: Government ownership of stations with rental of microwave link at educational program rates.

Model V: Commercial ownership of stations with joint use of facilities and microwave rental at commercial rates.

The analytical form of the models is presented in Table 2-5, and the associated coefficients are presented in Table 2-6. All that is necessary to use the data is to know the required number of transmitters and transmitter spacing.

Table 2-5. Terrestrial Cost Models

MODEL NUMBER	INVESTMENT COST	OPERATING COST
I	$N\ C_2$	$N\ (D\ K_8+K_3+K_2)$
II	$N\ (D\ C_3+C_1)$	$N\ (D\ K_4+K_1)$
III	$N\ C_1$	$N\ (D\ K_7+K_1)$
IV	$N\ C_1$	$N\ (D\ K_6+K_1)$
V	$N\ C_1$	$N\ (D\ K_8+K_3+K_1)$

Where:

N is the number of broadcast stations required for a system

D is the distance between adjacent transmitters for the specific transmitter, receiving antenna

C is an investment cost associated with the type of ownership and the service of the system

K is an annual operating cost associated with ownership and service of the system

Table 2-6. Summary of Basic Cost Coefficients

	PARAMETER	NUMBER OF CHANNELS 1	2	3	4	5
INVESTMENT COSTS						
BROADCAST STATIONS ($\$10^3$)						
GOVERNMENT OWNED	C_1	549	1021	1481	1941	2871
COMMERCIALLY OWNED	C_2	549	1098		2196	3294
MICROWAVE LINK ($/MILE)						
GOVERNMENT OWNED	C_3	1500	2010		2950	4320
COMMERCIALLY OWNED(1)	C_4	1500	2010		2950	4320
ANNUAL OPERATING COSTS						
BROADCAST STATIONS ($\$10^3$)						
GOVERNMENT DIRECT COSTS	K_1	42	82	113	142	212
COMMERCIAL DIRECT COSTS	K_2	42	85		171	256
INDIRECT COST	K_3	52	99		193	288
MICROWAVE LINK ($/MILE)						
OWNED FACILITIES						
DIRECT COSTS	K_4	150	210		330	450
INDIRECT COSTS(1)	K_5	150	201		295	432
RENTED FACILITIES						
EDUCATIONAL TV	K_6	300	435		680	900
GOVERNMENT	K_7	480	700		1090	1440
COMMERCIAL	K_8	480	960	1440	1920	2880

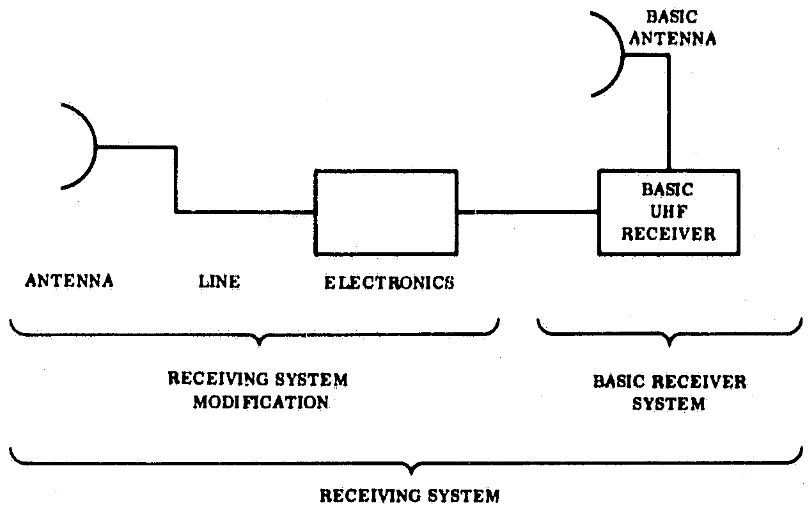
2.4 SYSTEM TECHNICAL ANALYSIS (PHASE 1)

2.4.1 PARAMETRIC DATA

This section presents examples of the subsystem and component data necessary for system cost optimization analysis.

2.4.1.1 Ground Receiver Equipment

In order to examine the cost and performance of the ground segment of the system, it was necessary to compile a set of data related to the portion of the ground receiver system, as shown in the following sketch.



This definition was used to permit relative cost evaluation of a satellite system with a competing terrestrial method; thus, it does not include components that would be common to both systems.

To provide a means of arriving at an optimum cost combination of components (as allocated to antenna or electronics), specific combinations of converter components were selected and cost estimates were made as a function of production quantity for varying performance. The converter components considered include different types of preamplifiers (normal, parametric, and cooled parametric) in combination with frequency and/or modulation converters, as required by the specific transmission case.

An example of the data generated is given in Figure 2-1, which shows the ground electronics data for X-band. Data was developed for the four frequency bands of interest and for the cases of Direct Broadcast or Special Service. To permit optimization of cost, the receiving antenna gain-cost relationship was assumed to be a continuous function. Typical data generated in Figure 2-2, which is for UHF.

2.4.1.2 Satellite Parametric Data

The cost, weight, and other significant characteristics of each satellite subsystem were developed as a function of the critical subsystem parameters that related to the performance requirements of the broadcast service. Example curves of subsystem data developed for weight versus the appropriate parameter are given for the power, attitude control, antenna, and structural subsystems in Figure 2-3 through 2-6. Example curves of the parametric

CONFIGURATION	NF (db)	UNIT COST ($) QUANTITY				
		10	10^2	10^3	10^4	10^5
FREQ CONVERTER + FM DEMOD	9.0	73	44	28	18	13
FREQ CONVERTER + PREAMP + FM DEMOD	5.2	84	51	32	21	14
FREQ CONVERTER + PARAMP + FM DEMOD	1.9	1546	903	528	309	183
FREQ CONVERTER + COOLED PARAMP + FM DEMOD	1.0	38K	22K	13K	8K	4K

Figure 2-1. Ground Electronics (8.4 and 12.2 GHz)

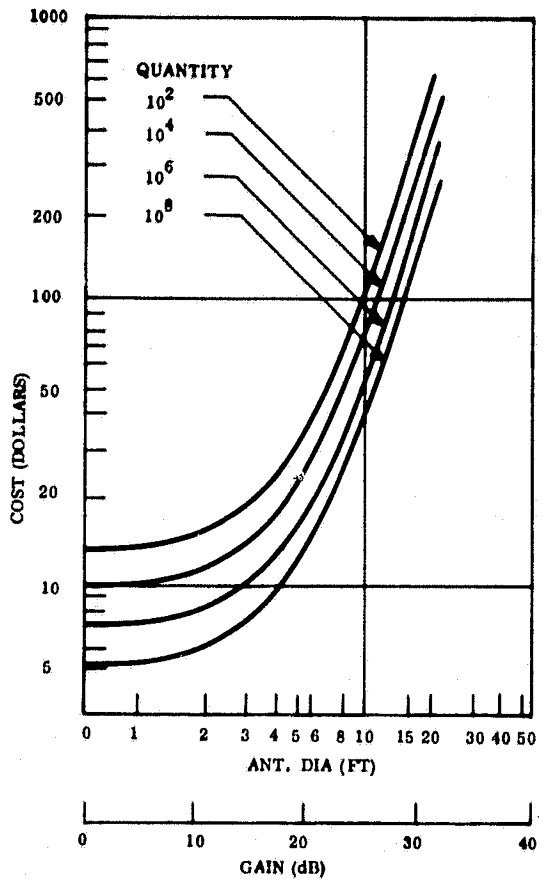


Figure 2-2. 0.8 GHz Ground Antenna Costs

cost data developed are presented in Figures 2-7 through 2-10, for the power, attitude control, transmitter, and heat pipe thermal control subsystem. Examples of additional subsystem parametric data that was necessary for system analysis are shown in Figures 2-11 through 2-14, which show transmitter efficiency, solar array area, and thermal radiator area. The curves are representative of the large amount of parametric data developed during this study and are presented to show the type of results achieved.

2.4.2 SYSTEM ANALYSIS

Extensive system feasibility and cost analysis for the wide study scope was required. A GE computer program developed before the start of the TVBS study contract was applied to the range of parameter requirements (see Table 2-1) to relate system costs to performance requirements. This GE computer program is the Parametric Analysis and Concept Evaluation System (PACES). The major components of this computer model are: (1) a receiver synthesis model, (2) a satellite synthesis model, and (3) a system cost model. The interrelation of these three models is shown in Figure 2-15.

The basic purposes of this computer program are to: (1) determine the lowest cost system to provide any specific service, and (2) to systematically explore the effects of variations of the major system and subsystem parameters on system costs.

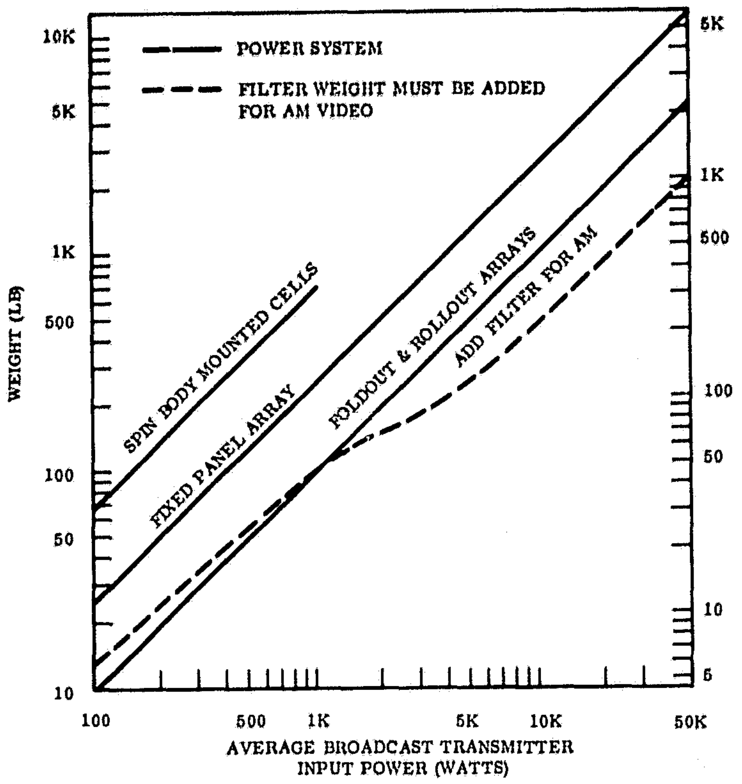


Figure 2-3. Power Subsystem Weight versus Broadcast Transmitter Power

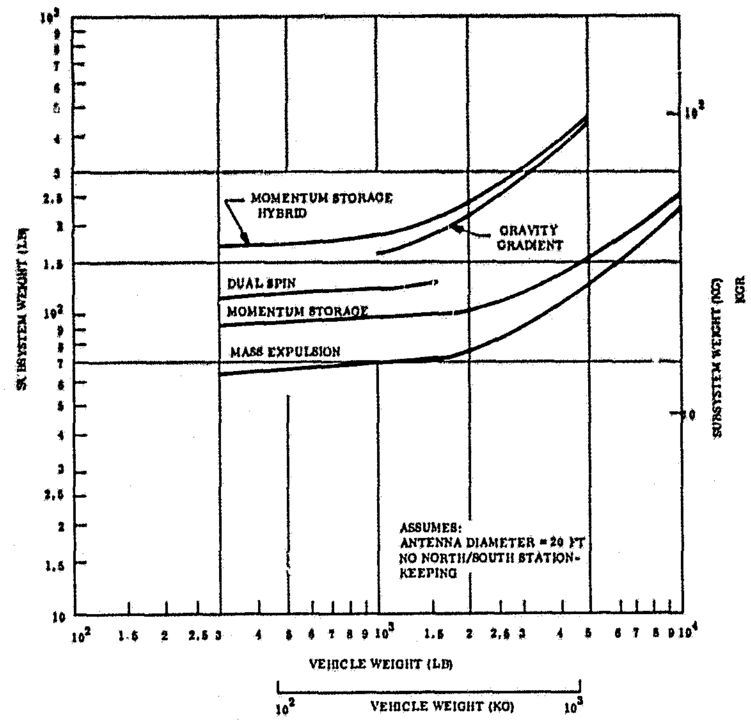


Figure 2-4. Attitude Control Subsystem versus Vehicle Weight

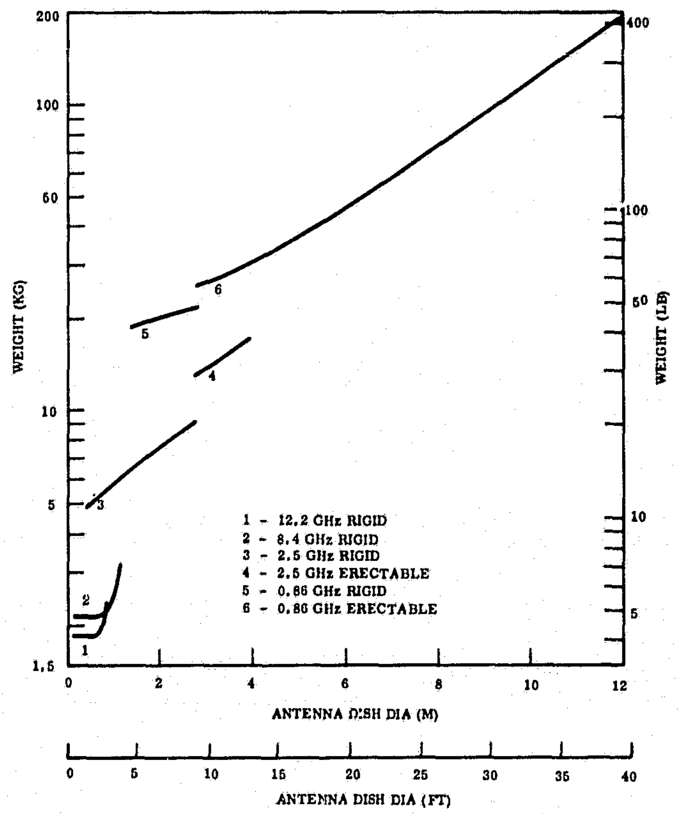
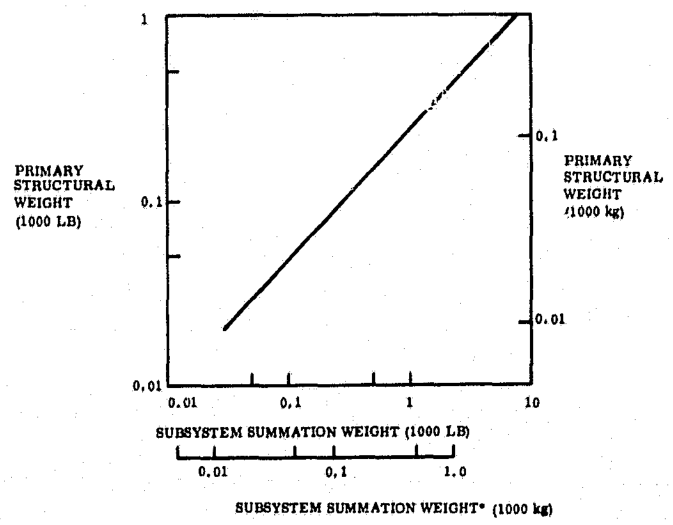


Figure 2-5. Paraboloid Antenna Weight versus Diameter



*INCLUDES ANTENNA, TRANSMITTER, POWER, ATTITUDE CONTROL, THERMAL CONTROL, RECEIVER-EXCITER.

Figure 2-6. Structural Subsystem Weight

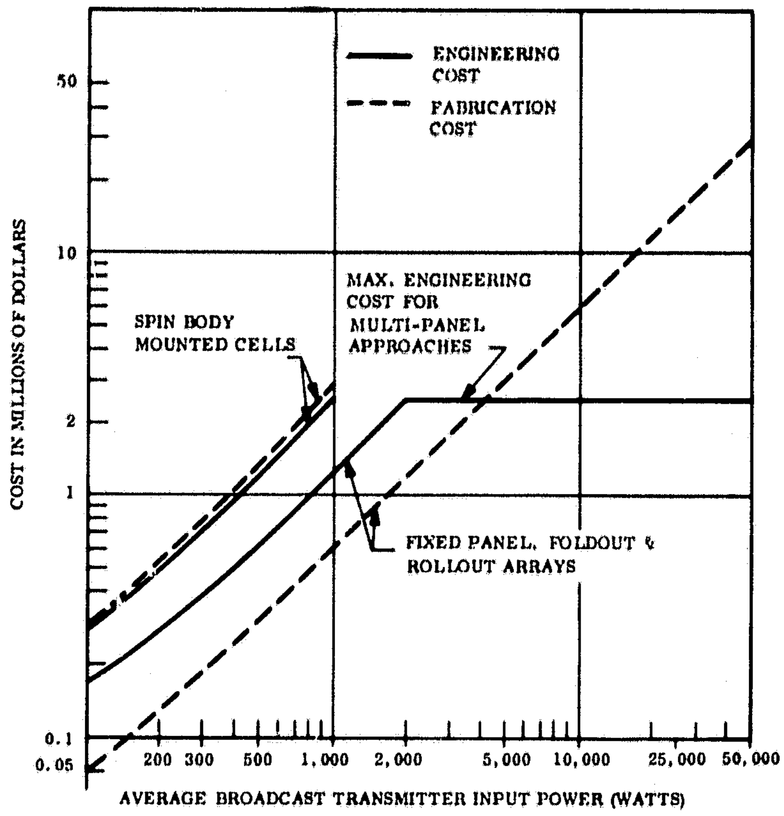


Figure 2-7. Power Subsystem Costs versus Broadcast Transmitter Power

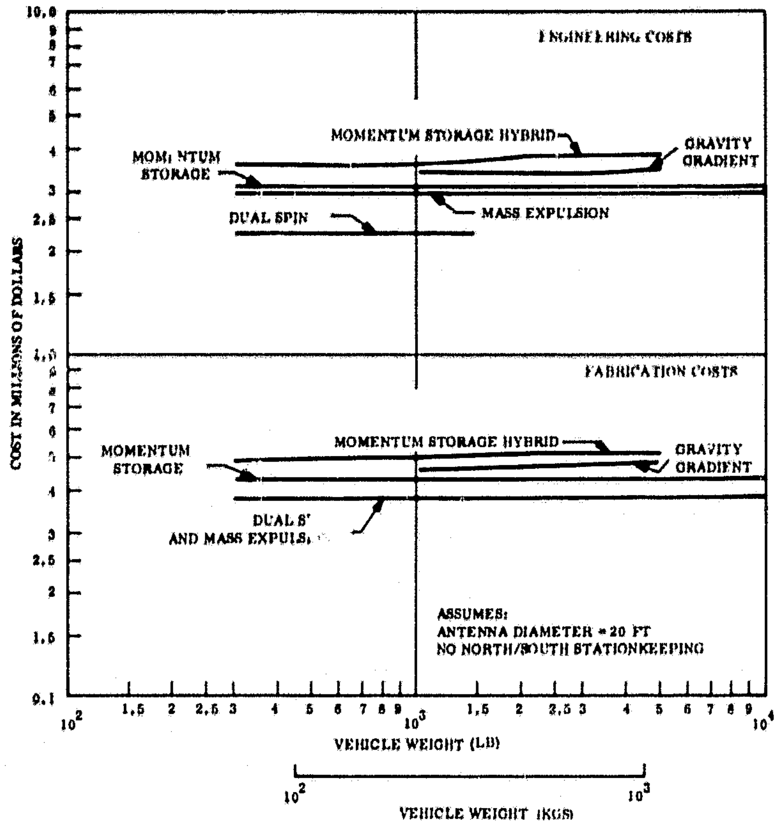


Figure 2-8. Attitude Control Subsystem Costs versus Vehicle Weight

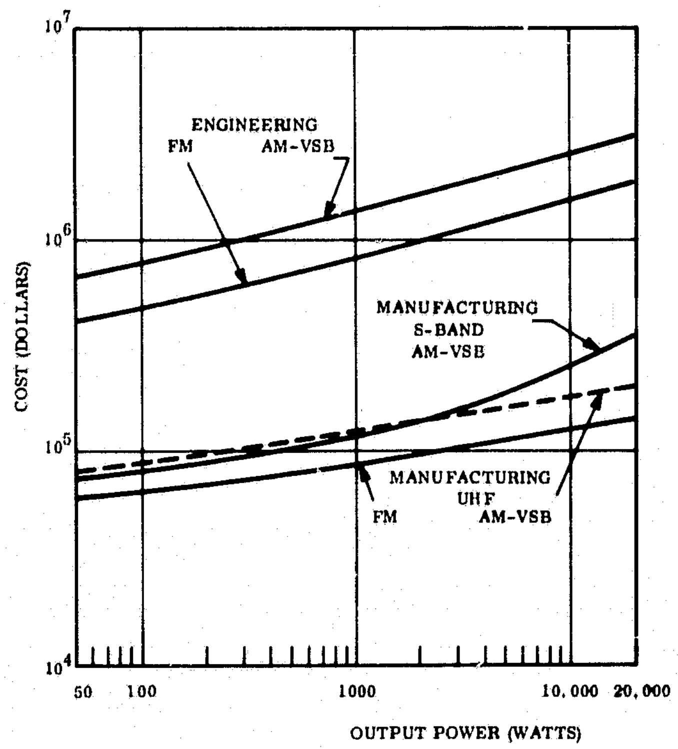


Figure 2-9. CFA TV Transmitter Cost

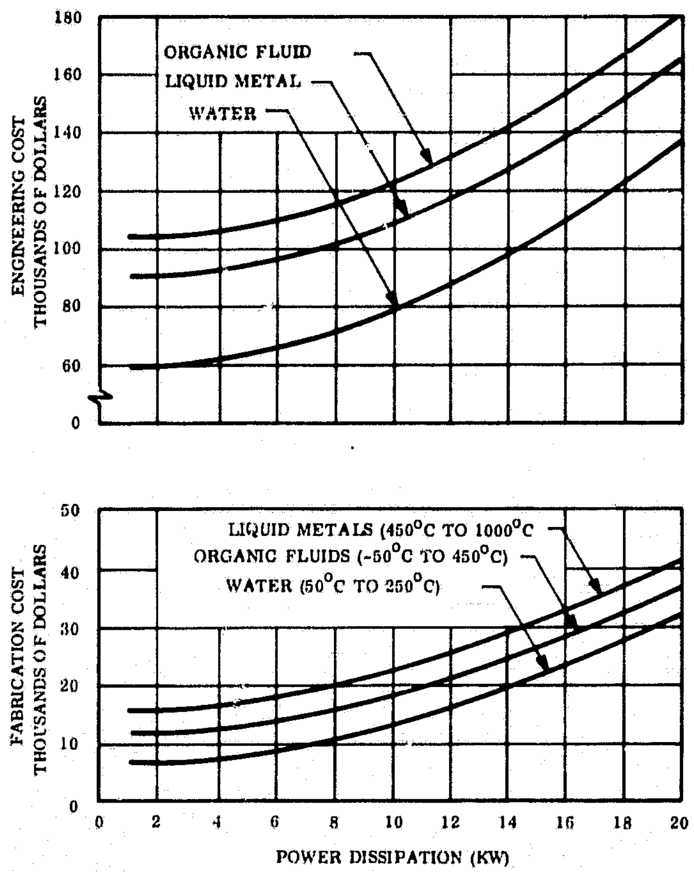


Figure 2-10. Heat Pipe System Cost

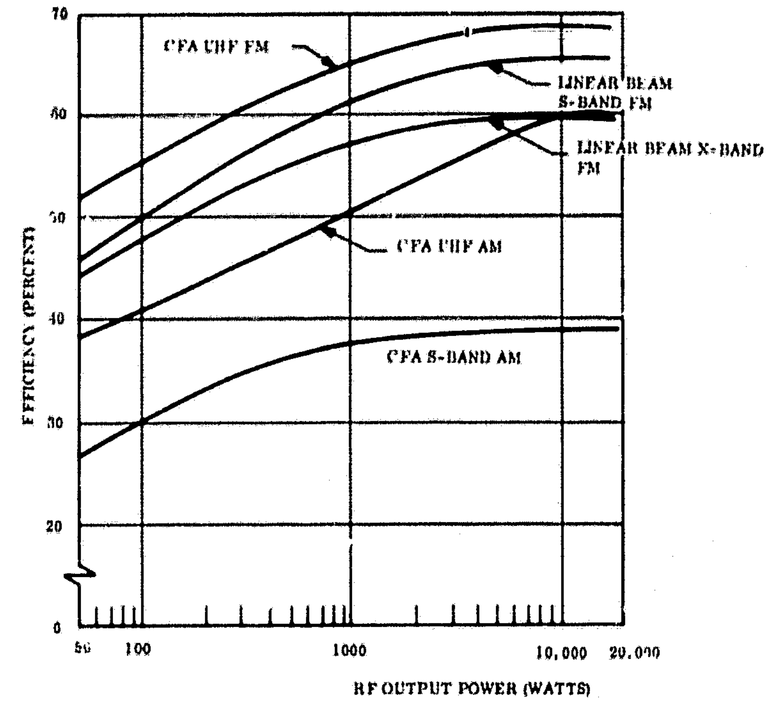


Figure 2-11. Microwave Tube Transmitters Efficiency

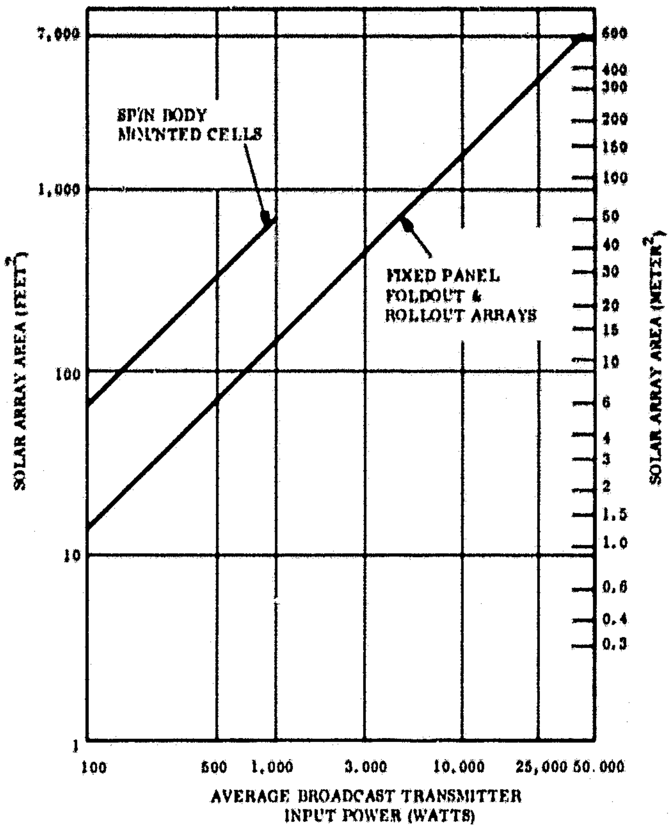


Figure 2-12. Solar Array Area versus Power Requirement

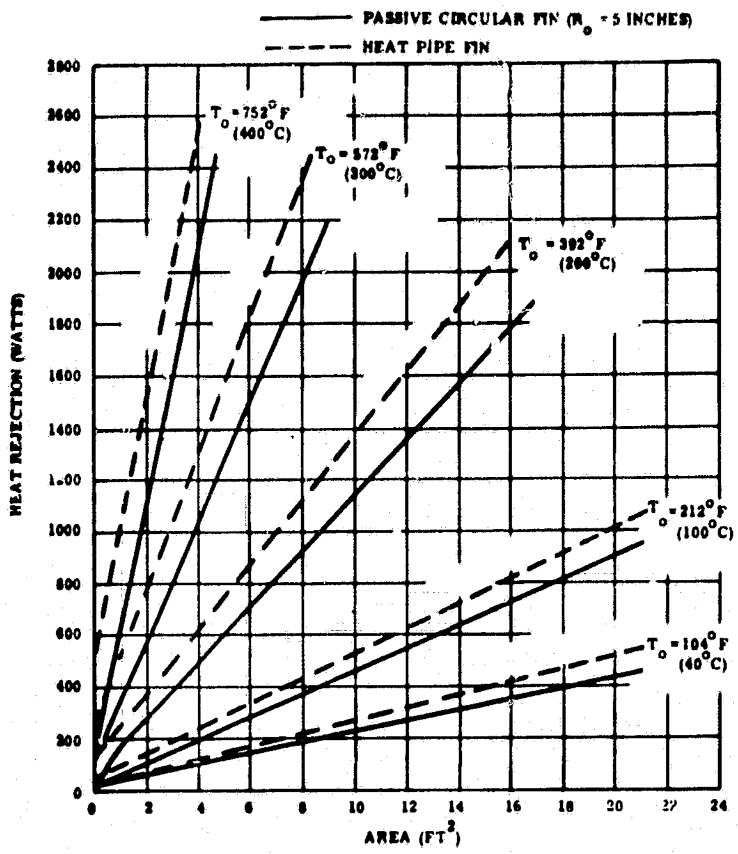


Figure 2-13. Radiator Area Characteristics

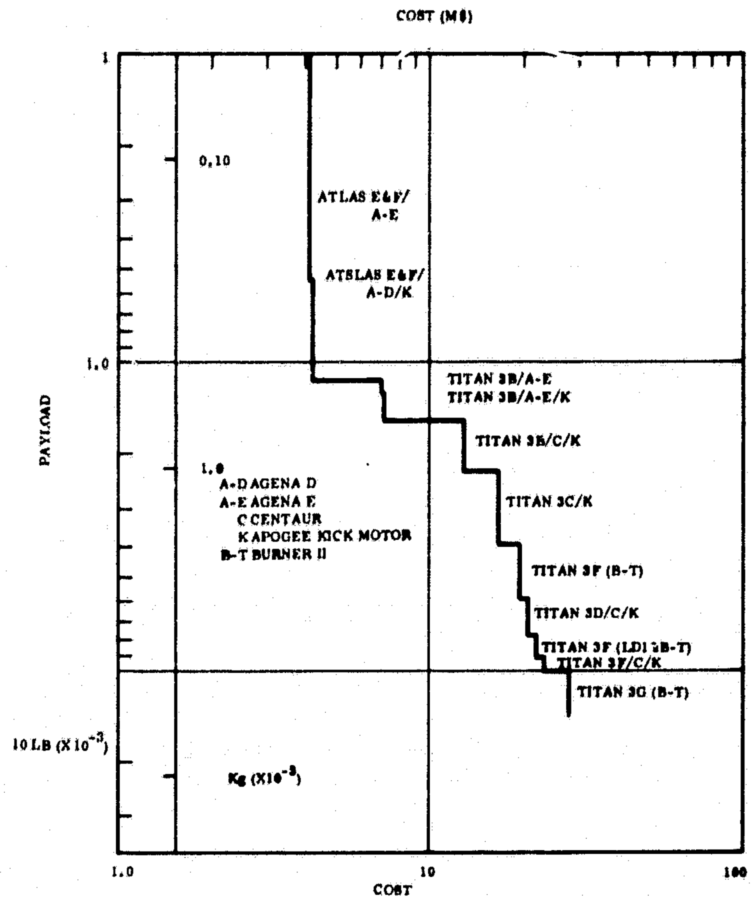


Figure 2-14. Launch Vehicle Cost versus Payload Weight

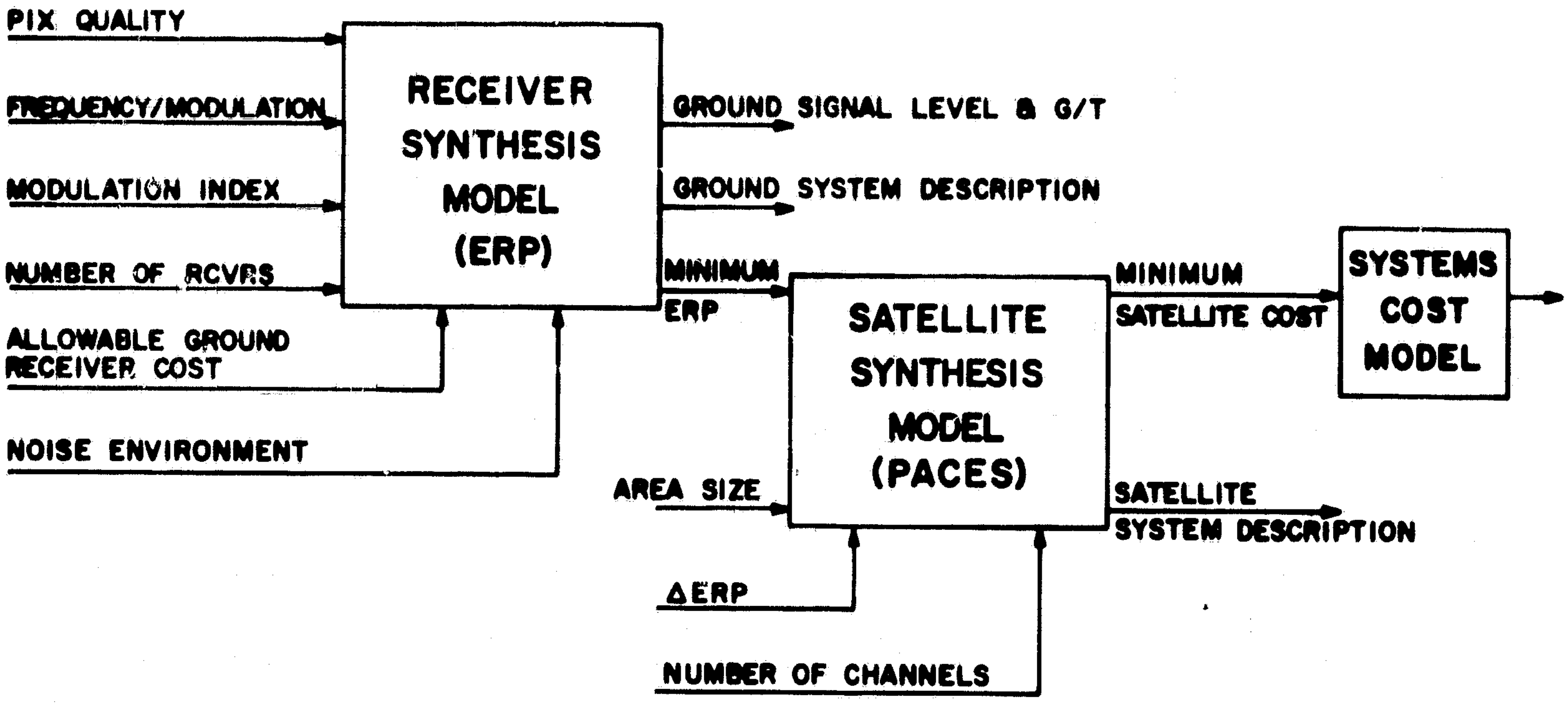


Figure 2-15. PACES Computer Synthesis Model

2.4.2.1 Receiver Synthesis Model

This model defines the maximum performance that can be achieved within a specific ground receiver cost limit. This receiver cost is the installed cost of the antenna, electronics, and the interconnection necessary to receive the satellite signal and supply an output capable of driving standard home television receivers or, in the case of special services, providing baseband output. Maximum performance results in the minimum effective radiated power (ERP) required from the satellite. The model operates on the input parameters of picture quality, frequency/modulation, modulation index, number of receivers, noise environment and the allowable cost per receiver. Where not defined as an input, the model will select that modulation index resulting in the minimum signal level.

The basic aspproach was to solve the link equation associated with RF transmission from synchronous altitude for all possible combinations of input service variables and electronic component performance characteristics. It was necessary to set this up for solution on a digital computer to examine the large number of input cost values desired and to iterate through the variety of electronics components and antenna data for all of the combinations of frequency, modulation audience size, noise location, and picture quality.

One use of this model is to develop curves showing the variation of required ERP as a function of the amount of ground receiver dollars (for each of the values of picture grade, frequency, modulation, noise environment, and number of receivers). Figure 2-16 is an example output for a frequency of 2.5 GHz, AM modulation, an urban noise environment, and 10^6 receiving stations. The model also defines the antenna and receiver electronics performance and cost which results in maximum performance for any specific total ground receiver cost.

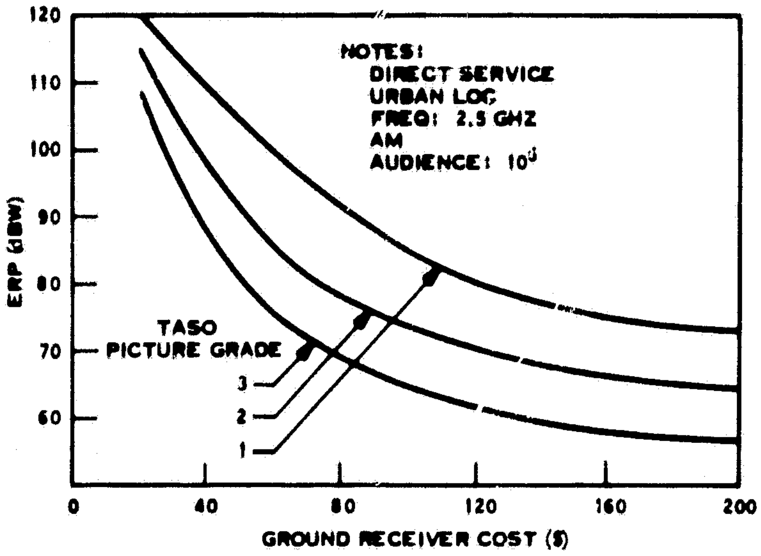


Figure 2-16. Signal Strength Requirements

2.4.2.2 Satellite Synthesis Model

The Satellite Synthesis model operates on the required ERP, the number of video and audio channels, and the desired coverage area size to define the combination of satellite subsystems that meets the performance requirements for minimum cost. It also defines the cost, weight, and performance for each subsystem. In addition, the model accepts inputs to adjust the ERP requirement (ΔERP) to account for the location of the coverage area and ionospheric and atmospheric transmission losses. Satellite subsystems are represented in the model in terms of engineering cost, manufacturing cost, and weight as a function of subsystem performance. The antenna, transmitter, power, attitude control, thermal control, structures, and propulsion subsystems are considered as variables in the model; other subsystems (e.g., TT&C) are treated as fixed points. The model considers antenna pointing accuracy ranges from 0.05 to 5 degrees. For each accuracy assumed, the required antenna beamwidth is defined for the required coverage area. This defines the antenna gain, and, therefore, the RF power output required to supply the defined ERP. The satellite power requirement is then a function of the transmitter dc to RF efficiency. Structural and propulsion subsystem weight requirements are calculated as functions of the summed weight of other subsystems. All the subsystem characteristics, primarily weight and cost, are then summed to represent the total satellite requirements. The minimum size booster capable of launching the satellite into geostationary orbit is selected and the subsystem data are combined to produce the overall satellite cost. Thus, the output of this segment of the computer model is subsystem characteristics, and their summations as required, and selection of the launch vehicle..

2.4.2.3 System Cost Summation Model

Outputs of the ground and space segment models are combined in the systems cost model to derive the system costs, which include management, supporting system investment, operational costs, and amortization. All reasonable combinations of the technical parameters are considered and the resultant costs in various forms are defined. The system costs generated by this model are:

1. Satellite Engineering Development Cost (SEDC) = design, development, and test for spacecraft and design and development of support equipment (i.e., AGE and manufacturing tooling).

2. Satellite Annual Operation Cost (SAOC) = 1/2 (satellite manufacture and launch vehicle), plus support subsystem operation (i.e., uplink, telemetry and control operation), plus 1/10 satellite ground investment (i.e., uplink, AGE, and manufacturing tooling).

3. Total Satellite Cost (TSC) = SEDC, plus 2 SAOC (note: this covers the initial 2 years of operation).

4. Total System Implementation Cost (TSI) = SEDC, plus 10 SAOC, plus unit ground receiver costs times the number of receivers (note: this covers the initial 10 years of system operation).

This cost portion of the program is operated directly in conjunction with the satellite iterative routine for antenna pointing accuracy, and the combination providing minimum SAOC is selected as the synthesized satellite. However, data output for all of the pointing accuracy options examined may be printed out.

2.4.3 SYSTEM TRADE DATA

The primary usage of the PACES computer program was to obtain overall system data to be used for cost-effectiveness analysis of broadcast service parameters. The output was system trade curves (Top Level Trade Curves) in the form of system cost data versus the ground receiving modification costs for varying coverage area size for each desired combination of the following broadcast service parameters: (1) type of service, (2) picture grade, (3) noise location, (4) frequency, (5) modulation, and (6) audience size. The ground receiver modification costs are called delta dollars (Δ \$). More than 4000 Top Level Trade Curves were generated with the combined computer mode.

Figure 2-17 is an example of the trade curve analysis, which shows how optimum operating points may be precisely located. The curves show SAOC and TSI plotted for two values of audience size as functions of Ground Receiver Cost, and with varying size of coverage area. The particular broadcast service would be a Special Service operating at 8.4 GHz/FM and would be providing 18 channels of CCIR Relay quality. The satellite annual operating cost decreases rapidly with receiver cost increase until about \$5000 expenditure, at which point the satellite is at near minimum in power requirements. The total system costs parallel the satellite costs for the low audience number (100) reflecting the domination of satellite costs. Ground costs clearly dominate the 1000 receiver case, where the total system costs increase rapidly with receiver cost at about \$5000. This indicates the false economy of using low power satellites and large expensive ground stations.

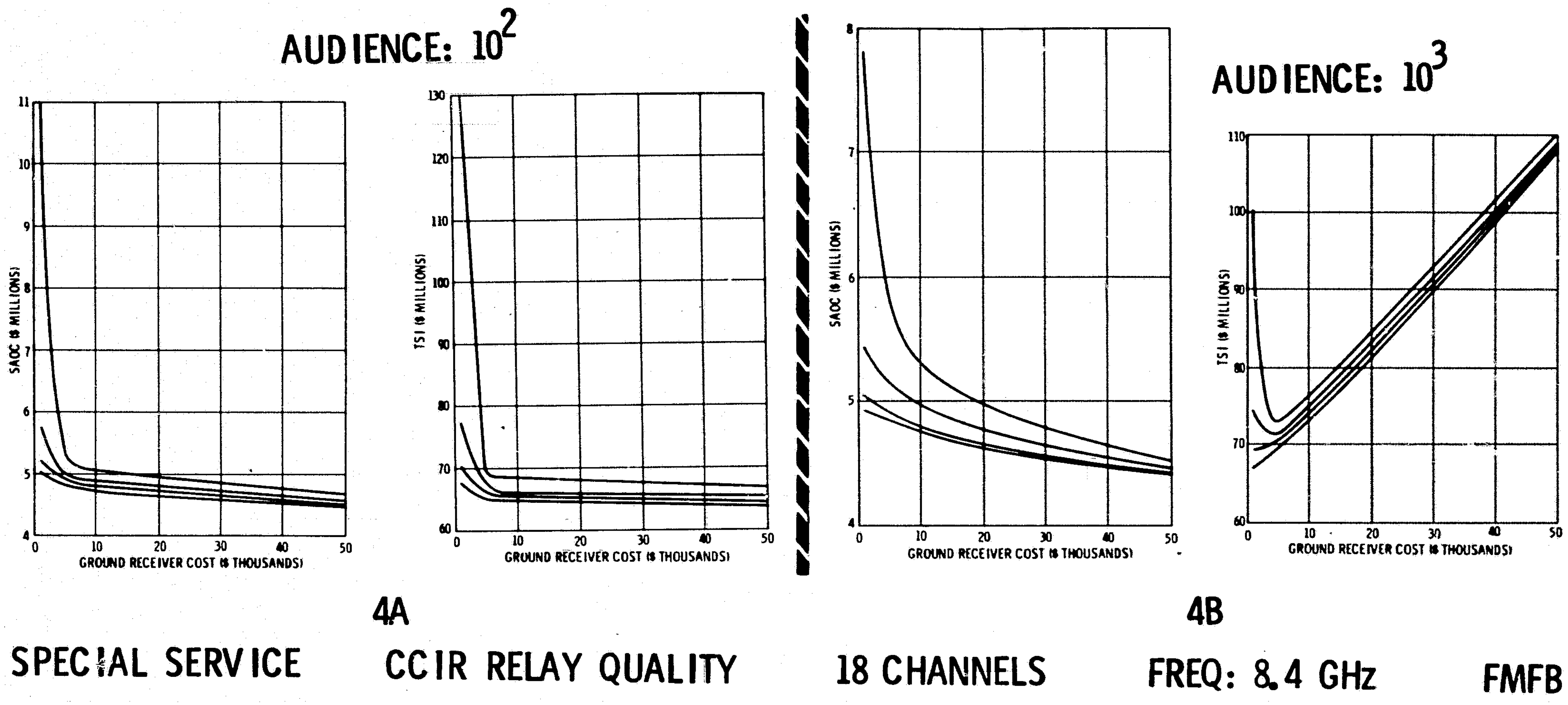


Figure 2-17. Television Broadcast Satellite Systems Cost Curves

2.5 SYSTEM PROTOCONCEPT DESIGNS (PHASE 2)

The general types of potential TV broadcasting services and parameter ranges of interest are listed in Table 2-1. Specific parameter values from Table 2-1 for selected services are shown in Table 2-6. These served as a basis for the generation of the TVBS protoconcept designs. All of the specific combinations were run on the PACES computer program, and the output data was compared with the purpose of selecting the minimum cost combinations consistent with all other criteria.

Table 2-6. TVBS Operational Requirements

Service Name	Example Target Area	Area $X 10^6$	Audience	Number Channels V - A	Signal Grade	Loc.	$\$\Delta$	Freq GHz	Modulation	ΔERP
DIRECT SERVICE										
*UN	- Africa	10	10^6	1-4	3	U	50	0.8	AM	1.38
Cultural	- USA	3	10^6	1-1	2	U	150	2.5	FM	0.83
*Cultural	- USA	3	10^6	1-1	2	U	150	0.8	AM	0.80
Cultural	- USA	3	10^6	1-1	1	U	150	12.2	FM	2.11
*Cultural	- USA	3	10^6	1-1	1	U	100	12.2	FM	2.11
Americas	- Cent. & So. America	3	10^6	1-2	3	S	50	0.8	AM	1.04
Rural/Suburban	- Australia	3	10^6	1-1	3	S	50	0.8	AM	0.34
*Rural/Suburban	- Australia	3	10^6	3-1 ea	3	S	50	0.8	AM	5.66
*Gen. Purpose (Community)	- India	1	10^6	1-4	2	U	50	0.8	AM	1.38
*Urban	- W. Europe	1	10^8	1-4	1	U	100	0.8	AM	2.48
*Urban	- W. Europe	1	10^8	2-4 ea	1	U	100	0.8	AM	5.64
Urban	- W. Europe	1	10^8	1-4	1	U	100	12.2	FM	3.64
*Urban	- W. Europe	1	10^8	1-4	1	U	65	12.2	FM	3.64
Urban	- W. Europe	1	10^8	1-4	2	U	50	0.8	AM	2.48
*Community	- India	1	10^6	1-4	2	U	50	0.8	FM	1.38
SPECIAL SERVICE										
*Instructional	- All USA	2-10^6	10^4	(6-1 ea)/Area	1	R	1K	2.5	AM	12.95
Instructional	- All USA	2-10^6	10^4	(6-1 ea)/Area	1	U	1K	12.2	FM	14.86
*Professional (Medical)	- USA	1/2	10^3	1-1	0	U	5K	12.2	FM	2.11
*TV Distribution	- All USA	3-1/2	10^3	(6-1 ea)/Area	0	U	5K	8.4	FM	16.07
TV Distribution	- USA	3-1/2	10^3	(6-1 ea)/Area	0	U	2K/3.5K	8.4	FM	14.1
*Americas	- Cent. & So. America	10	10^3	1-2		R	5K	2.5	FM	1.07
Americas	- Cent. & So. America	10	10^3	1-2	0	U	1K	8.4	FM	1.48

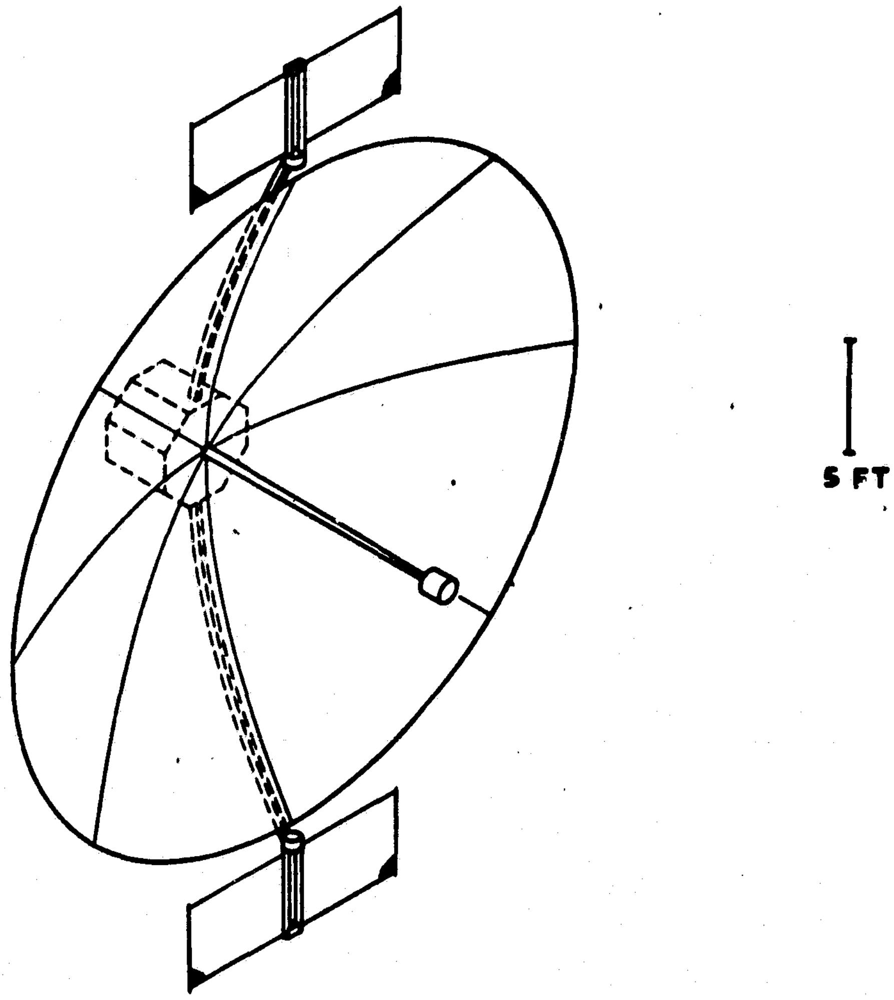
NOTE: V = Video Channel

A = Audio Channel

* = Selected for Protoconcept Design

Examination of the PACES results indicated that specific sets of satellite design parameter combinations would satisfy more than one desired mission, this "commonality" principle then permitted reduction of the number of protoconcepts to 13.

The protoconcept design phase then resulted in the evolution of 13 conceptual designs compatible with the requirements. The basic objective was to assess the feasibility of attaining practical satellite launch stowage and orbital configurations. An example of one of the designs is presented in Figure 2-18, along with a description of the potential mission.



(BROADCASTING SERVICE) COMMUNITY TELEVISION

A COMMUNITY TELEVISION SERVICE IS INTENDED PRIMARILY FOR USE IN EMERGING COUNTRIES THAT COULD NOT HAVE A NATIONAL TELEVISION SERVICE BY OTHER MEANS. EXTENSIVE USE OF RECEIVERS LOCATED AT COMMUNITY CENTERS, RATHER THAN IN HOMES, WOULD BE MADE. BECAUSE OF ITS SPECIALIZED AUDIENCE, COMPATIBILITY WITH EXISTING TELEVISION IS LESS IMPORTANT THAN COST.

THE SERVICE IS A COUNTRYWIDE EXTENSION OF THE "TELECLUBS" WIDELY USED WHEN TELEVISION IS BEING INTRODUCED, AND IS ALSO AN EXTENSION OF THE INFORMAL COMMUNITY VIEWING COMMON WHERE TELECLUBS ARE NOT FORMALLY ORGANIZED.

PROGRAMMING CHARACTERISTICS WOULD BE IDENTICAL TO THOSE FOR GENERAL TELEVISION.

Figure 2-18. TVBS Protoconcept Configuration

2.6 SYSTEM CONCEPTUAL DESIGN (PHASE 3)

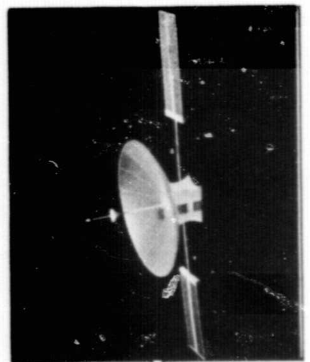
Four representative TVBS systems were examined to sufficient depth to establish feasibility, estimate cost, and compare costs to alternative terrestrial systems. Three of the systems were considered representative of operational TVBS systems. These were selected as a result of the evaluation of Phase 2 protoconcept designs. The fourth system (demonstration mission) was defined to encompass a wide range of mission requirements that would demonstrate a corresponding range of subsystem performance parameters.

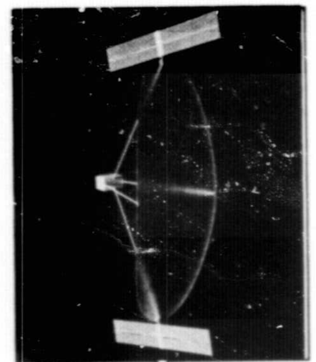
The three satellite systems selected as representative of operational TV space broadcasting were (1) a direct community TV service to India with an added distribution service, (2) a direct rural/suburban TV service to Alaska and, (3) a special instructional TV service to the continental United States. The demonstration satellite system is to provide a TV signal to interested technical and user audiences in the U. S. The baseline requirements for the four systems are shown in Table 2-7. The design description of the resulting systems is shown in Table 2-8. Descriptions of the example services and the key results of the design analyses follow.

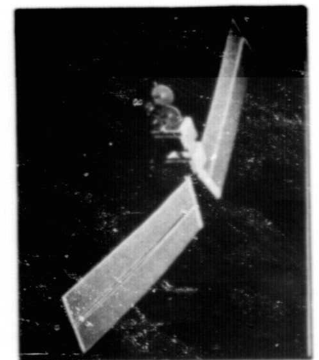
Table 2-7. TVBS Phase 3 Baseline Requirements

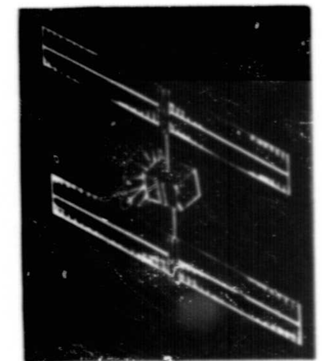
SERVICE DESCRIPTION	FREQUENCY (GHz)	MODULATION	COVERAGE AREA	SIGNAL QUALITY	RECEIVER COST ($)	NUMBER OF CHANNELS
COMMUNITY-DIRECT	0.8	FM	INDIA	2	< 50	1V/4A
REBROADCAST-SPECIAL	8.4	FM	INDIA	CCIR RELAY	1000–5000	1V/4A
RURAL/SUBURBAN-DIRECT	0.8	AM	ALASKA	2	<100	3
INSTRUCTION-SPECIAL	12.2	FM	USA	1	1000	6 EA TO 2 AREAS
DEMONSTRATION SATELLITE	2.5	FM	45°N-10°S	0/1	5000/150	2
	2.5	AM	45°N-10°S	0	1000	1
	12.2	FM	45°N-10°S	0/1	5000/1000	2

Table 2-8. Baseline Requirements for Four Possible Systems









	CASE I COMMUNITY/DISTRIBUTION SERVICE TO INDIA		CASE II DIRECT SERVICE TO ALASKA	CASE III INSTRUCTIONAL SERVICE TO U.S.	CASE IV DEMONSTRATION MISSION TO US
SATELLITE WEIGHT, LBS.	752		2043	983	2036
BOOSTER (CAPABILITY, LBS.)	ATLAS E/AGENA D/KICK (910)		TITAN 3B/CENTAUR/KICK (2260)	ATLAS E/AGENA E/KICK (910)	ATLAS (SLV-3C)/CENTAUR/KICK (2267)
SATELLITE DESCRIPTION	FIG. 7		FIG. 9	FIG. 11	
SI SOLAR CELL PANELS	2 AT 72 FT^2		4 AT 171 FT^2	2 AT 145 FT^2	[illegible] AT 2.00 FT^2
TOTAL CELL AREA (FT^2):	124		621	259	779
POWER LEVEL AFTER 2 YRS (KW):	1.1		5.5	2.3	7.0
ANTENNA TYPE & SIZE	2 CONCENTRIC PARABOLAS 21 FT (0.8 GHz), 2 FT (8.4 GHz)		ELLIPTICAL SEGMENT OF PARABOLOID 29 FT x 80 FT	4 PARABOLAS 2 AT 1.4 FT; 2 AT 2.25 FT	[illegible] PARABOLAS 9.0 FT (2.5 GHz) ; 1.4 FT (12.2 GHz
CONSTRUCTION:	DEPLOYABLE (UMBRELLA) AND RIGID		INFLATABLE WIRE GRID	RIGID	RIGID
GAIN & HPBW:	BOTH 4.1° CIRCULAR/32 DB		1.1° x 3.1°/39 DB	4.1° CIRC./32 DB; 2.5° CIRC./36.3 DB	3.0° CIRC./34.5 DB; 4.1° CIRC./32 DB
BEAM POINTING (.05° ACCURACY):	ANTENNA ELECTRICAL AXIS USING RF INTERFEROMETER		FEED TRANSLATION USING RF INTERFEROMETER	ORBIT INCLINATION FOR ELEVATION CONTROL, RF INTERFEROMETER FOR AZIMUTH POSITIONING	ORBIT INCLINATION FOR ELEVATION CONTROL, RF INTERFEROMETER FOR AZIMUTH POSITIONING
TRANSMITTER TYPE	CFA	TWT	CFA (SEPARATE VIDEO AND AUDIO)	TWT	CFA (S-BAND AM)(SEP. VID.& AUD.)
AVG RF POWER OUTPUT CH (W):	416	20	505	70 (MAX)	1830
OVERALL EFFICIENCY OF TRANSMITTER SYSTEM (%):	58	35	42	34	37
ATTITUDE CONTROL TYPE	3 AXIS ACTIVE-MOMENTUM WHEEL		3 AXIS-MOMENTUM WHEEL (FLYWHEEL AUGMENTED)	3 AXIS ACTIVE-REACTION CONTROL SYSTEM AUGMENTED WITH PITCH FLYWHEEL	3 AXIS ACTIVE-REACTION CONTROL SYSTEM AUGMENTED WITH PITCH FLYWHEEL
PERFORMANCE					
SATELLITE ERP/CH. (DBW):	58	45	71	50 (MAX)	71
FIELD STRENGTH (μV/M):	122	18	420	24	437
(REQ'D/ACT.) COVERAGE AREA, 10^6 MI^2:	1.1/2.3		0.6/≈1.2	3/≈7.6	-1/≈3.0
PICTURE QUALITY (TASO GRADE/S/N):	2/39.5 DB	CCIR RELAY/56.5 DB	2/39.5 DB	1/50.5 DB	1
AUDIENCE SIZE:	0.5×10^6	100	10^5	10[illegible]	
GROUND STATION COST ($):	50	2885	100	1100	2110
COST COMPARISON - TOTAL 10 YEAR PROGRAM					NOT APPLICABLE
SATELLITE ($ M):	87		155	95	
TERRESTRIAL ($ M):	151		325	1284	
TERR. TO SAT. RATIO:	1.7		2.1	13.5	

2.6.1 COMMUNITY/DISTRIBUTION SATELLITE FOR INDIA

2.6.1.1 General System Considerations

This system would provide a greatly needed instructional, educational, and information dissemination service for developing nations. By providing a simple community receiving system (minimal operation and maintenance requirements), audio-visual presentation can be implemented rapidly by utilization of broadcast satellites. India is a good example of this type of nation because its population is clustered in villages and spread over a large area. Because this type of service is directed toward nations in which use of the RF spectrum is now minimal, the broadcast service parameters can easily be optimized on a cost-effectiveness basis. A distribution service, at 8.4 GHz, was added in this satellite to deliver signals to ground television stations in the major cities.

The community service is the more demanding of the two services; thus, it is selected as the critical design condition for optimum satellite performance. Minimization of TSI cost is the optimization criterion used, since one entity would be likely to bear the entire cost. Figure 2-19 shows that TSI cost is minimized at an expenditure of approximately $50 on the ground receiver equipment, operating at UHF with frequency modulation. (Estimates are based on U. S. costs. Adjustments may be needed for other countries to obtain absolute values, but the relationships shown would remain constant.) A description of the selected ground receiver equipment is presented in Table 2-9 for the two services.

Table 2-9. Receiver Component Characteristics for TV Service to India

COMPONENT	DESCRIPTION	
	COMMUNITY SERVICE	DISTRIBUTION SERVICE
ANTENNA		
TYPE	HELIX	PARABOLOID
SIZE	12 INCH × 5 INCH DIA	13.9 FT DIA
HPBW (DEGREES)	49	0.59
GAIN (dB)	10	48.4 NOM (47.1 NET)
COST-INSTALLED ($)	37.00	2045.00
ELECTRONICS		
TYPE	PREAMP + MODUL CONV	PARAMP + FREQ AND MODUL CONV
NOISE FIGURE (dB)	3.0	1.9
COST ($)	10.50	903
TRANSMISSION LINE	30 FT TWIN LEAD COSTING $2.50	

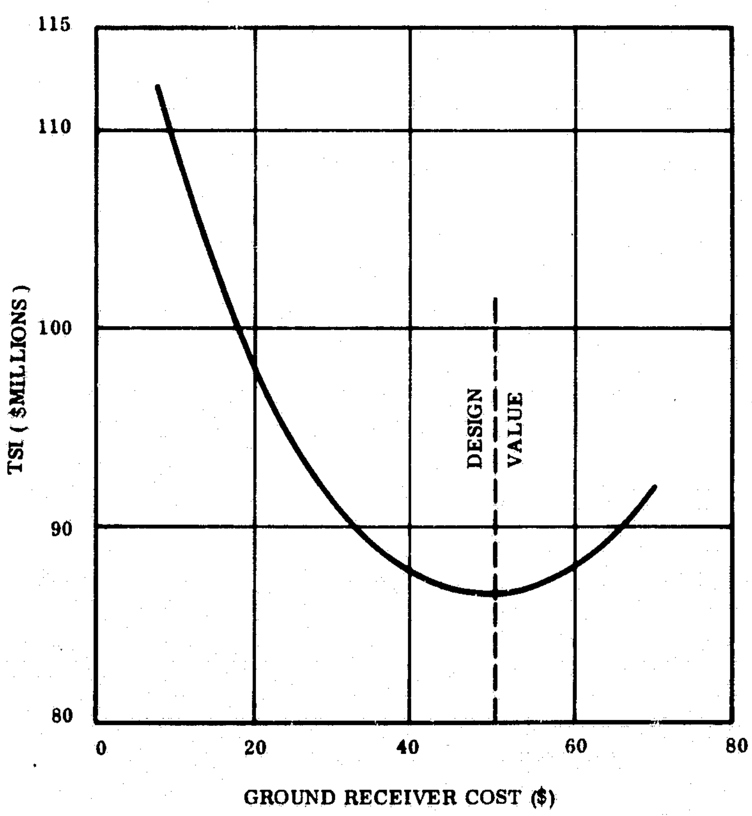


Figure 2-19. System Implementation Costs-Community Service

The satellite longitudinal positioning selected was the stable point at 77°E (which is within 2 or 3 degrees of the optimum location for India). The half-power beamwidth (HPBW) coverage provided is shown in Figure 2-20, with the beam centered at 79°E, 20°N. To cover the portion of India between E. Pakistan and Burma (Assam), the transmitting antenna would have to be of HPBW = 5°; but the rest of India can be conveniently covered by a HPBW = 4°, as shown. It was decided to provide the basic coverage to the major portion of India and increase ground receiving sensitivity in the Assam region. The cost of the additional ground antenna gain to provide the 4 to 5 dB for the extreme off-axis location in Assam is about $10 per antenna. With about 20,000 villages in Assam, the additional increment on the ground system cost would be $200,000. The cost of providing 1.9 dB (0.5 kw) additional power on the satellite would be about $1.8M for a 10 year period; thus, the trade is much in favor of the selected approach.

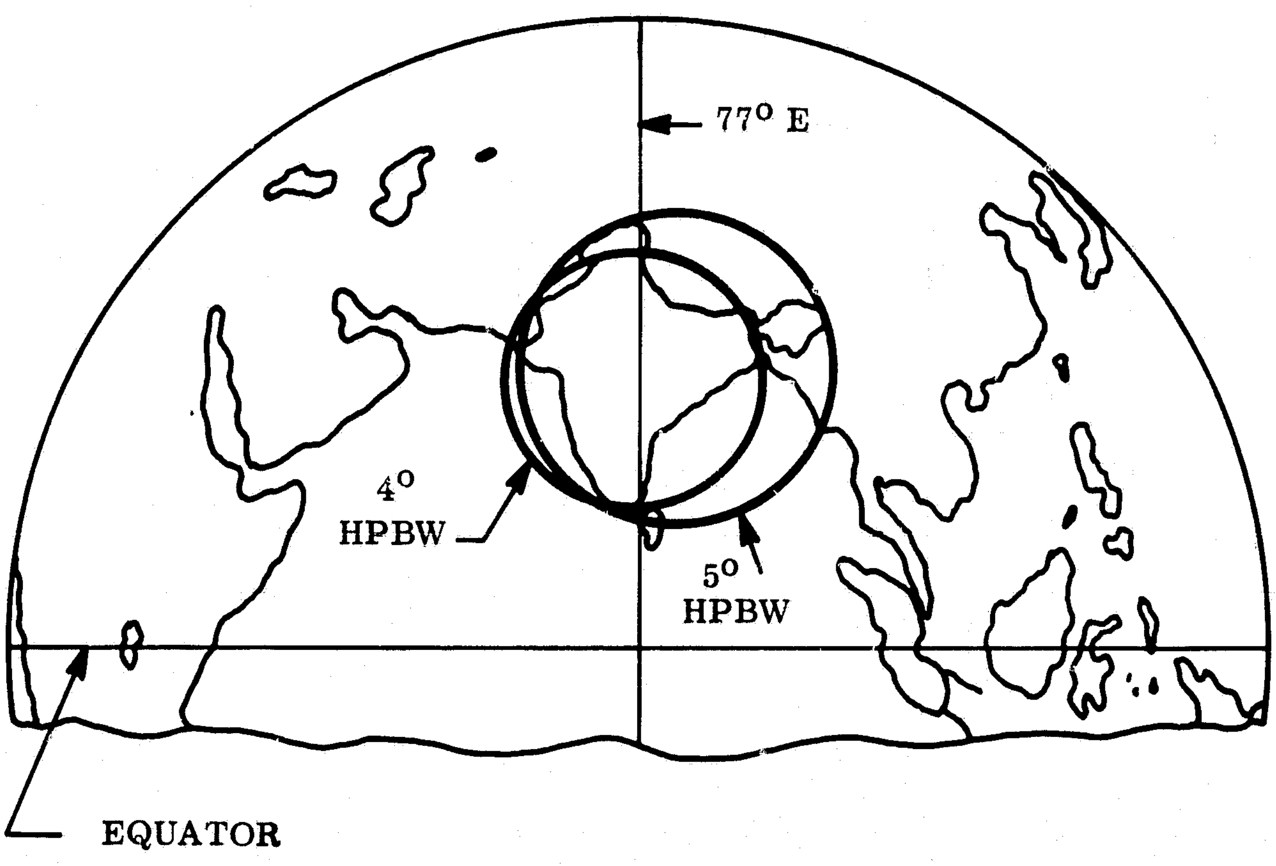


Figure 2-20. Community Service to India Beam Coverage

2.6.1.2 Satellite Configuration

The satellite for this service to India employs a sun orbit-normal reference system to fully orient the solar array to the sun and a cooperative ground beacon for pointing and transmitter to the desired location on the earth. This requires a full 360° per day rotation of the solar array assembly with respect to the antenna/body module and is accomplished with low voltage dc slip rings. Seasonal inclination of the solar array to track the sun would be accomplished by a $\pm 23\ 1/2^{\circ}$ motion, using a flex harness. The satellite antenna package consists of a deployable 21-foot diameter UHF antenna with a concentric X-band antenna (8.4 GHz) mounted on the back of the prime focus feed is accomplished by error signal detection from an RF interferometer system. CFA and TWT power amplifiers are used for the UHF and X-band systems, respectively. Total orbital weight of the satellite is 752 pounds. Because the booster selected (Atlas E or F/Agena D/AKM) has a payload capacity of 910 pounds, there is a weight margin of 21 percent. The AKM (Apogee Kick Motor) was assumed to be a nominal design of the Surveyor-type, employing a mass fraction of 0.9 and an Is_p of 290 seconds. The satellite configuration is shown in Figure 2-21 with pertinent characteristics. A cost breakdown of the satellite system and supporting systems is presented in Table 2-10.

Table 2-10. System Costs-Community Service to India

COST CATEGORY / ITEM	COST (MILLIONS $)			
	DEVELOPMENT/ ENGINEERING	FABRICATION, OR REPLACEMENT	ANNUAL OPERATION	INVESTMENT
SATELLITE SYSTEM	13.3	3.4	---	---
LAUNCH VEHICLE	1.0	4.2	---	---
SUPPORTING SYSTEMS	.5	---	.8	1.3
GROUND RECEIVERS	---	---	---	25.0

SAOC = 1/2 (3.4 + 4.2) + .8 + 1/10 (1.3) = 4.7

SEDC = 13.3 + 1.0 + .5 = 14.8

TSI = 10 (4.7) + 14.8 + 25.0 = 86.8

2.6.2 DIRECT BROADCAST-TO ALASKA

2.6.2.1 General System Considerations

This service provides general purpose television to sparsely populated remote regions. The advantages of this type of service would be (1) ready acceptance by inhabitants with available resources to purchase the needed equipment and (2) maintenance would be provided. The example target area is Alaska; three channels are provided.

The development and installation of this type of satellite system is likely to be borne by the U.S. government, the ground system installation cost borne by the user, and the operation conducted by a broadcasting company. This implies that either the satellite annaul operating cost and/or the receiver cost be the governing cost for minimization. For this service, it was decided to restrict operation to the current UHF/AM standards of terrestrial broadcast.

In this case, the cost factor evaluated was the sum of the amortized costs of the ground receiving equipment (using a 10-year amortization) and the satellite annual operating cost. As shown in Figure 2-22, this value decreases rapidly with increasing ground receiver cost up to about \$100. The ground cost of \$100 was chosen for this system because increases do not significantly reduce the total cost and would tend to make the service less attractive to the user. Ground receiving equipment for this service consists of an outdoor antenna, a preamplifier, and transmission line. The equipment characteristics are presented in Table 2-11.

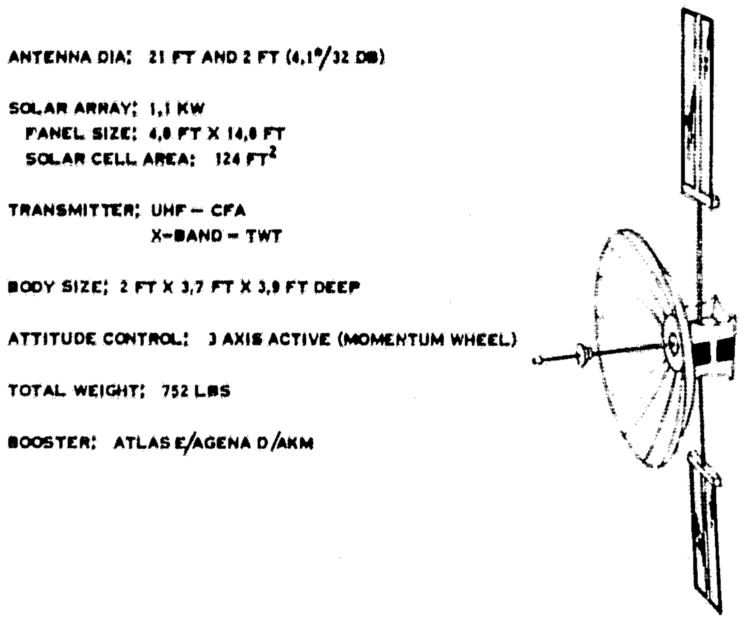


Figure 2-21. TVBS Community/Distribution Service-India, Satellite Configuration and Pertinent Characteristics

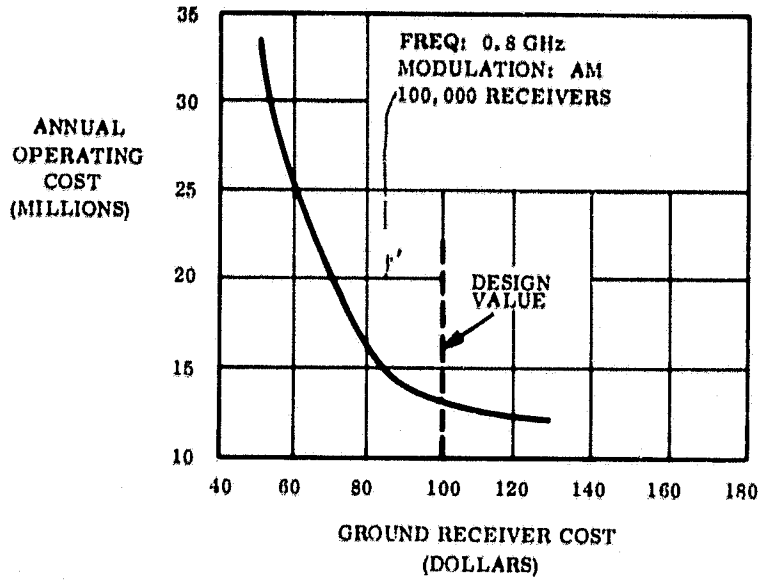


Figure 2-22. System Operation Cost-Direct Service To Alaska

Table 2-11. Receiver Component Characteristics for Direct Broadcast to Alaska Service

COMPONENT	DESCRIPTION
ANTENNA	
TYPE	PARABOLOID (PRIME FOCUS)
SIZE (FT DIA)	5.2
HPBW (DEGREES)	16.5
GAIN (dB)	19.5 NOMINAL (18.9 NET)
COST-INSTALLED ($)	65.00
ELECTRONICS	
TYPE	PREAMPLIFIER
NOISE FIGURE (dB)	3.3
COST ($)	12.50
TRANSMISSION LINE	30 FT TWIN LEAD COSTING $2.50

Longitudinal positioning of 135°W for the satellite was selected so that the satellite can receive an uplink from the Western U. S. and be able to transmit to any portion of Alaska, excluding the Aleutian chain. A more easterly location would be desirable so that the satellite could easily receive uplink transmission from the Eastern U. S., but the local time in Alaska precludes this. At 120°W, which would accommodate an Eastern U. S. uplink, the satellite eclipse at equinox would occur at approximately 9:30 PM, local Alaska time. Because 9:30 is too early, the satellite was positioned at 135°W to extend cut-off time to 10:30 PM.

The RF radiation pattern for Alaska should be squinted to compensate for the extreme latitude, because a circular beamwidth would give excess spillover in the N-S direction and result in inefficiency. A 3^{o} beamwidth in the E-W direction will adequately cover the region from Ketchikan to the Alaskan peninsula, and, if the beam is aywed, the N-S coverage can be achieved with a 1^{o} beam. Therefore, a 1^{o} x 3^{o} elliptical beam was selected, with the resultant coverage shown in Figure 2-23 for a 60^{o}N, 145^{o}W beam center location.

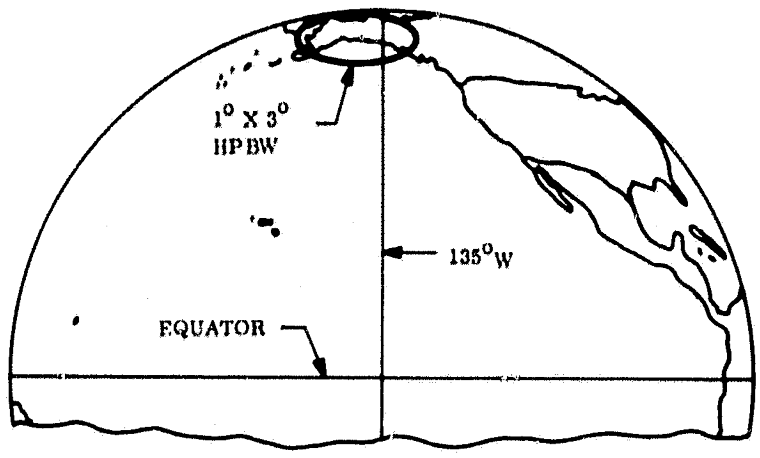


Figure 2-23. Direct Service to Alaska Beam Coverage

2.6.2.2 Satellite Configuration

Direct Service to Alaska would require significant increase in power levels and size from present day satellites. One reason for this is that broadcasting is done with existing standards, using AM modulation. This requires much higher power levels (≈5.5 kw). The other reason is that the restriction to UHF as the carrier frequency causes the squinted narrow-band antenna to be extremely large (29 feet by 80 feet). It may be possible to reduce the size of the antenna without paying a significant system penalty.

A large elliptical dish to track the earth is, therefore, required with the long axis approximately parallel to the satellite pitch axis. The high power level requires fully-oriented solar arrays that rotate about the pitch axis one revolution per day with respect to the antenna.

The size, orientation, and rotation requirements impose a serious constraint on the satellite configuration, because existing and proposed shroud dimensions require a deployable antenna and deployment of the solar array to a position beyond the antenna extremities. The configuration shown in Figure 2-24 includes an inflatable antenna reflector and two symmetrical solar arrays deployed with four telescoping tube assemblies. The satellite body is located in the vicinity of the antenna focal point, so that the feed location can be controlled from a sensor platform which is not separated from the feed by a "soft" structural link.

The solar arrays are articulated and rotated by independent drive assemblies at the junction of the array with the antenna. In addition, separate propulsion units are located at this junction to provide for balancing of torque during thrusting modes.

The satellite accomplishes attitude control with a constant-speed pitch flywheel to provide orbit normal stabilization, a modulation flywheel for pitch control, sun sensors at the solar array for full orientation, and an RF interferometer for pointing of the antenna in a "closed-loop" mode.

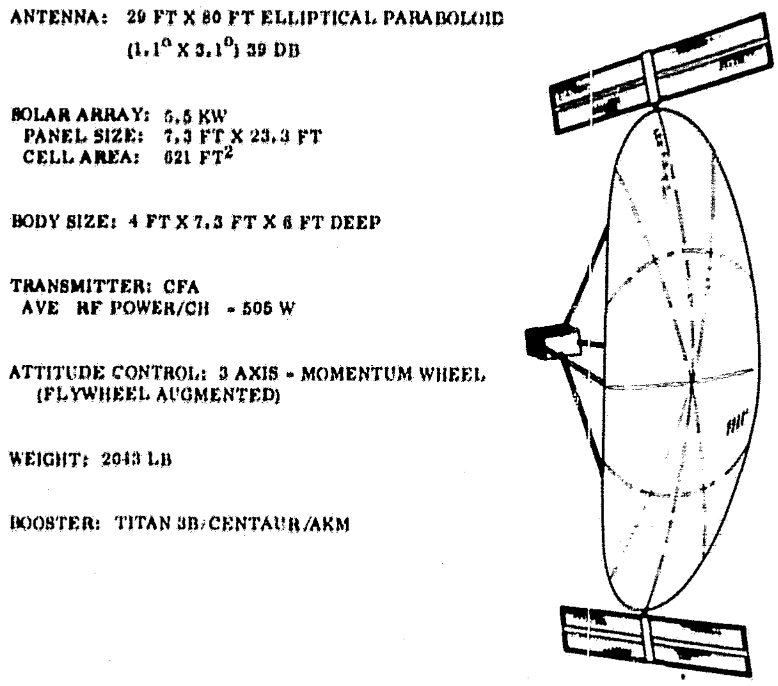


Figure 2-24. TVBS Direct Service-Alaska Satellite Configuration and Pertinent Characteristics

The weight totals 2043 pounds and is summed by subsystem in Figure 2-24. The booster selected for minimum cost was a Titan 3B/Centaur/AKM, which provides an in-orbit payload of 2260 pounds. This provides a 217-pound weight margin (about 11 percent). A cost breakdown of the system is shown in Table 2-12.

Table 2-12. System Costs, Direct TV to Alaska Service

ITEM \ COST CATEGORY	COST (MILLIONS $)			
	DEVELOPMENT/ ENGINEERING	FABRICATION, OR REPLACEMENT	ANNUAL OPERATION	INVESTMENT
SATELLITE SYSTEM	20.8	9.2	---	---
LAUNCH VEHICLE	1.0	13.0	---	---
SUPPORTING SYSTEMS	.9	---	.9	1.7
GROUND RECEIVERS	---	---	---	10.0

SAOC = 1/2 (9.2 + 13.0) + .9 + 1/10 (1.7) = 12.2
SEDC = 20.8 + 1.0 + .9 = 22.7
TSI = 10 (12.2) + 22.7 + 10.0 = 164.7

2.6.2.3 <u>An Alternative Approach for Direct Service to Alaska</u>

The above requirements for a satellite service to Alaska represent extreme conditions and result in a satellite considerably beyond the state of the art. The use of amplitude modulation (to minimize ground receiver cost and RF Bandwidth) requires a very high signal strength to achieve reasonable picture quality and, thus, requires high satellite power levels. The selection of UHF frequency and the necessity to conserve power results in a huge antenna. The india satellite (described in Section 2.6.1) could provide the desired 3-channel service to Alaska, but would sacrifice RF bandwidth and would require a modulation converter at each receiver.

2.6.3 INSTRUCTIONAL TELEVISION SATELLITE FOR THE U.S.

2.6.3.1 <u>General System Consideration</u>

This service would enable developed nations to supplement present educational methods and establish cultural/educational adult community programs. This would be done by utilizing ground receiving stations at discrete centralized locations, such as schools and libraries. High quality teaching instruction could be provided for general and specialized subjects for schools or special interest groups, regardless of local resources.

This service is assumed to require 12 channels (6 to each of two areas). Two beams would be provided to the U. S. during morning and early afternoon hours: one to the eastern region and one to the western region. When the eastern daytime programming is complete, the power used for U. S. transmission would be switched and divided among two previously inactive antennas aimed at Alaska and Hawaii. Daytime instruction for Alaska and Hawaii would then be possible for 5 to 6 hours. Afterwards, power could be switched back to the eastern U. S. the evening cultural/educational programs.

Optimum ground station receiver modification cost was based on total system implementation cost, since the project would likely be federally financed. Minimum system costs occur with frequency modulation of either X- or S-band. However, since the cost differences are small between operation at 2.5, 8.4, and 12.2 GHz, operation at 12.2 GHz was chosen, since allocation of spectrum appears more probable in this frequency band. Figure 2-25 shows that the cost minimum point occurs at a ground receiving cost of $1,100. This value was selected as the design point.

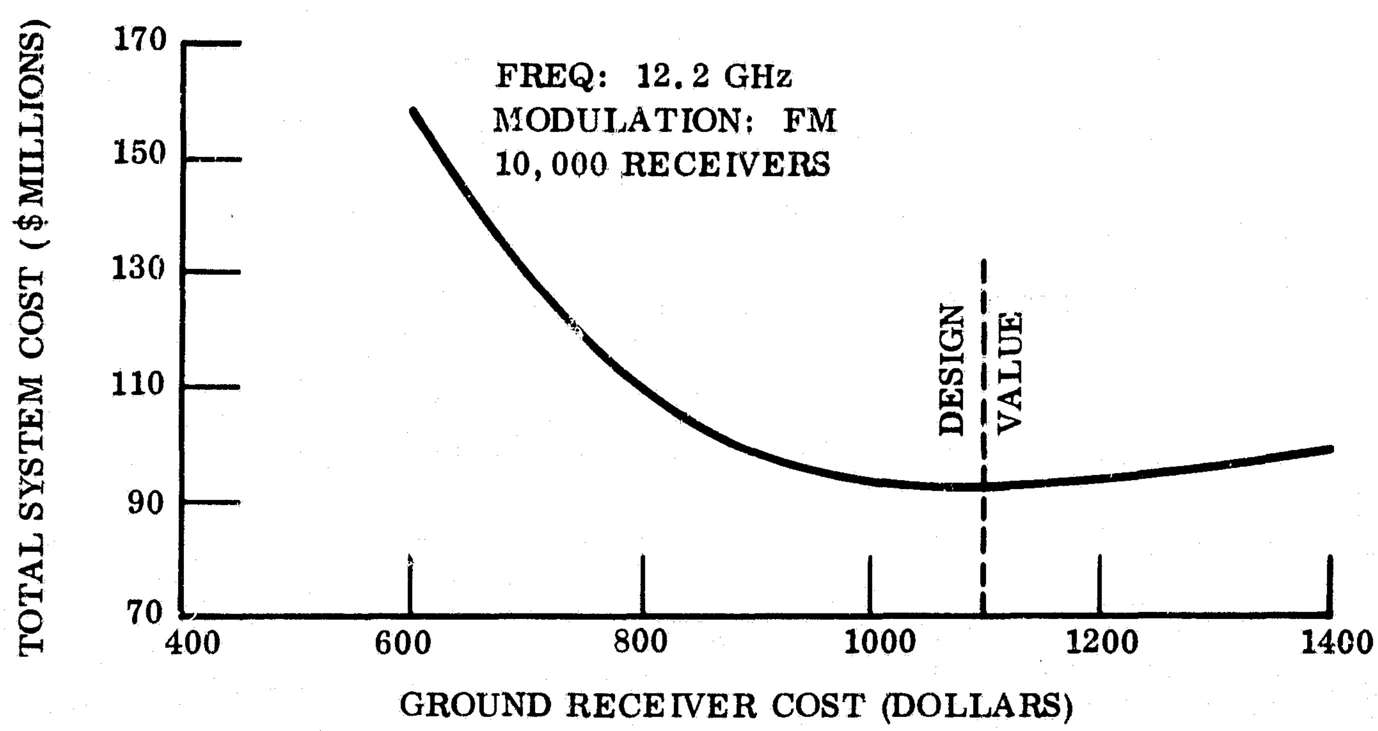


Figure 2-25. System Implementation Costs-Instructional Service

Positioning the satellite involved a trade study considering satellite beamwidth and subsatellite longitude. In many cases, in order to utilize circular beamwidths efficiently, it is desirable to displace the subsatellite longitude from that of the target area. Effective beam shaping is thus gained by creating an elliptical intersection of the conical radiation pattern and the spherical earth. It was determined that the location of 120°W would prevent satellite eclipse during the "prime" evening viewing hours, satisfy all other requirements, and balance out the slant and ground elevation angles between Maine and Alaska. As shown in Figure 2-26, the satellite can achieve coverage of the continental U. S. with two beams of HPBW = 4^{o} and cover Alaska and Hawaii with beams of HPBW = 2.5^{o}. The beam axis coordinates are shown in the following table:

Service	Latitude	Longitude
Eastern U. S.	47^{o}N	68^{o}W
Western U. S.	47^{o}N	88^{o}W
Alaska	72^{o}N	156^{o}W
Hawaii	22^{o}N	162^{o}W

The ground receiving equipment must provide bandwidth requirements for a 6-channel system. The preamplifier is assumed to handle three channels; consequently, the proposed design would use 2 preamplifiers, 2 frequency converters, and 6 demodulators. The resulting price for the 6-channel unit would be $475 for a production quantity of 10^4. The characteristics of the ground receiving system components are presented in Table 2-13.

2.6.3.2 Satellite Configuration

This atellite is a sun/orbit-normal reference system using an RF interferometer system to achieve antenna pointing accuracy of 0.05^{o}. Two fully oriented rollout solar arrays produce a prime power of 2.3 kilowatts. A power conditioning compartment (or module) is fixed relative to the solar array and jointed to the earth-tracking transmitting module through a high-voltage dc-slip ring bearing to provide the daily 360^{o} rotation. Seasonal tracking of the solar array is accomplished by a pivot on the power supply side of the slip ring. The use of dc rather than RF joints means much smaller losses than would be associated with RF joints at the X-band frequencies. The transmitting module contains the reference sensors and tracking electronics, transmitting subsystems for TV broadcasting, TT&C equipment, and a pitch flywheel to "stiffen" the roll and yaw stabilization.

Figure 2-27 shows the satellite configuration and a weight breakdown by subsystem. The broadcast transmitting antennas are fixed to one another, and the TWT power amplifier output will be switched by means of a mechanical RF switch/divider assembly in the waveguide feed system. Subsystem cost breakdowns are shown in Table 2-14.

Table 2-13. Receiver Component Characteristics for Instructional TV Service to U. S.

COMPONENT	DESCRIPTION
ANTENNA	
TYPE	PRIME FOCUS PARABOLOID
SIZE (FT DIA)	6.6
HPBW (DEGREES)	.64
GAIN (dB)	47.7 NOM (46.5 NET)
COST - INSTALLED ($)	620.00
ELECTRONICS	
TYPE	PARAMP+FREQ/MODUL CONVERTOR (6 CHANNEL)
NOISE FIGURE (dB)	1.9
COST ($)	475.00
TRANSMISSION LINE	30 FT TWIN LEAD COSTING $2.50

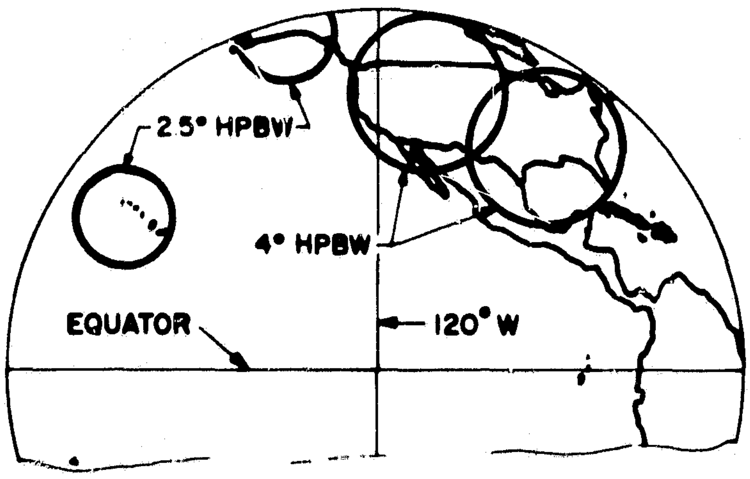


Figure 2-26. Instructional Service Beam Coverage

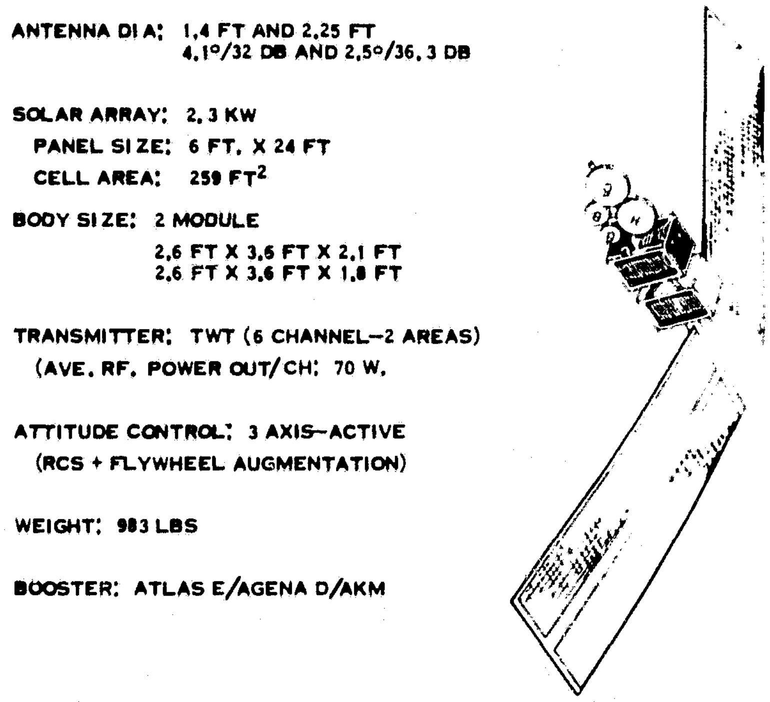


Figure 2-27. TVBS Instructional Service-U. S., Satellite Configuration and Pertinent Characteristics

Table 2-14. System Costs-Instructional TV Service to U. S.

ITEM \ COST CATEGORY	COST (MILLIONS $)			
	DEVELOPMENT/ ENGINEERING	FABRICATION, OR REPLACEMENT	ANNUAL OPERATION	INVESTMENT
SATELLITE SYSTEM	22.0	5.9	---	---
LAUNCH VEHICLE	1.0	4.2	---	---
SUPPORTING SYSTEMS	.6	---	.8	1.4
GROUND RECEIVERS	---	---	---	11.0

SAOC = 1/2 (5.9 + 4.2) + .8 + 1/10 (1.4) = 6.0
SEDC = 22.0 + 1.0 + .6 = 23.6
TSI = 10 (6.0) + 23.6 + 11.0 = 94.6

2. 6. 4 DEMONSTRATION SATELLITE - U. S.

2. 6. 4. 1 General System Considerations

This satellite is postulated as being typical of a satellite that would demonstrate the unique characteristics associated with television broadcasting from space. The primary ground rule for establishment of this system was to select the Atlas-Centaur as the launch vehicle and then establish the prime power available. The two carrier frequencies (2. 5 GHz and 12. 2 GHz) were selected to be representative of low and high values of the range under consideration, without going to the extreme antenna size associated with UHF. Both AM and FM modulation are included with required S/N_0 ratio established at the receiver for TASO Grade 1 and CCIR Relay Quality pictures.

It is desirable to demonstrate feasibility of critical technology items; the following items are included: (1) multiple channel/feed, (2) deployment of large solar arrays, (3) high dc power rotary joints, (4) high voltage power conditioners, (5) antenna pointing (movable feeds and/or gimbals), and (6) thermal control technology associated with heat pipe transmitter integration.

The demonstration satellite is selected to be centrally located with respect to the U. S., and the specific location is at the west stable point (about 107°W). This causes Maine to be the critical target area, and the three payloads on board were all based on the HPBW coverage extremity being in Maine. The possibility of positioning the satellite eastward exists, because it may be easier to inject at around 92°W; however, total propagation factors would not change appreciably. Beam center-line locations were derived from the coverage plots shown in Figure 2-28 and resultant parameters based on the Maine target area.

2.6.4.2 Satellite Configuration

The U. S. Demonstration Satellite configuration is shown in Figure 2-29. There are two RF carrier frequencies required: 2.5 GHz and 12.2 GHz, but the relative sizes of the antennae would induce unacceptable blockage to the S-band antenna if the X-band antenna were concentric to it; therefore, they are positioned side by side. The large solar array also would resist motion of the entire satellite to achieve antenna pointing; this pointing is accomplished with a gimbal that provides a 2-degrees-of-freedom translational motion.

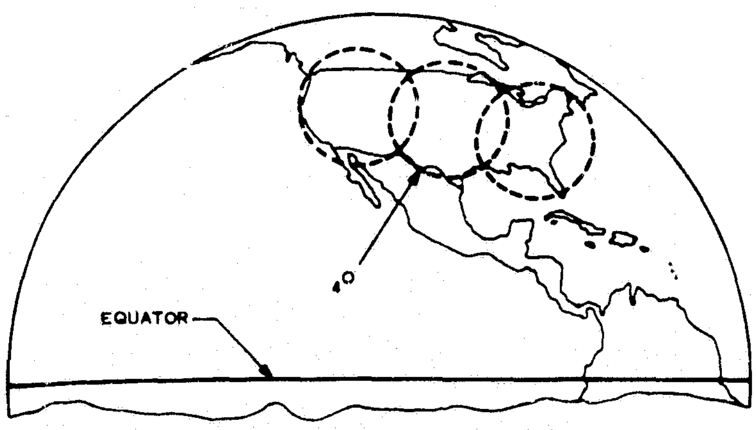


Figure 2-28. TVBS Demonstration Satellite Coverage

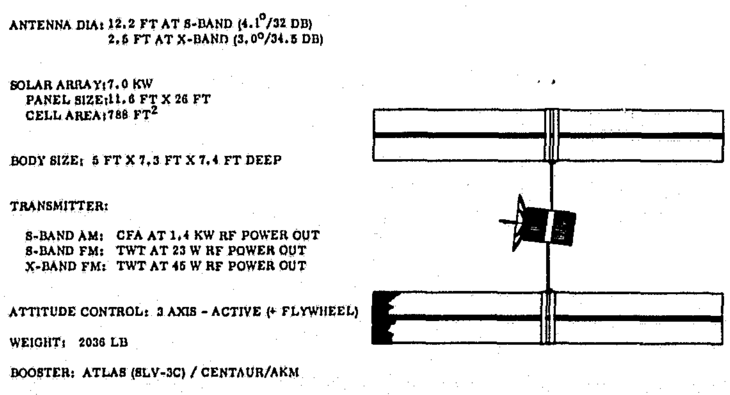


Figure 2-29. TVBS Demonstration-U. S. Satellite Configuration and Pertinent Characteristics

The attitude control and stabilization is accomplished by an earth/orbit normal reference system using a large pitch angular momentum to stabilize the vehicle frame to the orbit normal. The angular positioning required in pitch is derived from an error signal generated by the RF interferometer beacon from the ground target area.

The precise antenna pointing required is accomplished by means of the gimbal system mentioned previously in conjunction with a "closed-loop" control electronics employing the interferometer.

The large solar arrays are four rollout panels, each with almost 200 square feet of area, with a total solar cell area of 779 square feet. These arrays would be nominally oriented normal to the sun line, with seasonal motion requirements accomplished by means of a $\pm 23\ 1/2^{o}$ hinge employing flex harness (as for the other configurations).

Thermal control requirements are satisfied by employing four of the six sides for radiating surfaces and internal heat pipe loops to compensate for sun travel around the vehicle in a nominal X-Y plane.

2.6.5 TVBS LINK CALCULATIONS

The details of the calculations made to arrive at required satellite transmitter RF power out are summarized in Table 2-15. In the case of the multiple beam satellites (the Instructional TV-U. S. and the Demonstration Mission - U. S.) only the worst case design condition is shown.

2.6.6 PROGRAM PLANS AND COSTS

In order to display the several parallel and interrelated events on a time scale of the program, a typical summary and project schedule are presented for the U. S. demonstration satellite in Figures 2-30 and 2-31. The NASA Phased Project Planning approach was used as a basis for these schedules, as is noted by the general grouping of tasks on the summary schedules presented. Schedules are assumed to start from the award of a Phase B contract.

In general, an 11-month period is allowed for Phase B, a 24-month period for Phase C/D through Qualification Test, and about 12 months alloted for Phase D flight hardware fabrication, test, prelaunch, and launch. The overall schedule for the space segment of the program encompasses 47 months for the Direct Service to Alaska case, and 41 months for the other three cases. This reduction of 6 months results mainly from overlapping of flight hardware fabrication with final design and qualification test; justification for this would be greater confidence level associated with the smaller size and more straightforward design of these three satellites as compared to the Alaska satellite.

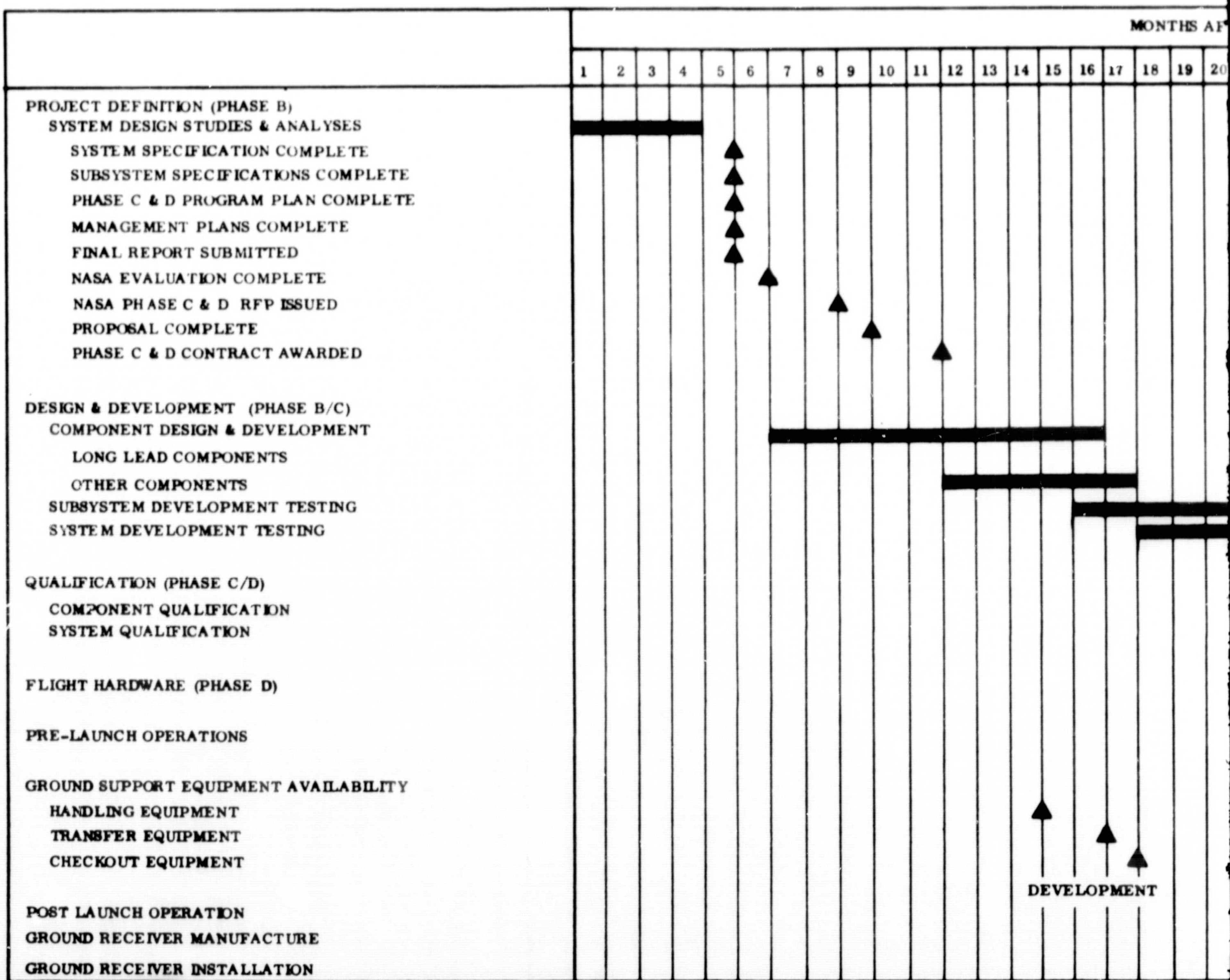
Note that a schedule block to account for postlaunch operation is included on the Summary Schedules. This would extent 48 months from flight date and would include all of the tracking, command, and maintenance activities associated with satellite operation.

Table 2-15. TVBS Link Calculations

ITEM	TV TO INDIA		DIRECT TO ALASKA	INSTRUCTIONAL U.S.(1)	DEMONSTRATION MISSION TO U.S.(3)
	COMMUNITY	DISTRIBUTION			
FREQUENCY, GHz	0.8	8.4	0.8	12.2	2.5
MODULATION	FM	FM	AM	FM	AM
MAXIMUM DISTANCE, 10^3 NM	20	20	22	21.55	21.20
MIN. GROUND ELEV. ANGLE, (DEGREES)	53	53	7.7	18	24
TV STANDARD, SYSTEM	B	B	M	M	M
PICTURE, TASO GRADE	2	CCIR RELAY	2	1	1
MODULATION INDEX	1.5	6.2	----	5.1	----
IF NOISE BANDWIDTH, MHz	35	101	6	61	6
OUTPUT S/N (WEIGHTED), DB	39.5	56.0	39.5	50.5	50.5
WEIGHTING & DE-EMPHASIS, DB	-16.4	-16.4	-6.0	-12.5	-6.0
MODUL. IMPROV., DB	-15.6	-34.8	----	-32.9	----
REQ'D IF C/N, DB	7.5	4.8	33.5	5.1	44.5
MARGIN, DB	1.5	1.5	1.5	1.3	1.5
ACTUAL IF C/N, DB	9.0	6.3	35.0	6.8	46.0
THRESHOLD, DB	8.8	4.8	----	5.1	----
RECEIVER SYST NOISE TEMP., °K					
RECEIVER AND CABLE	290	175	330	175	114
SKY	35	152	45	202	22
INDIGENOUS (MAN-MADE)	0	0	281 (2)	0	4
EARTH AND OHMIC LOSS	116	32	116	32	46
TOTAL	441	359	772	409	186
SYSTEM NOISE POWER, DBW	-126.9	-123.0	-131.9	-126.9	-138.1
RECEIVING ANTENNA					
GAIN, DB	-10.0	-48.4	-19.5	-47.7	-33.0
POINT LOSS, DB	0.0	0.8	0.1	0.7	0.1
POLARIZATION MISMATCH, DB	0.5	0.5	0.5	0.5	0.5
NET GAIN, DB	-9.5	-47.1	-18.9	-46.5	-32.4
CARRIER POWER REQ'D, DBW	-117.7	-116.9	-96.9	-119.7	-99.2
PROPAGATION LOSS					
IONO., TROPO., & REFR., DB	0.0	0.1	0.2	0.4	0.1
FADING, (DB)	0.0	0.0	0.9	0.0	0.0
CLOUD, (DB)	0.0	3.0	0.0	0.9	0.1
PRECIPITATION, (DB)	0.0	0.4	0.0	4.3	0.0
FREE SPACE, (DB)	182.5	202.5	182.7	206.2	192.3
TOTAL	182.5	206.0	183.8	211.8	192.5
REQUIRED ERP/CHANNEL, DBW	55.3	42.2	68.0	47.3	67.9
ON-AXIS SIGNAL STRENGTH, μV/M	122	18	420	24	437
ON-AXIS POWER DENSITY x 10^{12}, W/M^2	39	0.8	470	1.5	607

(1) WORST CASE SHOWN (EASTERN U.S.) (2) INCLUDES 252°K FOR LOW ELEVATION ANGLE EFFECT ON MAIN LOBE. (3) WORST CASE OF 3 PAYLOADS

A separate block for ground receiver fabrication and installation is shown as a lead item prior to flight date. This is an estimate based upon the desired quantities and is made on the assumption that manufacturing facilities are in place to provide the necessary output.



FOLDOUT FRAME

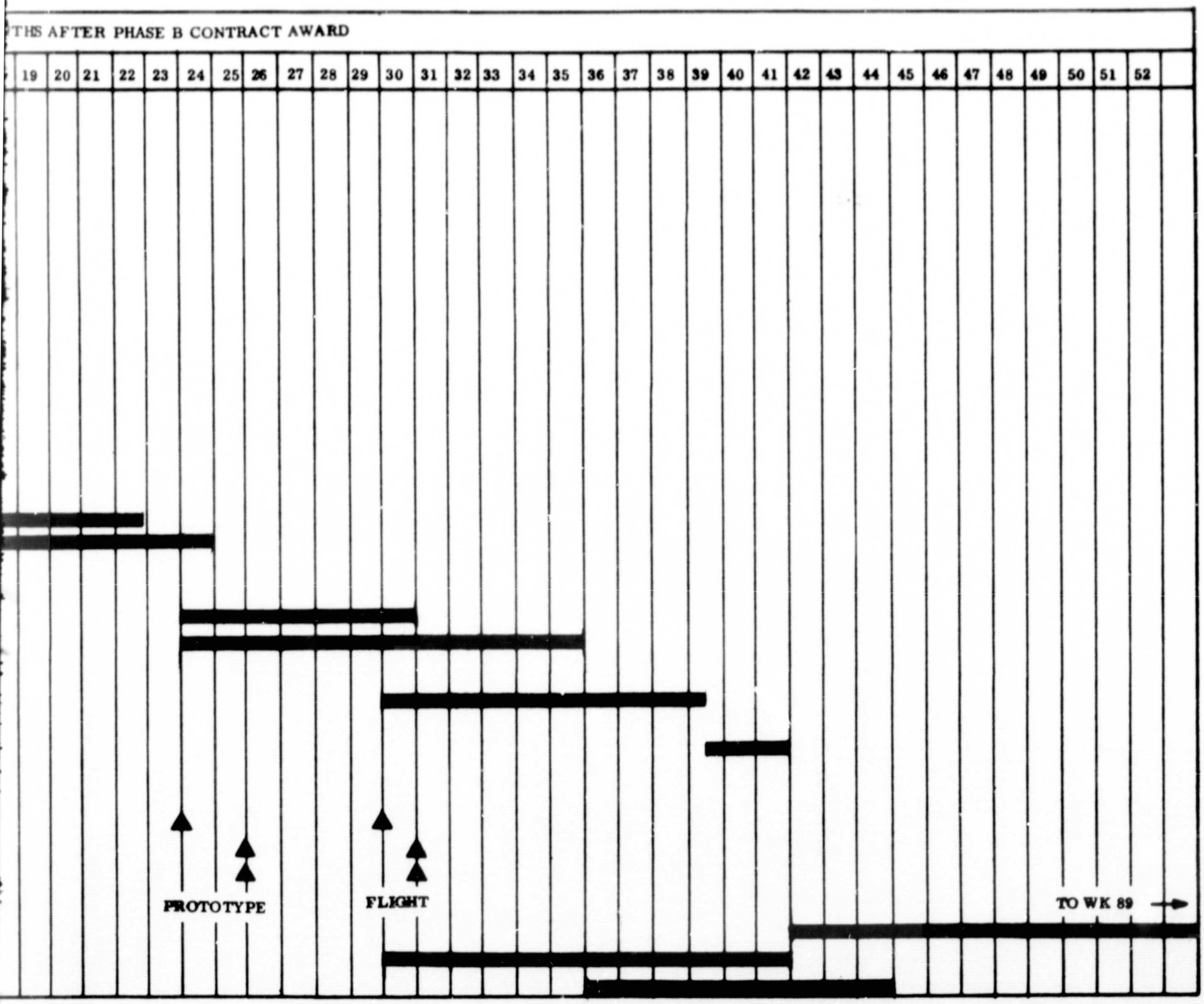
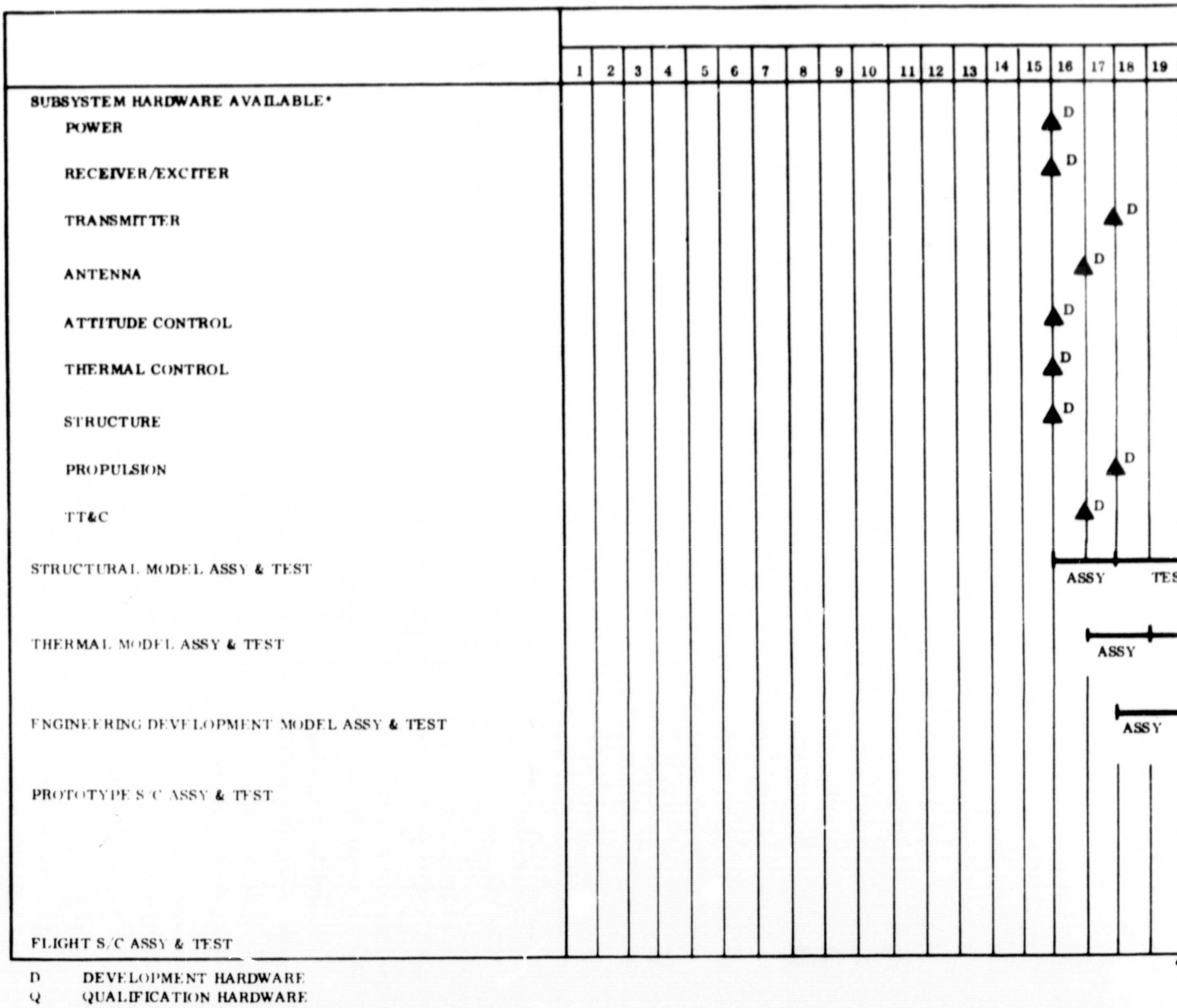


Figure 2-30. TVBS Demonstration-U. S., Summary Schedule

FOLDOUT FRAME 2



D DEVELOPMENT HARDWARE
Q QUALIFICATION HARDWARE
F = FLIGHT HARDWARE
SF = SIMULATED FLIGHT HARDWARE

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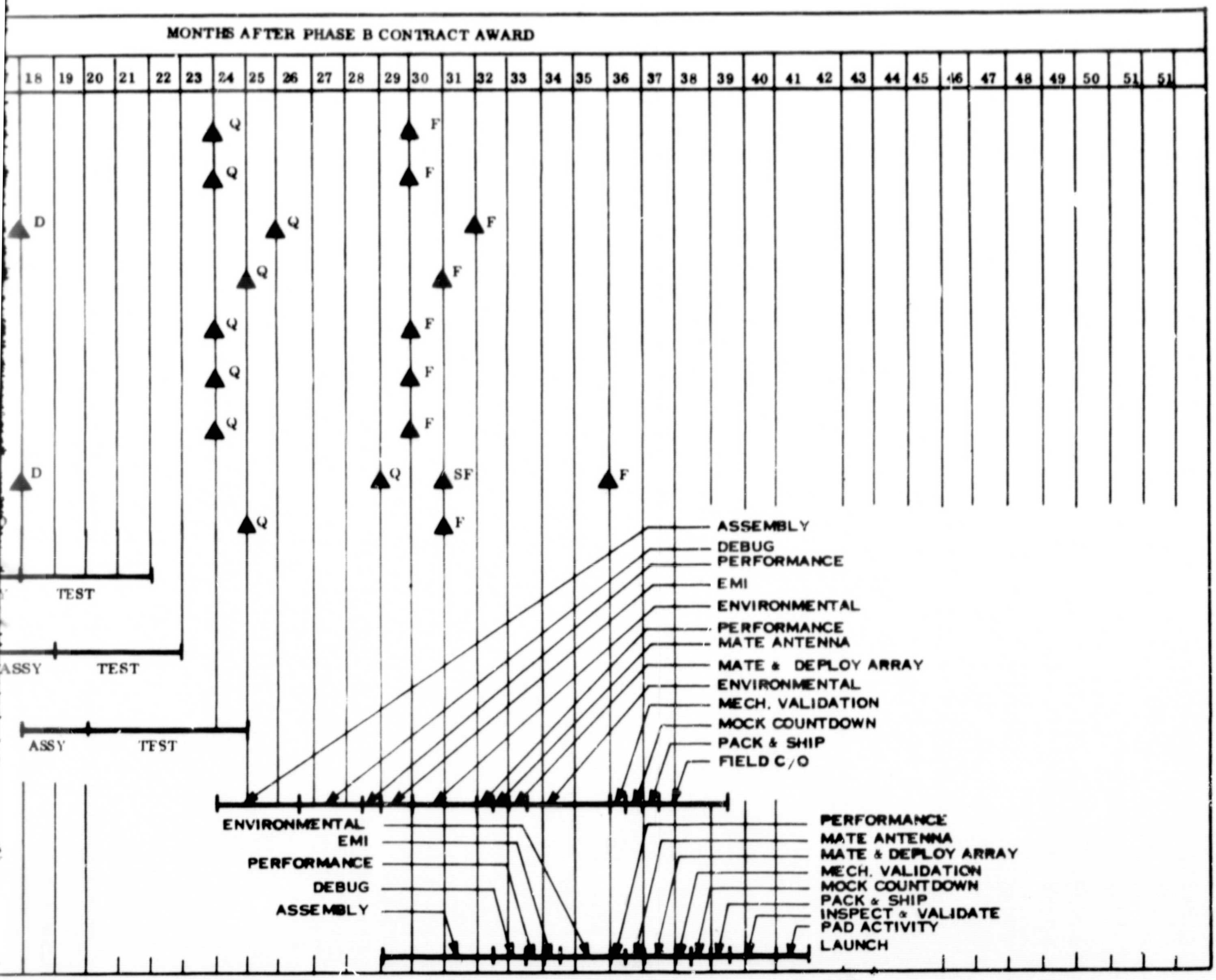

Figure 2-31. TVBS Demonstration - U. S., Project Schedule

FOLDOUT FRAME 2

The NASA Phased Project Planning schedules described above are more extended than those that would result from competitive commercial business after the technology had been developed by NASA. To arrive at schedules for operational systems, the Phase B would be eliminated and the Phase C and D tasks would be overlapped. Using these assumptions, the time between contract go-ahead and launch for the operational systems would be as follows:

1. Community Service to India ------------ 24 months

2. Educational TV Service to the U. S. ----- 24 months

3. Direct Service to Alaska -------------- 30 months

Costs of specific subsystems were determined from the parametric performance/cost data, as determined in Phase 1 of the program, to serve as the baseline for cost estimating. The summation of these subsystem costs was then modified by appropriate factors (integration, liaison, and management) and combined with ground receiver costs to develop the total costs.

A summary of the development, investment, and operation cost estimates for the four TVBS systems are presented in Table 2-16.

Table 2-16. TVBS System Cost Summary

Configuration	Satellite Development	10-Year Satellite Operation(2)	Ground Receiver Investment	Total 10-Year Program(1)
Community/Rebroad-cast Service to India	14.8	47.0	25.3	87.1
Direct Broadcast to Alaska	22.7	122.0	10.0	154.7
Instructional TV to U.S.	23.6	60.0	11.0	94.6
Demonstration TV to U.S.	23.3	27.8(1)	Not Applicable	51.1(1)

(1) In the case of the demonstration satellite, the totals are based on a 2-year period.

(2) This allows for 5 launches in the 10 year period.

2.6.7 COST COMPARISONS

The worth of a satellite broadcast system becomes evident when the satellite system is compared to the cost to implement and operate an equivalent terrestrial television system (the alternate approach to providing the TV services). The general terrestrial cost models developed for this study were described in Section 2.3.3. Cost comparisons for the Demonstration Mission are not applicable. The Community Service to India and the Direct Broadcast to Alaska Service were classified as Direct Services providing 85 percent area coverage, while the Instructional TV Service to the U. S. was considered a Special Service providing 65 percent area coverage. These values of area coverage were taken as reasonable estimates for a terrestrial system and will result in substantially lower than 100 percent coverage. Satellite systems will provide 100 percent coverage. The resultant terrestrial costs for the three operational systems are shown in Figures 2-32, 2-33, and 2-34.

2.6.8 SCHEDULE COMPARISONS

One significant advantage of the satellite broadcast system over the terrestrial broadcast system is the shorter length of time required to establish communication signal coverage to a majority of the population of large geographical areas (areas larger than 1/2 million square miles - roughly equivalent to one U.S. time zone).

In the United States, the first terrestrial television channel coverage was obtained in 6 years for 90 percent of the population. It took 16 years before 95 percent of the population had coverage. For developing and emerging nations, the time period for coverage will be extended considerably because they must industrialize before they can install and maintain a terrestrial system.

In contrast, television by satellites offers full national coverage from the beginning of service. The program schedules for establishing a television satellite system is 2 years for design of an operational satellite and 4 years for a satellite requiring development.

In the United States, it took 5-1/2 years to establish a market and distribute television receivers for 50 percent of the population. It took 12 years before 90 percent of the population had receivers, and it was 9 years later before 95% of the population had receivers.

The above time factors lead to the following conclusions:

1. An additional TV channel can be established for 100 percent coverage of the population of a developed nation via satellite in 1/4 to 1/8 of the time required to install an additional terrestrial system for 90 percent to 95 percent coverage of the population.

2. A new satellite TV service can be established for 100 percent of the population of developing and emerging nations many decades before a terrestrial system could be installed and maintained. The time period for the satellite system will be determined by the time selected for production, distribution, and maintenance of the television receivers. This time period can be shortened significantly by designing the system for the simplest of television receivers and by having these receivers produced in a developed nation.

2.7 TECHNOLOGY EVALUATION

The main objective of the technology evaluation was to identify and assess those significant technologies underlying the TVBS requirements to determine additional development programs needed. Candidate technologies for additional development were selected based upon current development programs and upon the expected effect which that development effort might have upon the system cost, weight, life and performance, or subsystem feasibility. The state of the art was assessed for each technology as a further indication of its critical nature and the need for additional development effort. The technologies were ranked according to the degree of system impact, which each improvement would have, and according to the technology development risk and required lead time.

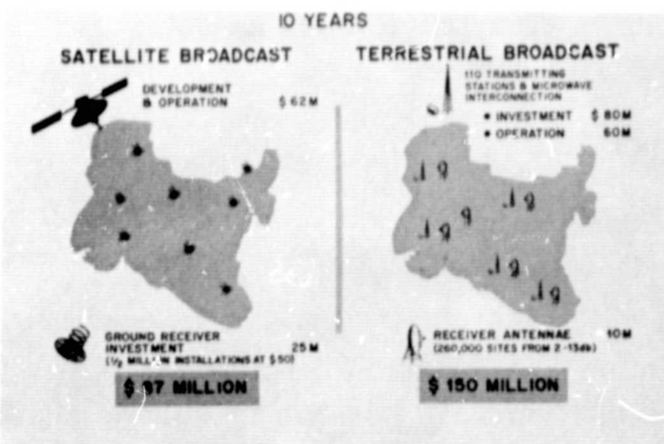

Figure 2-32. Cost Comparison/
Community to India

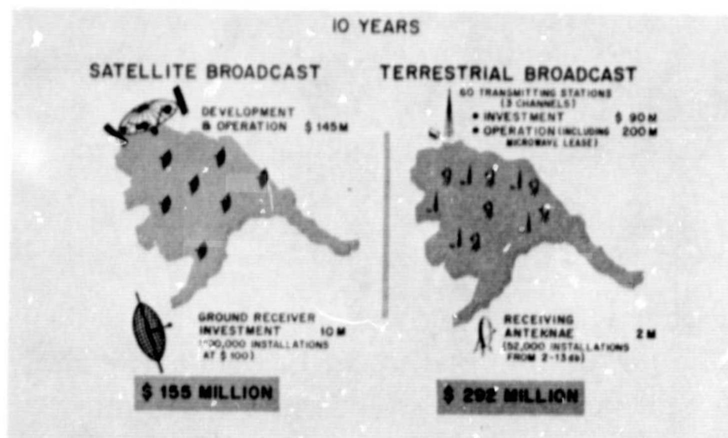

Figure 2-33. Cost Comparison/
Direct to Alaska

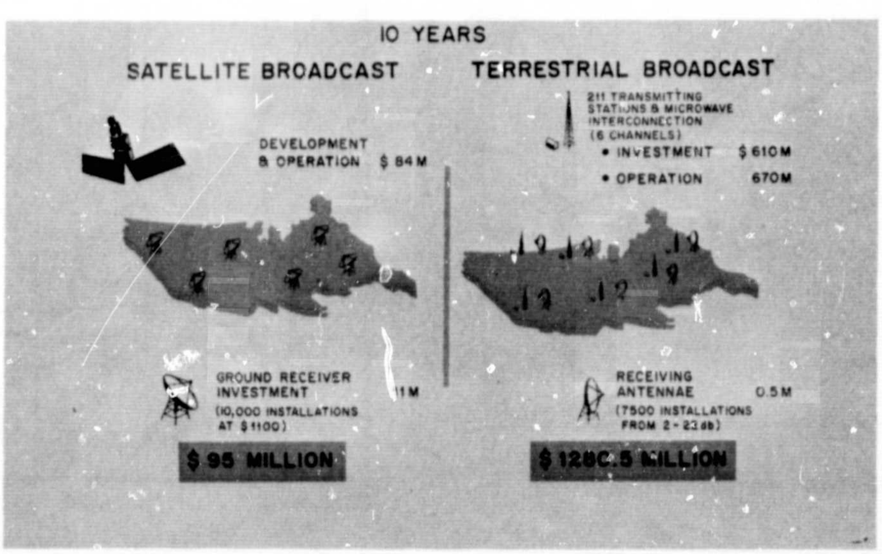

Figure 2-34. Cost Comparison/Instructional to U. S.

The following are the major technological problems associated with the TV Broadcast Satellite requirements:

1. The generation and handling of high dc and RF power and voltage in the space environment
2. The adequate dissipation and control of heat generated as a result of operating at high power levels
3. The deployment and orientation of large flexible structures (such as solar panels), also necessitated by the high power requirement
4. Long life reliability (with 2 to 5 year goals)

2.7.1 STATE OF THE ART FOR TECHNOLOGIES

2.7.1.1 Prime Power

The power subsystem is particularly significant because it represents a relatively high proportion of total system weight, volume, area, and cost. This can be seen by curves showing the percentage allocations of the satellite totals by subsystem as presented in Figures 2-35 and 2-36 for weight and fabrication cost. These curves were developed to aid in the evaluation of technology criticality.

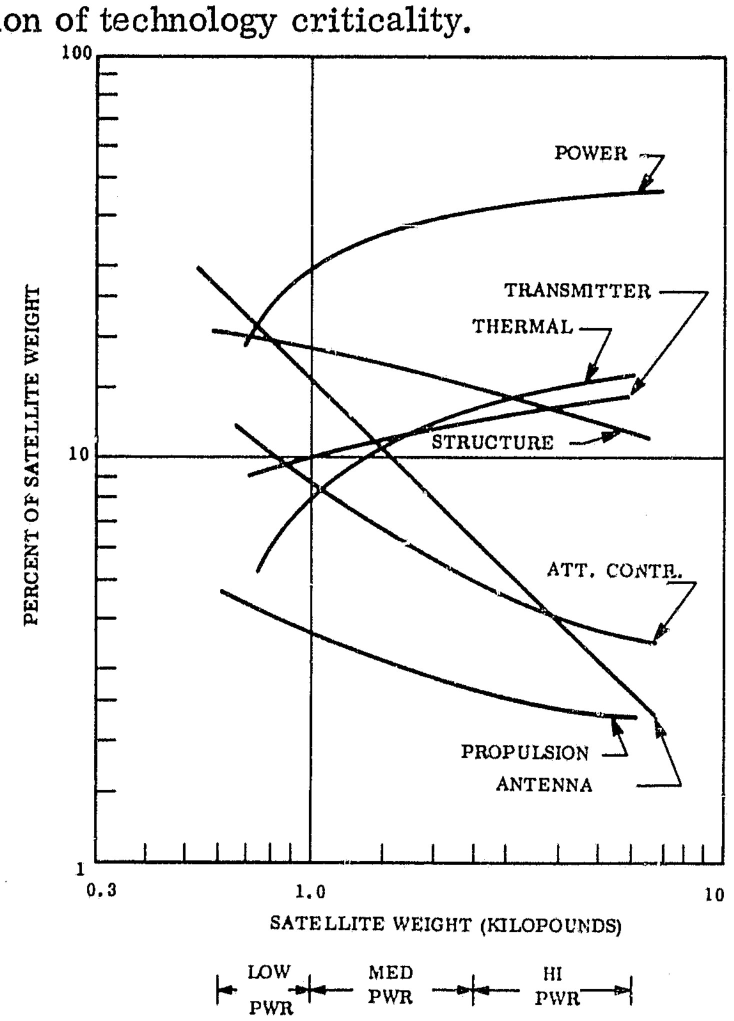

Figure 2-35. TVBS Sensitivity at UHF (0.8 GHz)

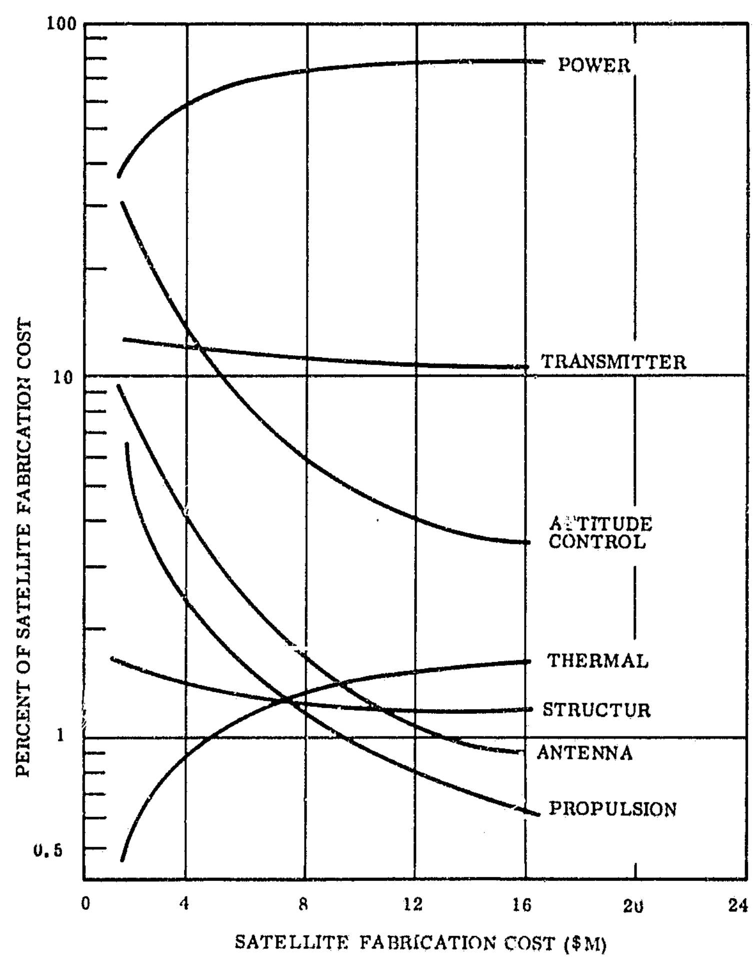

Figure 2-36. TVBS Subsystem Fabrication Cost Sensitivity at UHF (0.8 GHz)

The high labor costs associated with solar array fabrication should motivate the evolution of product techniques for automatic cell manufacture and laydown. System considerations indicate that the development of higher voltage (e.g., over 200 volts) solar arrays could result in easing the power conditioner design requirements.

2.7.1.2 Power Conditioning

Space technology for low-weight power conditioners at levels over 1000 watts and above 2000 volts is not well developed. The general problems associated with high-voltage breakdown of dielectrics need to be solved. The technical feasibility of high-power, high-voltage conditioners in the hard vacuum of space over periods of more than 2 years has yet to be shown. Techniques for greater efficiency and lower weight need to be developed.

2.7.1.3 Transmitter

The transmitter for TVBS applications is required to transmit high power (kilowatt levels) at UHF or higher frequencies in a space environment. High efficiency output devices and associated RF components for such a transmitter are still to be developed and space qualified. High frequency, high power output, high efficiency, linearity, broadband signal handling and thermal dissipation are the prime areas requiring development.

2.7.1.4 Thermal Control

The high values of heat dissipation density and temperature cocurring with high power RF transmitter stages and power conditioners make thermal control a critical technology for broadcast satellites. Heat pipes with over 2-kilowatt capacity need to be investigated for additional data on critical (or burnout) heat flux, so that weight and cost can be reduced by configuration optimization.

2.7.1.5 Antenna

The antenna problems are associated primarily with the stowage, deployment, and orientation of the antenna structure, particularly at the UHF frequencies considered. Beam pointing, beam shaping, and multibeam techniques require development. Very high power levels (greater than 10 kw) may make it necessary to use array antennas for distribution of the power among many feed elements to avoid RF breakdown. Side lobe suppression of multiple and movable feeds is necessary for certain broadcast services.

2.7.1.6 Rotary Joints

The dc rotary joint that might be required between the solar array and the spacecraft involves a number of potential problems related to brush, ring and bearing life, lubricants, outgassing, insulation materials, leakage paths, temperature control, size and weight. Adequate design data for high RF rotary joints between the spacecraft and antenna are lacking, particularly with regard to techniques required to eliminate high power breakdown and multipacting under vacuum conditions. The liquid metal slip ring should be investigated.

2.7.1.7 Attitude Control and Flexible Structures

Attitude control components for TVBS applications are not considered to involve critical technologies. However, significant errors in solar panel orientation and/or antenna pointing angles could result if the effects of motions of large flexible appendages attached to the spacecraft are not investigated and provided for in the attitude control subsystem design.

Flexible structure modes of vibration must be studied and the structure must be defined, in order to adequately assess the interactions of a large flexible structure with its space environment, the stationkeeping system, and an active attitude control system, so that degradation of control accuracy and functional performance can be avoided. A smalll number of configurations representative of deformation mode shapes should be analyzed over suitable ranges of sixes and frequencies to facilitate the selection of flight vehicle configurations, evolve design criteria, and evaluate the feasibility of actual final designs.

2.7.1.8 Ground Receiver Systems

The TV ground installation cost becomes a significant consideration, especially for large audiences, so that low-cost TV converters (frequency and modulation) and ground antennas with adequate gains in the 0.8 to 12 GHz range need to be developed.

2.7.2 RANKING OF TECHNOLOGIES

The initial selection of candidate technologies was based upon current development programs and upon those appearing to have a significant impact upon reduction of system costs, extension of system life, and improvement in system performance. This preliminary candidate list was screened to include only those which were not likely to be designed and constructed within an average two-year design cycle and for which inadequate development work is currently in progress.

Final ranking of the selected candidate technologies was based on criteria, which included the impact upon system weight and cost (using system sensitivity indixes similar to those shown in Figure 2-35 and 2-36), subsystem feasibility, system performance, long life and reliability, development risk, and lead time requirement.

TVBS satellites were grouped into three power level classifications as functions of an assumed launch date. These are shown in Table 2-17. The final priority listing of recommended technology candidates is shown in Table 2-18.

Table 2-17. Satellite Weight and Cost Ranges

	TV Broadcast Satellite Solar Array Power Range (kw)	Approximate Satellite Weight Range (lb)	Est. Satellite Fabrication Cost Range ($M)	Est. Launch Date
Low Power	1 to 3	600 - 1000	2.7 - 5.5	Early 1970's
Med. Power	3 to 10	1000 - 2500	5.5 - 13.6	Mid 1970's
High Power	10 to 30	2500 - 6000	13.6 - 32.0	Late 1970's

Table 2-18. TVBS Subsystem Technology Priority List

PRIORITY CATEGORY / SATELLITE CLASS	LOW SOLAR ARRAY POWER (1–3 KW, EARLY 1970'S)	MEDIUM SOLAR ARRAY POWER (3–10 KW, MID 1970'S)	HIGH SOLAR ARRAY POWER (10–30KW, LATE 1970'S)
FIRST	HIGH EFFICIENCY MICROWAVE TUBE GROUND RECEIVING SYSTEMS HIGH VOLTAGE POWER CONDITIONING HIGH EFFICIENCY GRIDDED TUBE UHF TRANSMITTER CIRCUITS	HIGH EFFICIENCY MICROWAVE TUBE GROUND RECEIVING SYSTEMS HIGH VOLTAGE POWER CONDITIONING ATTITUDE CONTROL OF FLEXIBLE STRUCTURES SOLAR ARRAY DEPLOYMENT HIGH EFFICIENCY GRIDDED TUBE UHF TRANSMITTER CIRCUITS	ATTITUDE CONTROL OF FLEXIBLE STRUCTURES HIGH EFFICIENCY MICROWAVE TUBE GROUND RECEIVING SYSTEMS HIGH VOLTAGE POWER CONDITIONING SOLAR ARRAY DEPLOYMENT HIGH EFFICIENCY GRIDDED TUBE UHF TRANSMITTER CIRCUITS HIGH VOLTAGE HANDLING HIGH VOLTAGE SOLAR ARRAY THERMAL–TRANSMITTER INTERFACE
SECOND	SOLAR ARRAY DEPLOYMENT HIGH VOLTAGE HANDLING THERMAL–TRANSMITTER INTERFACE HEAT PIPES DC ROTARY JOINT RF ROTARY JOINT	HIGH VOLTAGE HANDLING THERMAL–TRANSMITTER INTERFACE HEAT PIPES DC ROTARY JOINT RF ROTARY JOINT HIGH VOLTAGE SOLAR ARRAY HIGH POWER RF COMPONENTS 2–AXIS SOLAR ARRAY DRIVE	HEAT PIPES DC ROTARY JOINT RF ROTARY JOINT HIGH POWER RF COMPONENTS 2-AXIS SOLAR ARRAY DRIVE SOLAR CELL & ARRAY MANUFACTURE REFLECTOR ANTENNA POWER HANDLING REFLECTOR ANTENNA BEAM POINTING REFLECTOR ANTENNA MULTI–BEAMS MICROWAVE TRANSMITTER CIRCUITS
THIRD	HIGH VOLTAGE SOLAR ARRAY HIGH POWER RF COMPONENTS REFLECTOR ANTENNA POWER HANDLING REFLECTOR ANTENNA BEAM POINTING REFLECTOR ANTENNA MULTI–BEAMS MICROWAVE TRANSMITTER CIRCUITS	REFLECTOR ANTENNA POWER HANDLING REFLECTOR ANTENNA BEAM POINTING REFLECTOR ANTENNA MULTI–BEAMS MICROWAVE TRANSMITTER CIRCUITS MECHANICALLY STEERABLE ANT. ARRAY	MECHANICALLY STEERABLE ANTENNA ARRAY ELECTRONICALLY STEERABLE ANTENNA ARRAY

2.8 RESULTS

The TVBS study developed data that resulted in three fundamental conclusions: (1) broadcast satellites are feasible in the next decade, (2) broadcast satellites are more cost-effective than terrestrial systems for large coverage areas, and (3) turnkey operation can be achieved sooner by satellite than by terrestrial systems if the objective is a service to essentially the entire population. The following discussion elaborates on these three conclusions and several corollary conclusions.

2.8.1 FEASIBILITY

High power (1 to 30 kilowatts of solar array power) broadcast satellites are feasible in the 1970's if current technology and subsystem developments already started are continued as planned.

Development of key elements for high powered broadcast satellites is in process. Low cost ground converters are being developed, and solar array power design and development has been under way for many years. High power transmitters, high voltage power conditioners, and special antennas are being designed for broadcast satellites. Experience gained on current space programs is being applied to analyze the attitude control of large flexible vehicles, to develop high voltage and high power components, and to attain long life endurance in space.

2.8.2 COST EFFECTIVENESS

Broadcast satellites utilizing the above technology developments are more cost-effective than terrestrial-based systems for large coverage areas (greater than one time zone of the United States - approximately 1/2 million square miles). This is true for the whole range of missions in direct, community, and special services (e.g., education or distribution). It is important to note that even in cases where the signal is not aimed at direct reception in the home, there is no economic basis for the choice of high cost ground receivers and low performance satellites.

For developing or emerging nations that do not yet possess any terrestrial television channels, the broadcast satellite is clearly the least expensive method for obtaining the initial service.

For developed nations with a sizable dollar and technological investment in ground based television systems, the cost-effectiveness comparison is more complex and was beyond the scope of this study. However, the data developed indicates that expanding television coverage (increasing the number of channels or giving the service to sparsely populated areas) may be done most cost-effectively by supplementing the existing system with broadcast satellites.

2.8.3 EARLY TURNKEY CAPABILITY

For developing or emerging nations that do not yet possess any terrestrial television channels, the broadcast satellite is the quickest method of establishing the initial service. This initial service can be established for essentially the entire population many decades before a terrestrial system could be installed. The time period for the satellite system will be determined by the time selected for production, distribution and maintenance of the television receivers. This time period can be shortened significantly by designing the system for the simplest of television receivers and by having these receivers produced in a developed nation.

For a developed nation, turnkey operations for new channels can be established via broadcast satellite in 1/4 to 1/8 of the time it has historically taken to establish a first or second terrestrial channel for coverage of over 90 percent of the population.

2.8.4 NONTECHNICAL CONSIDERATIONS

Sociopolitical and programming problems associated with space broadcasting were beyond the scope of this study. The literature treats these difficult but soluble problems. As the public becomes aware of the benefits of this application of space technology, many of these problems will disappear.