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FINAL REPORT
INFORMATION TRANSFER SATELLITE CONCEPT STUDY

VOLUME II ✦ TECHNICAL

GENERAL DYNAMICS
Convair Aerospace Division

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15 May 1971

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National Aeronautics and Space Administration
AMES RESEARCH CENTER
Moffett Field, California

FOREWORD

This report was prepared by the Convair Aerospace Division of General Dynamics under Contract No. NAS 2-5571 for the office of Advance Research and Technology (OART) of the National Aeronautics and Space Administration. The work was administered under the Technical direction of the Advanced Missions and Concepts Division of OART located at Ames Research Center.

Major subcontract support was received from the Aerospace Group, Space Systems Division of Hughes Aircraft Company.

Mr. E. Van Vleck was the NASA Study Monitor for this contract.

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1

INTRODUCTION

The Information Transfer Satellite Concept Study was performed by the Convair Aerospace Division of General Dynamics Corporation for the Advanced Concepts and Missions group (was Mission Analysis Division) of NASA-Office of Advanced Research and Technology under contract number NAS 2-5571. This study was initiated on 27 June 1969, with completion of technical tasks scheduled for 30 September 1970 and final reporting completed by 31 January 1971.

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

As shown in Figure 1-1 the ITS Concept Study was preceded by two requirements studies whose primary objectives were to identify viable demands and

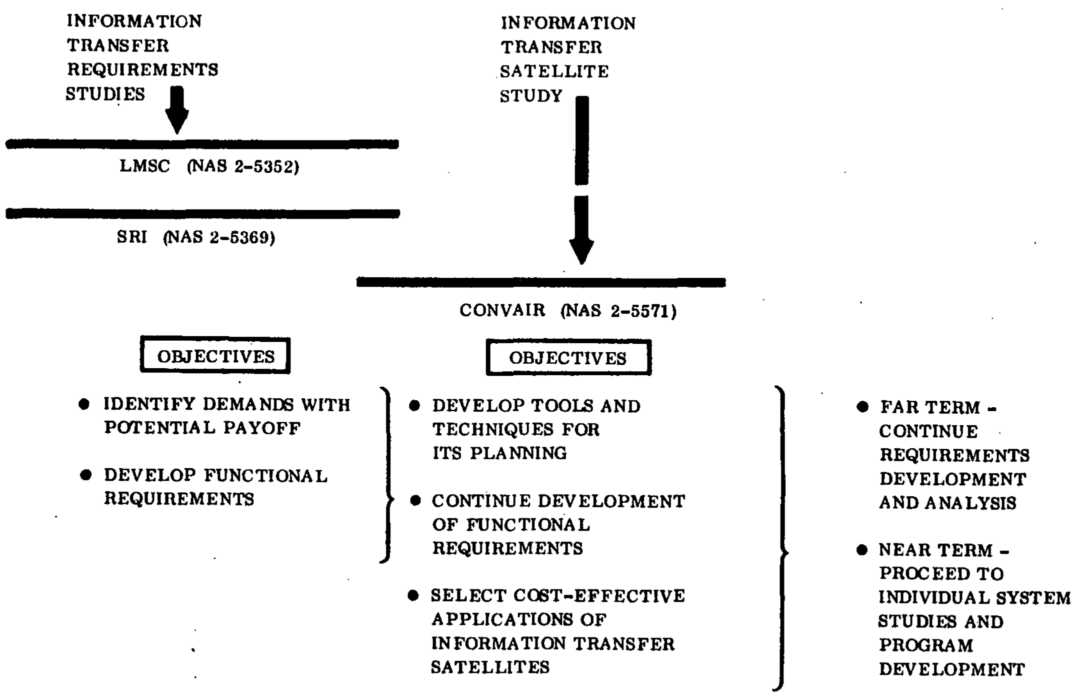


Figure 1-1. ITS Studies

to develop the functional requirements associated with these demands. In addition to continuing this basic activity the ITS Concept Study objectives were to:

1. Develop tools and techniques for planning advanced information transfer satellite communications systems.

2. Select viable systems for further analysis both in their near-term and in the far-term aspects.

1.1 SCOPE AND GUIDELINES

The Information Transfer Satellite (ITS) Concept Study is a broad conceptual study oriented toward developing planning techniques and tools for defining future-generation communications satellite systems and the technological developments required to allow these systems to come into being. NASA's role in these advanced systems would be to conduct the technology development programs, possible to the extent of an experimental satellite to demonstrate the technological capability and to assess the operating characteristics of such systems.

The intent is to make an overall review, in which perspective is of paramount importance, of user needs in order to identify potential solutions represented by advanced satellite systems. This is a dynamic problem because of the ever-increasing demands for information in all modes of transmission: audio, video, facsimile and digital data. As expressed by previous Stanford Research Institute (SRI) and Lockheed Missiles and Space Company (LMSC) studies, these demands are increasing exponentially. Their accommodation represents the single largest problem for future communication systems.

In addressing the problems associated with the demands several points should be kept in mind:

1. These are the real demands of real present users of telecommunications. Projections of the demands represent growth in these systems some of which would be normal extensions of their present operations. These can be more quantitatively defined and represent the requirements for near-term systems. Others represent expansion of their present operations because of the potential availability services that exceed present or planned capabilities. There are more qualitative and represent the "wish lists" or "desirements" for far-term missions. In this context many of the systems have both near and far term aspects.

2. While many of the present users are in operation they are dissatisfied with present services because of:

    a. Cost

    b. Schedule. This applies in both the sense of timely access to present systems and timely availability of expansions of the system or new services.

    c. Quality. Criticisms include noisy lines, fading, service interruptions, switching losses, etc.

3. While general commercial services (radio, television, telephone, telegraph) are being offered to 85-95% of the population, there are potential users who are not being served, viz:

    a. The remaining 5-15% of the population who are located in the Rocky Mountain and mid-western states, Alaska and Appalachia. These areas are typified by low population density and rugged terrain where the economics of terrestrial systems are most adverse.

b. Special interest groups such as the professional societies, who want such services as continuing Education TV or Teleconferencing. These are also labeled as "cultural minorities" or "special minorities" in other studies. They are intermingled with the general population so the present systems must be augmented to cope with their needs.

4. There is also a significant mixture of large and small users. Typically, the large users can support their own system. However, the small user cannot support a system dedicated to his needs but must share a system with other small users. Compatibility then becomes the critical issue.

Guidelines under which this study was conducted were flexible and broad in scope. They included the following considerations:

- TIME SCALE
  - Late 1970's to 1989
  - 1975 state-of-the-art
  - 1985 growth potential.
- INFORMATION TRANSFER SATELLITE SYSTEMS
  - Unmanned
  - Man-assisted
  - Single purpose
  - Multiple purpose
- ORBIT AND COVERAGE
  - All plausible, actually limited to geostationary equatorial orbit
  - Single and multiple beams
  - Global and spot coverage.
- LAUNCH VEHICLES
  - Atlas family
  - Titan family
  - Saturn V
    - Full and partial payloads
    - Single and multiple payloads.
- ANALYTICAL MODELS
  - Total system synthesis, modeling and costing.
  - Parametric data.
  - System and subsystem tradeoffs and sensitivities.

1.2 STUDY APPROACH

The overall study approach is shown in Figure 1-2. The sequence of events is:

1. Needs Research. Here the users were contacted and information solicited from them on their present operations and future plans.

2. Systems Analysis. Systems analysis properly includes the translation of user needs into functional requirements from which the communication satellite systems are synthesized. A computerized synthesis program has been developed to facilitate the complex and time - consuming calculations that must be performed. Also, because of the flexibility and ease of operation, the program permits the systems to be perturbed to show sensitivity to various forcing functions.

3. Iteration. This is one of the most significant steps in the ITS process. It involves the call-back, renegotiation, the second chance for the user to get the full implication of his previously - expressed needs. High cost is a factor that typically encourages (often forces) compromise.

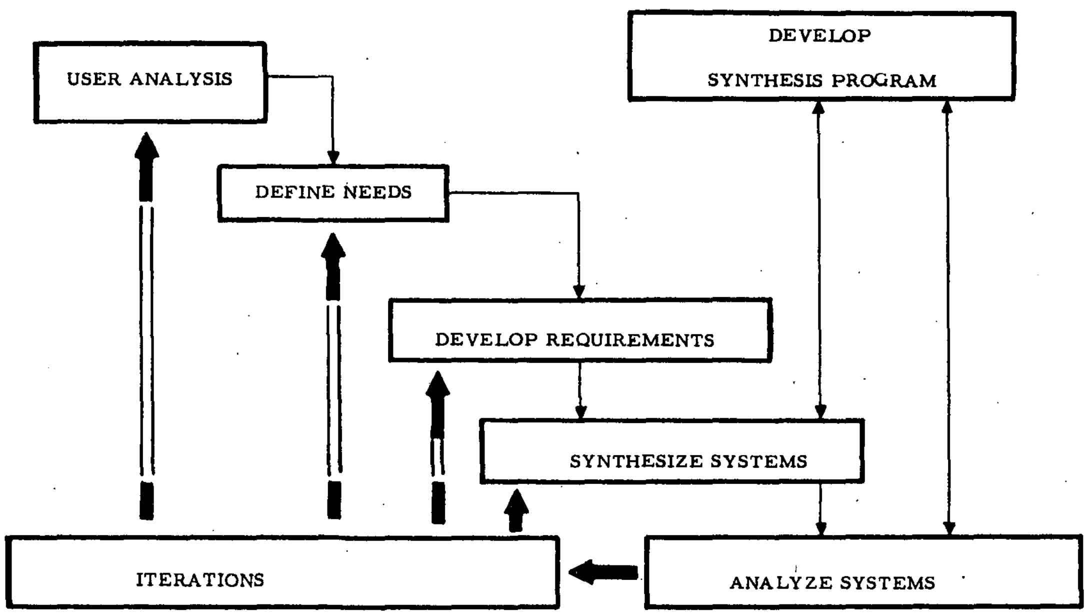


Figure 1-2. Overall Study Approach

A block diagram of the study tasks is shown in Figure 1-3 and summarized briefly, as follows:

1. Task 1. Simulation and Synthesis — This task includes all activities associated with developing and operating the synthesis program. It extends for the duration of the study.

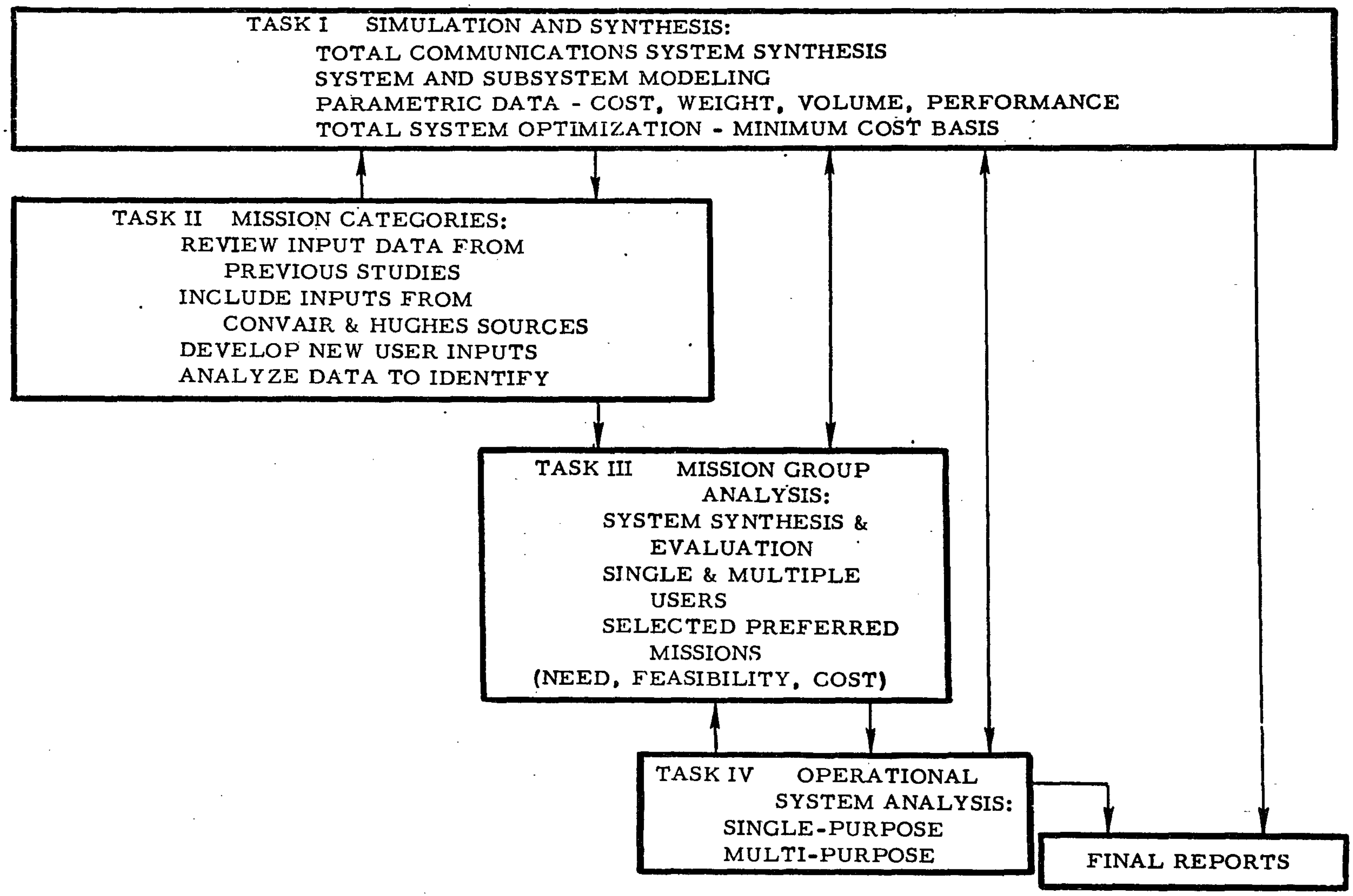


Figure 1-3. Information Transfer Satellite Concept Study Tasks

2. Task II. Mission Categories -- In addition to processing user/demand data developed in previous studies, this task includes the development and analysis of new user data.

3. Task III. Mission Group Analysis -- Analysis of single and multiple demands will result in selection of preferred missions. The basis for the selection includes need, feasibility, and cost as major items.

4. Task IV. Operational System Analysis -- Perferred missions are analyzed further to identify those missions most likely to proceed into an implementation phase.

5. Task V. Documentation -- This task includes the preparation and distribution of all reports.

The logical interactions of these tasks are shown in Figure 1-4. A series of candidate demands is identified in Task II and processed through the computer program to Task III where single-purpose missions are defined. Nothing is deliberately thrown away since the rejects from Tasks II and III are carried forward to Task IV where multiple-purpose missions are defined.

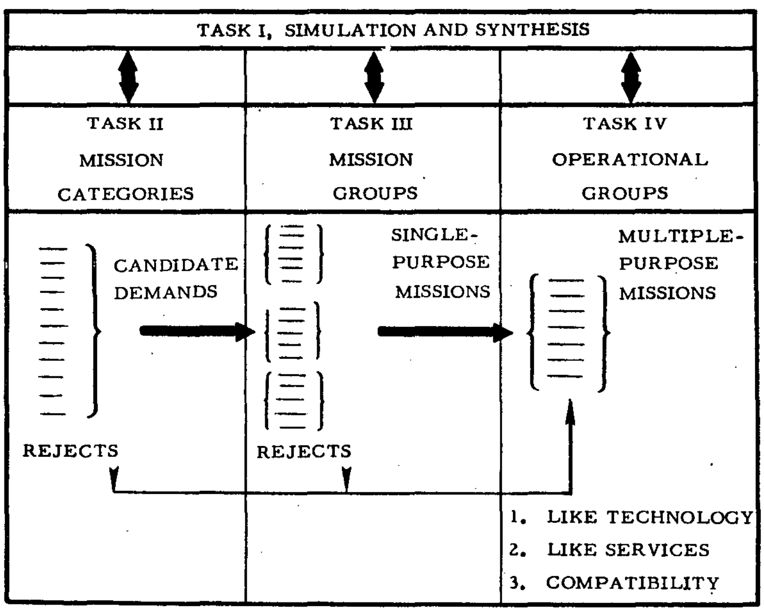


Figure 1-4. Study Logic

1.3 STUDY ENVIRONMENT

The ITS Concept Study, as shown in Figure 1-5, is at the focus of a wide range of activities oriented toward advanced communications systems. Previous studies of information transfer requirements and television broadcast systems have provided a basis for undertaking this more sophisticated and definitive study. While these previous studies have also pointed toward some technology requirements they lack firm footing in the specification of requirements.

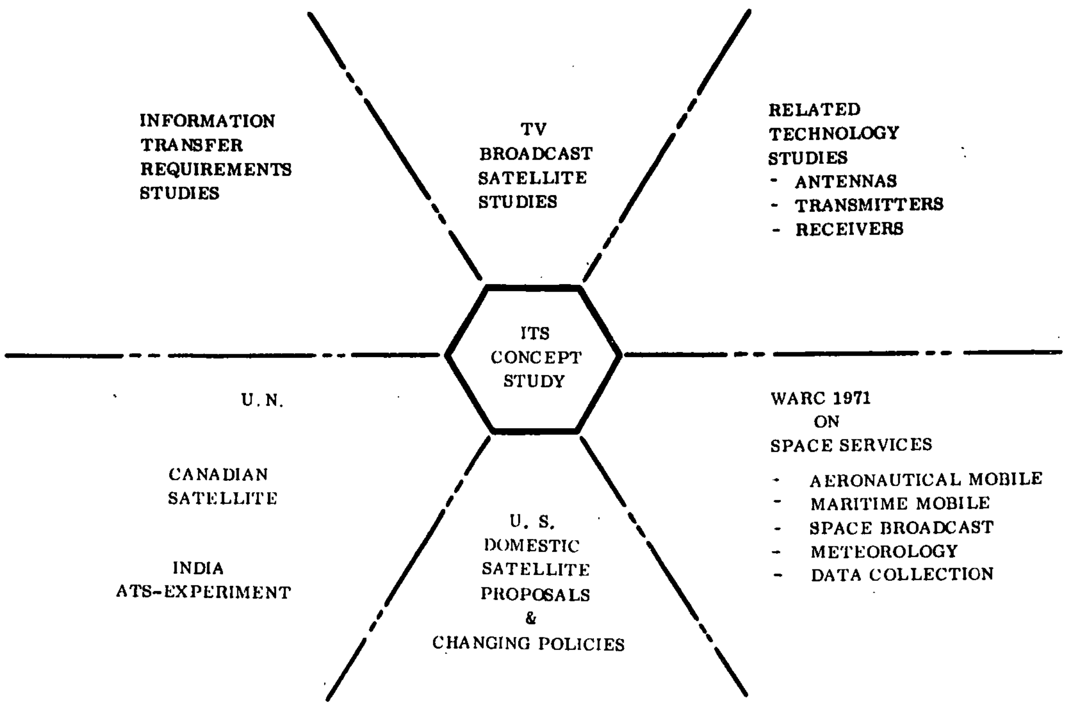


Figure 1-5. ITS Concept Study Environment

On the international scene a growing awareness of the potential benefits of space applications has led to the analysis and formulation of international policies. Space Broadcast is one of the topics for the World Administrative Radio Conference to be held in Geneva in June 1971. Correspondingly, Canada has embarked on a program to develop its own domestic satellite while India is participating with the U.S. in an Instructional Television experiment on the ATS-F&G satellites. The United Nations, in response to a joint resolution by Sweden and Canada, is also addressing itself to the problems associated with space broadcast. These include, not only the basic technologies, but also the social, cultural and legal problems. Developing nations are particularly concerned with maintaining their own identities in an environment of "cultural imperialism" they feel space broadcast is sure to bring.

At home, in addition to being an active participant in the international affairs, the U.S. is also considering domestic systems of one form or another. The Carnegie Commission on Educational Television released its findings in January 1967. It recommended the formation of The Corporation For Public Television to manage public television. Subsequently such a corporation was formed and it, the Corporation for Public Broadcasting, is active in the areas of program development and station interconnection. Several satellite proposals were taken under consideration by the FCC and a large series of inquires followed (under Docket No. 18294). In August of 1967 President Lyndon B. Johnson established the Task Force on Communications Policy under the leadership of Eugene V. Rostow, Under Secretary of State for Political Affairs. When released (December 1968), their report recommended a Pilot Program under the auspices of the Communication Satellite Corporation. A change in administration placed the entire matter back under executive consideration which culminated in a statement of policy which denied the previous sole-source approach and advocated an open competition for domestic satellites. An executive reorganization created the Office of Telecommunications Policy (OTP) which is now getting its charter and organization assembled under Dr. C. Whitehead.

In recent years communications policy in the U.S. has shifted its emphasis from sole-source, common carrier, international point-to-point service to competitive, non-common carrier domestic services of all kinds. The result has been to highlight the importance of studies of this type. When initiated in 1968, the ITS studies were unique. There are now several studies of this type in progress and sufficient recognition has been achieved to make requirements determination and analysis a necessary pre-requisite to the implementation of any communication service.

1.4 ORGANIZATION

In the context of the ITS Concept Study a satellite communication system includes all the elements shown in Figure 1-6. These include:

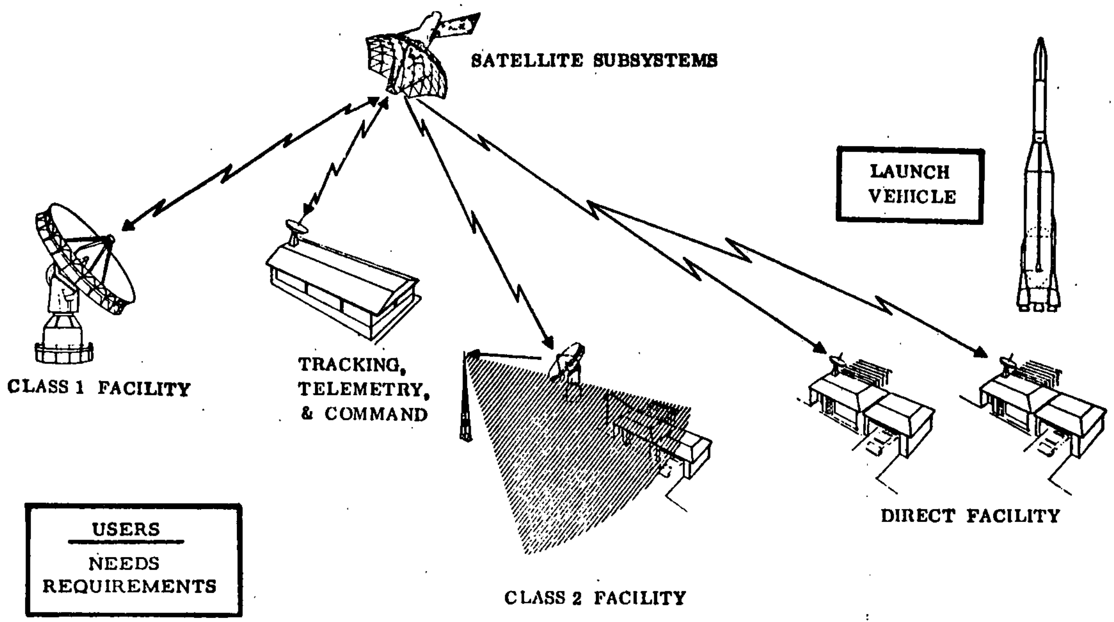


Figure 1-6. Satellite Communication System

1. User Needs/Requirements.
2. Communications links.
3. Ground Stations.
4. Satellite(s).
5. Launch Vehicles.

Each of these elements will be discussed in detail in the following chapters.

2

SYSTEM REQUIREMENTS

2.1 GENERAL

As shown in Figure 2-1 the technique used in the development of system requirements was based on direct contact with a large number of users of telecommunications in their present operations. This direct contact was accomplished by visiting a large number of users around the U.S. and discussing

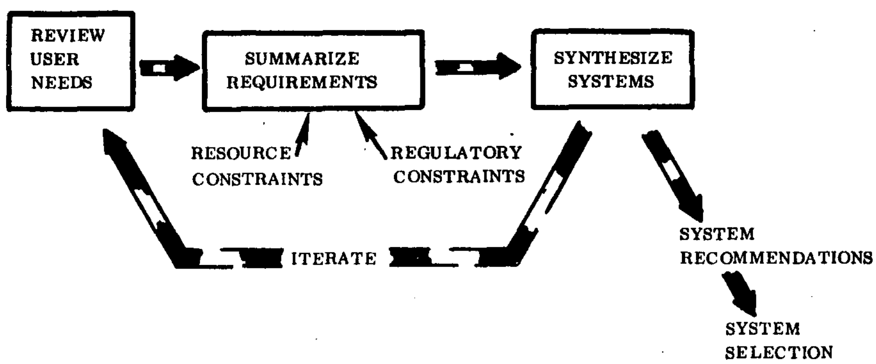


Figure 2-1. Study Technique

their information transfer needs, present and projected, with them. Specific items of interest included:

1. Locations of the users' sources and destinations.
2. Types of data - audio, video, facsimile or digital data.
3. Data Rates.
4. Duty cycles.
5. Other features, such as reliability, priority, privacy and response time, considered of importance in the user operations.

Data from these visits was then translated into technical inputs for the synthesis program and processed through the computerized analysis. Iterations of the results of this analysis with various users often resulted in changes to the requirements - compromises typically to reduce costs.

2.2 USER CONTACTS

Planning user contacts required some preliminary assessment of potential user agencies and their telecommunications interests. These are summarized in Table 2-1 and cover government, academic institutions, non-profit organizations, industry/firms and common carriers. Table 2-2 lists some of the contacts that were made in support of the ITS Concept Study. Neither list is exhaustive. Typically, each contact resulted in further referrals to the extent that the list of potential contacts was still expanding at the end of the study.

Significant data was obtained by attending the following conferences and conventions:

1. Annual Conventions of the National Association of Educational Broadcasters.
2. National Conference on Telecommunications Policy In Education sponsored by the Joint Council on Educational Telecommunications (ICET), Athens, Ga., 4-6 December 1968.
3. Annual Western Electronic Show and Convention (WESCON's).
4. Annual EDUCOM Meeting.
5. Annual EASCON's.
6. Conference on Communication Technology and American Education, co-sponsored by the JCET and The Johnson Foundation, Racine, Wisc., 3-5 December 1969.
7. AIAA Annual Communications Satellite Systems Conferences.

The open technical and non-technical literature provided many insights into the various systems.

Results of the previous Lockheed Missiles and Space Company (LMSC) and Stanford Research Institute (SRI) studies (Figure 2-2) provided close to 600 initial demands which had been filtered down to 31 demand categories as inputs to this study.

Table 2-1. User Agencies

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

Table 2-1. User Agencies (Cont'd)

CONTACT	INTEREST
Airlines & Travel Agents	Reservations & Communications
Stock Exchanges & Brokerage Quotation Services	Stock Market Quotations, Transactions & Messages
Banks	Credit Checks, Instant Check Cashing, Instant Fund Transfers, Etc.
Credit Card Companies	Credit Checks, Lost Card Checks, Billing, Etc.
Magazines & Newspapers	Facsimile Transmission, Remote Master Setup, Communications, Etc.
Trucking & Transportation	Location & Condition of all Units
Post Office & Telegraph	Instant Letters & Reproductions
Commercial TV Networks	Reach all Rural Areas & Communities
Dept. of Transportation	Road, Bridge, Rail Conditions, Weather Information & Communications
Dept. of Interior	State Park, Reservation & Resource Communications
American Medical Association	Continuing Education, Regional & National
	Rural Health Information Network Medicenters
Common Carriers :	Communications & Broadcast Services
European Broadcasting Union	Regional European Networking
UNESCO	Worldwide & Regional ETV & ITV, (e.g., India)
Cnae, Brazil	Communications System for Brazil, Including ETV
CETS	TV Distribution & Mass Communications for Europe
Foreign Governments :	Need to Establish Nationwide Commercial and ETV Networks
India, Philippines, Mexico, Australia, Brazil, East Africa, Etc.	
FAA	Air Traffic Control & Clearance; Navigation
Aeronautical Radio Service	Communications for Civil & Commercial Aircraft on Private Channels

Table 2-2. Users Contacted

No.	Name	Affiliation
1.	A. J. Altenberg	IITRI
2.	Gerard Appy	National Educational Television New York City
3.	J. A. Banghart Executive Vice-President	Standard & Poors Investors Management Services
4.	T. L. Banke ETV Coordinator	U.C. Medical Center
5.	Julius Barnethan	American Broadcasting System
6.	Dr. Jordon Baruch President	EDUCOM
7.	Edward A. Berg Vice-President, Operations	DATRAN

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

No.	Name	Affiliation
8.	Dr. Cliff Block	Dept. of State/AID
9.	W. Briscoe Managing Director	CATV Association
10.	J. Broger Director	Armed Forces Radio & Television Services
11.	Robert Bruce Director-Planning	Public Broadcast Service
12.	John T. Caldwell Manager of Operations	Ed. Foundation/WGBH
13.	Ben Carmichael	Appalachia Educational Laboratory
14.	Dr. R. Carpenter	JCET
15.	L. Madison Coombs	Bureau of Indian Affairs/Education
16.	Bernarr Cooper Chief, Mass Communications	State University of New York
17.	Col. L. Cruciana	Armed Forces Radio & Television Services
18.	Father J. Culkin	Fordham University
19.	W. Cumber Manager - T/C Planning	American Airlines
20.	John Curtis Consultant	DATRAN
21.	Frank W. Cyr Director	Rural Supplementary Education Center
22.	J. F. Daniel	U.S. Geological Survey
23.	Ruth Davis, PhD	National Institute for Health
24.	Ted Dixon Superintendent	San Diego County Department of Education
25.	Inspector J. Daunt	FBI/NCIC
26.	Mr. R. DuMont Director	AMA - Radio, TV and Motion Picture Department

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

No.	Name	Affiliation
27.	Rev. Walter C. Flaherty Director	Boston Catholic TV Center
28.	Paul Fogarty T/C Systems Manager	Bankers Trust Co.
29.	Wm. F. Fore Executive Director	National Council of Churches
30.	Col. Fradenberg	DOD/Office of Assistant Secretary for Education
31.	A. Fredette Coordinator of Instructional Communications	Albany Medical College
32.	Dr. L. Frymire Executive Director	N. J. Public Broadcasting Authority
33.	Dr. R. Gable	Dept. of Commerce Office of T/C
34.	LCDR. E. Gilbert USCG	D. O. T. /NDBSPO
35.	Dr. H. Greene Executive Director	Indiana Higher Education T/C Commission
36.	M. Grushki Chief Engineer	Stanford ITV Network
37.	Dr. R. Hallgren	D. O. C. /ESSA
38.	W. Harley	National Education Association & NAEB
39.	R. Hausser Vice-President	Crocker-Citizens Bank
40.	Dr. E. Hayden	D. O. C/Office of T/C
41.	Rev. Healy Director	Diocese of New York Communications Center
42.	Dr. R. Hilliard	FCC Educational Broadcasting Branch
43.	M. Horowitz	N. Y. Times
44.	Thomas P. Hoving Chairman	National Citizens Communication for Public TV

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

No.	Name	Affiliation
45.	G. Jacobs	USIA
46.	K. Jones Professor	San Diego State College
47.	J. Jordon President	Reservations World
48.	Irving B. Kahn	TelePrompTer
49.	William J. Kirkley Captain, USCG	U.S. Mission to U.N.
50.	B. Kubasik	National Citizens Committee for Public TV
51.	J. LeGates	EDUCOM
52.	A. J. Lipinski	Institute For The Future
53.	Claire List	Ford Foundation
54.	Norman Locke Director ITV	Boston University School of Education
55.	Dale Lovell	USN Service School Command
56.	Len Marks	United States Information Agency
57.	Charles Marquis	National Association of Educational Broadcasters
58.	T. McDonough	Department of Agriculture/REA
59.	Rev. J. Meyers	National Catholic Education Association
60.	J. Miles	Purdue University
61.	John Morrison Director of Programming	Eastern Ed. Network (EEN)
62.	Tom Nelson	Department of State
63.	Tom Nesbitt	Department of State
64.	C. Northrip Executive	Alaska Public Broadcasting Commission

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

No.	Name	Affiliation
65.	Frank W. Norwood Executive Secretary	Joint Council on Education Telecommunications
66.	Monsignor J. O'Keefe	Diocese of New York Committee on Education
67.	Dick Oldham Chief Engineer	Ed. Foundation/WGBH
68.	Dr. B. Paulu Head of Broadcasting	University of Minnesota
69.	N. Penwell Chief Engineer	CATV Association
70.	Peter Perry	U.N. Information Center
71.	C. A. Petry Systems Development	Aeronautical Radio, Inc.
72.	Rev. J. Pindar	National Catholic Office for Radio and Television
73.	Dr. Dave Pollen Deputy Assoc. Commissioner	Bureau of Research, HEW
74.	Dr. Donald G. Potter Director	Audio-Visual Center University of Nevada
75.	John Powell	Office of Economic Opportunity
76.	Don Quayle	Corp. for Public Broadcasting
77.	Ray Reid Television Coordinator	General Services Office Of State of California
78.	Mr. C. E. Reilly Executive Director	National Catholic Office for Radio and TV
79.	Marvin Robinson	U.S. Secretariat
80.	C. J. Robinove	U.S. Geological Survey Washington, D.C.
81.	D. Roderick, S.A.	FBI/NCIC
82.	George Sitts Chief Engineer	Diocese of Brooklyn TV Center
83.	G. Slater	Ford Foundation

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

No.	Name	Affiliation
84.	S. Skala	Swedish Mission to the U. N.
85.	Hugh Smith Commissioner	Commission Nevada Educational Communications
86.	B. R. Smyth Sr. Vice-President	Federal Reserve Bank of Chicago
87.	Lt. Col. Souville	Armed Forces Radio & Television Services
88.	R. Stanley	Health Education Welfare
89.	Herbert S. Steffens Director, Project West	Nevada State Dept. Education
90.	E. Steinhardt Professor	W. Virginia University
91.	Dr. John Sullivan Executive Secretary	National Education Association
92.	Robert Swenson	Comsat Corporation
93.	Sidney Tickton Executive Director	President's Council on Instructional Technology
94.	A. D. Tinklenberg Systems Development	Federal Reserve System
95.	Kane Thornton Network Engineer	National Institute of Health/ National Library of Medicine
96.	J. Gordon Vaeth	D. O. C. /ESSA
97.	H. Valentino Staff	Armed Forces Radio & Television Services
98.	D. Vincinanza Director-Communications	Reservations World
99.	Dr. Harold E. Wigren President	Joint Council on Education Communications
100.	John Witherspoon	NET, San Diego

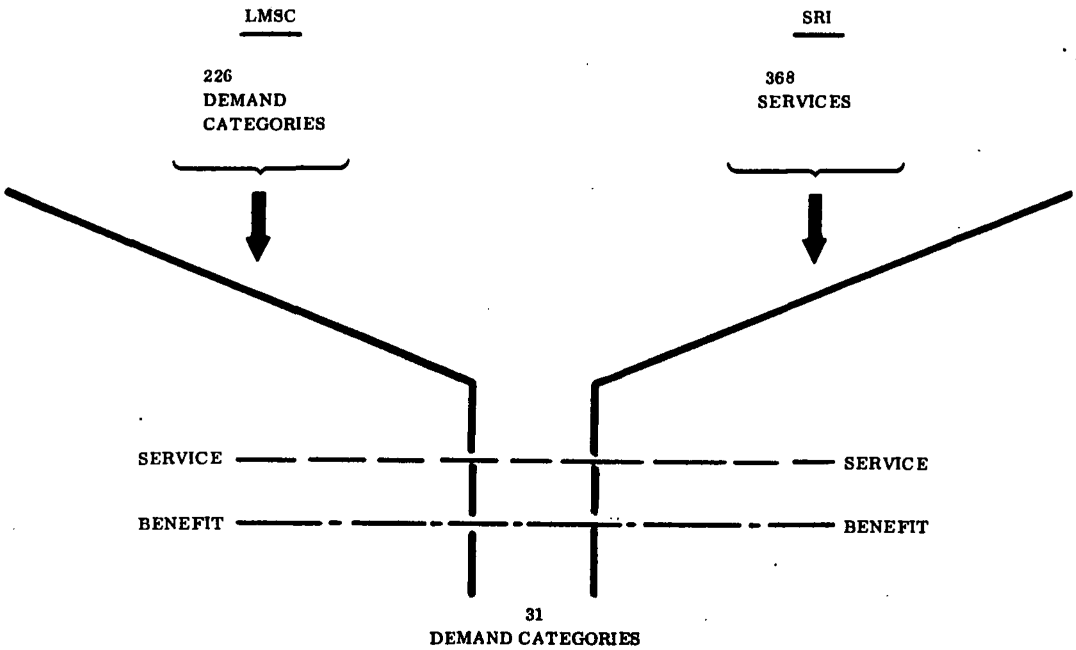


Figure 2-2. Data From Previous Studies

While all of these contacts are important for rounding out the total perspective on the various mission groups it should be made quite clear that they are not equally important. In fact, in terms of specific data obtainable, some of the contacts had little to offer. These were dropped from further consideration. Those who provided a reasonable amount of data and who seemed interested in the overall study and its results were maintained on the active contact list and farther contacts were made as opportunities arose. As stated earlier, the list of potential contacts has not been exhausted. This aspect of the study is not presented as completed. It is presented as a reasonable start, within the scope of the ITS Concept Study, and as a foundation for further investigation by NASA.

2.3 USER ANALYSIS

Several iterations of analysis and combination were required to generate a manageable set of Mission Groups for analysis. The sequence was, as follows:

1. LMSC & SRI Demands. Nearly 600 demands were identified.
2. LMSC & SRI Midterm, June 1969.
   At this point in time LMSC had applied a partial Benefit and Service analysis to the demands and selected 39 for definition.
3. Convair Review, August 1969.
   By eliminating the one catch-all LMSC demand and by combining the remainder under more generalized titles, Convair defined 19 Mission Groups.
4. LMSC Final, December 1969.
   As a result of further analysis LMSC defined 31 viable demand categories. This was accomplished by eliminating 25 of the previous demands, by selecting 1 new demand and by expanding the remaining demands into several demands. In only 1 instance was there a consolidation of previous demands under a new title.
5. Convair Midterm, January 1970.
   With the later LMSC data in hand a new set of 14 Mission Groups was defined. This was accomplished by eliminating 2 of the previous groups:
   a. No. 6 - Telephone was eliminated because of the extend of domestic common carrier service.
   b. No. 17 - Time Signals was eliminated because no user interest had been defined.

   In 3 instances several missions were combined under new titles.
6. Convair Final, September 1970.
   In the final analysis, and based primarily on expressed user interest, a set of 10 Mission Groups was defined. The derivation from the previous set of 14 was accomplished by eliminating No. 14/Space Mission Support (at COR's direction), by generating 3 new categories and by combining other categories under more generic titles.

This entire process is shown in Table 2-3. The ten Mission Groups selected for analysis were:

1. Television Services. This mission group encompasses all technical aspects (except program generation) of the distribution of commercial and non-commercial television programming to the user areas of interest. In general, this group does not include users which may require other services in addition to video. Modes of service considered included direct to user and reception and redistribution via conventional terrestrial techniques (rebroadcast, CATV).
2. Remote Area Telecommunications Services. The primary objective of this group is to provide general telephony and television services to remote areas (e.g., Alaska and the Rocky Mountain States), where, because of adverse terrain and weather and low population density, these services are not provided by terrestrial common carriers.
3. Educational and Instructional Services. This group is composed of those users which require telecommunications services for instruction and enrichment in all levels of education - elementary, secondary, college and trade schools as well as for continuing adult education. Both public and private institutions may be served as well as special facilities for minorities (e.g., Bureau of Indian Affairs schools). The services included are audio, video for instruction/education and digital data for computer aided instruction (CAI) and school administrative requirements.
4. Data Collection and Distribution Services. This mission group addresses itself to those requirements of collection of data from remote sensing platforms. The discipline included are meteorology, hydrology, seismology, and oceanography. The platforms are dispersed over large areas of the globe and may report synoptically or upon command from a central facility. The data from these inaccessible platforms is generally perishable and requires distribution to users within a short time after collection.
5. Civic Safety Services. The service offered is that of an integrated communications system consisting of audio, video, facsimile, and digital data for distribution of law enforcement data, natural disaster warnings and civil defense data. In

Table 2-3. Mission Group Definition

LMSC Midterm June 1969	LMSC Final December 1969	August 1969 Convair 1st Cut	January 1970 Convair Midterm	June 1970 Convair Final
1. Law Enforcement *	3. Developing Nations	1. Law & Justice (+33)	1. Law & Justice (+9)	5. Civic Safety Services (1, + part of 9)
2. Education	10. Preschool 12. Grade School 13. Adult	2. Education	2. Education	3. Educational & Instructional Services (2, 12 + part of 8)
3. Mail *	23. Ailing at Home 27. High School 28. Criminal Rehabilitation 29. Rural	3. Mail	3. Mail	
4. Medical	1. Medical Diagnostic	4. Medical	4. Medical	8. Biomedical Communication Network (4, + part of 8)
5. Banking & Finance *		5. Banking & Finance	5. Banking & Finance (+12)	9. Business Management Services
6. Ground-to-Ground T/C *		6. Telephone (22, 23, 24) *		
7. News Services & Publications *		7. News Service & Publications (7 & 38)*	6. News Service & Publications	7. Mobile Communication Services (7, 11)
8. A/C Communications *		8. A/C Communications (14 & 20)	7. A/C Communications (+19)	
9. Mobile/Ground *		9. Mobile Ground Communications		
10. Library *		10. Library	8. Library	
11. Welfare	16. Employment Records & Placement			
12. Security Exchange Transactions *		12. Securities Exchange Transactions		
13. Weather	4. Balloons 6. Buoys 17. Satellites 18. Ships			
14. ATC (enroute)	11. Collision Avoidance 30. ATC (enroute)			
15. Marine Communications *		14. Marine Communications (15 & 16)	11. Marine Communications	
16. Marine Position & Navigation *				
17. Internal Revenue *				
18. Oceanography *				
19. Entertainment *				
20. A/C Status (enroute)	5. Flight Performance Testing			
21. Meetings	15. U.N. 24. Legislative 25. Political	15. Special Events (21, 25, 31, 33, 39) (Including 19. Entertainments 31. Cultural)	12. Special Events	

Table 2-3. Mission Group Definition (cont'd)

LMSC Midterm June 1969	LMSC Final December 1969	August 1969 Convair 1st Cut	January 1970 Convair Midterm	June 1970 Convair Final
22. Scheduling *				
23. Inventory Control *				1. Television Services
24. Freight Movement *				
25. Language Translation *				2. Remote Area Telecommunications
26. Agriculture Sciences				
27. Geology	2. Earth Resources			6. Travel & Recreational Services
28. Hydrology				
29. Civil Defense	14. Emergency Communications 26. Emergency Warnings			10. Domestic Wideband Services (3, 6, 13 + part of 9)
30. Time Signals *		17. Time Signals *		
31. Cultural Programs *				
32. Migration	19. Fish Migration 20. Animal Migration			
33. Court Proceedings *				
34. Computer Services	31. Time Sharing	16. Computer Services	13. Computer Services	
35. Space Mission Support	7. Manned Orbit Support 9. Satellite Control 21. Deep Space 22. On-Orbit Assembly	18. Space Mission Support	14. Space Mission Support *	
36. Ground Traffic Control *		19. Ground Traffic Control/Reservations		
37. Screened Demands *				
38. Electronic Publication *		11. Government Communications (11, 17, 29)	9. Government Communications	
39. Electronic Travel *				
	8. Astronomy	13. Science Monitoring (13, 18, 26, 27, 28, 32)	10. Science Monitoring	4. Data Collection & Distribution
39	31	19	14	10
Transition Procedure	1. Dropped 25 categories * 2. Took basic/generics and split them into details 3. Added a new category 4. In only one instance was there a consolidation (26 + 27 + 28) = 2	1. Reverted to original LMSC 39 categories 2. Dropped 1 category * 37. Screened Demands 3. Combined categories in 8 cases	1. Dropped 2 categories * 6. Telephone * 17. Time Signals 2. Combined categories in 3 cases	1. Dropped 1 category * 14. Space Mission Support by NASA Direction 2. Separated subcategory in 1 case - Reservations 3. Generated 3 new categories 4. Combined categories in 5 cases

general, it is directed toward specific agencies (e.g., police departments) but can reach the entire populace.

6. Travel and Recreational Services. This is primarily a digital data inquiry/ response system designed to provide the inquirer with data on all types of reservations. User organizations would include hotels/motels, car rental agencies, airlines, rail, bus services, theaters, sports events, and even camping sites.
7. Mobile Communications Services. The intent of this service is to provide a central source(s) capable of locating and communicating with mobile equipment. The services consist of two way audio and digital data links for aircraft, ships, trucks and railway cars.
8. Biomedical Communications Network Services. This is an integrated communications service addressed specifically to the needs of the biomedical community. The users include hospitals, medical schools, medical libraries, physicians, nurses, technicians, administrators and all other supporting functionaries. The intent of the services is to provide dial access information systems, remote diagnoses, library browsing, and instructional and educational systems, The range geographic regions vary from remote areas with low medical densities to large metropolitan medical centers.
9. Business Management Services. This service provides audio, video, facsimile and digital data services for the business community. These services may provide for teleconferencing, processing of business data, inventory and stock control, credit card authorizations and other such business functions.
10. Domestic Wideband Services. This is basically a wideband digital data service to implement or supplement some of the proposed microwave services. The types of services included are computer time-sharing, computer-to-computer interchange, remote publishing and other functions which require wide bandwidths over long distances.

These mission groups form the generic categories under which all of the demands examined in this study were found to fit.

2.4 TRANSLATION OF USER NEEDS INTO REQUIREMENTS

2.4.1 INTRODUCTION. To synthesize information transfer demand categories, it is necessary to convert user inputs to appropriate models for entry into a computer program. User inputs describe the services required by the user. To define the parameters of a communication network capable of implementing these user demands, translation of some of the user inputs is required. Figure 2-3 illustrates the process whereby user input parameters are converted into computer models.

The information transfer categories that are considered are voice, digital data, television and facsimile. There is in some cases overlap between these categories. For instance, digitized voice and facsimile can be treated as digital data for purposes of defining communication network parameter requirements although translation of user needs requires separate treatment of each of the categories. Similarly, multiple access parameters are treated under voice for frequency division multiple access (FDMA) and under digital data for time division multiple access (TDMA).

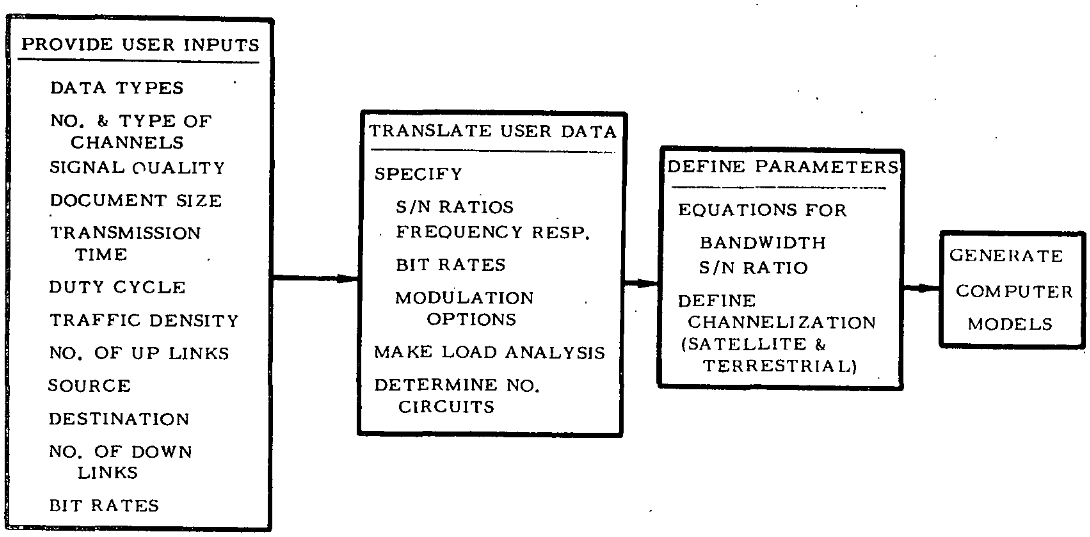


Figure 2-3. Development of Parameters For Computer Models

2.4.2 VOICE. To determine channel requirements for telephone service, it is necessary to perform a load analysis based on traffic density and grade of service. For traffic density data, the number of calls required during a mean busy hour is derived. Grade of service, in addition to specifying quality such as volume, distortion, noise, and fidelity also refers to the probability of making a connection. Erlang formulas are generally used to ascertain the number of circuits required to accommodate a given traffic load at a particular loss probability. The load analysis results specify the number of circuits required in a commercial switched system or the number of multiple access channels in a satellite system.

2.4.2.1 Circuits Required vs. Traffic Load. (Figure 2-4).

To define multiple access system parameters it is first necessary to specify the traffic requirements. Included in these requirements is the number and type of channel and the grade or quality of service required for each channel. Type of channel refers to whether it is telephone, facsimile, digital data, teletype or TV. The "grade of service" has different meanings for the

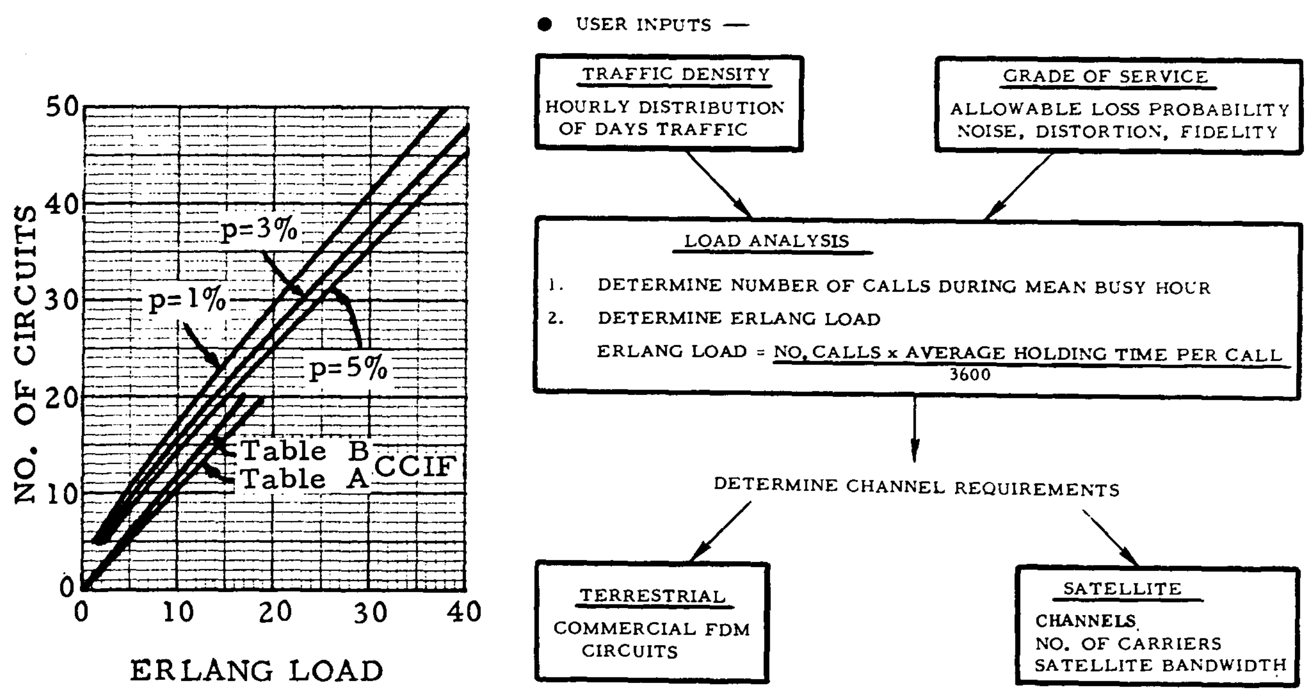


Figure 2-4. Voice Channels Load Analysis & Modeling

different channel types. For telephone channels, in addition to specifying the number of completed calls that fall within certain specified quality with respect to volume, distortion, noise and fidelity, grade of service in a switched system also refers to the probability of making a connection. This definition is also applicable to digital data or record transmission over a switched network. In a store-and-forward or message-switching system grade of service defines the average time to forward a message through the system.

This connotation for grade of service is particularly pertinent in assessing the traffic load for a demand assigned multiple access satellite communication system. Erlang formulas are generally used to ascertain the number of circuits required to accommodate a given traffic load at a particular loss probability. There are three so-called blocking formulas in use. The formula most frequently used by CCITT and ITU is the Erlang B which assumes all blocked calls are "lost" or "cleared" because of the caller "hanging up" immediately instead of waiting. CCITT has recommended that the loss probability during the mean busy hour should not exceed 1%. Thus the loss probability for a single-circuit route will be 1% when carrying only 0.01 Erlang. (An Erlang is defined as that traffic load whose calls if placed end to end will keep one path continuously occupied). In order to determine the Erlang load the stations busy hour must be determined based on an hourly distribution of the day's traffic. Then the Erlang load is calculated based on the formula.

$$\text{Erlang load} = \frac{\text{No. of calls} \times \text{average holding time per call (sec.)}}{3600}$$

Based on a required loss probability and the Erlang load, the number of required circuits can be determined using the Erlang formula or a table based on the Erlang formula as shown in Table 2-4.

Similar techniques might be used to determine the number of circuits required for other than telephone channels. Analysis of all traffic loads will result in the requirement for a communication network that must provide a given number of demand assigned and fixed assigned circuits of various bandwidths between each of the terminal stations in the network.

Table 2-4. Erlang No. 1 Formula for Loss Probabilities of 1, 3, and 5 Percent*

Formula:

Let p = loss probability
y = the traffic to be carried (in erlangs)
n = the number of circuits

$$E_{1,n}(y) = p = \frac{y^n/n!}{1 + y/1 + y^2/2! + \cdots + n^n/n!}$$

n	$p = 1\%$	$p = 3\%$	$p = 5\%$	n	$p = 1\%$	$p = 3\%$	$p = 5\%$
1	0.01	0.03	0.05	51	38.80	42.89	45.52
2	0.15	0.28	0.38	52	39.70	43.84	46.52
3	0.46	0.715	0.90	53	40.60	44.80	47.53
4	0.87	1.26	1.52	54	41.50	45.77	48.53
5	1.36	1.875	2.22	55	42.41	46.73	49.53
6	1.91	2.54	2.96	56	43.31	47.69	50.52
7	2.50	3.25	3.74	57	44.22	48.66	51.52
8	3.13	3.99	4.54	58	45.13	49.62	52.50
9	3.78	4.75	5.37	59	46.04	50.6	53.5
10	4.46	5.53	6.22	60	46.95	51.5	54.5
11	5.16	6.33	7.08	61	47.86	52.5	55.5
12	5.88	7.14	7.95	62	48.77	53.4	56.5
13	6.61	7.97	8.83	63	49.69	54.4	57.5
14	7.35	8.80	9.73	64	50.60	55.4	58.5
15	8.11	9.65	10.63	65	51.52	56.3	59.5
16	8.87	10.505	11.54	66	52.44	57.3	60.5
17	9.65	11.37	12.46	67	53.35	58.3	61.5
18	10.44	12.24	13.38	68	54.27	59.2	62.5
19	11.23	13.115	14.31	69	55.19	60.2	63.6
20	12.03	14.00	15.25	70	56.11	61.2	64.6
21	12.84	14.885	16.19	71	57.03	62.1	65.6
22	13.65	15.78	17.13	72	57.96	63.1	66.6
23	14.47	16.675	18.08	73	58.88	64.1	67.6
24	15.29	17.58	19.03	74	59.80	65.1	68.6
25	16.12	18.48	19.99	75	60.73	66.0	69.6
26	16.96	19.39	20.94	76	61.65	67.0	70.7
27	17.80	20.305	21.90	77	62.58	68.0	71.7
28	18.64	21.22	22.87	78	63.51	69.0	72.7
29	19.49	22.14	23.83	79	64.43	70.0	73.7
30	20.34	23.06	24.80	80	65.36	70.9	74.7
31	21.19	23.99	25.77	81	66.29	71.9	75.8
32	22.05	24.91	26.75	82	67.22	72.9	76.8
33	22.91	25.84	27.72	83	68.15	73.9	77.8
34	23.77	26.78	28.70	84	69.08	74.9	78.8
35	24.64	27.71	29.68	85	70.02	75.9	79.9
36	25.51	28.65	30.66	86	70.95	76.9	80.9
37	26.38	29.59	31.64	87	71.88	77.8	81.9
38	27.25	30.53	32.63	88	72.81	78.8	82.9
39	28.13	31.47	33.61	89	73.75	79.8	84.0
40	29.01	32.41	34.60	90	74.68	80.8	85.0
41	29.89	33.36	35.59	91	75.62	81.8	86.0
42	30.77	34.30	36.58	92	76.56	82.8	87.0
43	31.66	35.25	37.57	93	77.49	83.8	88.1
44	32.54	36.20	38.56	94	78.43	84.8	89.1
45	33.43	37.15	39.55	95	79.37	85.7	90.1
46	34.32	38.11	40.54	96	80.31	86.7	91.1
47	35.21	39.06	41.54	97	81.24	87.7	92.2
48	36.11	40.02	42.54	98	82.18	88.7	93.2
49	37.00	40.97	43.54	99	83.12	89.7	94.2
50	37.90	41.93	44.53	100	84.06	90.7	95.2

*CCITT Red Book, vol II bits, Geneva, 1961

2.4.2.2 Frequency Division Multiple Access. A limiting case of multiple access is the assignment of channels on a per call basis whereby each voice channel modulates a separate carrier. Figure 2-5 illustrates the additional repeater bandwidth that would be required compared to multiplexing several channels on a carrier. Table 2-5 shows how the bandwidth varies for a 1200 channel FDMA system as a function of the number of carriers.

Table 2-5. Repeater Bandwidth as a Function of Number of Carriers for a 1200 Channel FDMA System

No. of Carriers	No. of Telephone Channels per Carrier	Total BW (MHz)
5	240	135
10	120	178
20	60	226
50	24	332
100	12	424

2.4.2.3 Time Division Multiplexing Parameters. There are two methods suggested for encoding telephone voice channels.*

a. Encoding individual telephone channels (TDM-PCM) as is being done in the AT&T T-1 system and most operational PCM systems worldwide. Based on a sampling rate of 8000 samples/sec., seven bits per voice channel.

b. Encoding the FDM baseband (FDM-PCM) - The above referenced CCIR report suggests the following parameters be used to provide relay quality voice for 120 or more digitized FDM voice channels:

number of bits per sample = 8

sampling frequency = 2.3 F_m or 2.3 (4200n)

where F_m is the highest baseband frequency, and n is the number of telephone channels.

With 5% added for synchronization, the bit rate for n channels is then

(1.05)(2.3)(4200n)(8)   81,000n bits per second.

* CCIR, Oslo 1966, Volume IV, part 2, Report 211-1, page 309.

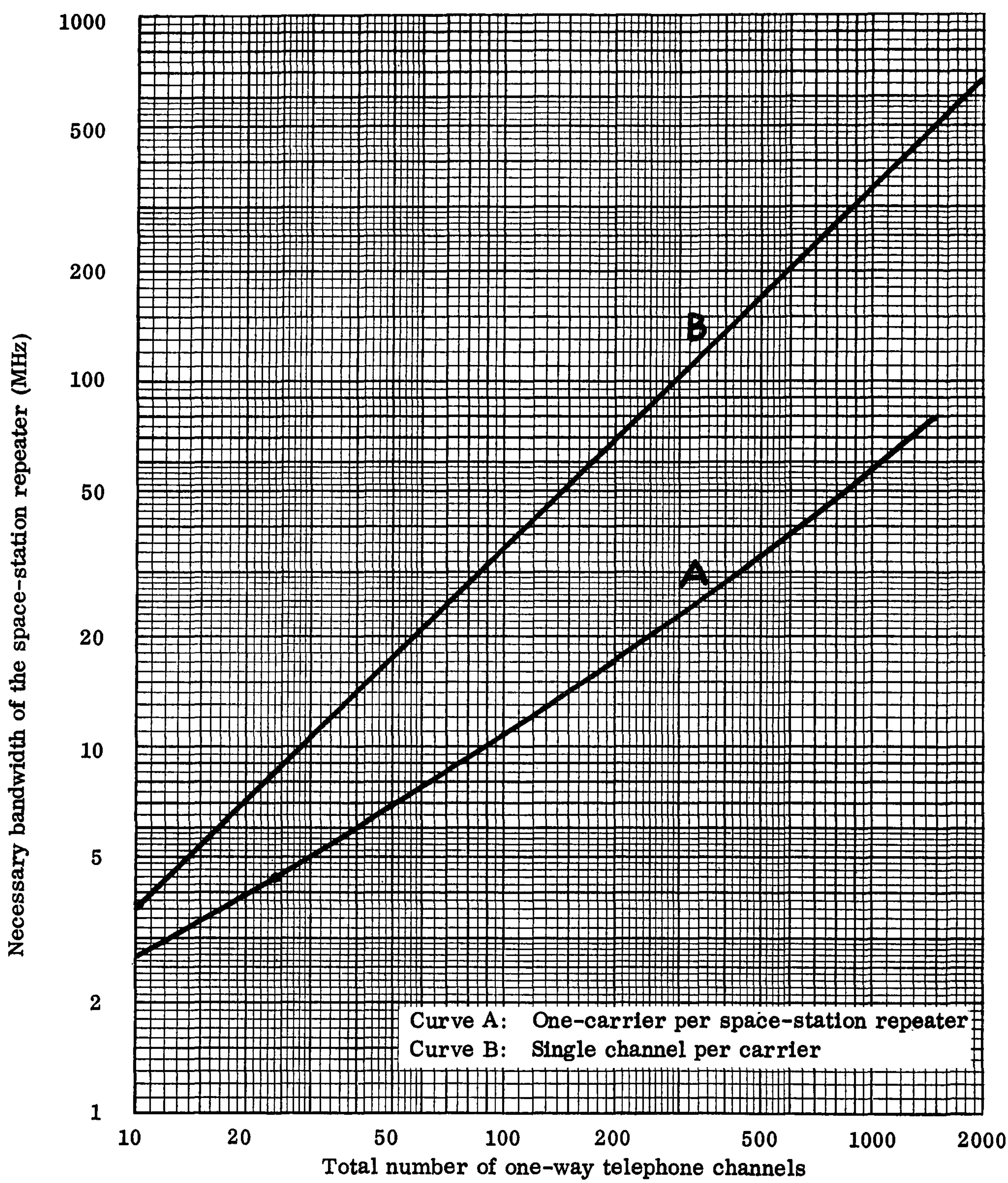


Figure 2-5. Necessary Space-Station Bandwidth for Multiple-Carrier FDM-FM Systems

Assuming an r.f. bandwidth of 1.2 × bit rate, Table 2-6 compares bandwidth requirements as a function of the number of telephone channels for TDM-PCM-PSK, FDM-PCM-PSK and FDM-FM.

Table 2-6. Required Bandwidth for Single Access Multiplexed Channels

Total Number of Channels	12	24	60	120	240	600	960	1200
TDM-PCM-PSK Occupied BW in MHz	0.97	1.93	4.84	9.68	19.3	48.4	77.4	96.8
FDM-PCM-PSK Occupied BW in MHz	1.17	2.34	5.86	11.7	23.4	58.5	93.8	117.0
FDM-FM Occupied BW in MHz	2.96	4.64	8.1	12.5	19.0	36.5	51.6	64.7

It may be noted that PCM requires less bandwidth for less than 240 channels and FDM-FM is more conservative of bandwidth for more than 240 channels.

2.4.3 TRANSLATION OF DIGITAL DATA (Figure 2-6). User digital data requirements specify bit rate, allowable error rate, type of circuit (simplex or duplex), source and destination, nature of data (message, tabular, or numerics), and delivery time requirements. The standard input signal is a binary (two-level) serial pulse stream, although the input data might be in parallel and multilevel. The basic input format is manipulated and converted in various ways, depending upon data transmission requirements. If user data is incomplete it is necessary to assign bit rates, error rates, circuit type and, in a store-and-forward or message-switching system the grade of service based upon the average time to forward a message through the system.

Having defined and translated all user requirements, the service required from either a common carrier or a satellite system is specified. In the case of the common carrier, the number and type of circuits and associated modems are specified. For a satellite system, the requirements specify

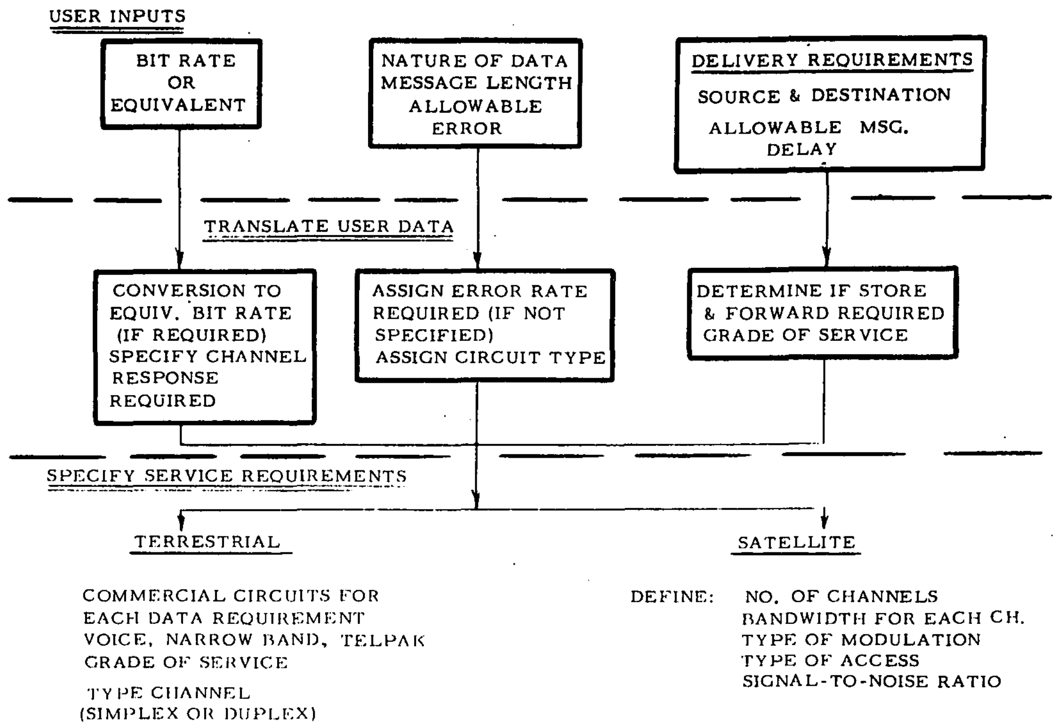


Figure 2-6. Translation of Digital Data

the design and capacity of the satellite repeater and associated ground stations in many cases it could be a mix of these two systems or a hybrid terrestrial/satellite network.

2.4.3.1 <u>Narrowband.</u> Narrowband service is that class of service that has a nominal bandwidth of 150 Hz and will accommodate either one 75 baud teletype channel or digital data with bit rates to 150 b/sec. Teletype data can be transmitted on a voice grade channel with twelve 75 baud teletype channels transmitted on a signal would modulate one of twelve tones spaced by 170 Hz within the 425 - 2975 Hz frequency band.

2.4.3.2 <u>Voice Grade.</u> The allowable bit rate that can be transmitted on a voice channel depends on the grade of line and the sophistication of the modem. At the present time 2 kilobits per second is the typical data rate for a voice channel on a switched network. AT&T projects an improvement to 4.8 KBS by 1975 on a switched voice band channel. Private voice grade circuits allow a 2.5 kilobit per second data rate with a projected rate of 9.6 KBS by 1975. Conditioned private lines can be provided at extra cost to allow use of higher bit rates. Private lines also have predictable properties whereas a dialed up call will result in a random selection of lines that will yield different properties for each data transmission.

Table 2-7 lists services available on common carrier voice grade circuits. Achieving bit rates of 4800 and 9600 bits per second on a voice channel is accomplished by using multi-level and multi-phase modulation techniques. Using these techniques requires a higher signal-to-noise ratio for a given allowable bit error rate. The effect of distortion and noise is to increase the bit error rate probability. On telephone networks within the U.S., on an average of one character error will occur for each 100,000 characters transmitted.

Table 2-7. Available Voice Grade Service

Line Grade	Allowable Bits/Sec. Rate	Modem	
		Type	Supplier
Dial Service	2000	201 A Dataphone	AT&T
Dedicated C2	2400	201B Dataphone	AT&T
Broadband Switched	2400		W. U.
Dial Service	3600	203A Dataphone	AT&T (Future)
Dedicated C2 & C4	4800	TE-216A -4 - AD	Collins
Dedicated C4	9600	SEBIT-96	Rixon

2.4.3.3 Wideband Service. Wideband service may be defined as that requiring a greater bit rate than can be provided on a voice grade channel. There is a large discontinuity in data services available between voice grade and wideband. The next option above voice grade is the group band of nominal 48 KHz bandwidth. Modems are available that utilize the half group bandwidth at a 19.2 KBS bit rate. However, the entire 48 KHz service must be ordered. The unused portion can be arranged for up to six telephone channels. Common carrier wideband services are listed in Table 2-8.

Table 2-8. Wideband Services

Circuit Type	Allowable Bit Rate	Data Set
Group Telpak A	19.2 KBS & 40.8 KBS	AT&T 301B
	50 KBS	AT&T 303C
Super Group Telpak C	230.4 KBS	AT&T 303D
Greater than Super Group (Telpack D)	460.8 KBS	AT&T

2.4.3.4 Digital Data Transmission Costs. In spite of the increase in volume of digital data transmission, the data market is still less than one percent of the telephone market. Cost forecasts, based on bit rate capability of data transmission systems, show that decided cost advantages should accrue as higher bit rates are transmitted and points to the advantages of all - digital types of data transmission. Figure 2-7 illustrates this cost trend.

Cost of leasing common carrier lines for digital data transmission, shown in Table 2-9, was taken from "The Challenge of the Computer Utility".* This is substantially in agreement with Chipp and Cosgrove.

The data from Table 2-9 has been plotted and fitted with a regression line as shown in Figure 2-8.

*D.E. Parkhill, Addison-Wesley, 1966

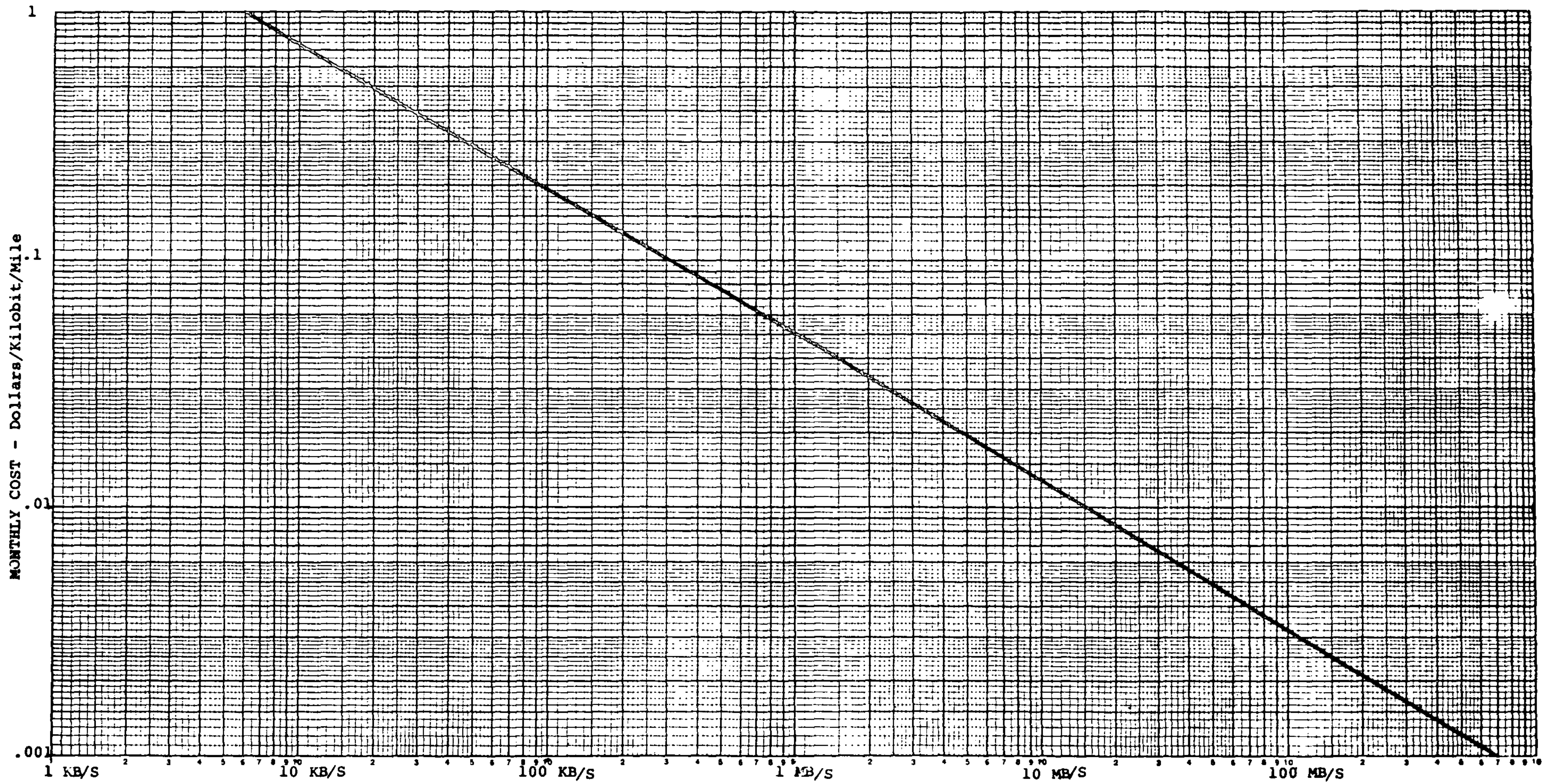


Figure 2-7. Digital Transmission Capability - Bits per Second

Table 2-9. Basic Transmission Costing Data

Type of Service (AT&T Nomenclature)	$/Mile/Month*	Bits/sec
Schedule 1	.70	45
Schedule 2	.70	56
Schedule 3	.77	75
Schedule 4	1.79	2,400
Telpak A	15.00	41,000
Telpak B	20.00	82,000
Telpak C	28.00	230,000
Telpak D	60.00	1,000,000
Western Union (Spec.)**	287.50	12,000,000

* Normalized to 1000 mi. distance

** This is a special service provided to the military on a one-time basis.

Digital communications terminal equipment cost data is presented in Table 2-10. Figure 2-9 is a plot of this data with a trend line based on the data points. This data agrees in general with quoted lease cost for modems in the range up to 10,000 bits/sec. Above this bit rate recently developed modems tend to level off in cost up to 100,000 bits/sec.

Table 2-10. Basic Cost Data for Data Terminal Devices

Data Point	Type	$/Mo.	Bits/Sec.
1	Dataphone 100	20	200
2	Dataphone 200	40	1,200
3	Dataphone 200	72	2,400
4	Telpak A	435	41,000

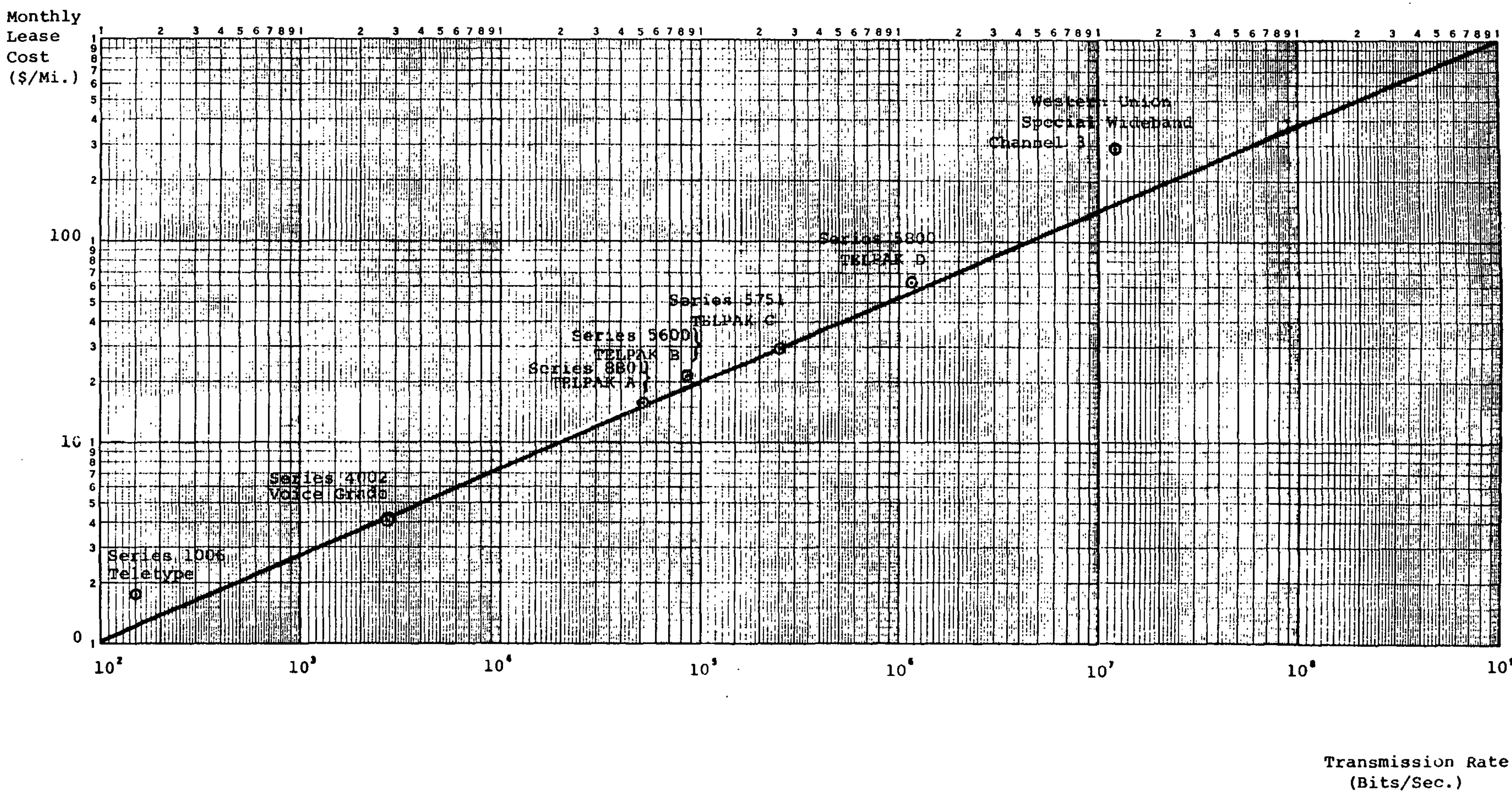


Figure 2-8. Communications Line Costs as a Function of Data Rate

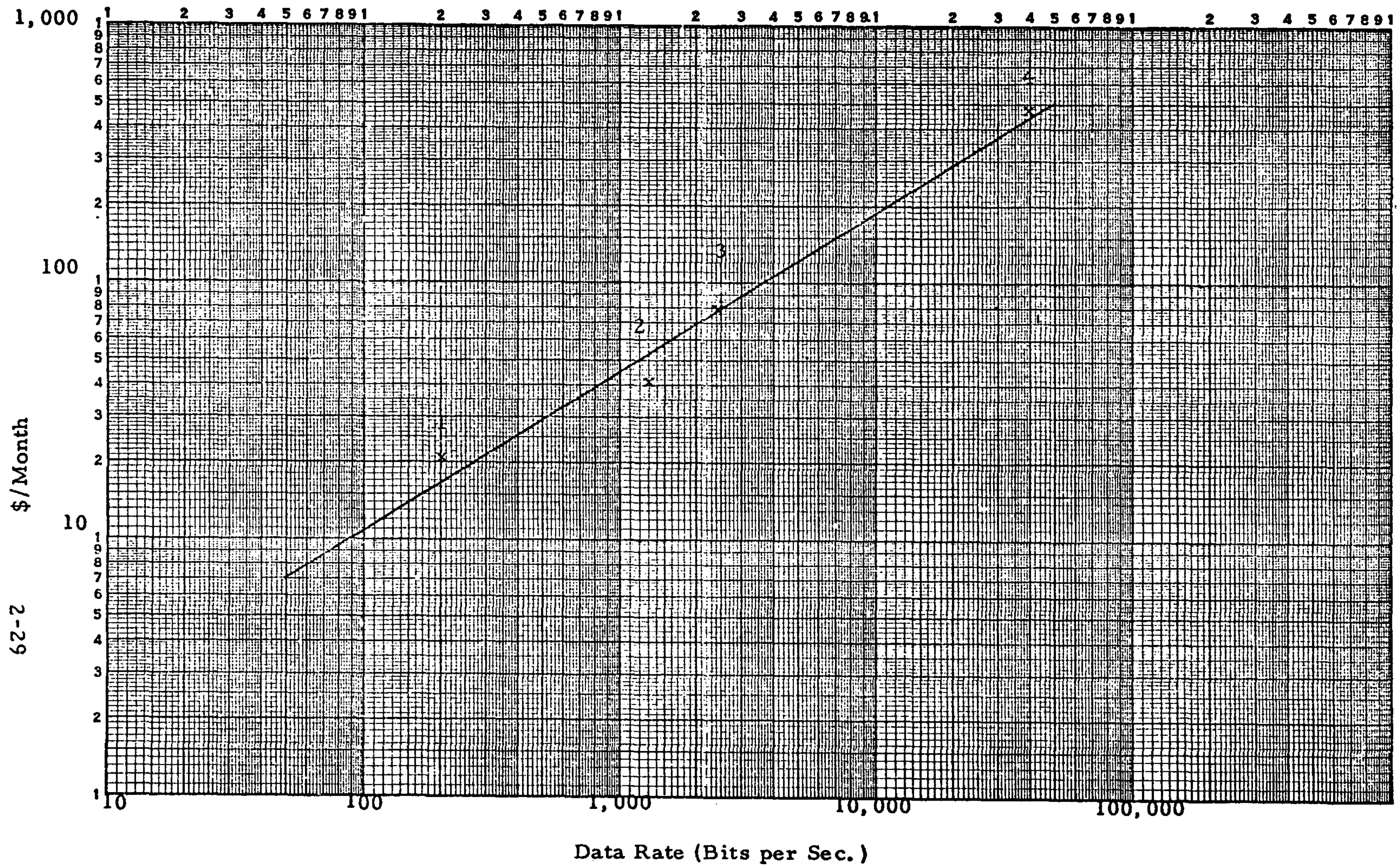


Figure 2-9. Terminal Equipment Rental

2.4.3.5 The Bell T-1 System. The Bell T-1 system, providing for analog-to-digital conversion of voice channels to a PCM time division multiplex format, allows transmission of 24 voice channels over a 2-wire pair, thus accommodating voice transmission economically over a switched network. This system is expected to eventually replace all analog voice channels in the 1970's. Table 2-11 shows the present capability of the T-1 circuit to handle asynchronous digital data.

Table 2-11. T-1 Digital Data Capability

T-1 Line Loading	No. of Channels per Line	Max Data Rate in KB/S	Max. Timing Error
1/8	8	64	± 1/3 microsecond
1/4	4	128	± 0.65 "
1/2	2	256	± 0.35 "
1/1	1	512	± 0.17 "

2.4.3.6 Efficiency of Information Transmission. Since the cost of information transfer can ultimately be expressed in terms of cost per bit, it is desirable to minimize the number of bits required to transmit a given message. Shannon has defined methods of calculating the information content or entropy, H, of the written language. If the language is translated into binary digits the most efficient way, the entropy H is the average number of binary digits required per letter of the original language. The average information per word of a message with n possible words of probability P_1 to P_n, respectively, is

$$H_{\Delta V} = -\sum_{j=1}^{n} P_j \log P_j \text{ bits/word}$$

Based on tabulations of word frequencies Shannon has plotted logarithmically word probability against frequency rank, yielding a resultant slope of -1 such that if P_n is the probability of the nth most frequency word, then roughly $P_n = \frac{0.1}{n}$. The total probability becomes unity for n = 8,727; therefore

$$H_{\Delta V} = - \sum_{1}^{8727} P_n \log_2 P_n = 1.82 \text{ bits/word}$$

or 2.14 bits/letter based on an average of 5.5 letters per word.

The information content of a typewritten 8-1/2 × 11" page of English text, assuming a 300 word average is 11.82 × 300 = 3550 bits. Converting each character of a 8-1/2 × 11" typewritten page to a 7 bit binary word results in 300 × 5.5 × 7 = 11,550 bits per page. If the same typewritten page were to be transmitted by facsimile at a density of 100 lines per inch the number of bits required would be $8.5 \times 11 \times 100^2 = 935,000$ bits. Due to the predominance of white areas in a document containing typewritten text, significant data compression is possible. One data reduction technique that can be used is run length coding which is based upon transmitting one data word for each group of consecutive white elements and one data bit for each black element. A data compression ratio of about 4:1 can be achieved using this technique, thus reducing the number of bits per page to 935,000/4 = 233,750 bits, which is still 20 times greater than the number of bits required to represent the characters of printed text digitally. Therefore, if there is a choice, English text messages should be generated and transmitted by teletypewriters or similar devices rather than by facsimile if efficiency of information transfer is to be achieved.

2.4.3.7 <u>Determination of Basic Parameters for a TDMA System.</u>
In order to compare and optimize the various multiple-access techniques it is necessary to define the communications network configuration the data flow requirements, and the basic system parameters. Since TDMA is still in an experimental stage it is necessary to make some assumptions concerning the implementation of a TDMA system. These assumptions are based mainly on the results of TDMA experiments that

have been initiated by Comsat. Assumptions for the configuration of a TDMA system are as follows:

No. of preamble bits	47
Guard time	100 nanoseconds
Frame period	125 microseconds
No. of bits per voice channel	8
Type of modulation	DPSK

A fixed access system will have a fixed number of information bits in each burst within a frame whereas in a demand access system the total number of channels will remain constant but the distribution of channels between bursts of the participating stations will vary.

A TDMA Example

Based on the above assumptions it is desired to define the bit rate, bandwidth and TDMA efficiency of a 5 station demand access system that has a total capacity of 300 voice channels or equivalent.

The total information bits per frame = $300 \times 8 = 2400$

The no. of bursts per frame is 5 and the number of preamble bits per frame is $47 \times 5 = 235$.

The system bit rate

$$= \frac{\text{information bits + preamble bits}}{\text{frame period}}$$

$$= \frac{2400 + 235}{125 \times 10^{-6}} \text{ bits/sec.}$$

$$= 21 \times 10^{6} \text{ bits/sec.}$$

The information bandwidth for the receivers in the satellite and the participating ground station is

$1.2 \times$ bit rate or 26 MHz.

The TDMA efficiency is the ratio of information bits to preamble bits within a frame or

$$\text{TDMA efficiency} = \frac{\text{information bits}}{\text{information bits + preamble bits}}$$

$$= \frac{2400}{2400 + 235}$$

$$= 0.91$$

The effect of guard time has been neglected in these calculations. Based on a 21×10^6 bits/sec. rate the number of equivalent guard time bits is

$$\frac{\text{guard period}}{\text{bit period}} = 0.1 \times 10^{-6} \times 21 \times 10^{+6} = 2.1 \text{ bits per guard period}$$

or assuming 2 bits guard period, 10 bits per frame are allocated for guard channels. This has negligible effect on bit rate or TDMA efficiency.

2.4.4 TELEVISION MODEL PARAMETERS (Figure 2-10). Television video user requirements specify the number of channels, quantity, whether color or monochrome and quality in terms of TASO grade or other quality criteria. Associated audio channels must be defined as to the number of audio per video channel and the audio fidelity required. User channel requirements specify whether broadcast, two-way talkback, up and down-link needs, and whether operation is limited to certain frequency bands and the allowable spectrum.

In the translation of user data, grade of service is translated to signal-to-noise ratio. Audio fidelity requirements are translated to S/N and frequency response. Regulatory frequency and spectrum constraints specify allowable modulation type whether FM or VSB-AM. Duty cycle analysis determined the total number of channels required.

After user data has been translated and modulation techniques and base-band constraints specified, parametric data is generated which mathematically defines the signals in a form adaptable to modeling for computer input.

20

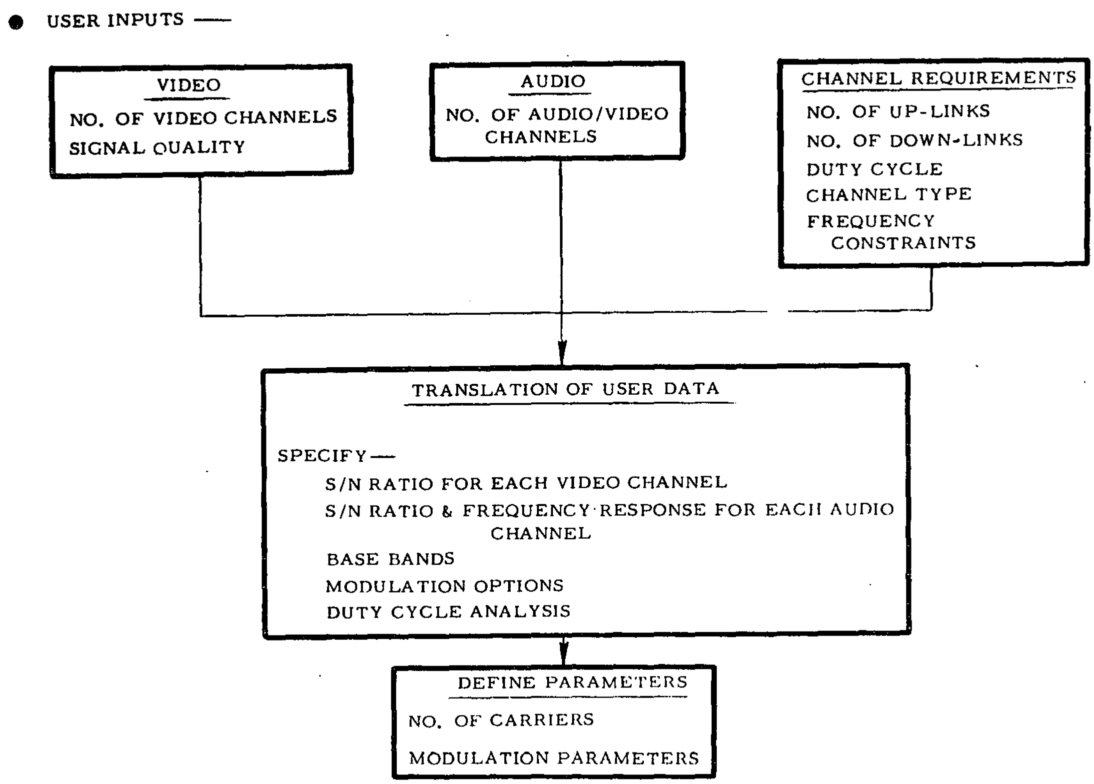


Figure 2-10. Television Model Parameters

2.4.5 TRANSLATION OF USER DATA – FACSIMILE. The chart, Figure 2-11, illustrates the procedure whereby user facsimile requirements define data transmission signal parameters. The type of the document determines the scanning line density. For instance, photographs with 85-line halftone screens require 600 lines per inch resolution for satisfactory quality. The number of reproducible gray levels specify the signal-to-noise ratio. Frequency response of the signal channel, FM, is dependent upon scanning line density, document size, and the allowable time for transmitting a document. If the data is to be transmitted digitally, the corresponding bit rate is 2 × FM.

2.4.6 TYPICAL TIME LOADING OF SATELLITE CHANNELS.

Grouping of users on the basis of compatibility includes consideration of the complementary nature of the users. As shown in Figure 2-12 three different users with three different operating loading profiles can be integrated into one satellite system with near-optimum loading.

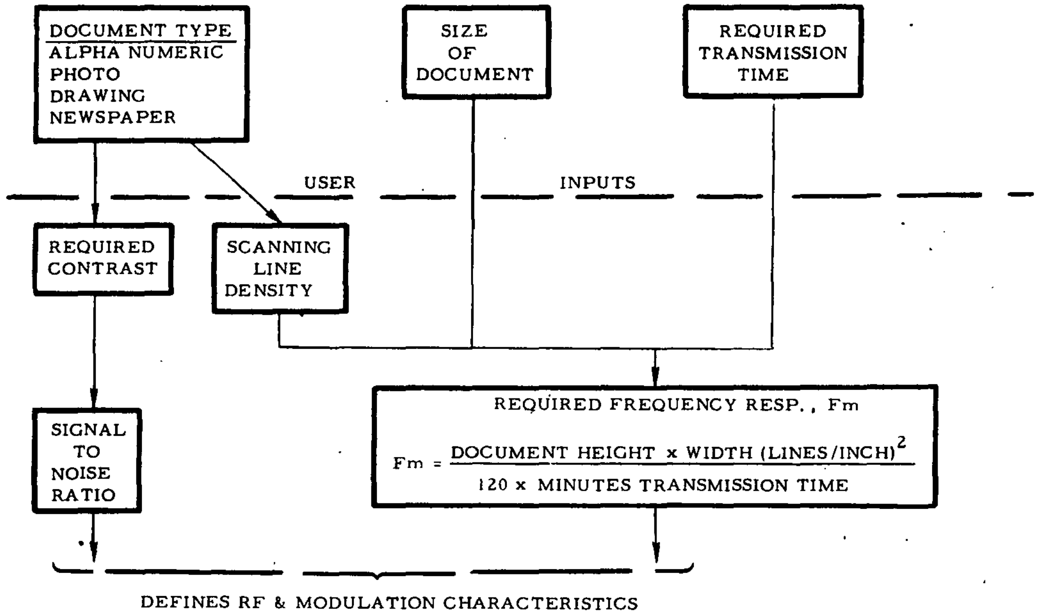


Figure 2-11. Translation of User Data - Facsimile

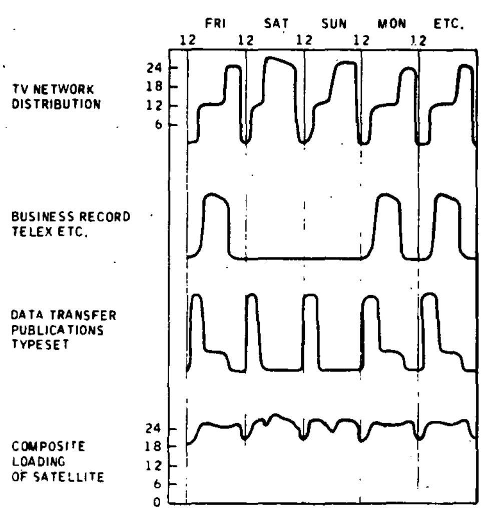


Figure 2-12. Typical Time Loading of Satellite Channels

3

LINK ANALYSIS

The satellite communications link consists of four major parts. These are: 1) Originating ground transmitting station (Class 1); 2) Relay satellite consisting of antennas and transponders (receiver and transmitter for each channel); 3) ground receiving station (Class 2 or Direct); and 4) the propagation media between satellite and ground stations. The paragraph following gives a detailed description of the link permitting determination of the radiated power level necessary to produce the signal-to-noise ratio required for high quality data transmittal (or picture display) in the case of television.

3.1 DESCRIPTION OF THE LINK

The ITS communication link covers the portions of the system enclosed within the dotted line of Figure 3-1. All of the major portions of the link are treated in three "models" which permit the functional expression of the communications link in terms

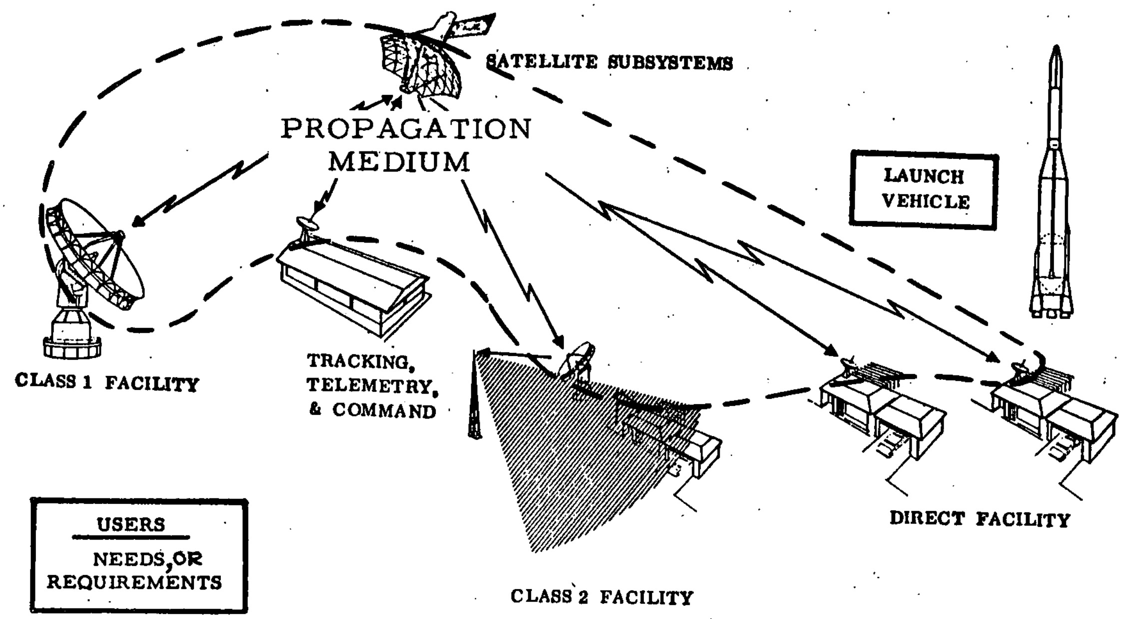


Figure 3-1. Total Communication System

of the system parameters.

a. Basic communications model (transmission, propagation medium, and reception),

b. Orbit and antenna coverage model (allows relating satellite location, antenna gain functions and satellite pointing to the link performance),

c. Noise and propagation model (considers propagation loss and noise generation from transmitter output to receiver front end input).

3.1.1 COMMUNICATION LINK ANALYSIS. This section describes the communications links as modeled in the synthesis program. The following equations are written in power ratios to facilitate the encoding of the power additions as are encountered in the system noises. The communications links are modeled using the relations shown in Figure 3-2, where:

G is antenna gain,

P is transmitter power,

L is system attenuation and is the reciprocal of the loss,

N is system noise power,

$\frac{C}{N}$ is carrier-to-noise ratio,

A is the satellite transponder gain.

The subscripts are defined as follows:

u denotes uplink (at frequency f_u),

d denotes downlink (at frequency f_d),

g denotes a ground based station,

s denotes satellite,

1 denotes ground station 1

2 denotes ground station 2

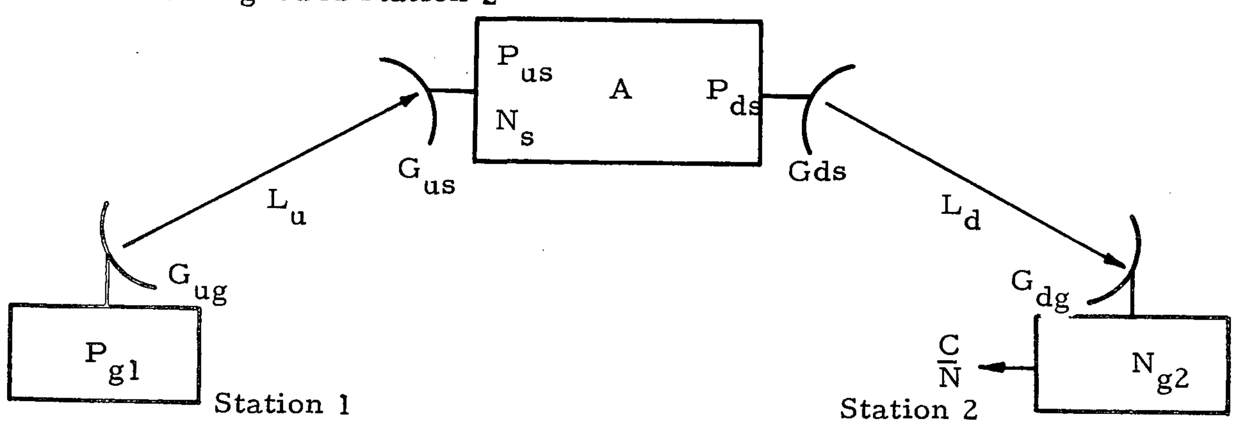


Figure 3-2. Communications Link Analysis Model

The fidelity of information transfer is determined by each user's needs (this may be television image quality, bit error rate or other figure of merit). Knowing the quality of reception and the modulation method it is possible to specify the carrier-to-noise ratio at the receiver input, $\left.\frac{C}{N}\right|_2$.

The received carrier-to-noise ratio of the signal transmitted by station 1, transponded by the satellite, and received by station 2 for a constant gain transponder is

$$\left.\frac{C}{N}\right|_2 = \frac{P_{g1} \cdot G_{ug1} \cdot L_u \cdot G_{us} \cdot A \cdot G_{ds} \cdot L_d \cdot G_{dg2}}{N_{g2} + N_{im} + N_s \cdot A \cdot G_{ds} \cdot L_d \cdot G_{dg2}} \tag{3-1}$$

where N_{im} is the intermodulation noise due to multiple carrier operation through one transponder. The total noise is composed of three terms

a. Receiving system noise, N_{g2}

b. Intermodulation noise, N_{im}

c. Noise on the downlink due to the uplink, $N_s\ A\ G_{ds}\ L_d\ G_{dg2}$, (i.e., noise input to the transponder, N_s, amplified and transmitted to the ground receiving station).

Considering the reverse link from station 2 to station 1, equation (3-1) may be written as

$$\left.\frac{C}{N}\right|_1 = \frac{P_{g2} \cdot G_{ug2} \cdot L_u \cdot G_{us} \cdot A \cdot G_{ds} \cdot L_d \cdot G_{dg1}}{N_{g1} + N_{im} + N_s \cdot A \cdot G_{ds} \cdot L_d \cdot G_{dg1}} \tag{3-2}$$

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

$$P_{ds} = (P_{us} - N_s)(A - \epsilon) = (P_{us} - N_s)\,A' = P_{us}A' - N_sA'. \tag{3-3}$$

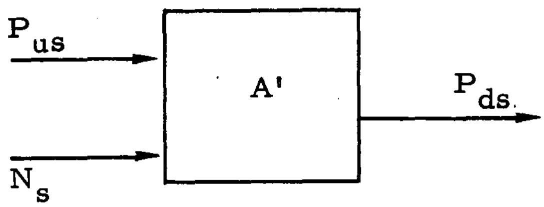


Figure 3-3. Constant Power Amplifier Model

From equation (3-3),

$$P_{us} A' = P_{ds} - N_s A' \tag{3-4}$$

The first four factors in the numerator of equation (3-1) are equal to P_{us}. $P_{us}A'$ from equation (3-4) may be substituted for $P_{g1} \cdot G_{ug1} \cdot L_u \cdot G_{us} \cdot A$ in equation (3-1) giving the constant power transponder equation relating satellite transmitted power to carrier-to-noise ratio at the receiver input,

$$\left.\frac{C}{N}\right|_2 = \frac{(P_{ds} - N_s \cdot A') \, G_{ds} \cdot L_d \cdot G_{dg2}}{N_{g2} \quad N_{im} \quad N_s \cdot A' \cdot G_{ds} \cdot L_d \cdot G_{dg2}} \tag{3-5}$$

The physical significance of the "effective gain, $A' = (A - \epsilon)$ is that ϵ represents the phenomenon of "limiting" when the amplifier is driven into saturation. As the limiting point is approached with multi-channel inputs, part of the amplifier power is dissipated as intermodulation distortion products. Table 3-1 illustrates loss in available power due to cross modulation[1].

To limit the effect of distortion for preservation of fidelity in telephony and television, it is necessary to operate the output amplifier at a level reduced beyond the loss of Table 3-1 by an amount known as the "transmitter backoff." This is defined as the total multiple carrier output power relative to the single carrier saturated output power. For a given carrier-to-noise requirement $\left(\frac{C}{N}\right)$, the back-off to limit the carrier-to-

1. A. L. Berman and E. I. Podraczky, "Experimental Determinations of Intermodulation Distortion Produced in a Wideband Communications Repeater," IEEE International Convention Record, Part II, pp 69-88, 1967.

intermodulation noise $\left(\frac{C}{N_{im}}\right)$ to a given value is shown in Figure 3-4.

Table 3-1. Effect of Additional Carriers On Satellite Output Power. After Berman and Podraczky[1]

Number of Equal Carriers	Ideal Available Output Power Per Carrier Relative to a Single Carrier at Saturation (dB)	Loss of Useful Power Relative to the Power Obtained from a Single Carrier at Saturation (dB)	Available Output Power Per Carrier Relative to a Single Carrier at Saturation (dB)
1	0	0	0
2	-3.0	1.20	-4.21
4	-6.0	1.31	-7.33
6	-7.8	1.37	-9.15
8	-9.0	1.46	-10.49
100	-20.0	1.50	-21.50

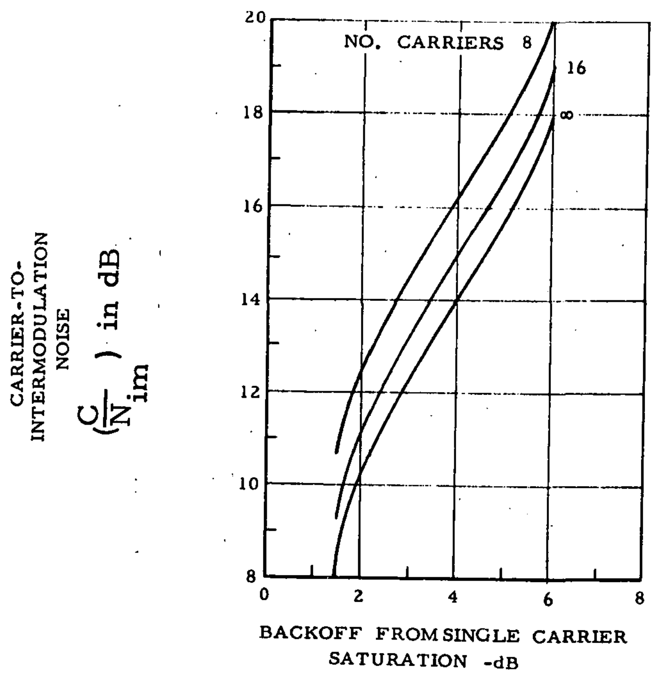


Figure 3-4. Transmitter Backoff For Multicarrier Operation

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

a. Antenna Pattern Coverage. The first program accepts as inputs (See Figure 3-5):

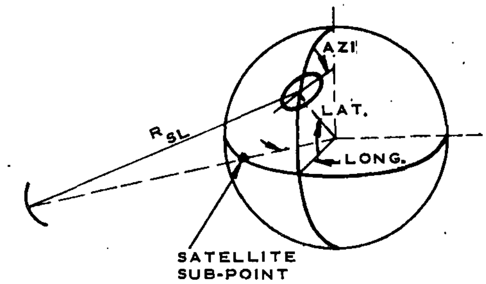
1. Satellite position (longitude of the sub-point).
2. The coordinates of the antenna beam center (latitude and longitude of the center of the desired coverage).
3. The orthogonal beamwidths for a pattern function resulting from a uniform phase distribution and an amplitude tapered distribution $(1-r^2)$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

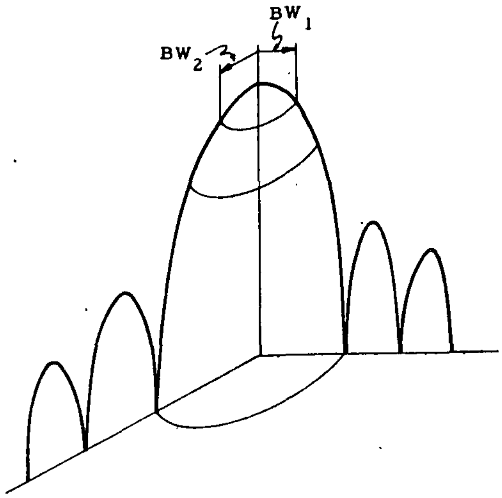
This program permits computing the power level contours on the surface of the earth. The SC4020 plotter plots these contours superimposed upon a Mercator projection of the earth as in Figure 3-6. These contours are useful in determining the effectiveness of the coverage and the flux density at any point in the area covered.

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

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

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





- SATELLITE POSITION
- BEAM CENTER COORDINATES
- BEAM AZIMUTH
- ANTENNA PATTERN

Figure 3-5. Antenna Pattern Model

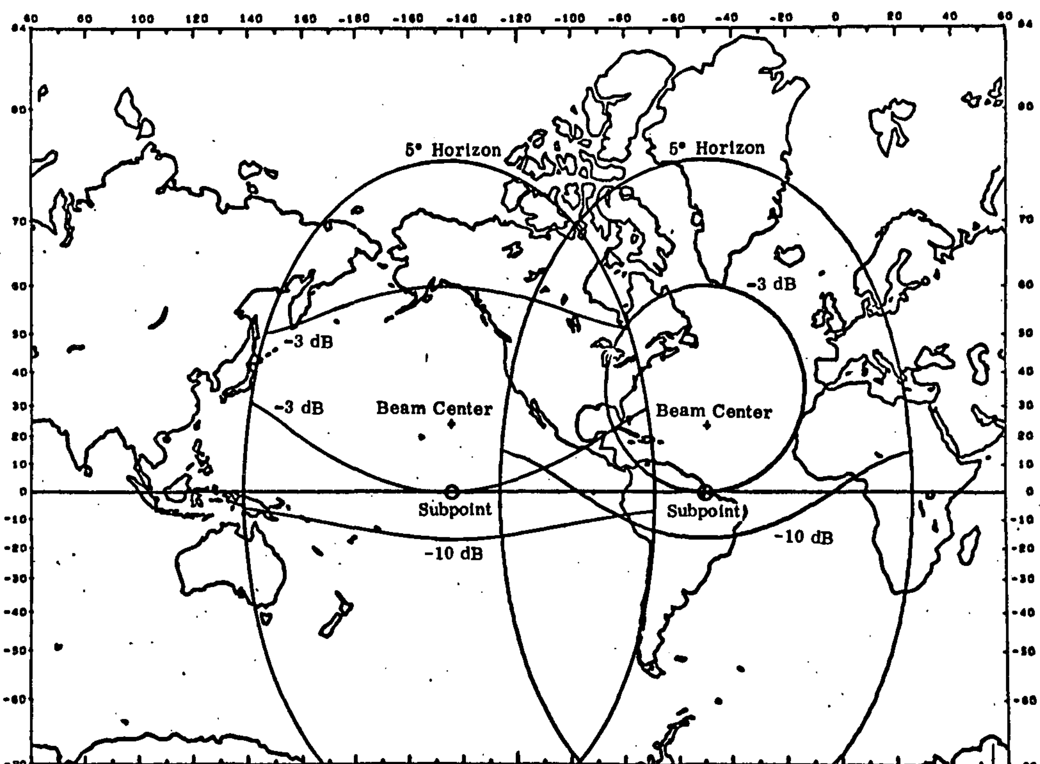


Figure 3-6. Antenna Projections

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

3.1.3 NOISE AND PROPAGATION MODELS. The basic models are shown in Figure 3-7. Given the elevation angles and the slant ranges for each satellite antenna beam, the attenuations due to clouds, rain, water vapor, oxygen and the ionosphere, as well as circuit losses, are determined. Additionally, the noise contributions due to these elements are calculated. Table 3-2 itemizes the terms and equations used in the models. In these equations, the attenuation term, L, is the reciprocal of the loss due to each element such that the value of L lies between 0 and 1. The effective noise seen by the receiver is then

$$T_g = L_{tl}\, T_{ant} + T_t + T_{rcvr} \tag{3-6}$$

where

$$T_{ant} = (T_{cos} + T_i + T_a + T_c + T_r)\,\overline{G}_s + T_m\overline{G}_m + T_e\overline{G}_e \tag{3-7}$$

$\overline{G}_s$, $\overline{G}_m$, $\overline{G}_e$ are relative antenna gains over the three regions - sky, man-made noise, and earth.

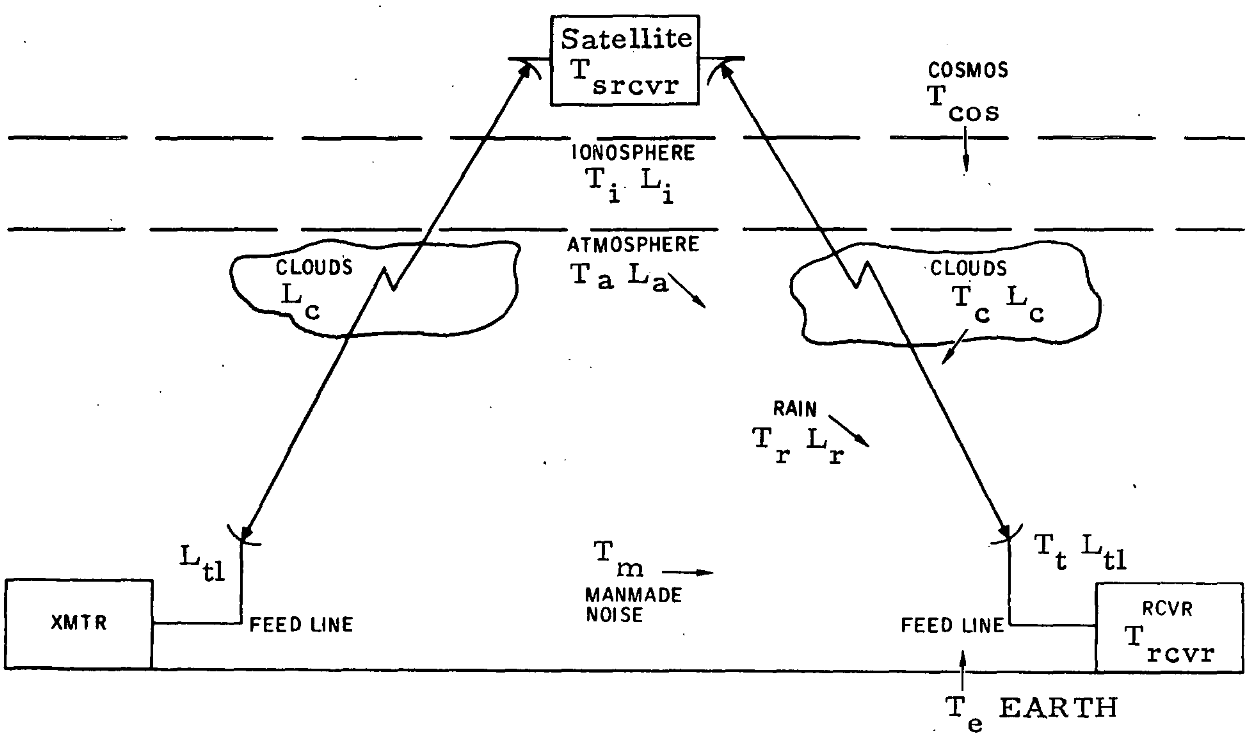


Figure 3-7. Noise and Propagation Models

Table 3-2. Terms and Equations of Propagation and Noise Models

Region	Attenuation	Absorption	Ambient Temperature	Effective Temperature at Receiver
Cosmos	-	-	T_{cosmic}	$T_{cos} = L_i L_a L_c L_r T_{cosmic}$
Ionosphere	L_i	$1 - L_i$	T_{ion}	$T_i = L_a L_c L_r (1-L_i) T_{ion}$
Atmosphere	L_a	$1 - L_a$	T_{atm}	$T_a = L_c L_r (1-L_a) T_{atm}$
Clouds	L_c	$1 - L_c$	T_{cloud}	$T_c = L_r (1-L_c) T_{cloud}$
Rain - LOS to Satellite	L_r	$1 - L_r$	T_{rain}	$T_r = (1-L_r) T_{rain}$
- Horizontal path	L_{rh}	$1 - L_{rh}$	T_{rain}	
Environment	-	-	T_{man}	$T_m = L_{rh} T_{man}$
Earth	-	-	T_{earth}	$T_e = T_{earth}$
Transmission Line	L_{tl}	$1 - L_{tl}$	T_{tl}	$T_t = (1-L_{tl}) T_{tl}$
Receiver	-	-	-	T_{rcvr}

It is helpful to explain further some of the terms in equations (3-6) and (3-7). See Table 3-2.

a. T_{ant} includes the sum of all external noise entering the system via the receiving antenna. The noise sources are discriminated against as defined by the relative antenna gains, G_s, G_m and G_e.

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

c. $T_{cos} = L_r\, L_c\, L_a\, L_i\, T_{cosmic}$

Exoatmospheric cosmic noise temperature

T_{cosmic} attenuated by the ionosphere.

T_{cosmic} attenuated by the ionosphere, and the atmosphere (oxygen and uncondensed water vapor).

T_{cosmic} attenuated by the ionosphere, the atmosphere and clouds.

T_{cosmic} attenuated by the ionosphere, the atmosphere, clouds and rain.

d. $T_i \doteq L_r\, L_c\, L_a\, (1 - L_i)\, T_{ion}$

Ionospheric ambient noise.

Fraction of signal energy absorbed in the ionosphere.

Communications signal excited ionospheric noise generator.

Ionospheric noise temperature successively attenuated by the atmosphere, clouds and rain.

e. T_a and T_c follow model of (c) and (d) above.

f. $T_m = L_{rh}\, T_{man}$

Man-made environmental noise.

Environmental noise attenuated by horizontal path through rain.

g. G_s, G_m and G_e are expressed as the integral of the antenna pattern function normalized in steradians. The limits of integration divide the antenna's surrounding environment into the three regions - sky, surface and earth.

Figures 3-8, 3-9, 3-10, 3-11, 3-12, and 3-13 give, respectively, the antenna "regional" noise discriminations, the equivalent noise temperature for man-made noise, attenuation due to rain, clouds and the atmosphere.

3.2 EXAMPLE OF SYNTHESIS PROGRAM PRINTOUT OF LINK PARAMETERS

The development and use of the communication system synthesis computer program is treated in detail in Chapter 8. When a network description results from use of the program, the printout permits reading not only the major system characteristics but also all essential parameters describing the link.

Table 3-3 presents the results of the link analysis performed for the U.S. ETV Direct case. In this case high-quality (TASO 1) color television programming is broadcast directly to modified conventional television receivers. This table shows the level of detail considered in the program and identifies the elements that are inputs to the program, derived within the program and printed in the program output — sufficient to describe the RF link(s) in detail.

Table 3-3. U. S. ETV Direct

Uplink Power Budget, $\boxed{0.85}$ Hz*

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

Table 3-3. U. S. ETV Direct (Continued)

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

Downlink Power Budget, $\boxed{0.8}$ GHz*

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

* = inputs

☐ = on printout

ANTENNA DISCRIMINATION TO NOISES

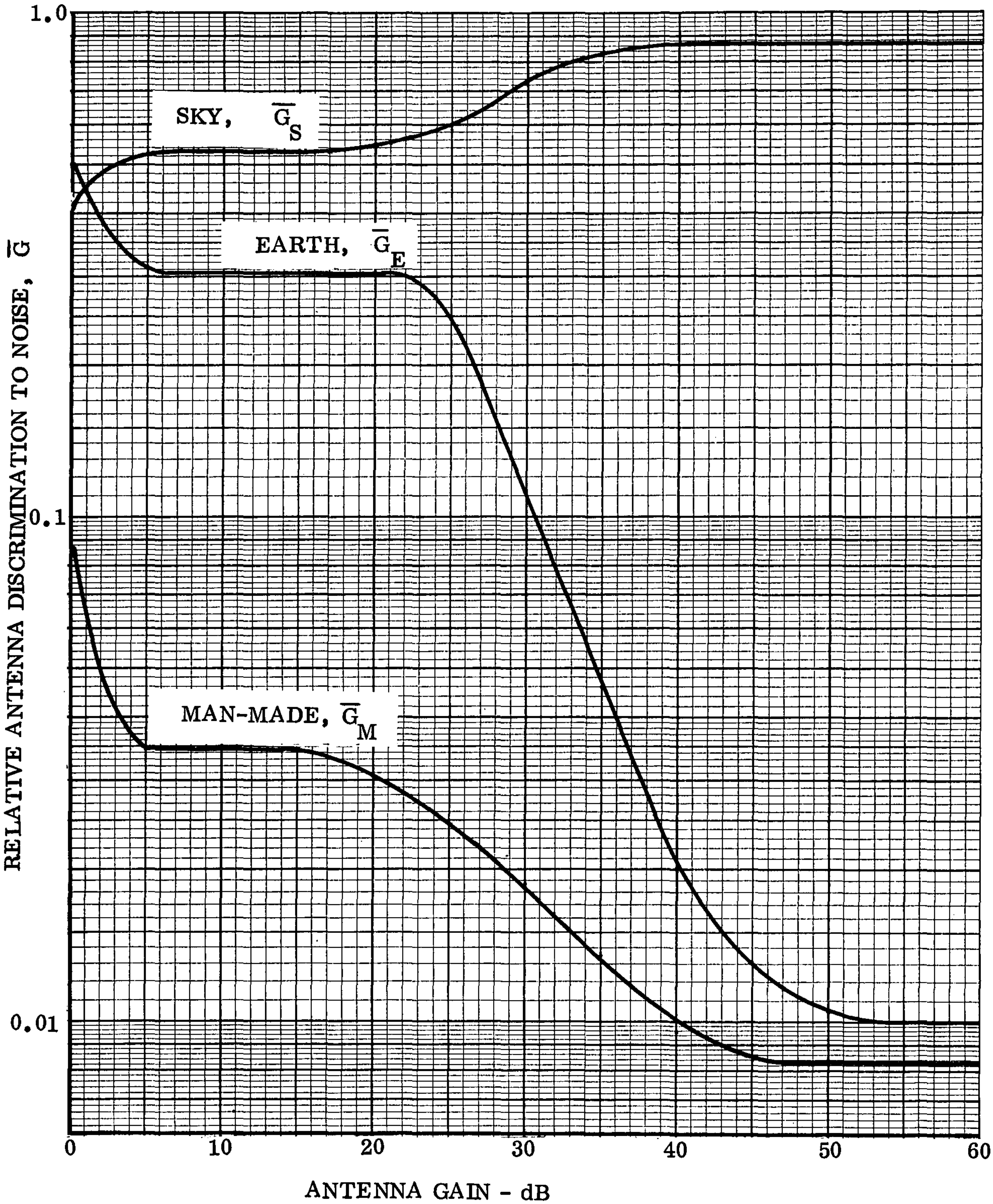


Figure 3-8. Main Lobe Gain - dB

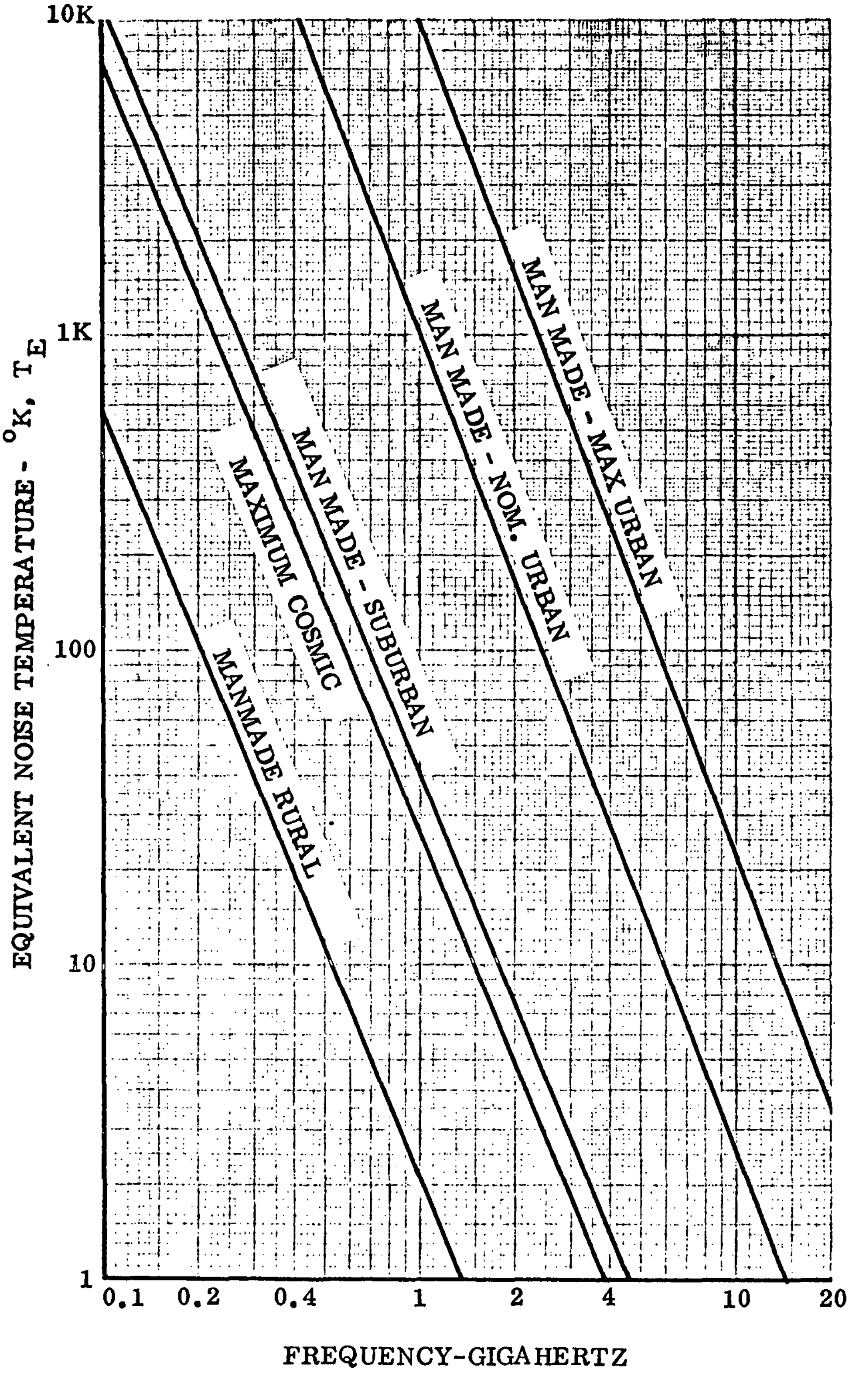


Figure 3-9. Man-Made Noise

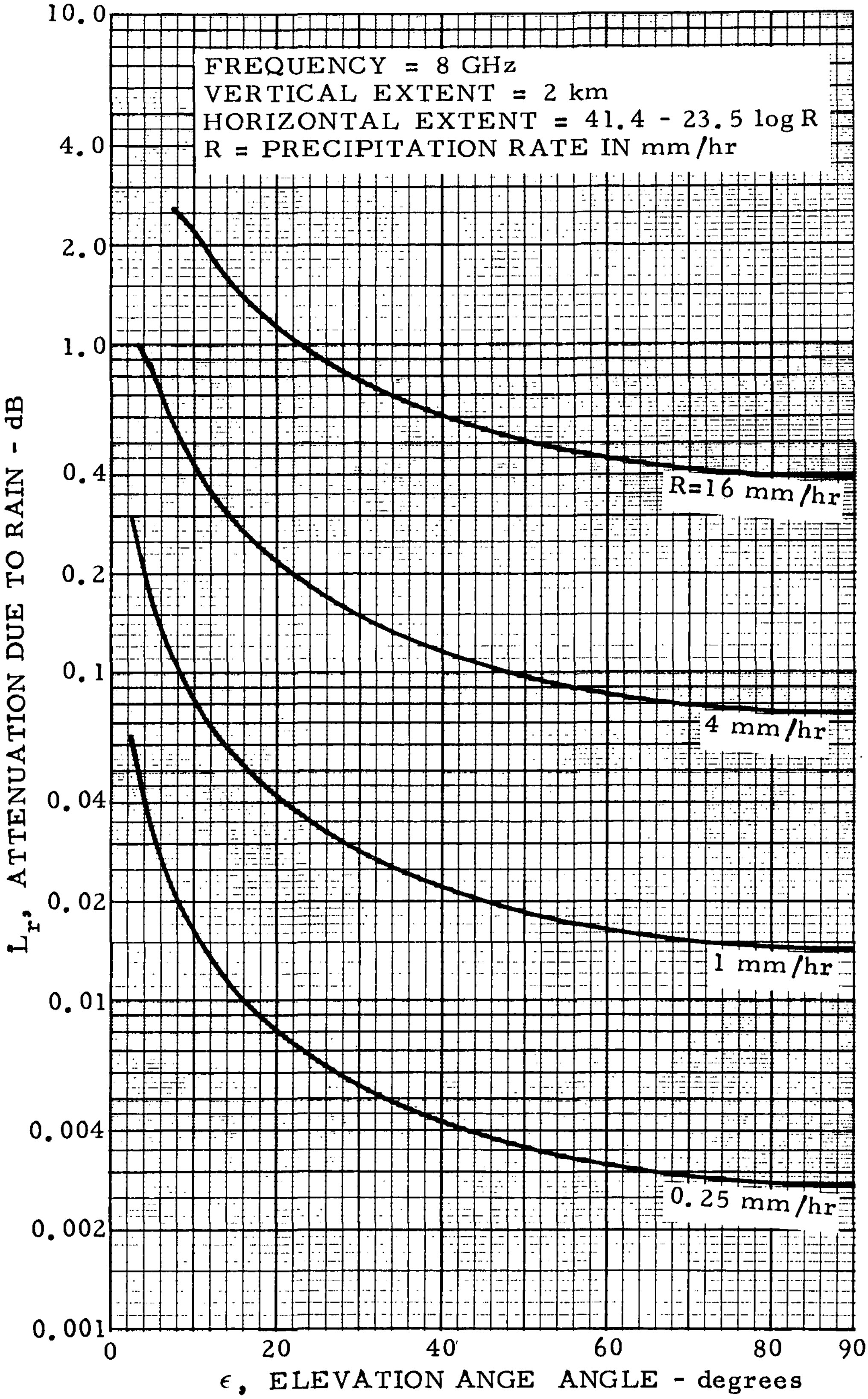


Figure 3-10. Attenuation due to rain at 8 GHz.

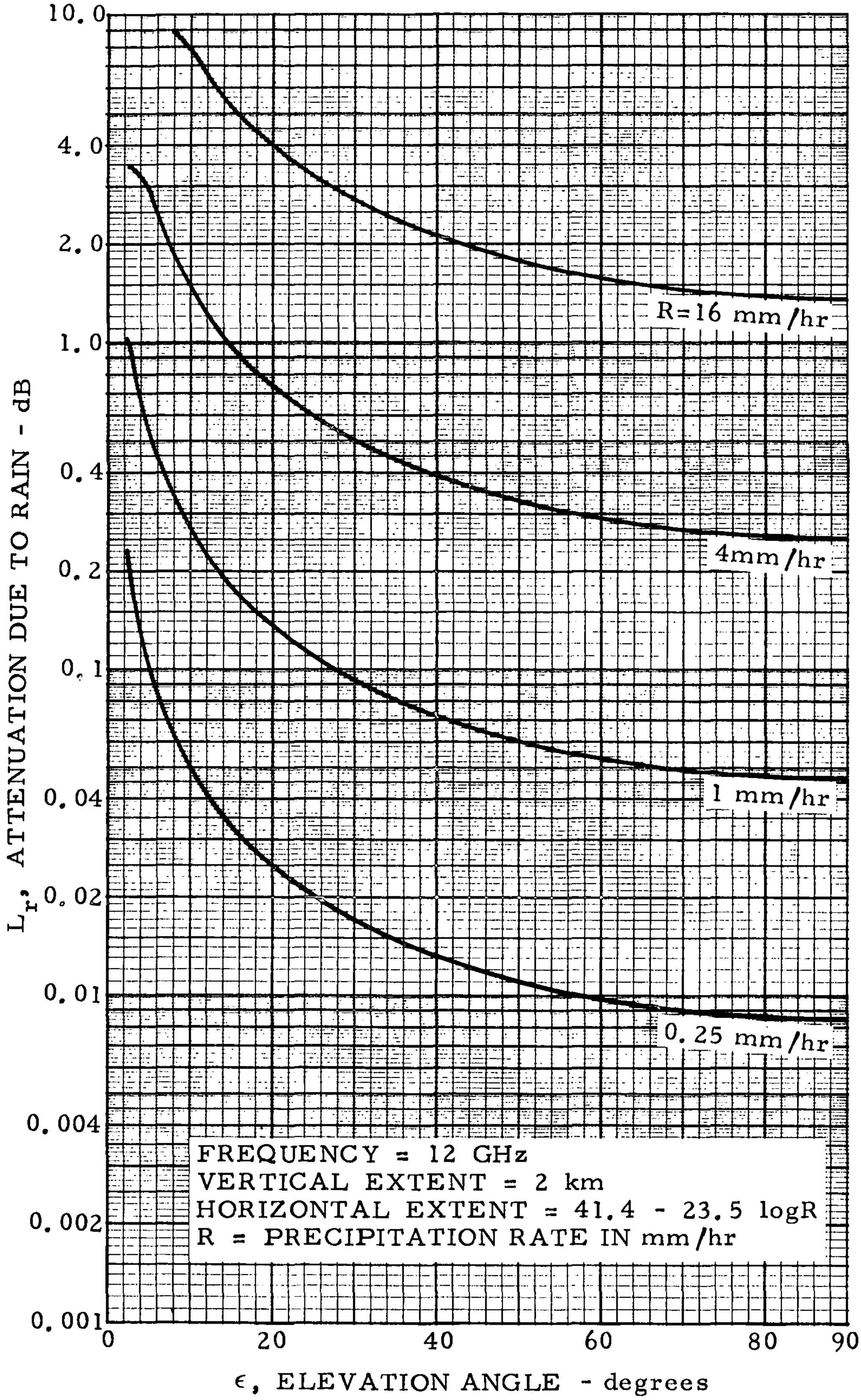


Figure 3-11. Attenuation due to rain at 12 GHz.

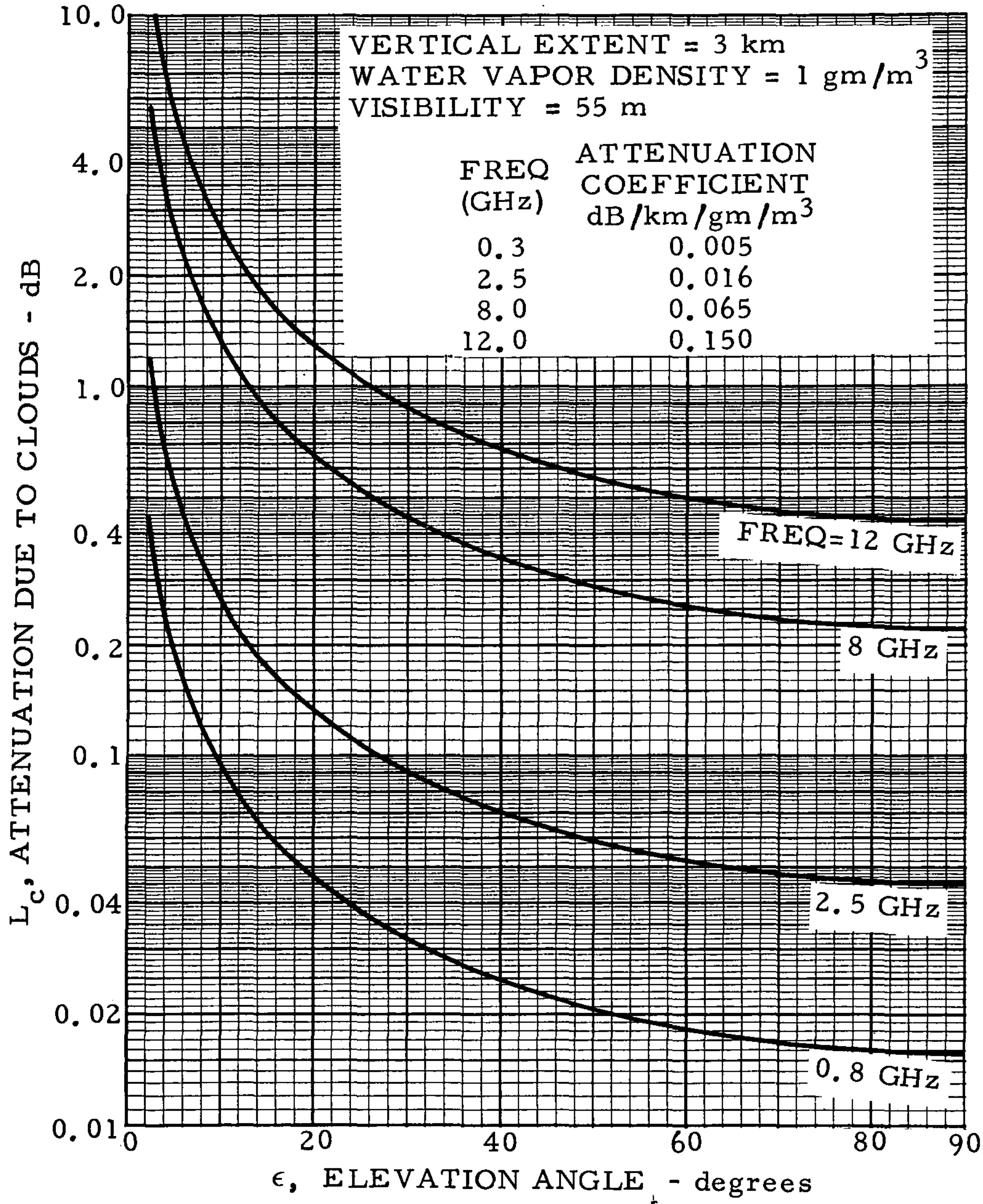


Figure 3-12. Attenuation due to clouds.

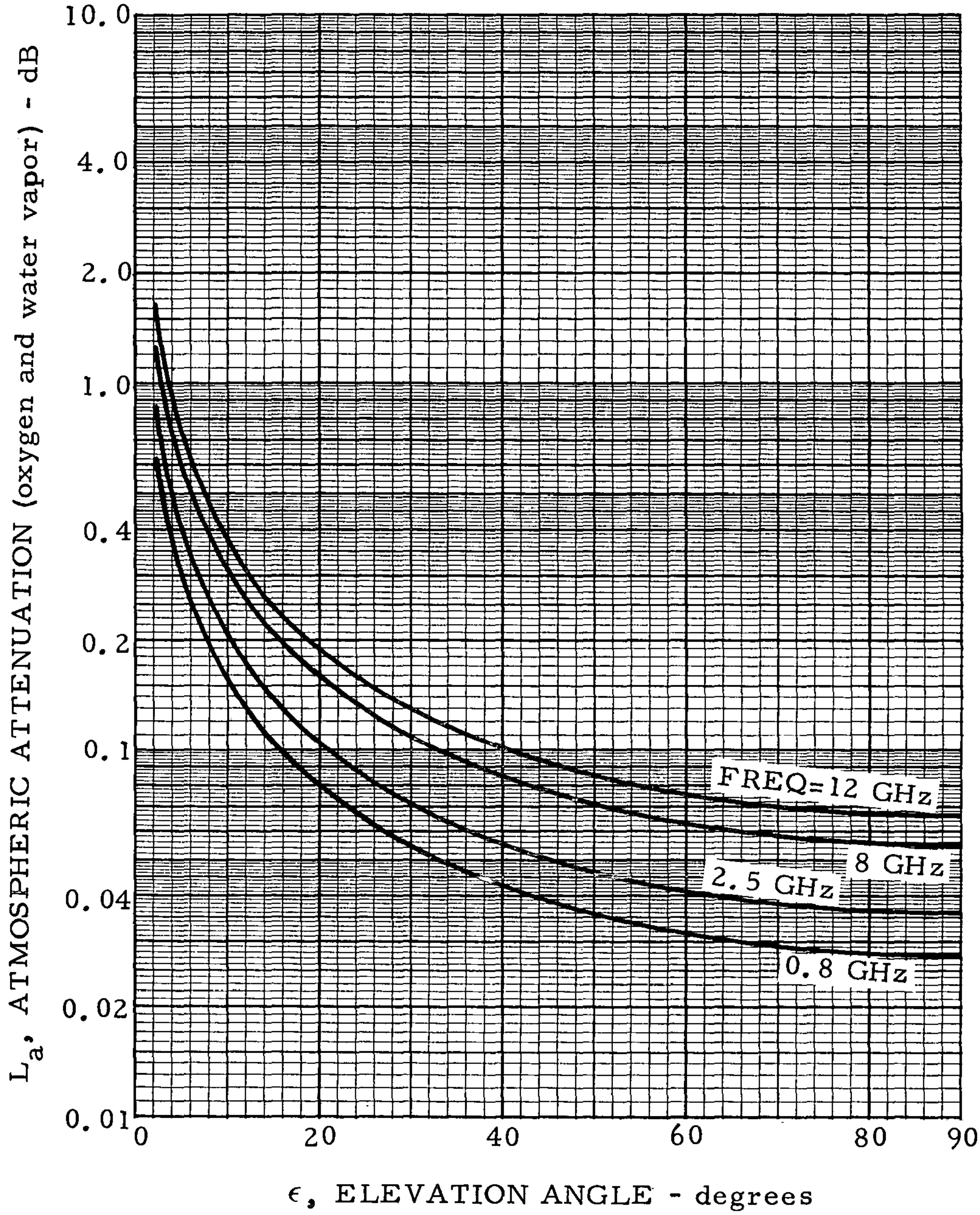


Figure 3-13. Attenuation due to atmosphere (oxygen and water vapor).

4

GROUND STATIONS

Consistent with the total system approach utilized in this study, ground stations with a full complement of subsystems, itemized in Table 4-1, assure a realistic view of the economics of system implementation. The portions of the total system sketch enclosed within the dotted line boxes of Figure 4-1 are the portion of the system to be discussed in the following paragraphs. In addition to the communications oriented equipment - i.e., transmitters, receivers, and antennas - the models include the building to house the equipment, the terminal equipment to interface with a ground network, standby power and test equipment as well as personnel required to operate the facility. The model terminates at the output of the ground station, e.g., any further distribution of the signals is not considered in this program.

4.1 SYSTEM OPTIONS

The model developed for the synthesis program considers three classes of ground stations - denoted class 1, class 2 and direct stations. The first two classes have the full complement of subsystems of Table 4-1 while the direct stations consist only of the receiver/preamplifier and antenna. The classes may differ in number, channel capacity, signal quality and transmit/receive capability.

The system options available for analysis are shown in Table 4-2. System topologies that may be synthesized range from a direct broadcast mode (Option 1) to a complex telecommunications system with direct reception (Option 9). More complex topologies may be analyzed by expanding the number of station classes, as was done in the Alaskan Telecommunications analysis, but it increases computer storage requirements and execution time.

4.2 ECONOMIC MODEL

The economic model for the ground stations is divided into four major parts as follows: (see Table 4-3) the unit recurring or unit hardware cost,

Table 4-1. Ground Stations Major Items

Item	Item
Building	Standby Power
Terminal Equipment	Test Equipment
Transmitters	Installation and Checkout
Receivers	Personnel
Antennas	

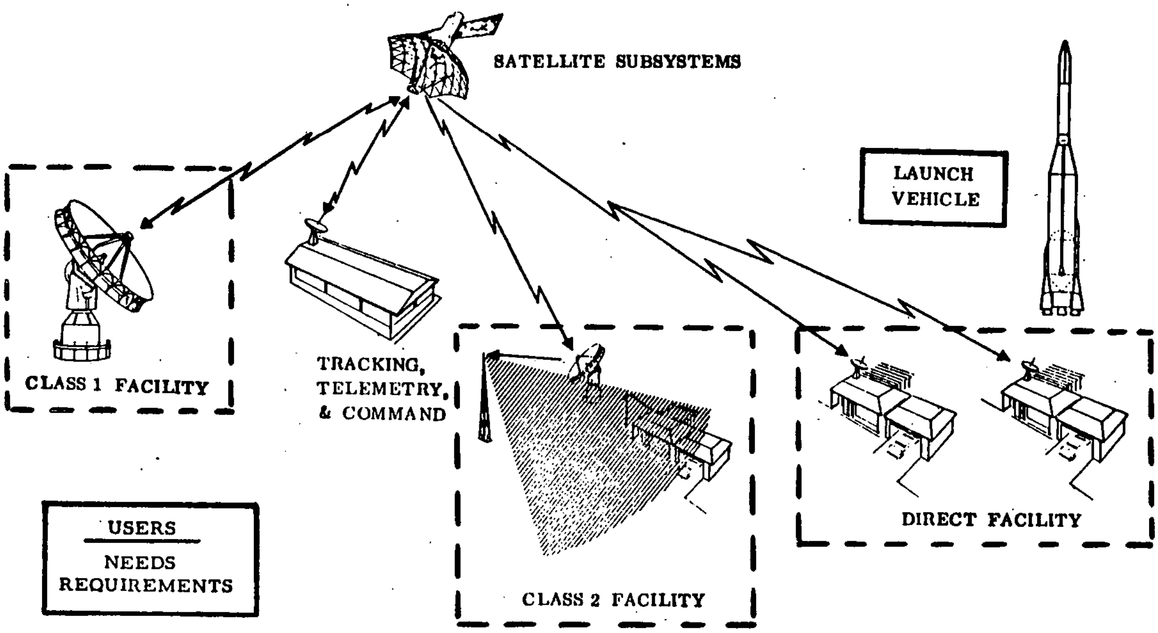


Figure 4-1. Ground Stations

Table 4-2. Synthesis Program System Options

Option Number	Class 1 Station	Class 2 Station	Direct Station	Example
1	Xmit	-	Rcv	Direct Broadcast
2	Xmit	Rcv	-	Redistribution Broadcast
3	Xmit	Rcv	Rcv	Direct & Redistribution
4	Xmit /Rcv	-	-	Single Level Information Transfer
5	Xmit /Rcv	-	Rcv	Single Level Information Transfer & Direct Broadcast
6	Xmit /Rcv	Rcv	-	Single Level Information Transfer & Redistribution Broadcast
7	Xmit /Rcv	Rcv	Rcv	Single Level Information Transfer, Direct & Redistribution Broadcast
8	Xmit /Rcv	Xmit /Rcv	-	Dual Level Information Transfer
9	Xmit /Rcv	Xmit /Rcv	Rcv	Dual Level Information Transfer & Direct Broadcast

Table 4-3. Ground Stations Cost Model

Subsystem	Unit Recurring	Installation	Operations	Maintenance
Building	X			X
Terminal Equipment	X	X	X	X
Transmitters	X	X	X	X
Receivers	X	X	X	X
Antennas	X	X		X
Standby Power	X	X		X
Test Equipment	X			
Installation & Checkout		X		
Personnel			X	

installation cost, operations cost and maintenance cost. Each cost element in the model is defined by cost estimating relationships (CERs) derived from available parametric data. The following paragraphs define the parmetric data and CERs used in this study.

4.2.1 BUILDING (CLASS 1 AND 2 STATIONS). The ground facility building is assummed to house only the equipment and offices and specifically excludes studios. The costs are broken down as shown in Table 4-4. The terminal is assummed to have 900 square for offices and 600 square feet per transmitter/receiver pair. The general CER is then

$$C_{fac} = (900 + 600 \cdot N_{t/r}) \cdot \$39.00$$

or $C_{fac} = 0.0351 + 0.0234 \cdot N_{t/r}$ \$Millions. The annual maintenance cos cost for the building is 2% of the acquisition cost. Figure 4-2 gives the ground facility building cost as a function of the number of transmitter/receiver pairs.

Table 4-4. Itemization of Building Cost Components

		Unit Cost	Cost/ft^2
Acquisition of Site	2 Acres/1000 ft^2 of Building	\$3000/Acre	\$ 6.00
Site Preparation	1 Acre/1000 ft^2 of Building	\$1500/Acre	\$ 1.50
Building Construction			\$25.00
Air Conditioning	1 Ton/250 ft^2 of Building	\$1000/Ton	\$ 4.00
Q-Flooring			\$ 2.50
TOTAL			\$39.00

4.2.2 TERMINAL EQUIPMENT (CLASS 1 AND 2 STATIONS). The multiplex equipment for audio, facsimile and digital data is priced per channel at \$2000 per duplex circuit. The installation cost is 100% of unit recurring, operations is 5% and maintenance is 10%.

Video terminal equipment includes a video tape recorder and a slide-film chain. While helical scan VTRs are much less expensive than those with

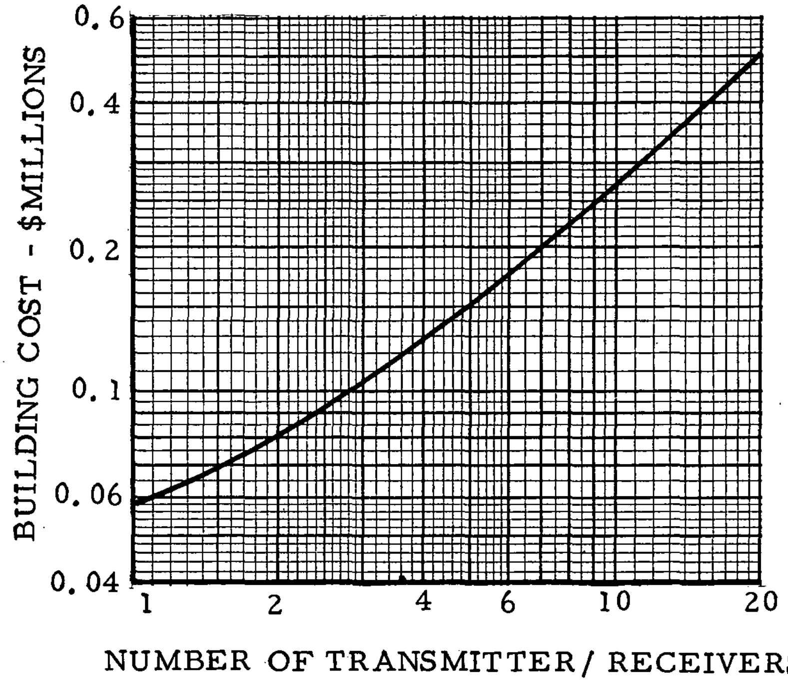


Figure 4-2. Ground Facility Building Cost

quadruplex scan, they produce a tape that may be played back only on a recorder of similar type and make. The costs of the terminal equipment are as follows:

	Monochrome	Color
Helical Scan VTR	$1K to 9K	
Quadruplex VTR	$20K	$70K
Film and Slide Chain	$20K	$50K

Installation costs are 10% of the recurring, operations are 5% and maintenance is 10%.

4.2.3 TRANSMITTERS (CLASS 1 AND 2 STATIONS). The transmitter subsystem includes the heat exchanger, power amplifier, modulator/exciter, RF control and display and power supply. Table 4-5 lists the elements and their respective costs. Table 4-6 gives some transmitter cost data for several power output levels. These data come from Hughes, G.E. and DCA. The Hughes data are for transmitter in the 6 to 8 GHz range, the General Electric data are for 8 GHz and the DCA data is for 0.4 to 4 GHz.

Table 4-5. Cost of Transmitter Elements

Subsystem	Ground Station Equipment (No Redundancy)	Cost
Transmitter	a. Cooling System This includes heat exchangers, but not air-conditioning for the building.	$ 5K
	b. Power Supply Power conditioning equipments costs are included.	33K
	c. Power Amplifier Applies for 5-kw TWT or 10-kw klystron.	35K
	d. Exciter	7K
	e. Transmitter, R-F Display and Control Equipment	20K
	f. Transmission line - 100' at $10/foot Includes labor, materials, and all fittings.	1K
	g. FM Modulators	5K
Options (as needed)	h. Up-Converters (double conversion)	15K
	i. Hardware for minimum orderwire capability	7K

Table 4-6. Transmitter Cost Data

Power Output, Watts	Cost in Thousands		
	Hughes	G.E., Video	DCA
20	12		
300	36	96	
1k	55	125	57
5k	105	195	
10k	105	240	100
75k			240
100k			260

Table 4-7 gives some additional data on acquisition and operating cost for various power level transmitters.

Table 4-5, 4-6 and 4-7 are the basis for the transmitter acquisition and operation cost curves in Figure 4-3. These curves were "fitted" to arrive at the transmitter cost model used in the computer system synthesis program.

Table 4-7. Transmitter Acquisition and Operating Costs as a Function of Frequency

Transmitter		
Tube Type and Power Out	Initial Cost	Annual Operating Cost
5-KW TWT or 10-KW Klystron *	$100 K	$100 K
1-KW TWT or Klystron	$ 50 K	$ 45 K
300-W TWT	$ 31 K	$ 22 K
20-W TWT	$ 7 K	$ 5 K

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

4.2.4 <u>RECEIVERS</u>. While all classes of facilities have receiving capability, the cost of the receiving systems is essentially the same for class 1 and 2 facilities but may be expected to be less for direct class by virtue of large scale production. The cost models for all classes reflect:

a. Transmission line cost (Figure 4-4).

b. Annual maintenance cost of 10% of acquisition cost.

4.2.4.1 <u>Class 1 and 2 Receivers</u>. The unit cost of FM and AM receivers is shown in Figures 4-5 and 4-6 for 0.8, 2, 8, and 12 GHz, as a function of receiver noise figure[1]. Some discrepancies in the above referenced

1. Jansky and Bailey Systems Engineering Department of Atlantic Research Final Report, "Technical and Cost Factors That Affect Television Reception From A Synchronous Satellite," NASA contract NASW-1305, 30 June 1966.

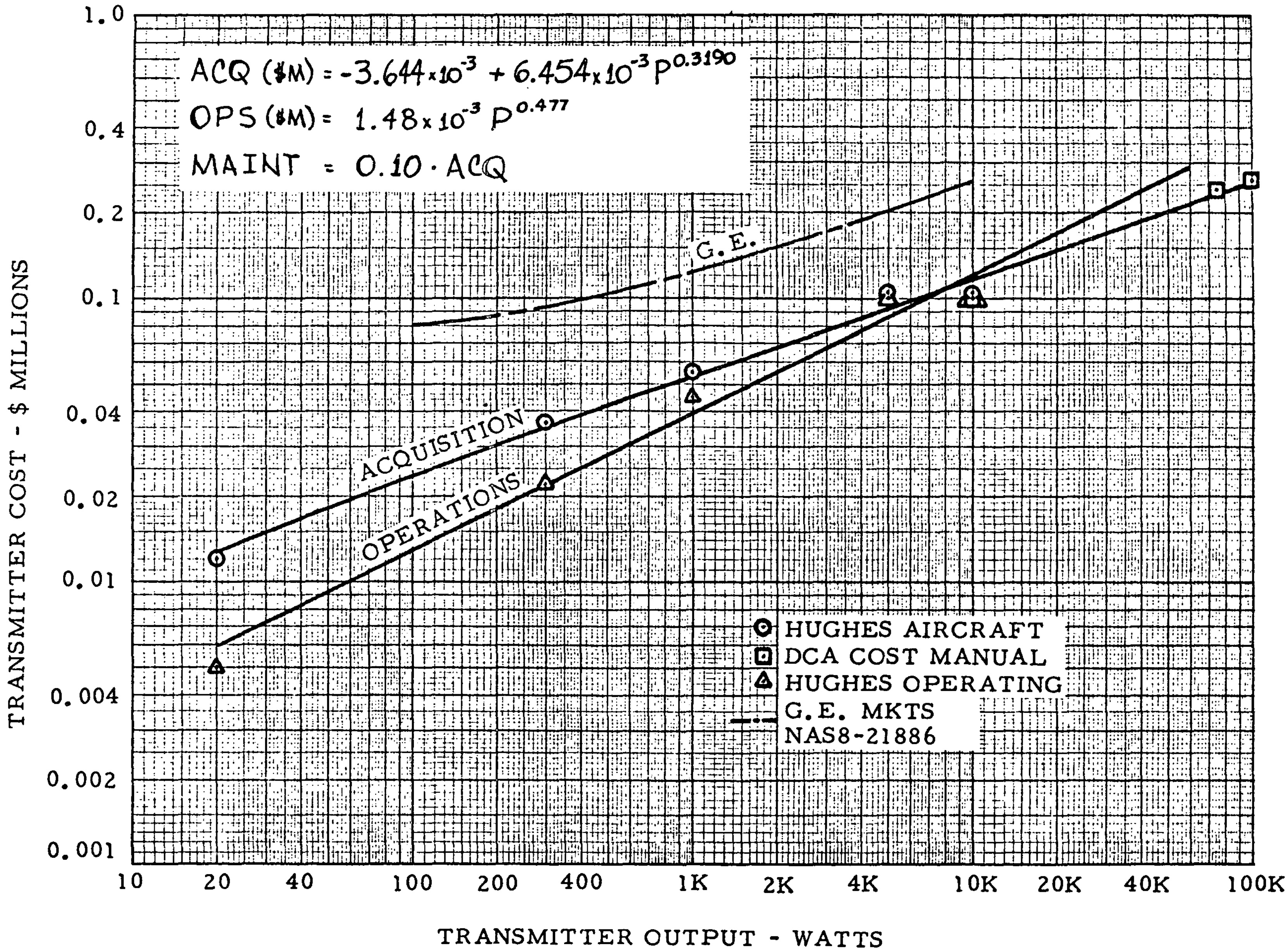


FIGURE 4-3. GROUND TRANSMITTER COST

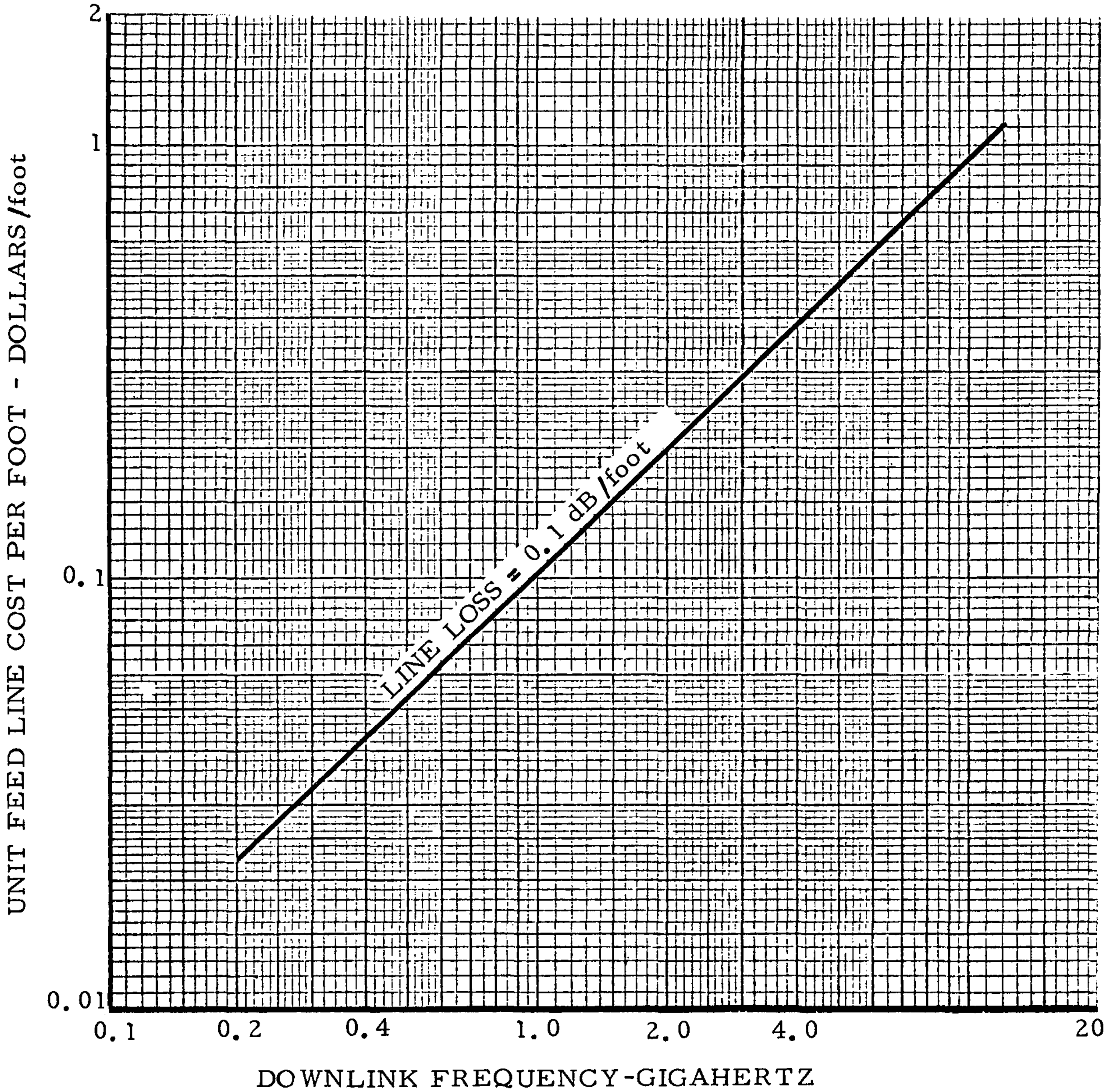


FIGURE 4-4. TRANSMISSION LINE COST

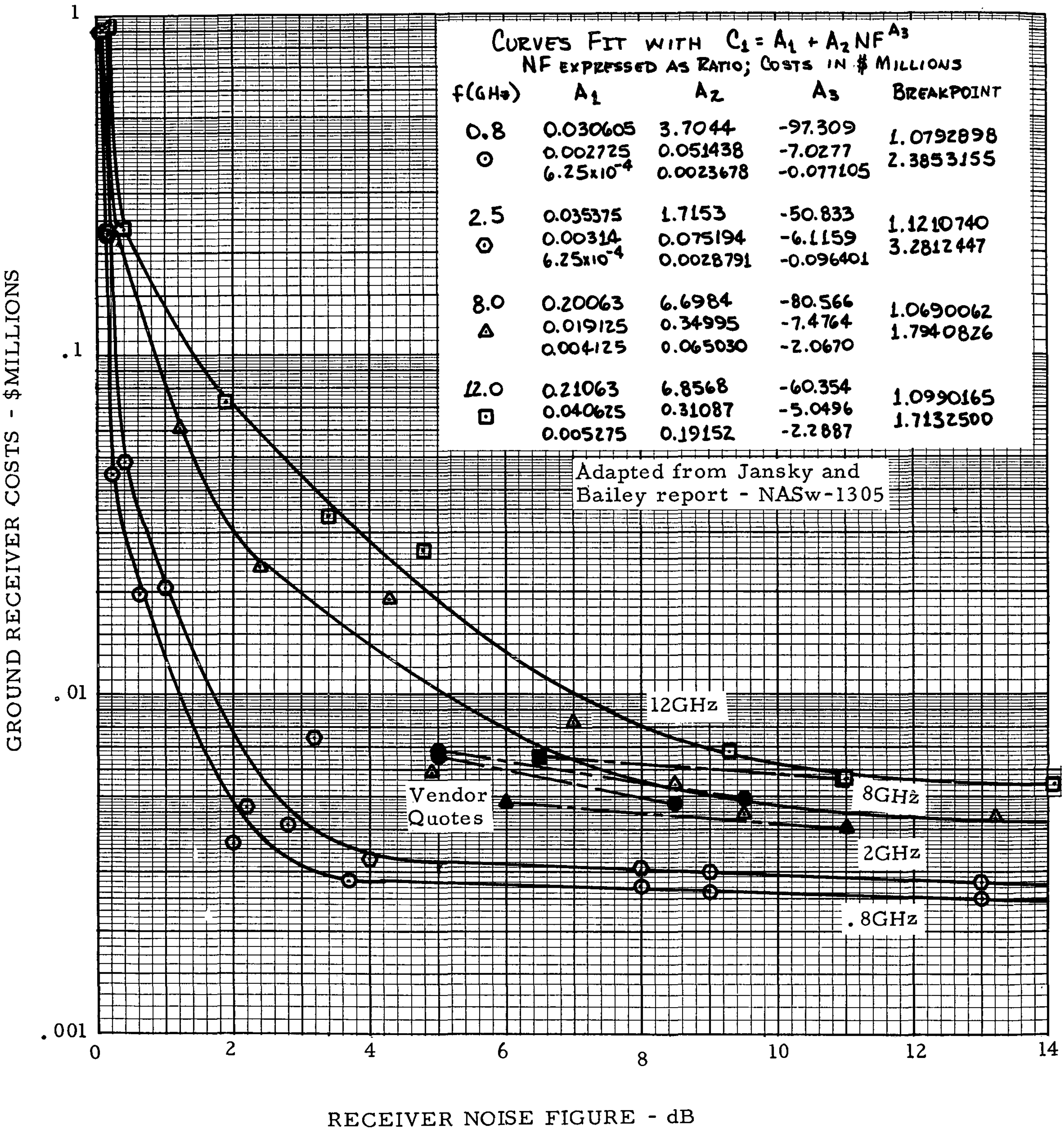


FIGURE 4-5. FM COMMERCIAL GROUND RECEIVER COST

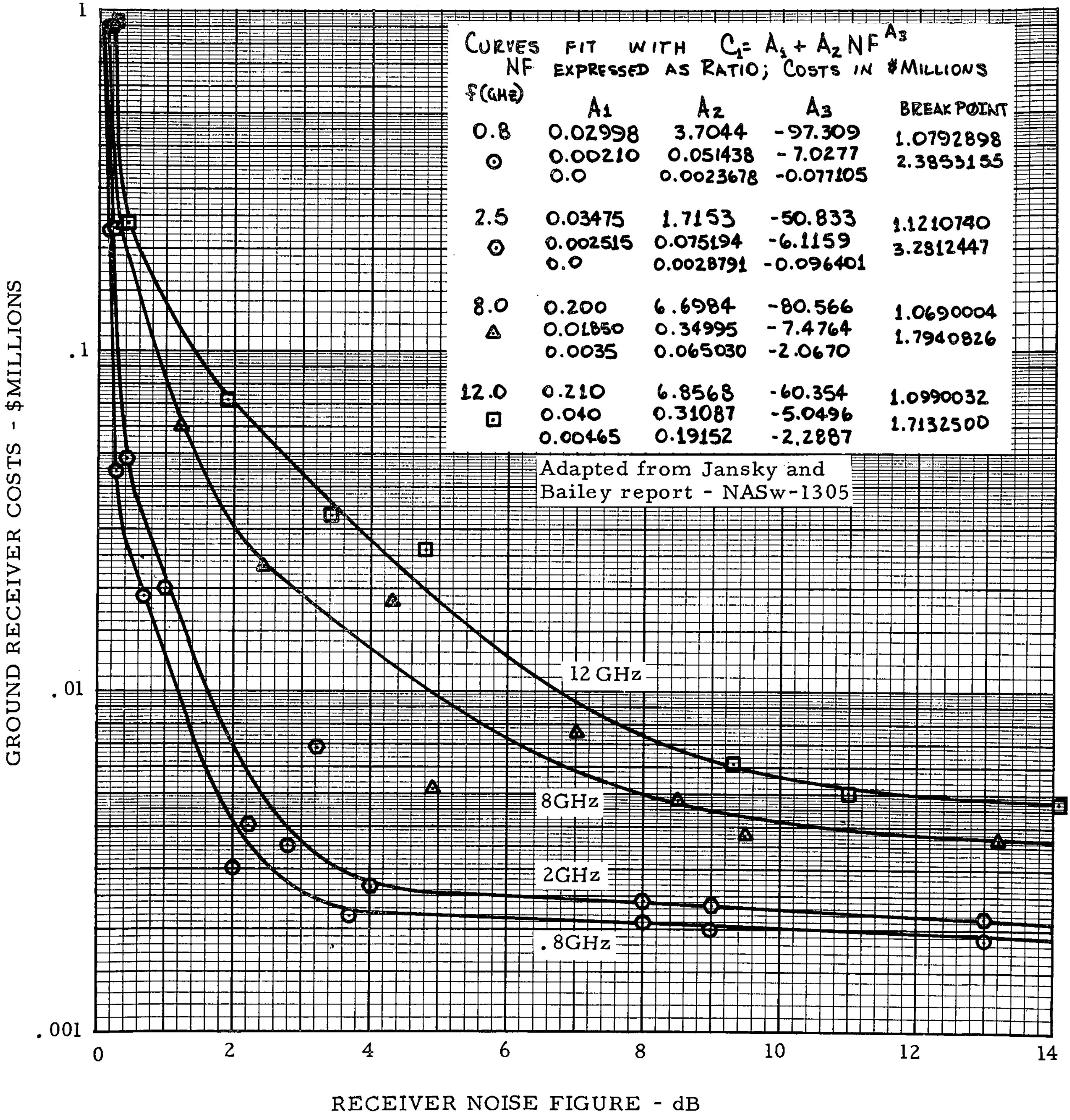


FIGURE 4-6. AM COMMERCIAL GROUND RECEIVER COST

data were noticed and corrected. Additional cost information came from the General Electric TVBS study[2]. Figure 4-5 gives cost data from FM receivers as obtained from vendors' quotations. These values were extrapolated to a quantity of one unit for use in Figure 4-5. An 85% learning curve, Figure 4-7, is used to determine costs for more than one unit. The curves of Figures 4-5 and 4-6 were fitted by the method of least squares to obtain the functional expressions for the receiver cost model used in the synthesis.

The class 1 and 2 receiver models include:

a. Annual operation cost of 5% of the acquisition cost.

b. Installation cost of 15% of the acquisition costs.

4.2.4.2 Direct Class Receivers. The costs allowed for direct facility receivers include installation and operation cost is considered negligible for purposes of system synthesis. Direct receivers may become very significant cost items because of the large quantities possible in some services. Figure 4-8 shows the large quantity (1000 units/yr) cost for receivers at various frequencies and noise temperatures (or noise figures). Figure 4-9 the effect of extension to very much larger numbers (10^6 annually). The cost would be expected to reduce to almost one-half over the frequency range of 0.8 GHz to 12.2 GHz. The additional cost as a function of the annual production for multiple channel capability is shown.

4.2.5 ANTENNAS. Several types of antennas may be used in a satellite communication system for one or more of the facility classes. In the antenna discussion following there was no allowance for operation which is believed negligible. Maintenance is covered as 10% of the acquisition cost for all antenna types.

4.2.5.1 Steerable Parabolic Antennas (Class 1 and 2 Facilities). Antenna pointing capability is required to employ the highest gain earth facility antennas. Figure 4-10 shows the cost for various diameter steerable, parabolic antennas. The cost shown includes installation, feeds and mechanical drive but not the servo system for antenna pointing.

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2. General Electric, Space Systems Organization, Report NAS CR-72579, 15 November 1969, "Television Broadcast Satellite (TVBS) Study," Vol. III, NASA contract NAS 3-9708.

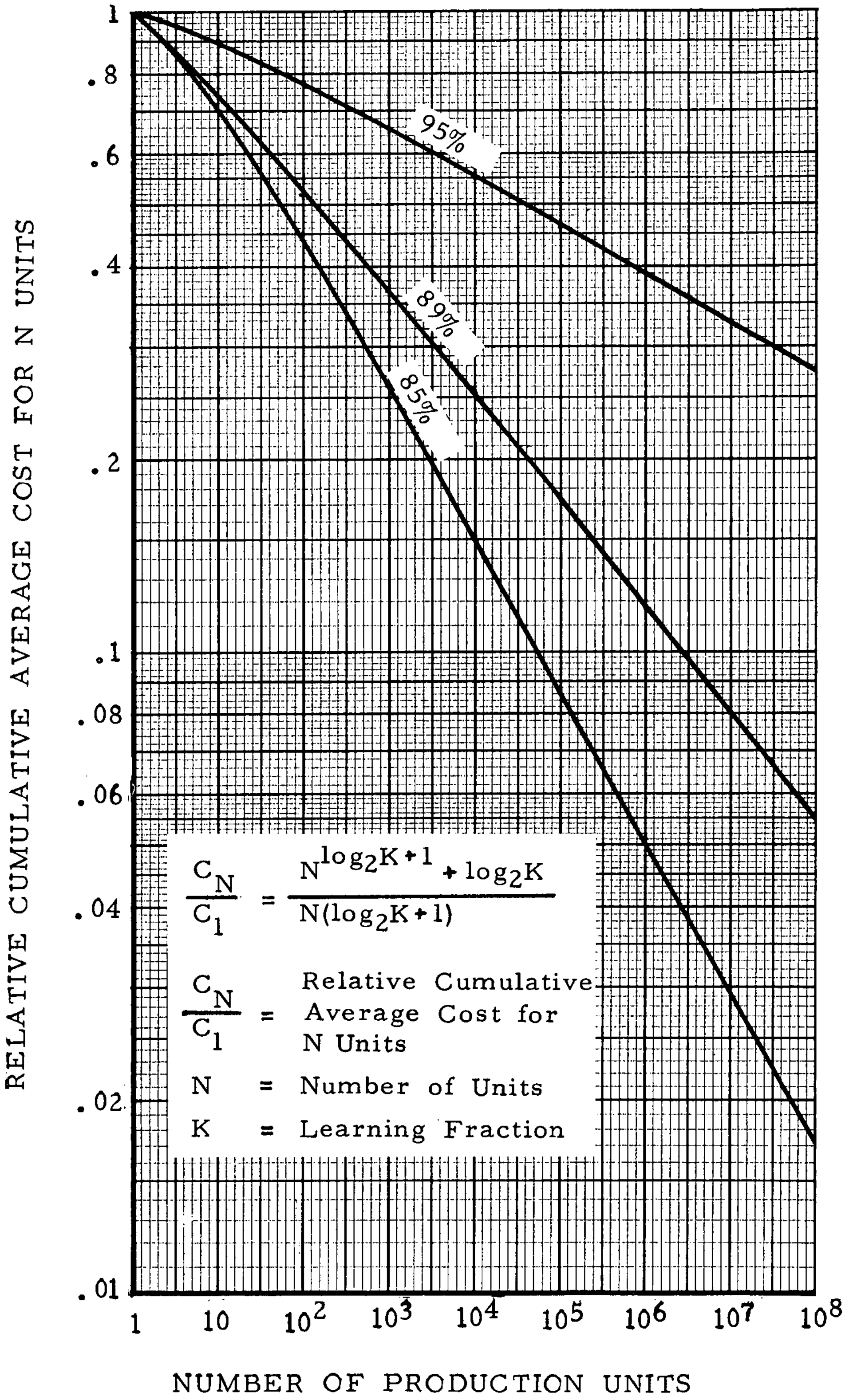


FIGURE 4-7. MANUFACTURING LEARNING CURVES

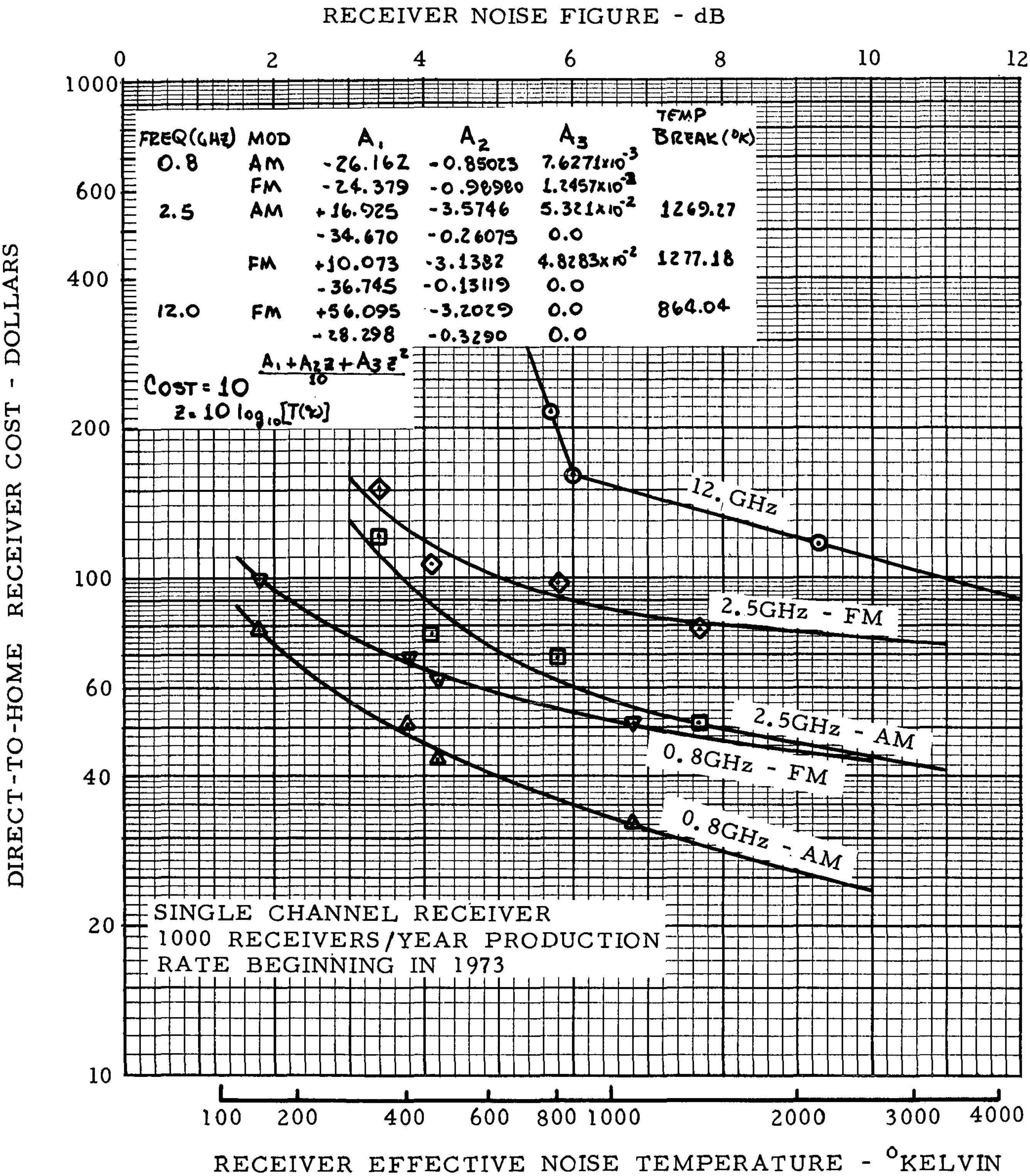
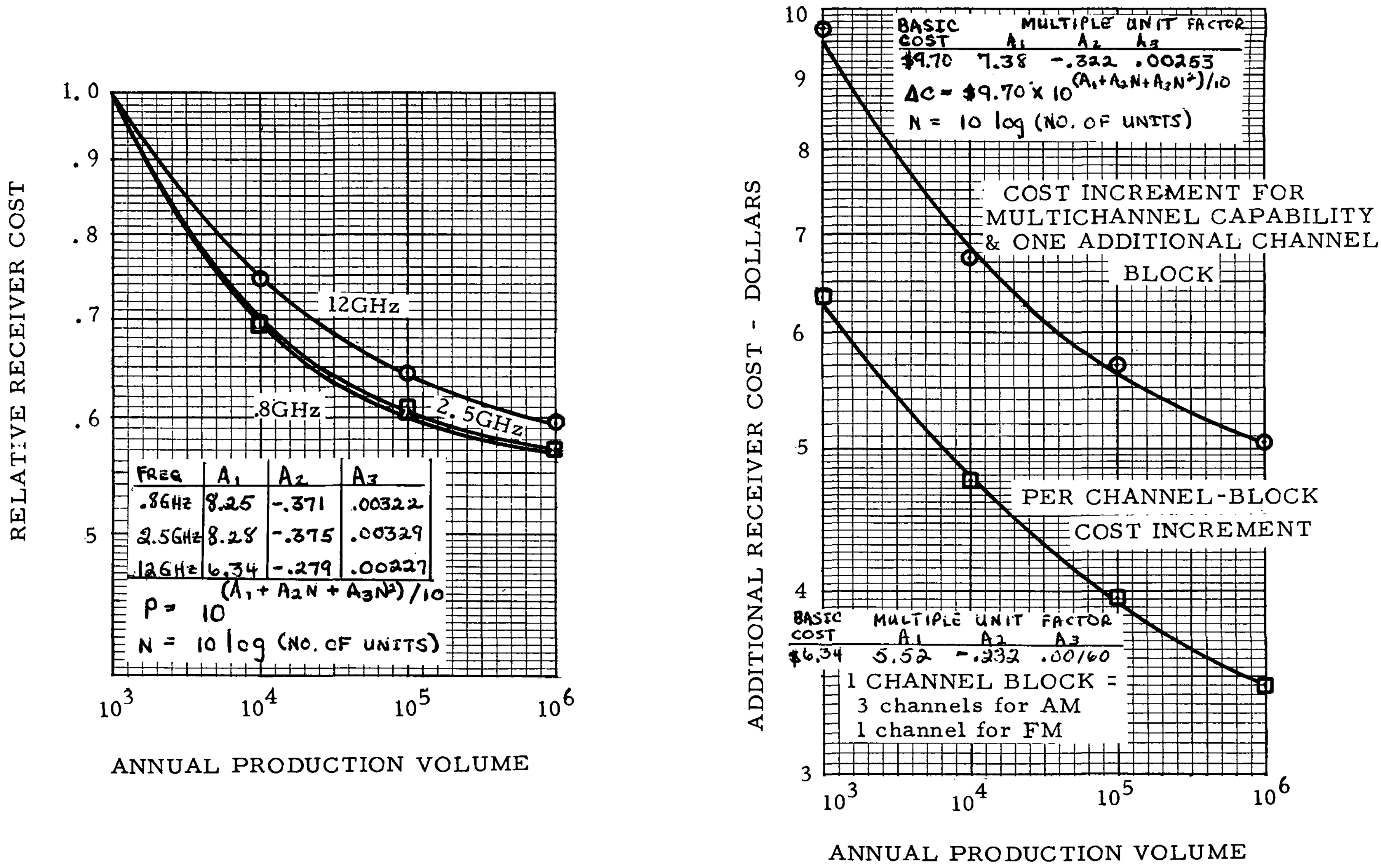


FIGURE 4-8. CONSUMER GROUND RECEIVER COST



(a) Cost Reduction for Mass-Produced Components

(b) Multiple Channel Cost Increments

FIGURE 4-9. RECEIVER COST/PRODUCTION

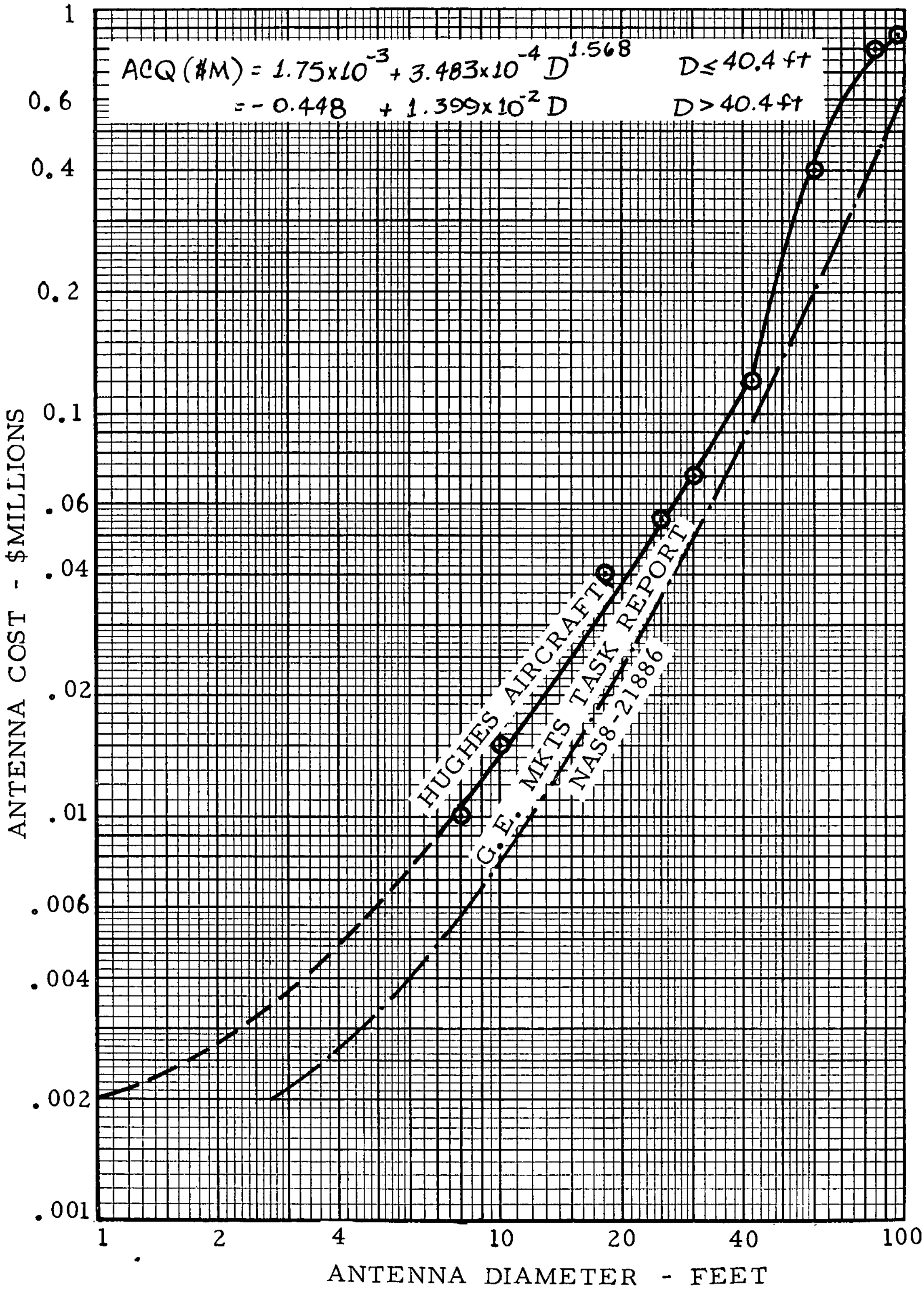


FIGURE 4-10. STEERABLE, CIRCULARLY POLARIZED PARABOLIC ANTENNA COST

4.2.5.2 Non-Tracking Antennas

a. Parabolic Linear Polarization (Class 1, 2 and Direct Facilities). This antenna requires a sufficiently broad beam so any deviation of the satellite from its desired fixed position has insignificant effect on the link performance. Figure 4-11 gives the cost as a function of diameter. Installation cost is given by Figure 4-11. Cost reduction for larger quantities is by the 95% learning curve (Figure 4-7).

b. UHF Wideband Arrays (Direct Facility). As in the previous case this antenna of relatively lower gain does not require a tracking capability. Installation costs are also given by Figure 4-11 and the acquisition cost by Figure 4-11. Here, too, the reduction through quantity production is by the 95% learning curve (Figure 4-7).

4.2.6 STANDBY POWER. Costs for several types of and power rating generators were obtained from the Defense Communication Agency Cost Manual. Additional cost information was supplied by Mr. E. Van Vleck of NASA Ames Research Center. These data are shown in Table 4-8. The "permanent fixed station - precise, no break" type generator was used with a 1% power efficiency transfer factor to arrive at the acquisition cost curve of Figure 4-12. The annual maintenance is 5% of the acquisition costs. This serves as the basis for a standby power cost model for system synthesis.

4.2.7 TEST EQUIPMENT. The acquisition cost only is used for an inventory of test equipment for purposes of the system synthesis. These costs are:

a. Class 1 Facility - $50,000.
b. Class 2 Facility - $25,000.
c. Class Direct Facility - no test equipment required at the individual user level.

4.2.8 INSTALLATION AND CHECKOUT. This item covers the Class 1 and 2 Facilities. The cost used for the syn.model is 15% of the acquisition costs for the hardware items:

a. Terminal Equipment
b. Transmitters
c. Receivers

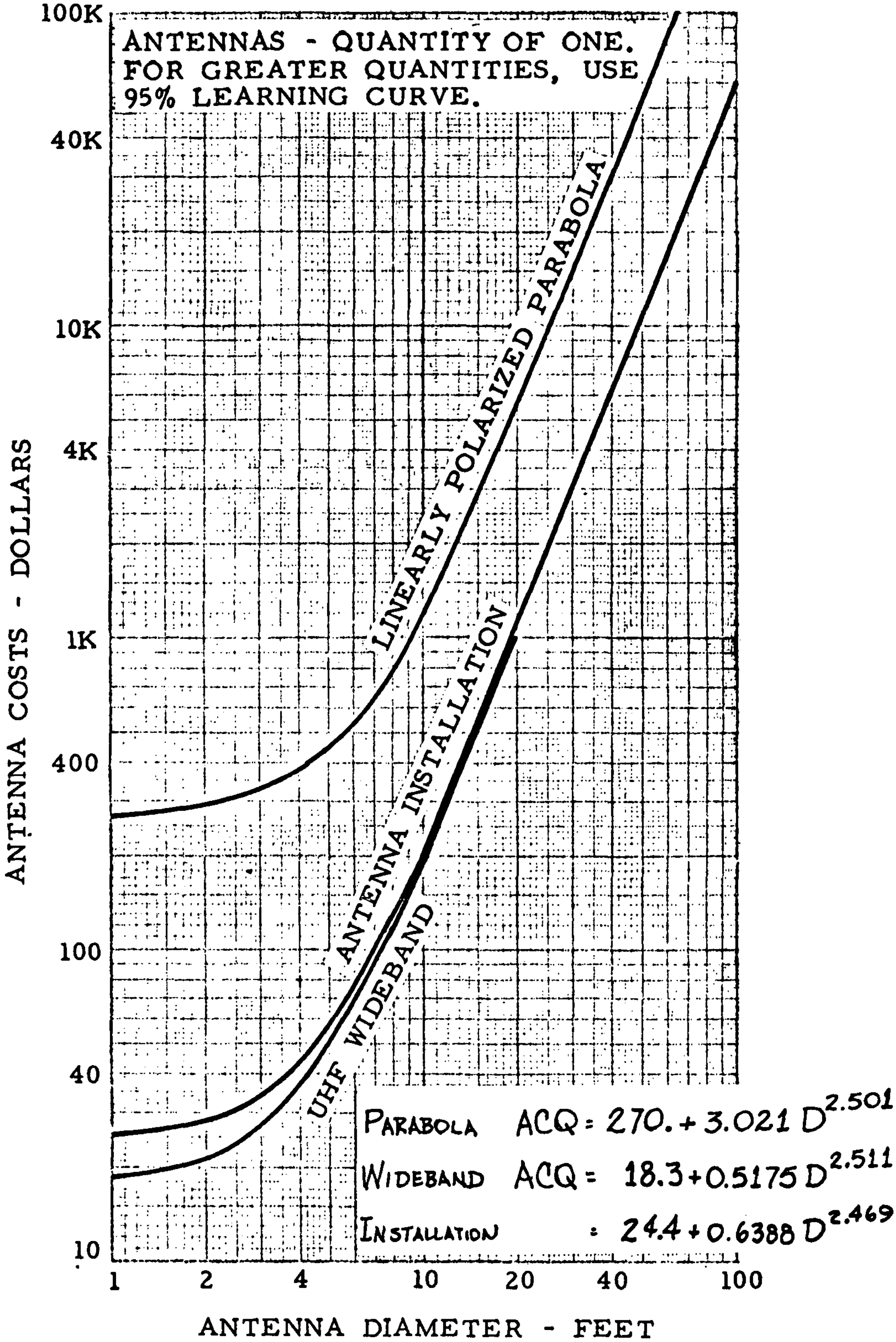


FIGURE 4-11. NON-TRACKING ANTENNA AND INSTALLATION COSTS

Table 4-8. Standby Power Source[3]

Power Rating (KW)	Costs In Thousands Of Dollars					
	PSM	PMM /PTM	PFS	PFS-P	PFS-PNB	1800 RPM
5	4.3	4.9	4.5	5.5	17.0	
10	4.4	5.0	4.6	5.5	18.5	
15	4.6	5.12	5.06	5.58	24.9	
20	5.3	6.8	5.24	5.65	28.25	
30	5.4	7.2	5.4	6.5	32.6	
40	5.5	7.5	5.44	6.7	36.25	
50	5.8	7.8	5.74	6.875	39.35	
60	6.4	8.4	6.44	7.6	43.5	5.375
100	12.62	15.05	12.55	12.85	62.5	6.165
150	16.08	36.0	16.01	16.42	67.5	8.47
200	20.3	43.0	20.2	20.7	81.25	11.43
250	24.46	47.0	24.35	24.85	92.65	
300	28.52	50.0	29.44	28.84	100.8	17.905
350				33.25		21.28
500		64.0				400/ 22.575
600					150.0	
700		84.0				
1050		145.0				

[3] From DCA Cost Manual, Chapter 10, Appendix A and cost data supplied by E. Van Vleck, NASA ARC, pages 61.1-1 thru -3.

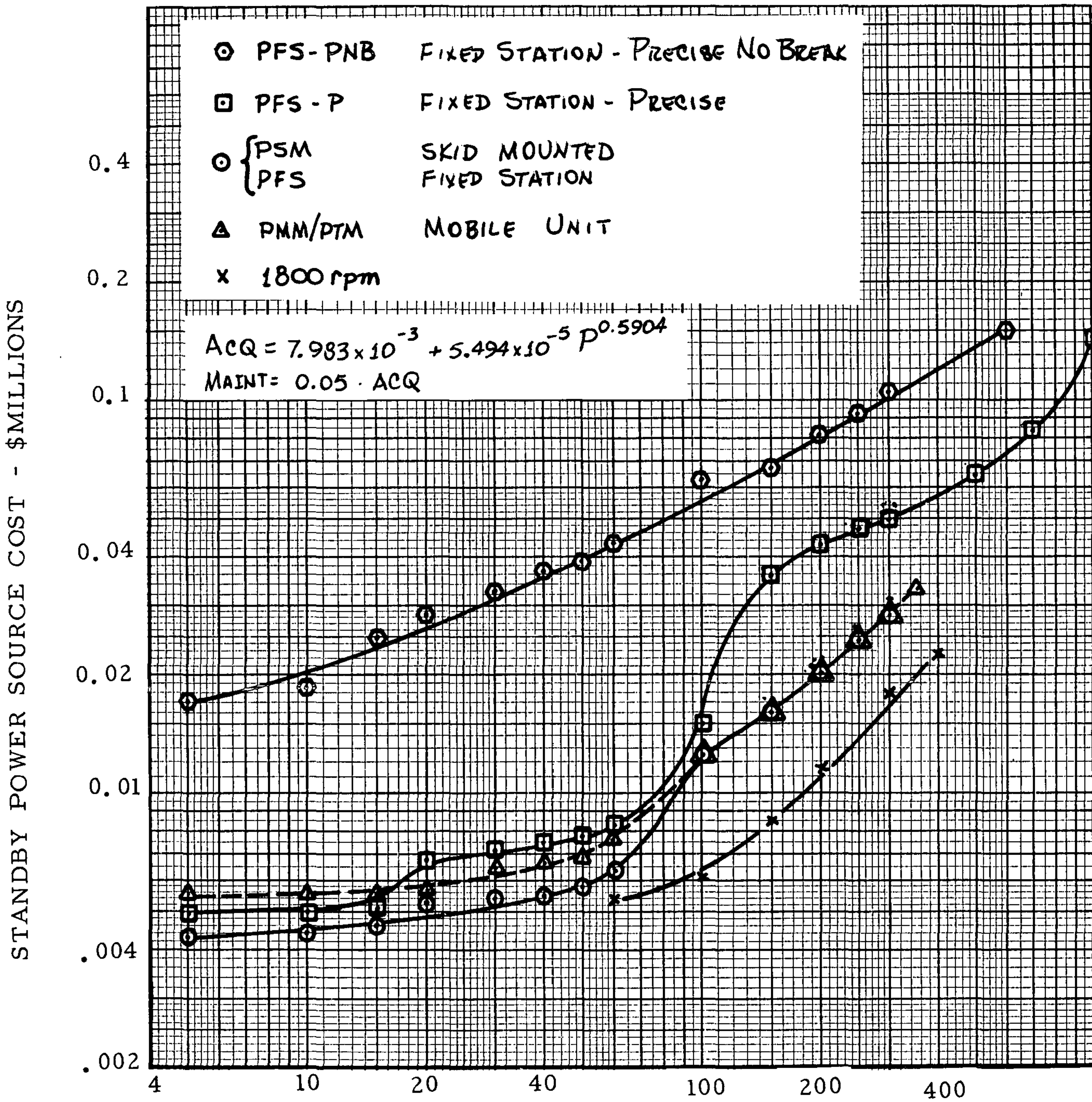


FIGURE 4-12. STANDBY POWER COST

d. Antennas

e. Transmission lines

f. Standby power.

4.2.9 PERSONNEL. The annual personnel cost data was developed according to the following rational:

a. 1 transmitter/receiver pair - 2 men

   4 transmitter/receiver pairs - 4 men

   9 transmitter/receiver pairs - 6 men

   $N_{t/r}$ transmitter/receiver pairs - $2 \cdot (N_{t/r})^{0.5}$

b. The cost per man is $15,000 per year.

c. The second shift differential is 10%

d. The third shift differential is 20%

Figure 4-13 reflects these criteria.

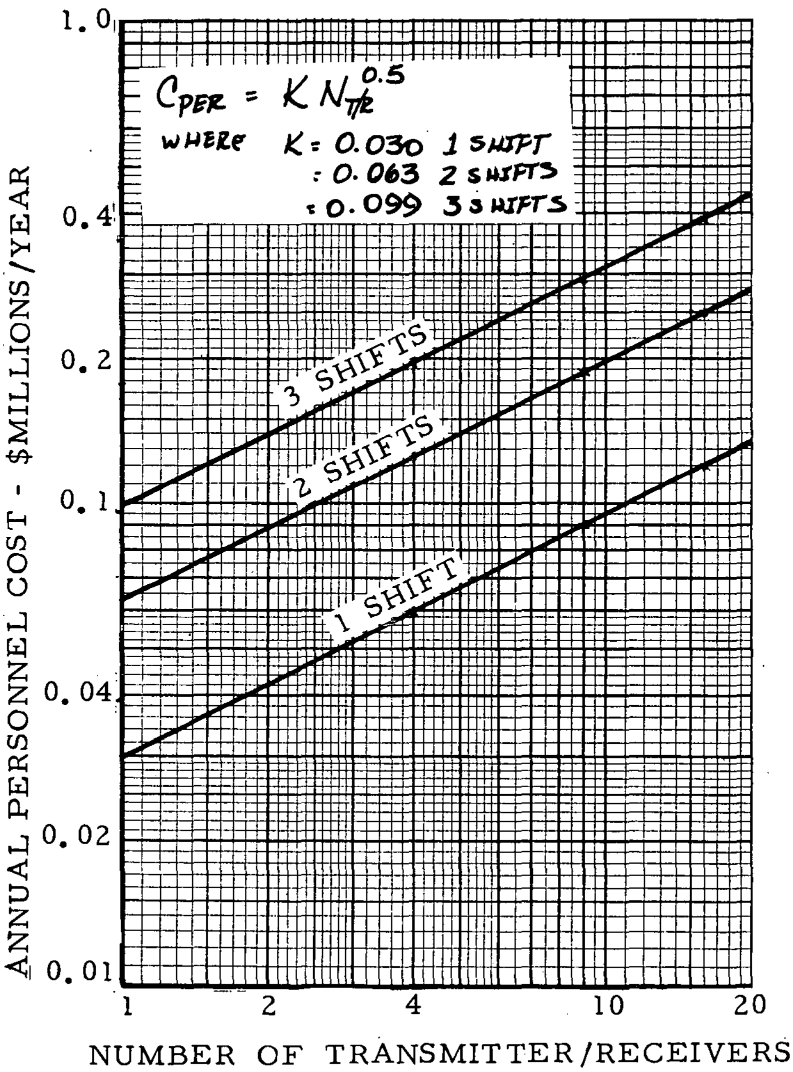


FIGURE 4-13. ANNUAL PERSONNEL COST

5

SATELLITE SYSTEMS

The Convair Communications System Synthesis Program describes the total system in terms of a number of major system elements. Figure 5-1 illustrates the system elements. The satellite system and its subsystems are shown within the dotted line box. Each subsystem may be described in terms of various variables or parameters. Certain of these parameters are identified as the "driving" parameters determining the physical characteristics of the subsystems. For example the noise figure of a receiver may be related to cost. A plot of this relationship permits determination of a functional dependence between cost and noise figure. This "parametric" analysis of the receiver subsystem may be used in the cost determinations resulting from the total system synthesis least cost study (subject to any required constraints).

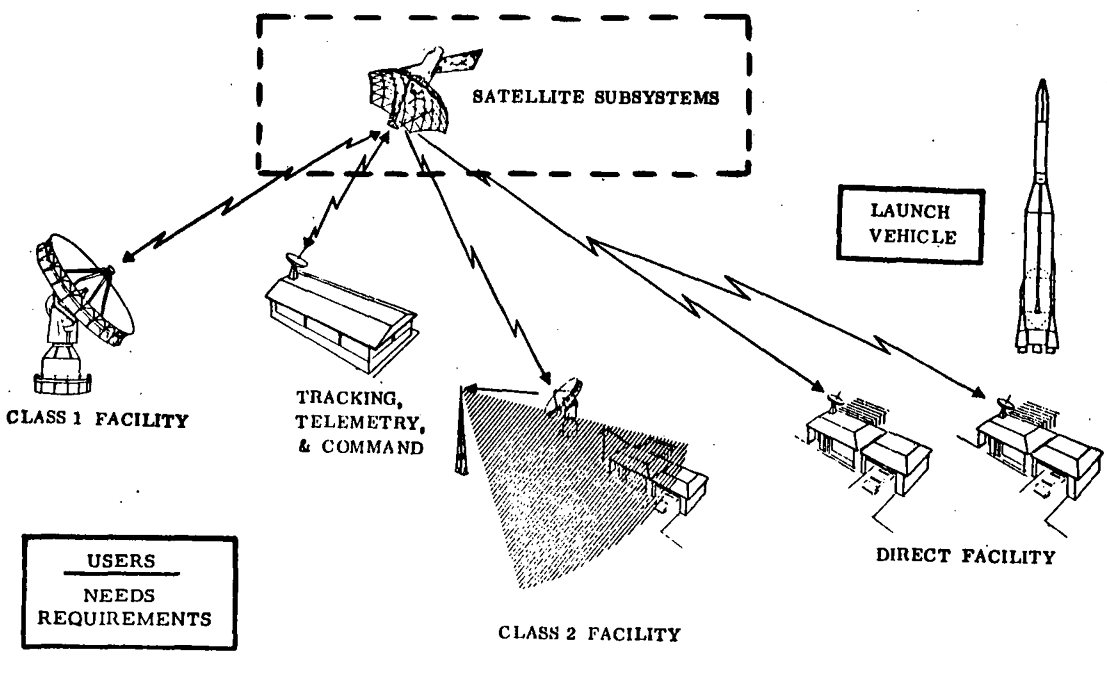


Figure 5-1. Elements of Communication System

5.1 SATELLITE CONFIGURATION CONSTRAINTS

Each launch vehicle imposes constraints upon the physical characteristics of the payload. In addition to the weight and volume limitations, the diameter of the stowed payload and the selection of type of satellite antennas are dictated by the type of launch vehicle. These characteristics affect the selection of deployable or rigid antennas, the available moment arm for attitude control as well as the mounting for the solar array, i.e., the solar array may be mounted on booms if a large antenna cannot support an edge mounted array. The satellite constraints are given in Table 5-1.

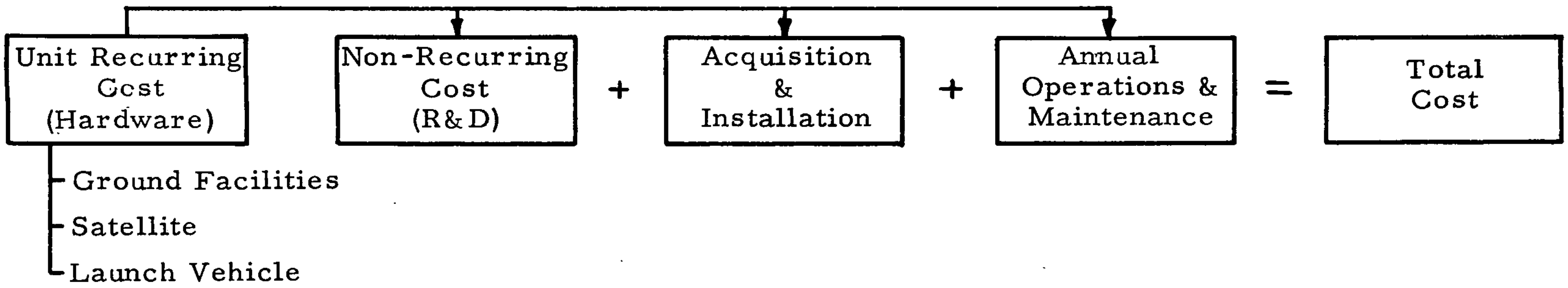
5.2 SATELLITE SYSTEM MODEL

A cost model is employed to collect costs associated with each major "element" shown in Figure 5-1. Figure 5-2 shows the cost model and the subdivision of the satellite to obtain a model for cost analysis. The satellite is composed of eleven subsystems. One of these, the power subsystem, is further divided into four parts. In addition five significant non-subsystem cost elements are used to arrive at the total satellite system cost.

Table 5-1. Satellite Physical Constraints for Various Launch Vehicles.

Launch Vehicle	Weight (Pounds)	Volume (Cubic Feet)	Diameter (Feet)
SLV-3A/Agena	550	250	5
SLV-3C/Centaur D-1/B-II	1650	1200	9
SLV-3X/Centaur D-1/B-II	2700	3000*	13
SLV-3X/Centaur (3-Burn)	1800	3000*	13
Titan IIIC	2600	4000	9
Titan IIID/Centaur D-1T	7100	2800	9
Saturn V	52500	6000	20

* With proposed Viking nose fairing.



<u>Unit Recurring</u>

Power Subsystem
  Prime Power
  Secondary Power
  Conditioning
  Distribution
Antenna
Transmitter
Multiplexer
Receiver
Attitude Control
Stationkeeping
Thermal Control
Structure
Manned Provisions
Telemetry &
  Command

<u>Non-Recurring</u>

Power Subsystem
  Prime Power
  Secondary Power
  Conditioning
  Distribution
Antenna
Transmitter
Multiplexer
Receiver
Attitude Control
Stationkeeping
Thermal Control
Structure
Manned Provisions
Telemetry &
  Command
Prototype
Design, Integration
  & Management
Ground Support Equipment
Center Support

<u>Acquisition & Installation</u>

Unit Recurring
  Cost
    Plus
Integration,
  Assembly, &
  Checkout
Center Support

<u>Operations & Maintenance</u>

This item is not applicable to satellite since costs are incurred prior to placing the satellite in service.

Figure 5-2. Synthesis Program Cost Model for Satellite

5.3 SATELLITE SUBSYSTEMS MODELS

The satellite has been described as an assembly of subsystems. Each subsystem or a group of subsystems is described by a technical model to explain its function. Having done this it is possible to perform a parametric analysis relating performance to certain "driving" parameters. Existing and projected hardware is compared with the parametric data to determine weight, volume and cost relationships to permit the total system synthesis.

The synthesis program uses an iterative process to size the various satellite subsystems as indicated in Figure 5-3. Once the transmitter powers required to fulfill the links are determined, the power requirements are traced back to the prime power source considering the efficiency of each element in the system.

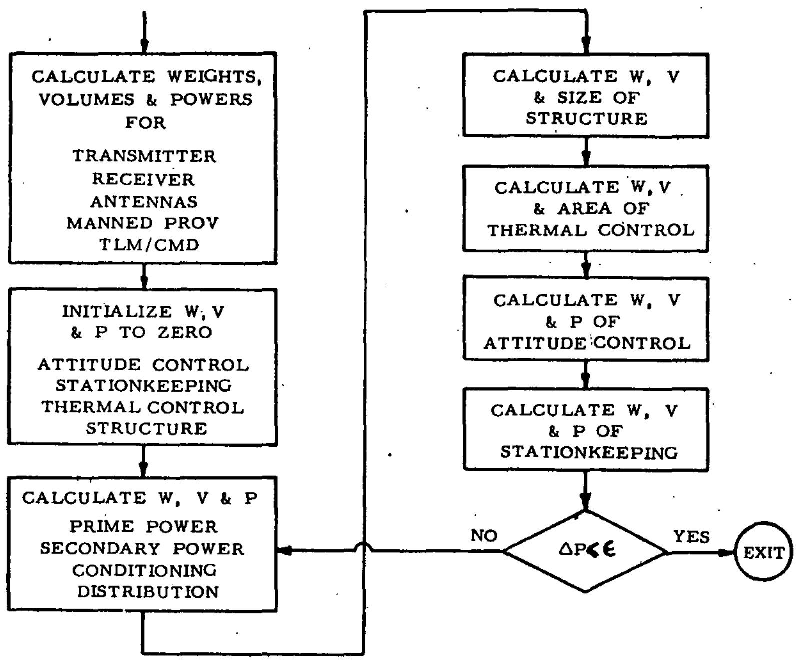


Figure 5-3. Iterative Process For Sizing Satellite Subsystems

However, the interdependence among the satellite subsystems precludes an explicit solution of attitude control and stationkeeping parameters. The attitude control weight, volume, and power are a function of solar array area and the stationkeeping characteristics are a function of all other subsystem weights. Due to these relationships, an implicit solution is dictated as in Figure 5-3. The characteristics of each of the independent subsystems are determined and are constant throughout this process. An initial estimate is made for the characteristics of the other subsystems -- attitude control, stationkeeping, thermal control and structure. The power subsystem is then sized for these initial conditions. The structure is then sized as a function of the contained equipment; the thermal control requirements are determined for the required power dissipation; the attitude control subsystem characteristics are computed for the solar array area; and the stationkeeping subsystem is sized as a function of the weight of all other subsystems. The process is continued until the change in prime power requirements is small. The resulting satellite subsystem characteristics are then mutually compatible.

5.3.1 POWER SUBSYSTEM. The power subsystem is subdivided into four parts to simplify the parametric analysis. There must be a long life prime source, a secondary storage source, conditioning to a form for using and distribution to the various power consuming subsystems. Figure 5-4 shows the interrelationship of the parts of the power subsystem to the satellite system.

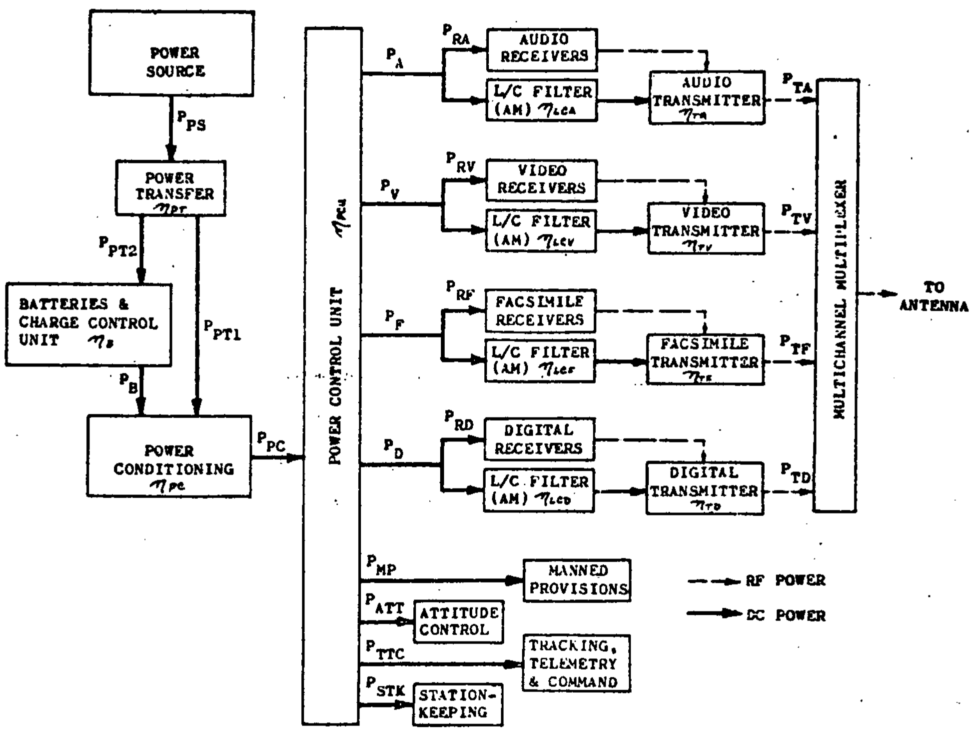


Figure 5-4. Power Subsystem Model

5.3.1.1 Prime Power. The primary source of electrical power for a communications satellite must have a lifetime of several years. Present technology offers only two basic types:

ONE - Sources deriving continued energy replenishment from the satellite environment.

TWO - Sources generating electric power by consuming fuel with a high available power output to weight and volume ratio.

These types presently exist only in solar cells and various types of nuclear reactors.

a. Comparison of Solar Cells and Nuclear Reactors. Table 5-2 summarizes relative merits of solar cell arrays and two types of nuclear power sources. At first glance it might appear that there are considerable advantages in favor of nuclear sources. However, when all of the characteristics are modeled and simultaneously synthesized, the resulting system may not appear, at first glance, to be optimum. The results of the multiple interrelationships among these characteristics are usually

Table 5-2. Electrical Power Subsystem Power Source

POWER SOURCE	MAIN ADVANTAGES	MAIN DISADVANTAGES
1. SOLAR CELL ARRAY	1. STATIC SYSTEM. 2. STRONG TECHNOLOGY BASE. 3. ADAPTABLE TO A WIDE VARIETY OF CONFIGURATIONS. 4. LONG LIFE	1. SENSITIVITY TO SPACE ENVIRONMENT 2. NONOPERATIVE IN ORBITAL DARK PERIODS. 3. ASSEMBLY FROM LARGE NUMBER OF SMALL COMPONENTS.
2. NUCLEAR REACTOR	1. SEMI-STATIC SYSTEM 2. SNAP-2, -10A, -8 & SPUR-50 DEVELOPMENT PROGRAMS IN PROGRESS. 3. COMPACT SYSTEM.	1. LIMITED LIFE. 2. HEAVY SHIELDING REQUIREMENTS. 3. LOW EFFICIENCY.
3. RADIOISOTOPE THERMOELECTRIC GENERATOR	1. LONG LIFE 2. SEMI-STATIC OR STATIC SYSTEM. 3. COMPACT SYSTEM	1. SAFETY-RADIATION HAZARDS. 2. TECHNOLOGY BASE INADEQUATE AT POWER RANGE OF INTEREST. 3. ISOTOPE AVAILABILITY -QUANTITY & COST.

not obvious by comparions of characteristics in a qualitative manner. It may be said, however, that the present state of technology in the two fields weighs heavily in favor of solar cells even though a secondary source of power is required for operation during solar eclipse. These two systems, solar arrays and reactors, are compared further.

b. Nuclear Power Systems. Tables 5-3 and 5-4 summarize some characteristics of Nuclear Reactor and Radio Isotope Thermoelectric generators. Figure 5-5 shows the method of generating the cost versus power output curves for a nuclear reactor. The cost points are numbered referring to the list of numbered references, paragraph 5.5.1.

Table 5-3. Electrical Power Subsystem
Nuclear Reactor Systems

SYSTEM	POWER (KWe)		CONVERSION SYSTEM	WEIGHT (LB)	LIFE* (YR.)	STATUS
	DESIGN	POTENTIAL				
SNAP-2	3	10	RANKINE CYCLE	1,470	1	COMPONENT DEVELOPMENT
SNAP-10A	0.5	2	T/E	1,000	1	FLIGHT TESTED
SNAP-8	30	300	RANKINE CYCLE	6,000	1	SYSTEM DEVELOPMENT

* EXTEND OPERATING LIFE BY -

1. INCREASE VOLUME FOR FUEL.
2. INCREASE QUANTITY OF FUEL.
3. DECREASE OPERATING TEMPERATURE

Table 5-4. Electrical Power Subsystem
Radioisotope Thermoelectric Generators

SNAP	POWER (W)	USE	FUEL	DESIGN LIFE (YR.)	STATUS
3	2.7	DOD NAVIGATION SATELLITE	Pu^{238}	5	IN ORBIT
9A	25	DOD NAVIGATION SATELLITE	Pu^{238}	5	IN ORBIT
11	25	SURVEYOR	Cu^{242}	0.25	TESTED
13	12.5	THERMIONIC DEMONSTRATION	Cu^{242}	0.25	TESTED
19	30	NIMBUS B	Pu^{238}	5	UNDER DEVELOPMENT
27	50	APOLLO LUNAR SURFACE EXPERIMENT PACKAGE	Pu^{238}	1	UNDER DEVELOPMENT
29	500	DOD APPLICATION	Po^{210}	0.25	UNDER DEVELOPMENT

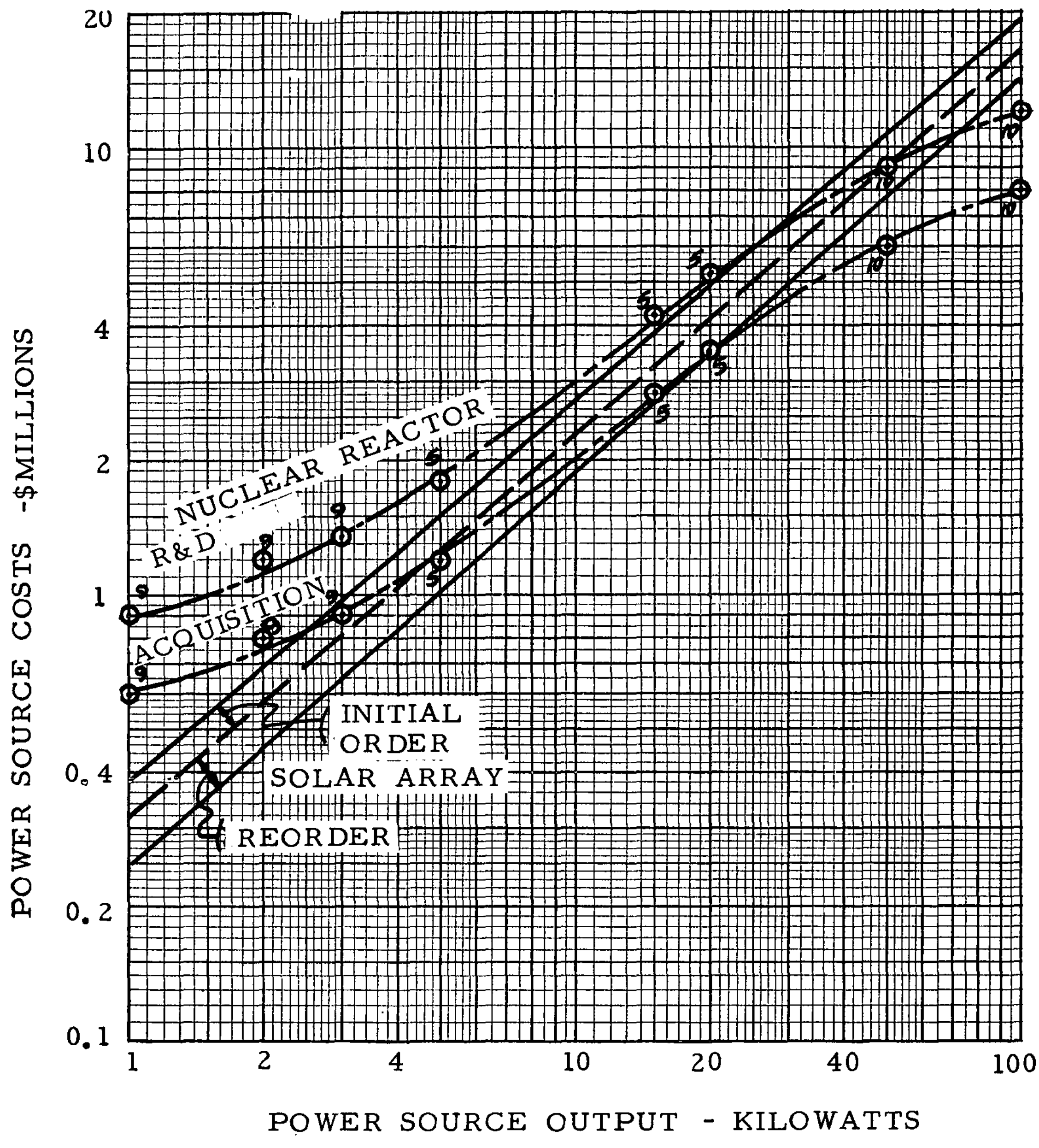


FIGURE 5-5. PRIME POWER SOURCE COST DATA

c. Solar Cell Arrays. The cost of solar cell arrays was derived from Figure 5-5, adapted from reference 1 of paragraph 5.5.2. Array lifetime, weight and volume were developed from reference 2. Lifetime of the solar cell array is an important consideration. Figure 5-6 shows relative degradation of N/P and P/N types of solar cells with long time usage. The cost relations inset are used in the system synthesis. Table 5-5 summarizes some array characteristics.

d. Parametric Curves and Equations for Solar Cells and Reactors. The cost, weight and volume of solar cell arrays and nuclear reactor sources are given in Figures 5-7, 5-8, and 5-9 respectively. The functional equations relating these parameters to the source power output in watts are inset. In the case of costs both R&D and flight article acquisition costs are shown.

5.3.1.2 Secondary Power. Solar cell arrays transform the sun's heat to electrical energy only when illuminated. Energy must be stored in batteries to supply power when the satellite is in the earth's shadow. As in the case of the primary power source, lifetime, cost, weight and volume are the parameters of interest in battery selection. Figures 5-10, 5-11 and 5-12 give the cost, weight and volume of three types of batteries with respect to capacity in watt-hours power usage. Nickel-cadmium has the least favorable weight and volume to capacity ratios. This type is, however, lower cost. In addition nickel-cadmium offers longer lifetime. The functional expressions for synthesis of the battery parameters in terms of watt-hours are inset in the figures. The use of these relationships in the synthesis porgram results in the most favorable battery choice. The information presented on batteries is based upon cost and battery characteristic quotations supplied to Convair by battery vendors.

5.3.1.3 Power Conditioning. Power conditioning equipment consists of several types of operations. The equipment to perform these operations may be segregated into numerous small modules or grouped. The grouping used for the system synthesis is power conditioning (including inverter, converter and regulator), power control and charge control and an L/C filter (for AM system only).

Parametric data of costs, weights and volumes for the power conditioning subsystem were obtained from various sources located by Convair and from

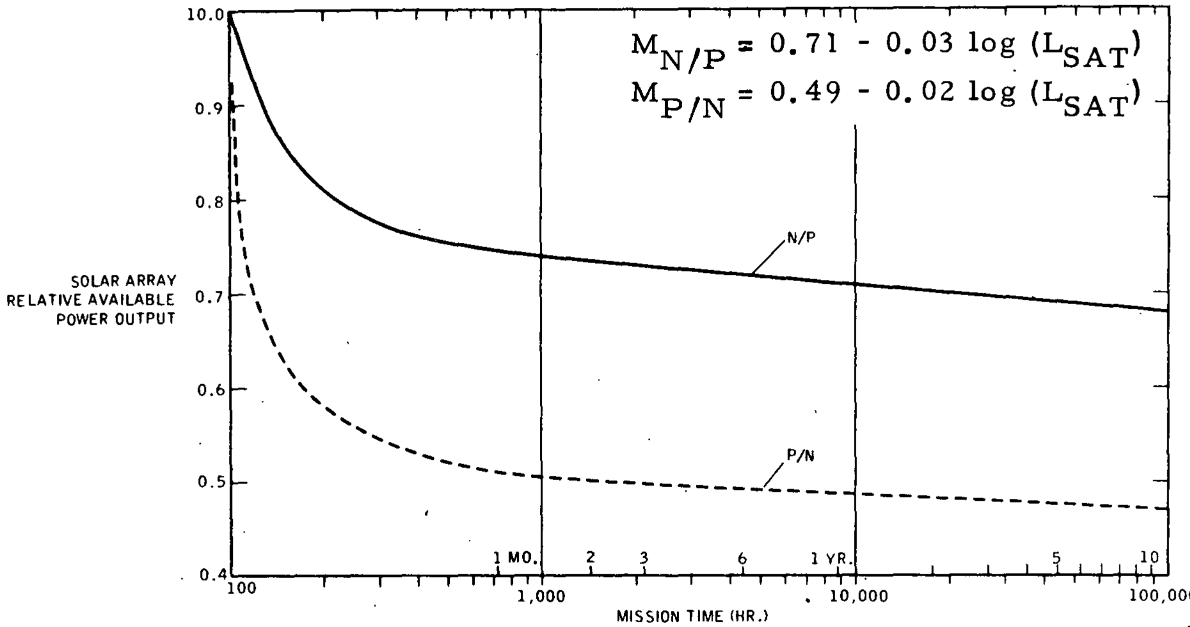


Figure 5-6. Solar Array Degradation

Table 5-5. Electrical Power Subsystem Solar Cell Arrays

PARAMETER	1970	1975	1980
SIZE/TYPE	2 x 2 CM N/P SILICON*	2 x 6 CM N/P SILICON	4 x 6 CM N/P SILICON
THICKNESS	8 TO 12 MILS	6 TO 8 MILS	4 MILS
CONTACTS	WRAP-AROUND	WRAP-AROUND	WRAP-AROUND
POWER/CELL	72.8 mW	225 mW	450 mW
EFFICIENCY	13%	12%	12%
COVERGLASS THICKNESS	4 MILS (MIN.)	6 MILS (MIN.)	6 MILS (MIN.)
AREA - THEORETICAL	13 TO 15 W/SQ.FT.	15 TO 20 W/SQ.FT.	15 TO 20 W/SQ.FT.
AREA - PRACTICAL	10.3 W/SQ.FT.	15 W/SQ.FT.	16 W/SQ.FT.
WEIGHT**	48 W/LB.	55 W/LB.	60 W/LB.

* 2x6 cm & 4x4 cm cells may develop sufficient usage to be available in large quantities at competitive prices.

** Not including substrate/structures

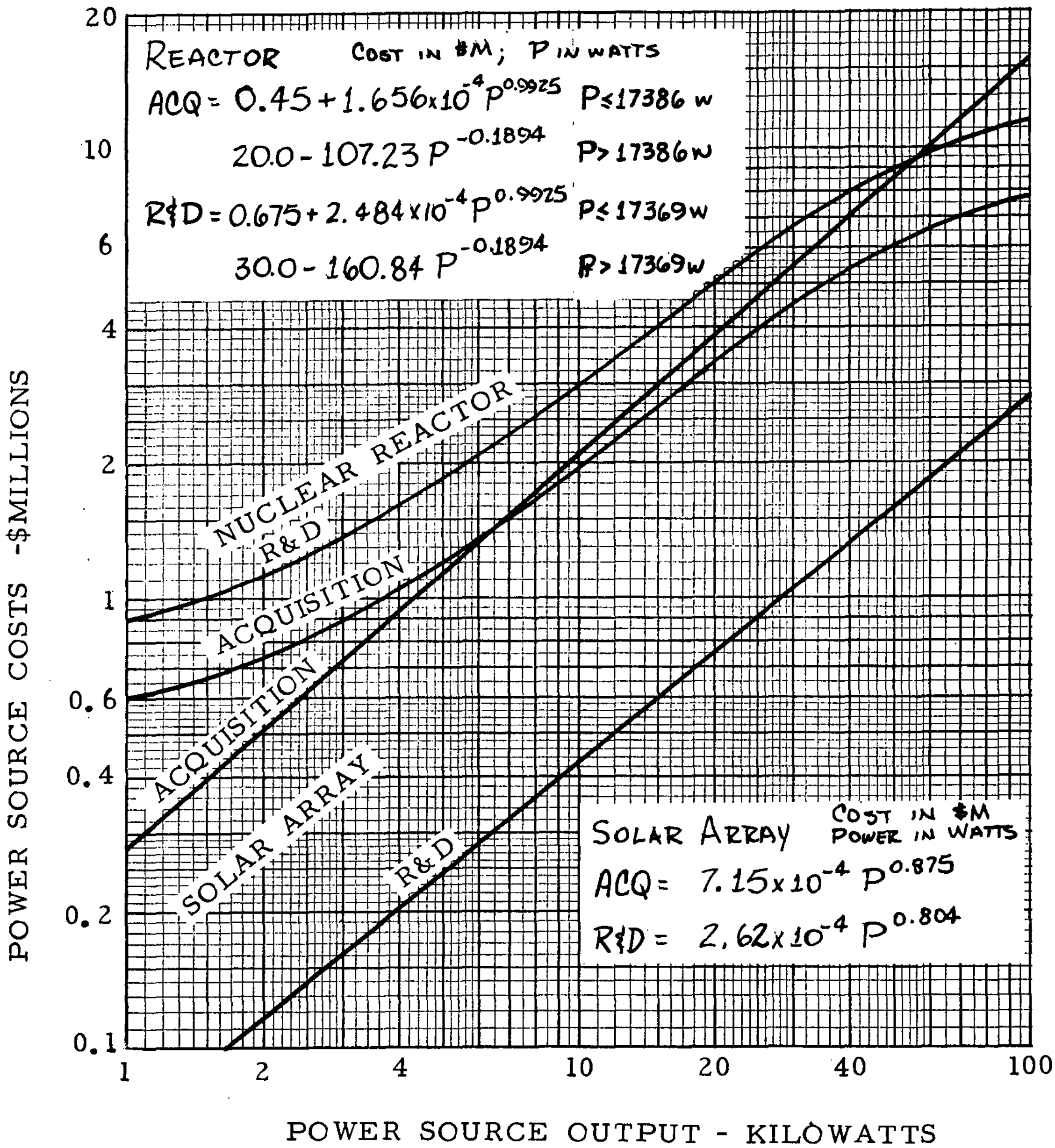


FIGURE 5-7. PRIME POWER SOURCE COST

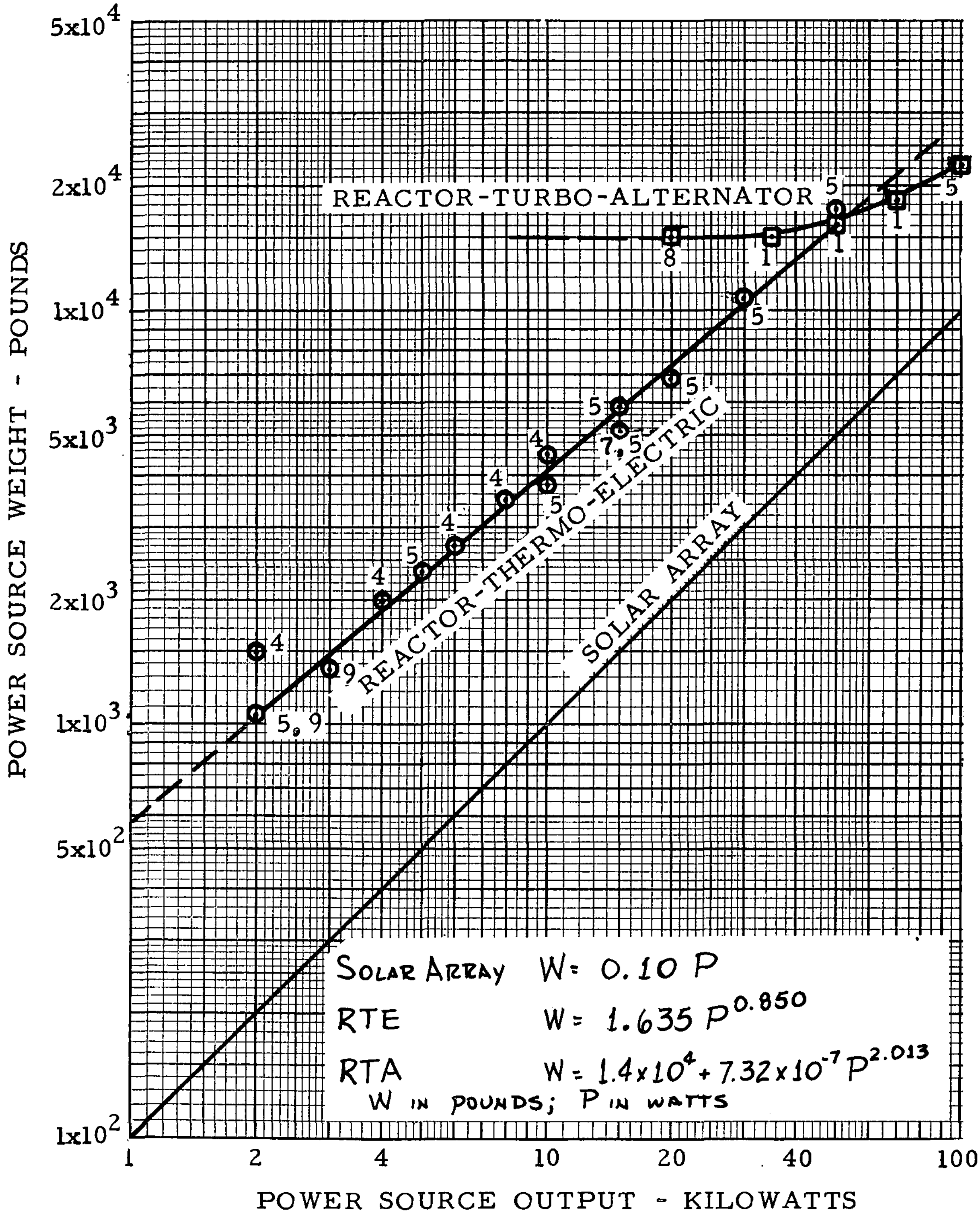


FIGURE 5-8. POWER SOURCE WEIGHT

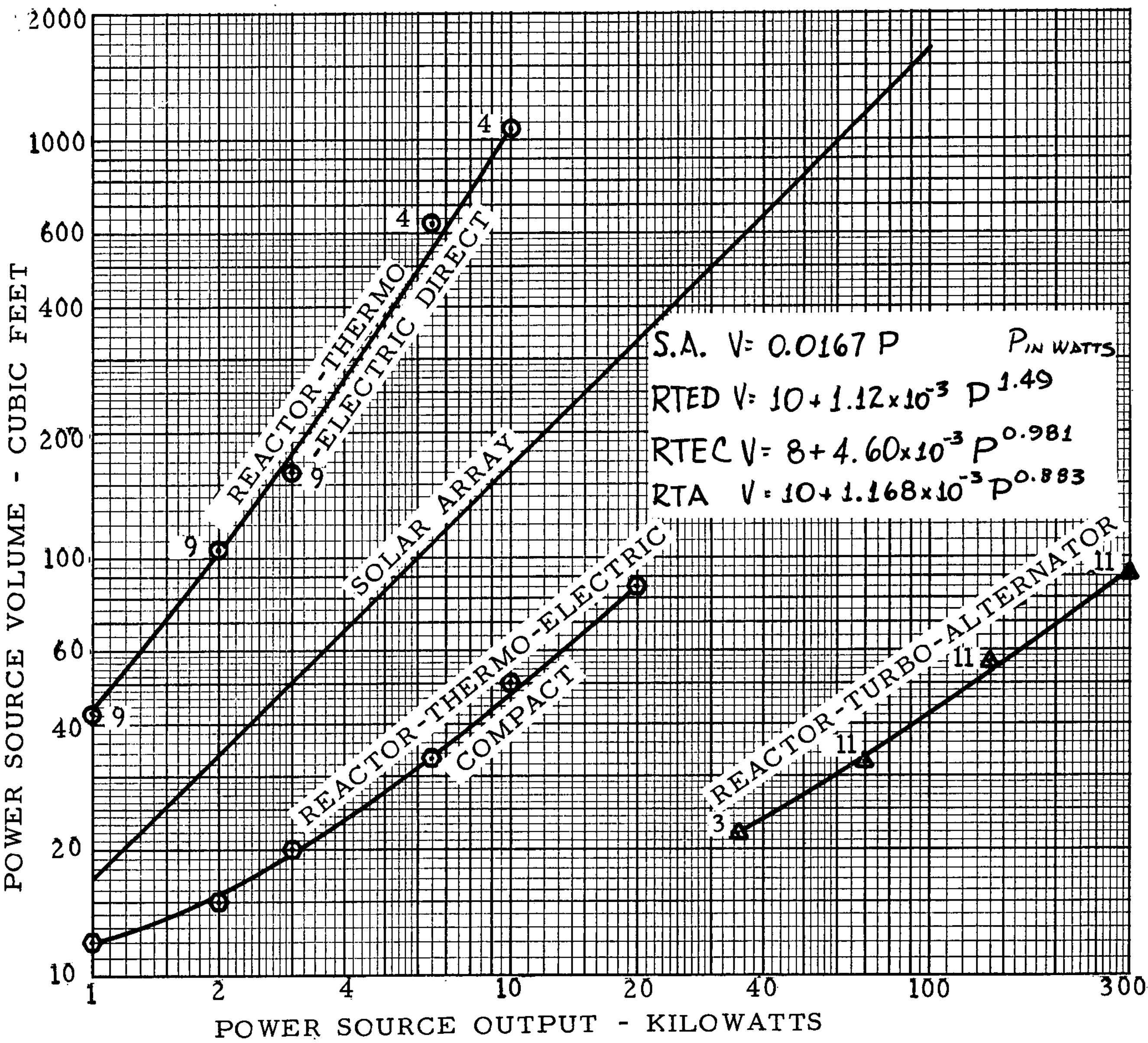


FIGURE 5-9. POWER SOURCE VOLUME

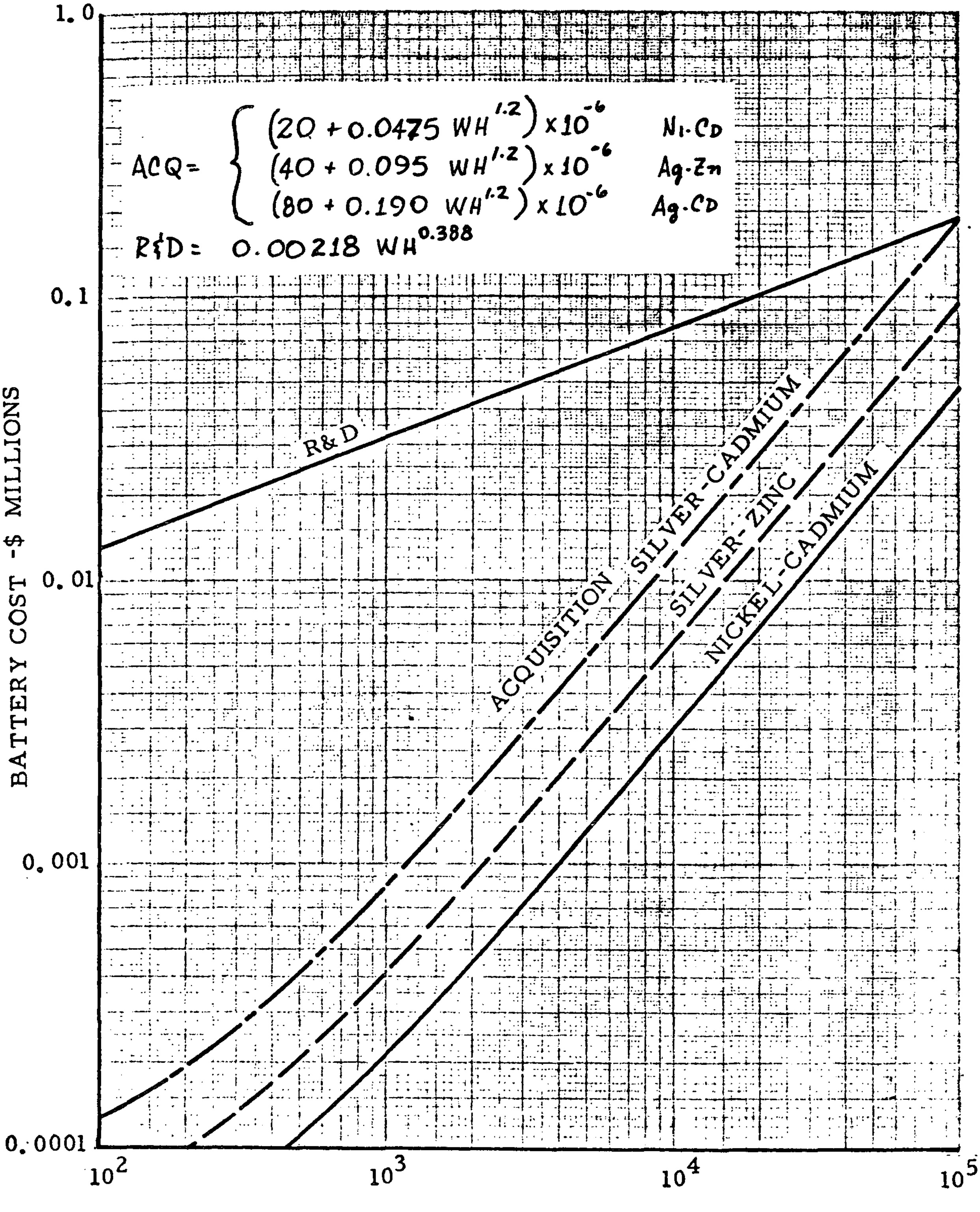


FIGURE 5-10. BATTERY COST

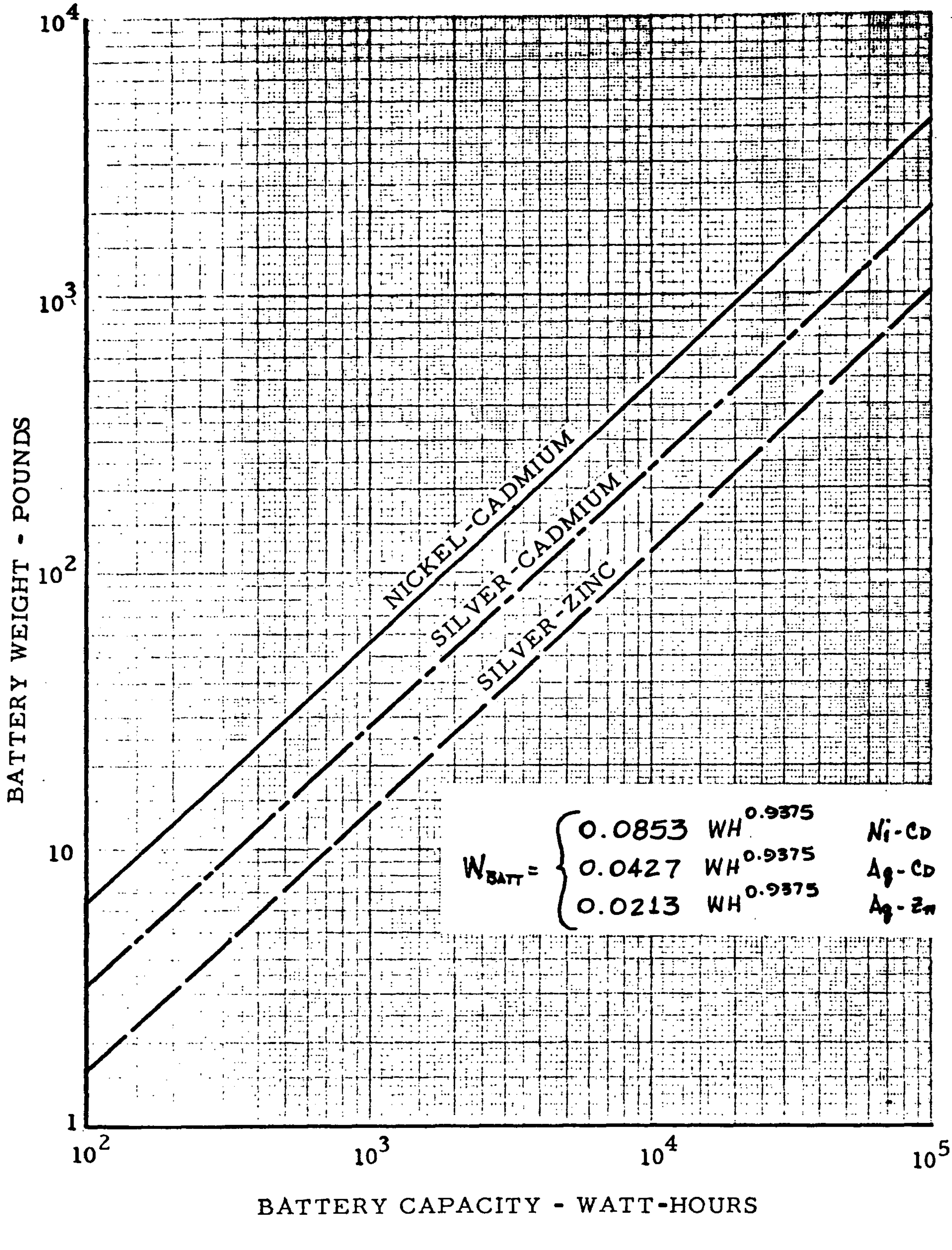


FIGURE 5-11. BATTERY WEIGHT

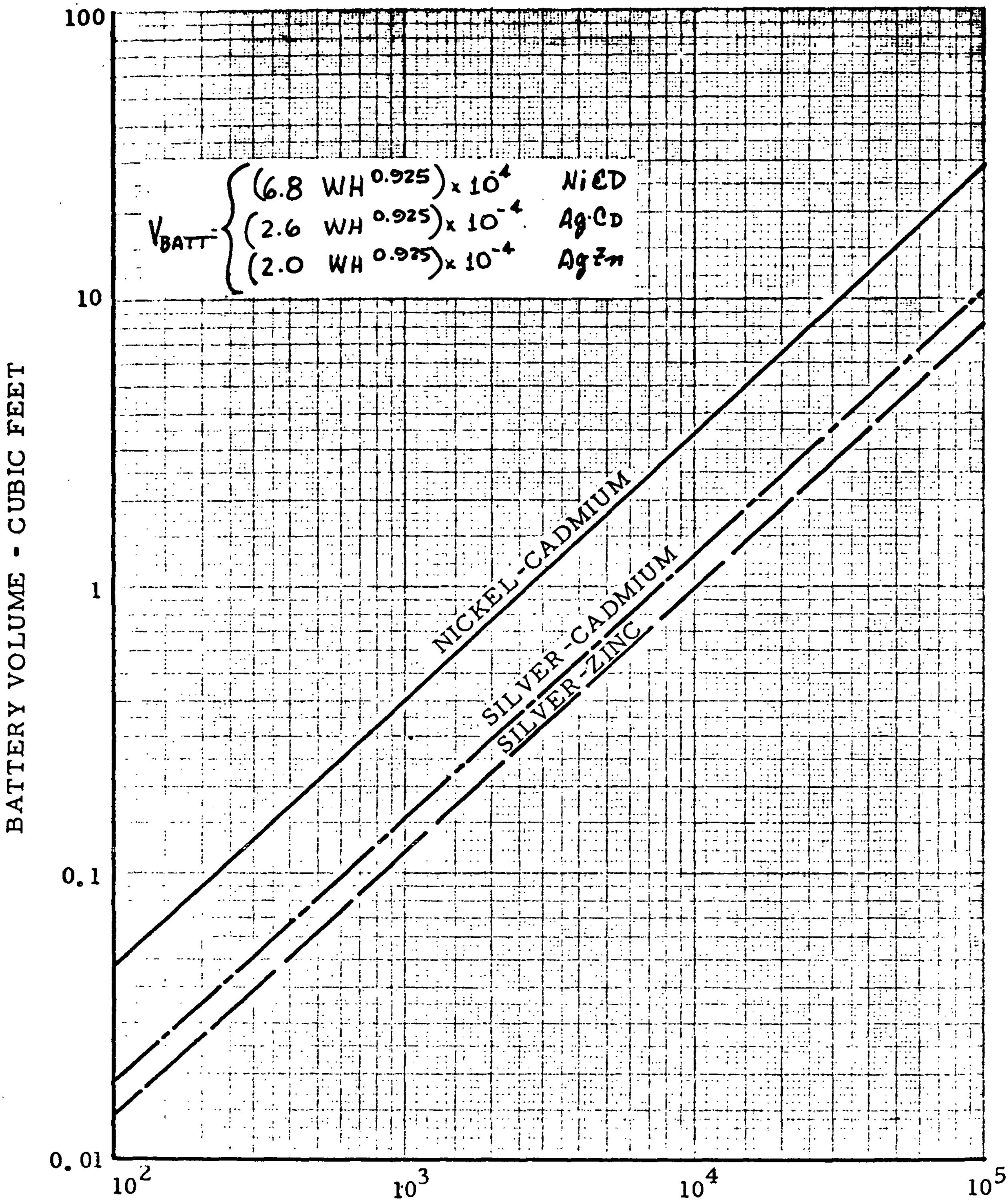


FIGURE 5-12. BATTERY VOLUME

Hughes Aircraft Company in support of the Television Broadcast Satellite Study.[1] These sources of data are listed in paragraph 5.5.3. The reference numbers on the following curves refer to these sources of data. The parametric curves are as follows:

1. Figure 5-13. Power conditioning and control unit costs as a function of power rating.
2. Figure 5-14. Power conditioning weight as a function of power rating.
3. Figure 5-15. Power conditioning volume as a function of rating.
4. Figure 5-16. Power control unit weight and volume as a function of power rating.
5. Figure 5-17. Battery charge control unit costs as a function of power rating.
6. Figure 5-18. Battery charge control unit weight and volume as a function of power rating.
7. Figure 5-19. L/C filter costs as a function of peak sync power rating.[2] (Used for amplitude modulation only)
8. Figure 5-20. L/C filter weight and volume as a function of peak sync power rating.[2] (Used for amplitude modulation)

The data points were curve fit with one of the functions used in the synthesis program. The corresponding function is inset into the curves.

5.3.1.4 Power Distribution. This subsystem consists of a transfer unit to direct the solar cell output directly to power conditioning or by way of charge control and battery storage. The harnessing and associated connectors, slip rings and switches accomplish the distribution. In the case of power distribution, the source of information is Convair's own experience in missiles (Atlas), space launch vehicles and boosters (SLV and Centaur) and satellites (OV-1 series). Figures 5-21 and 5-22 give the power transfer and harnessing costs, weights, and volumes respectively as a function of the power ratings. The parametric relationships describing the curves are inset into the figures.

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[1] Appendix A, Fourth Monthly Report, "Television Broadcast Satellite Task Review," 16 April 1969 to 15 May 1969, NASA/MSFC contract NAS8-21036, with Convair Division of General Dynamics.

[2] General Electric Report No. 68SD4268, 10 June 1968, "Multikilowatt Transmitter Study for Space Communications Satellites," NASA/MSFC contract NAS8-21866.

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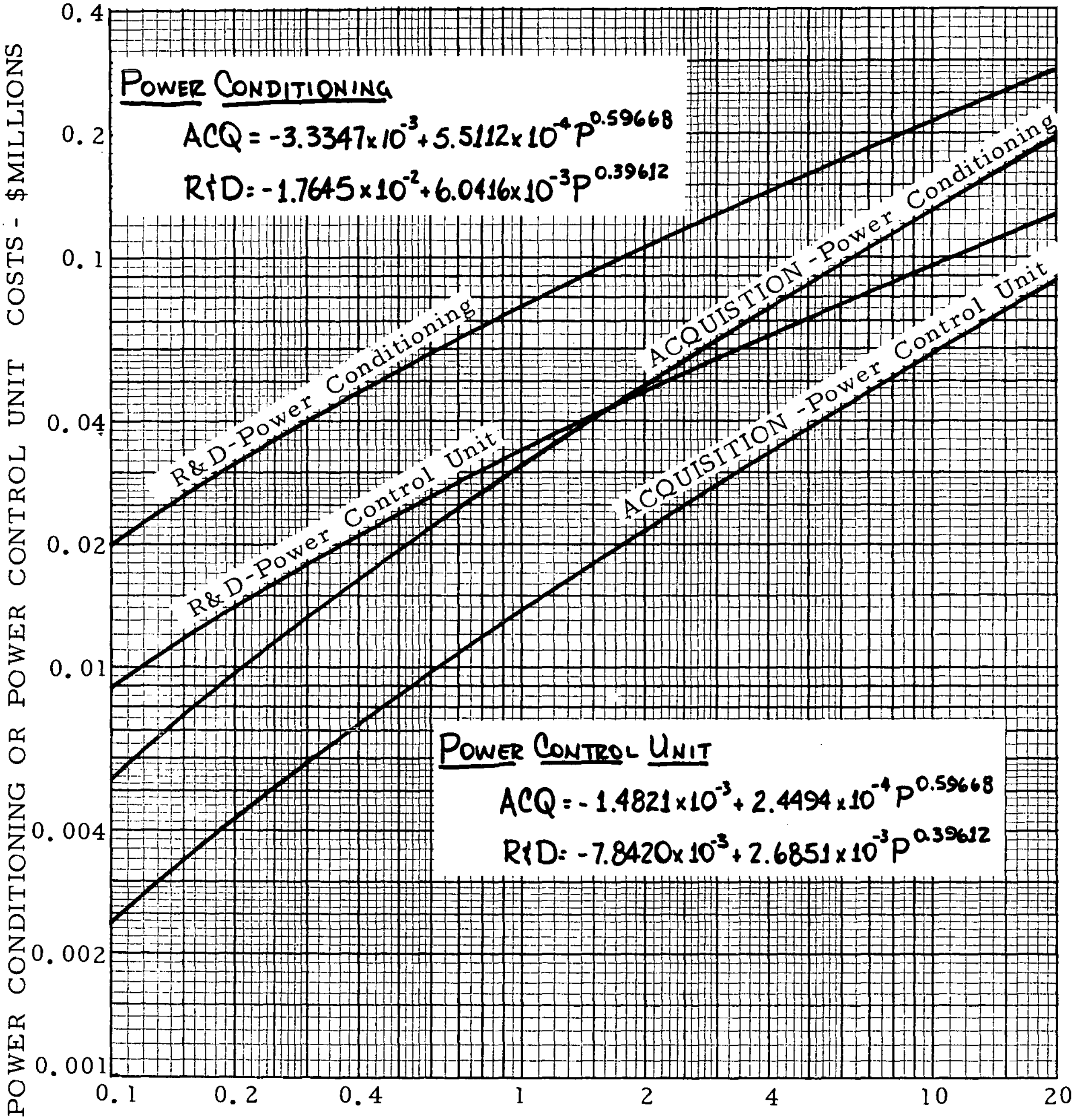

FIGURE 5-13. POWER CONDITIONING AND CONTROL UNIT COST

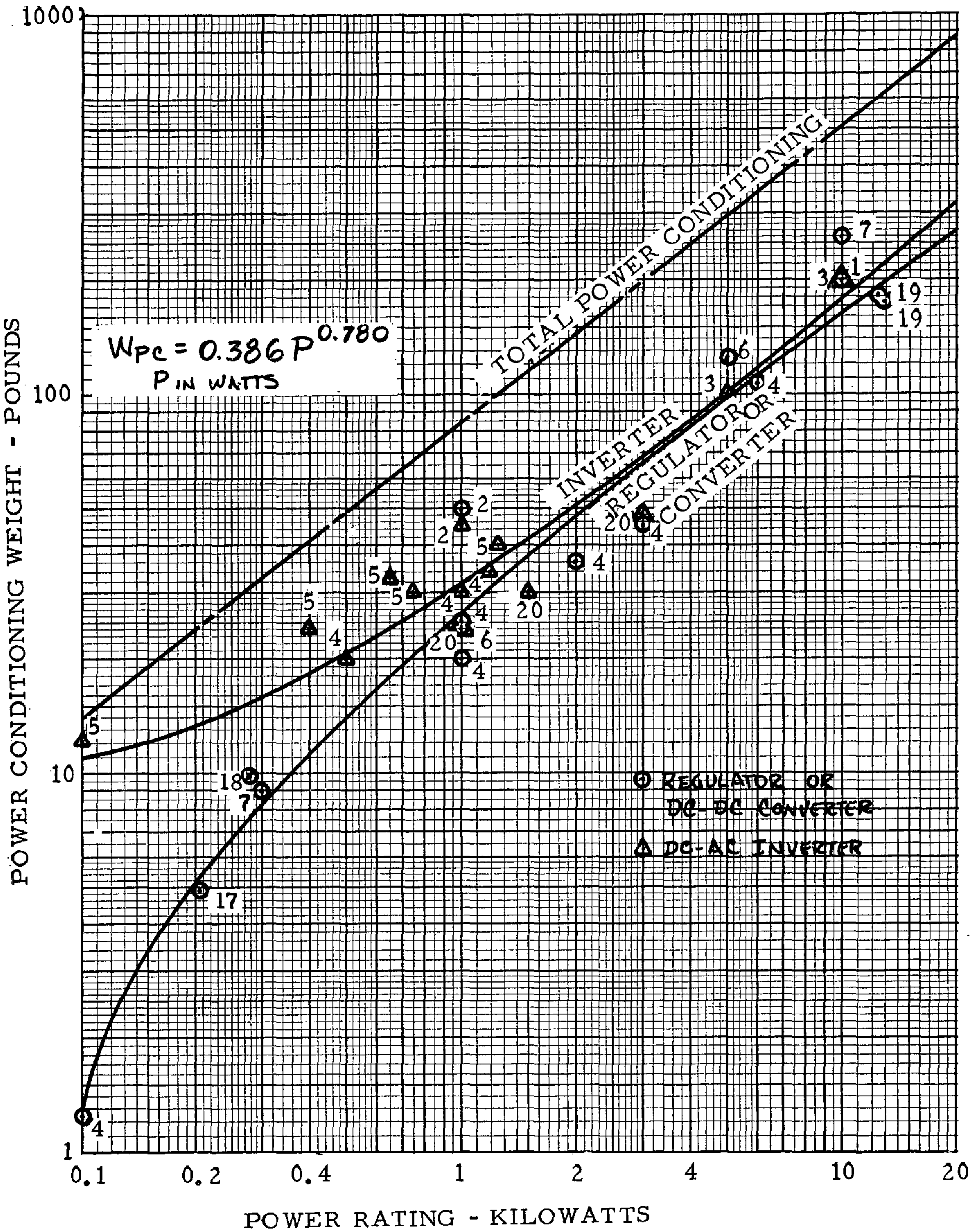

FIGURE 5-14. POWER CONDITIONING WEIGHT

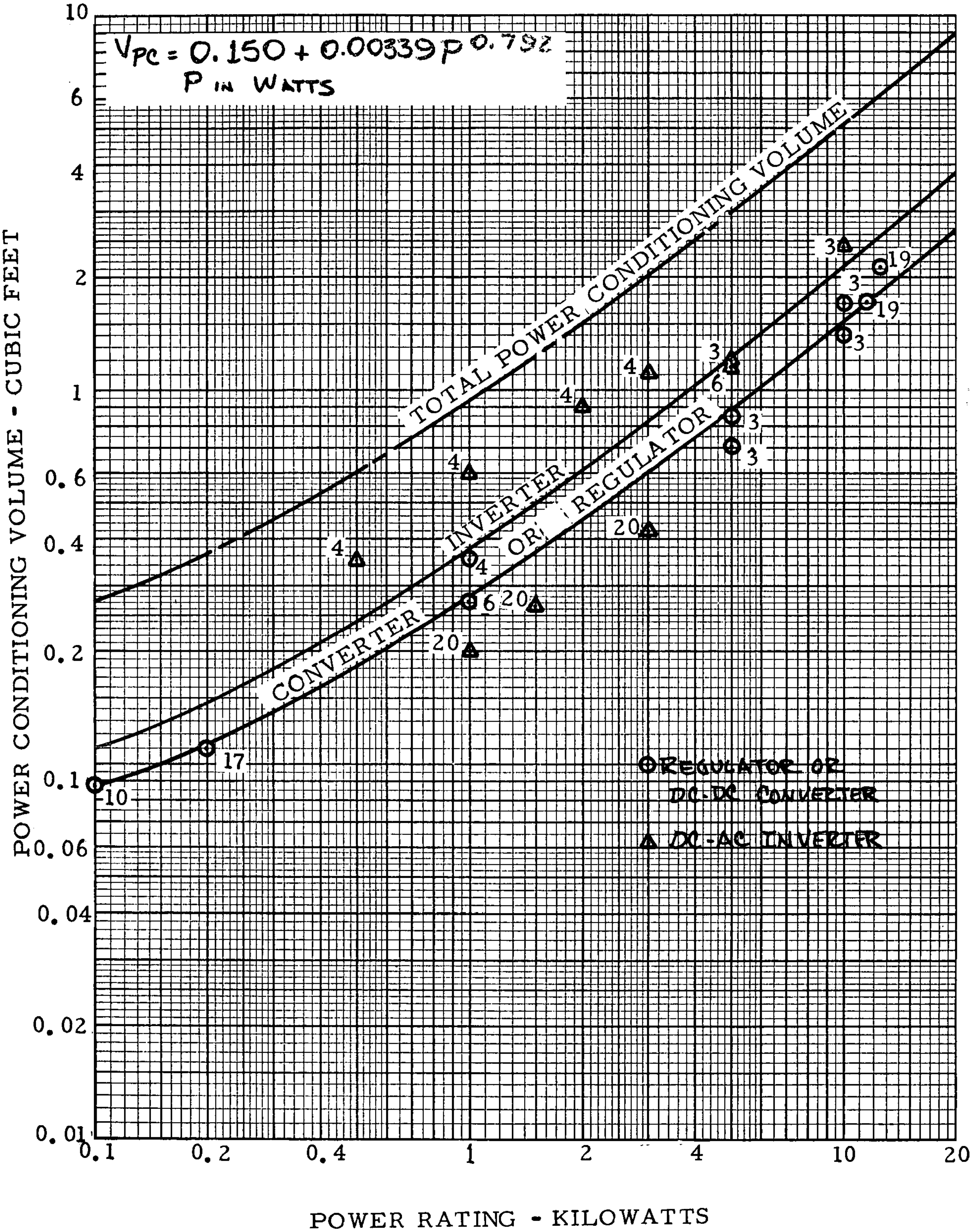

FIGURE 5-15. POWER CONDITIONING VOLUME

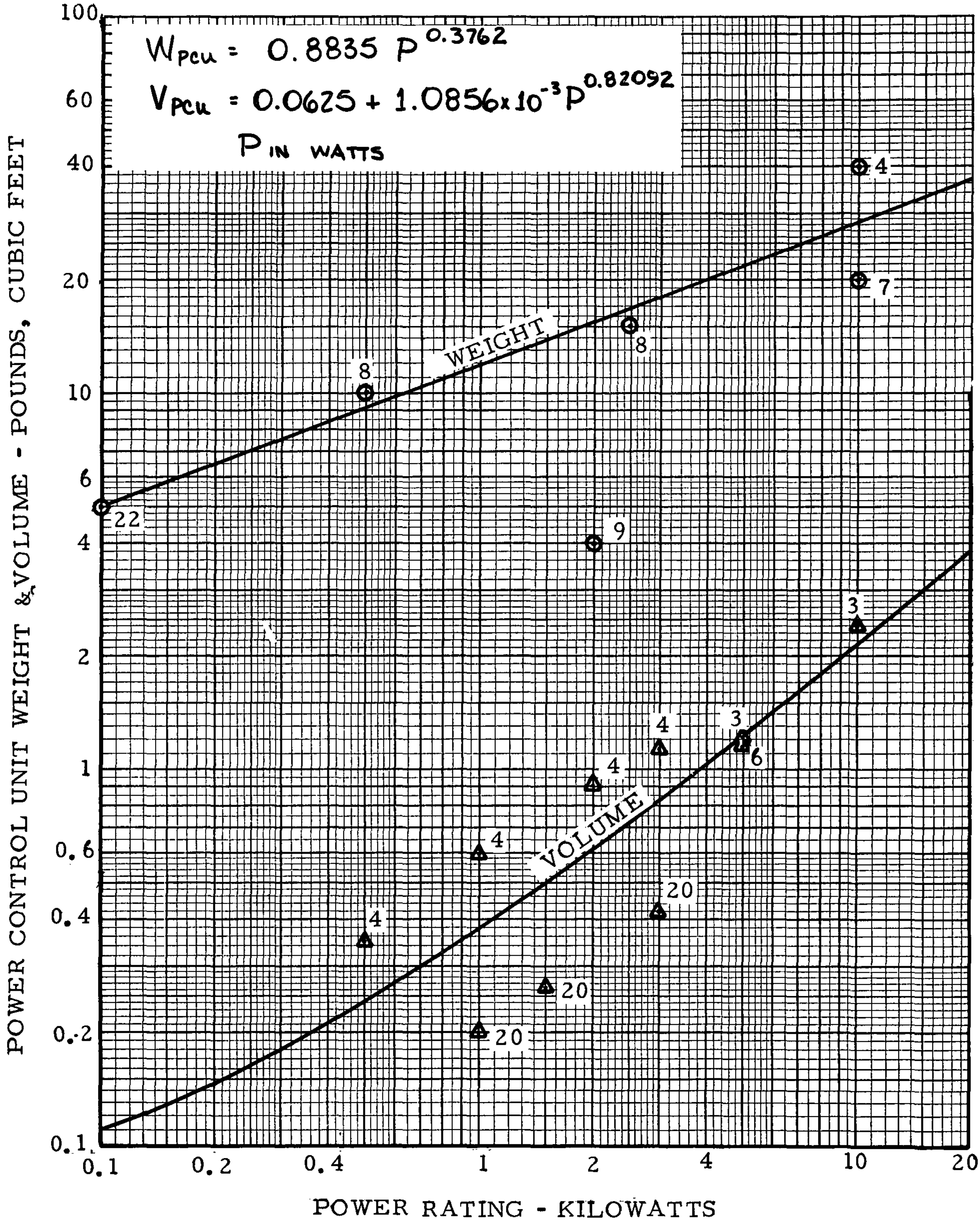

FIGURE 5-16. POWER CONTROL UNIT WEIGHT AND VOLUME

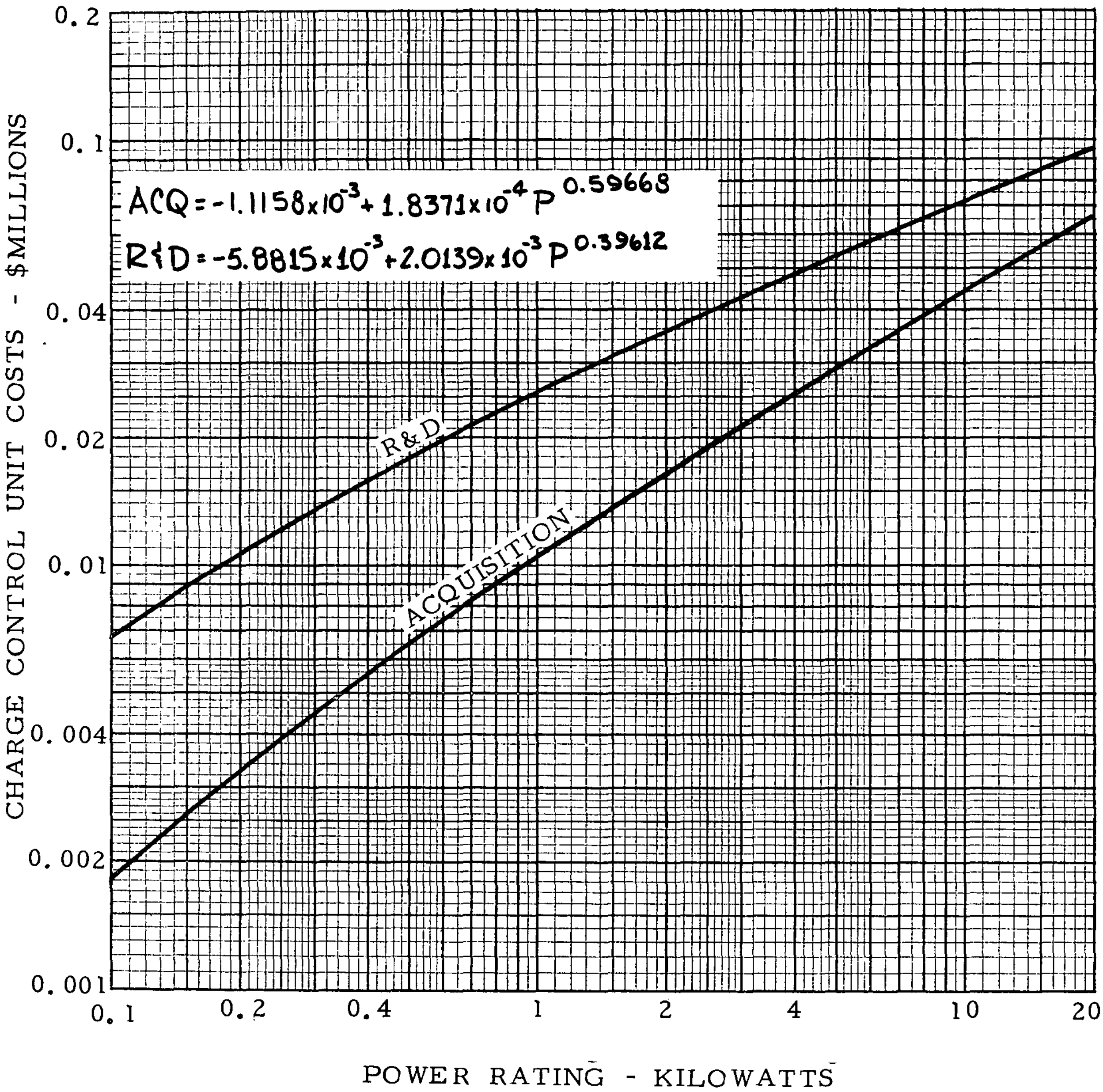

FIGURE 5-17. CHARGE CONTROL UNIT COST

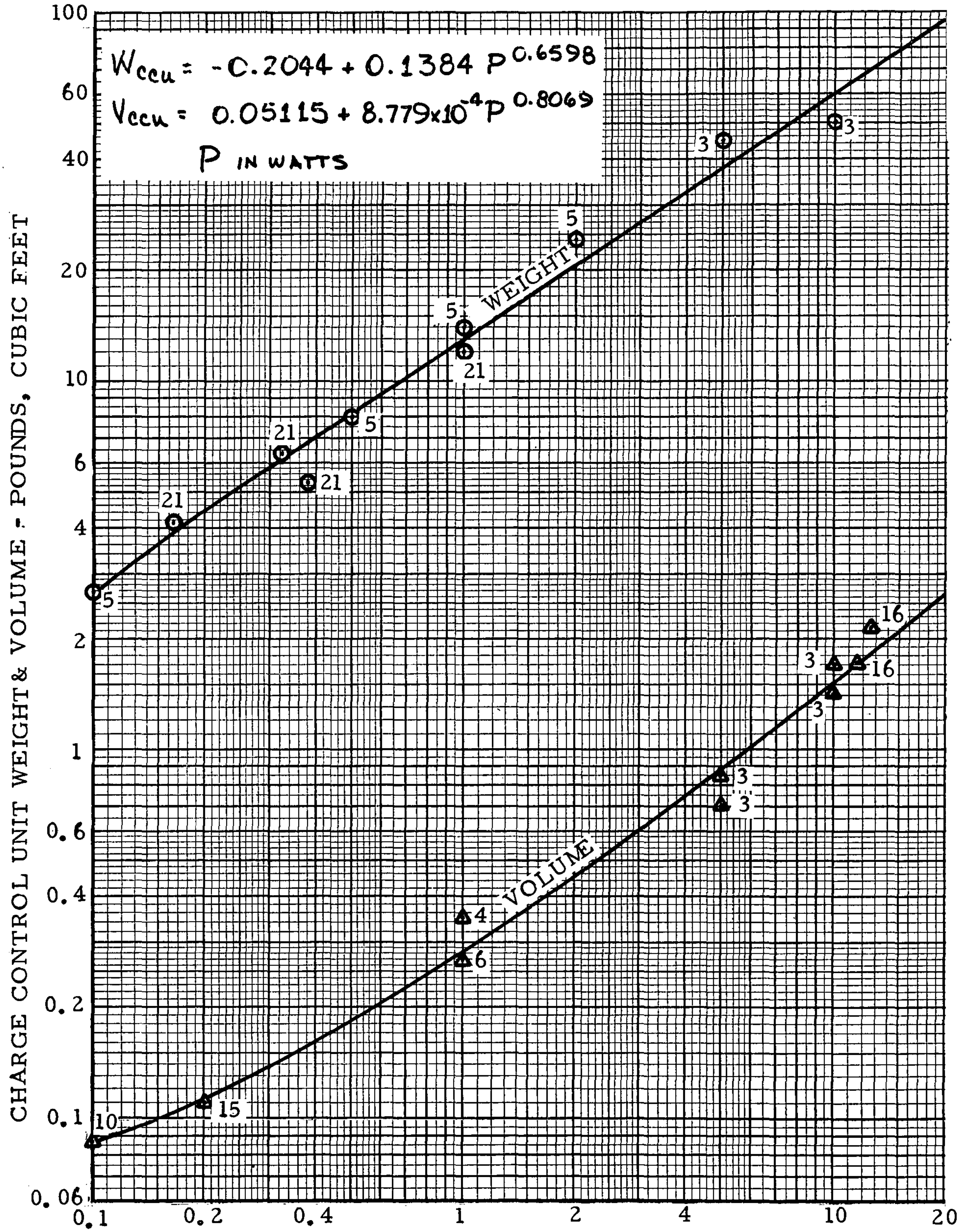

FIGURE 5-18. CHARGE CONTROL UNIT WEIGHT AND VOLUME

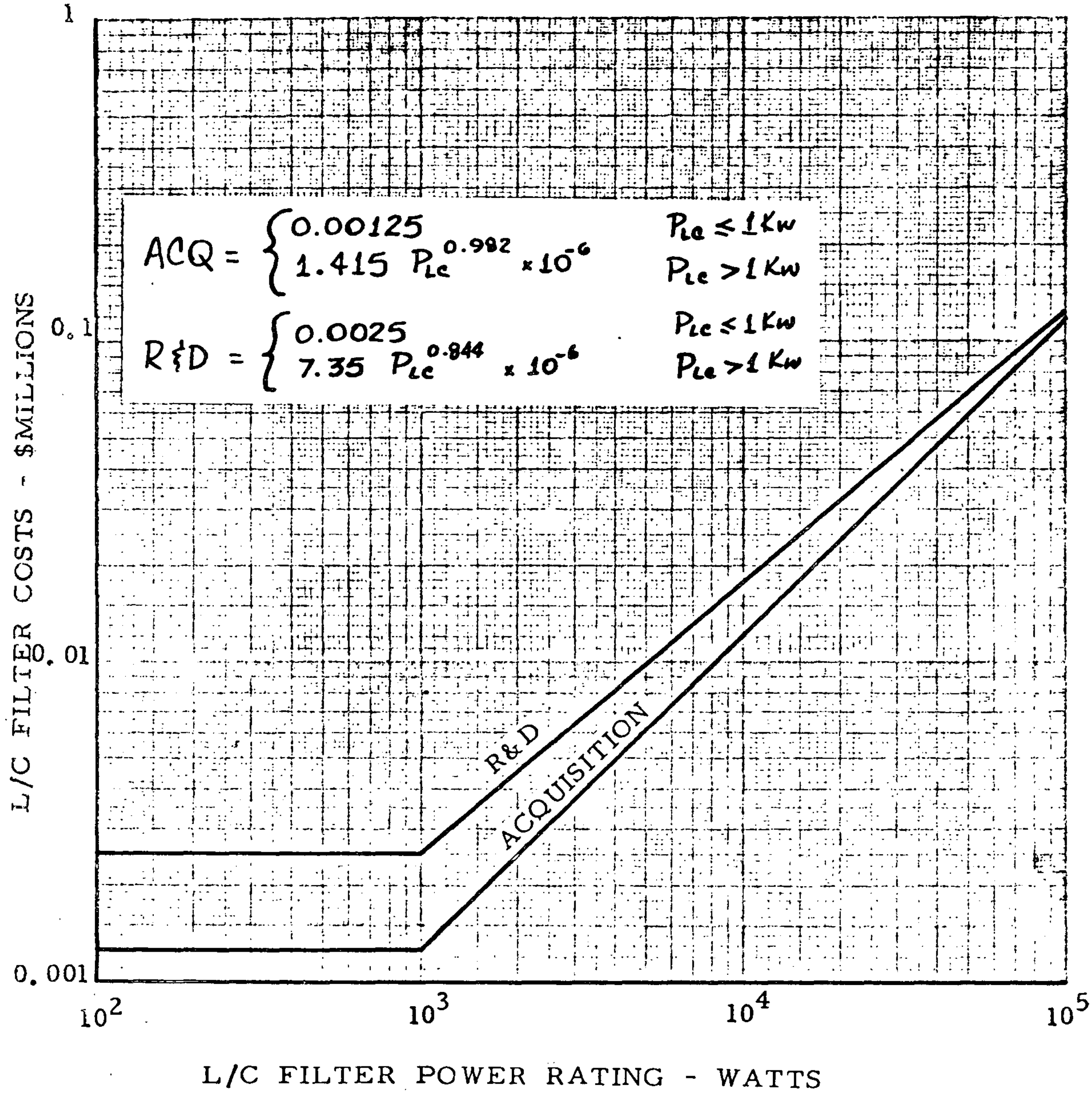

FIGURE 5-19. L/C FILTER COST

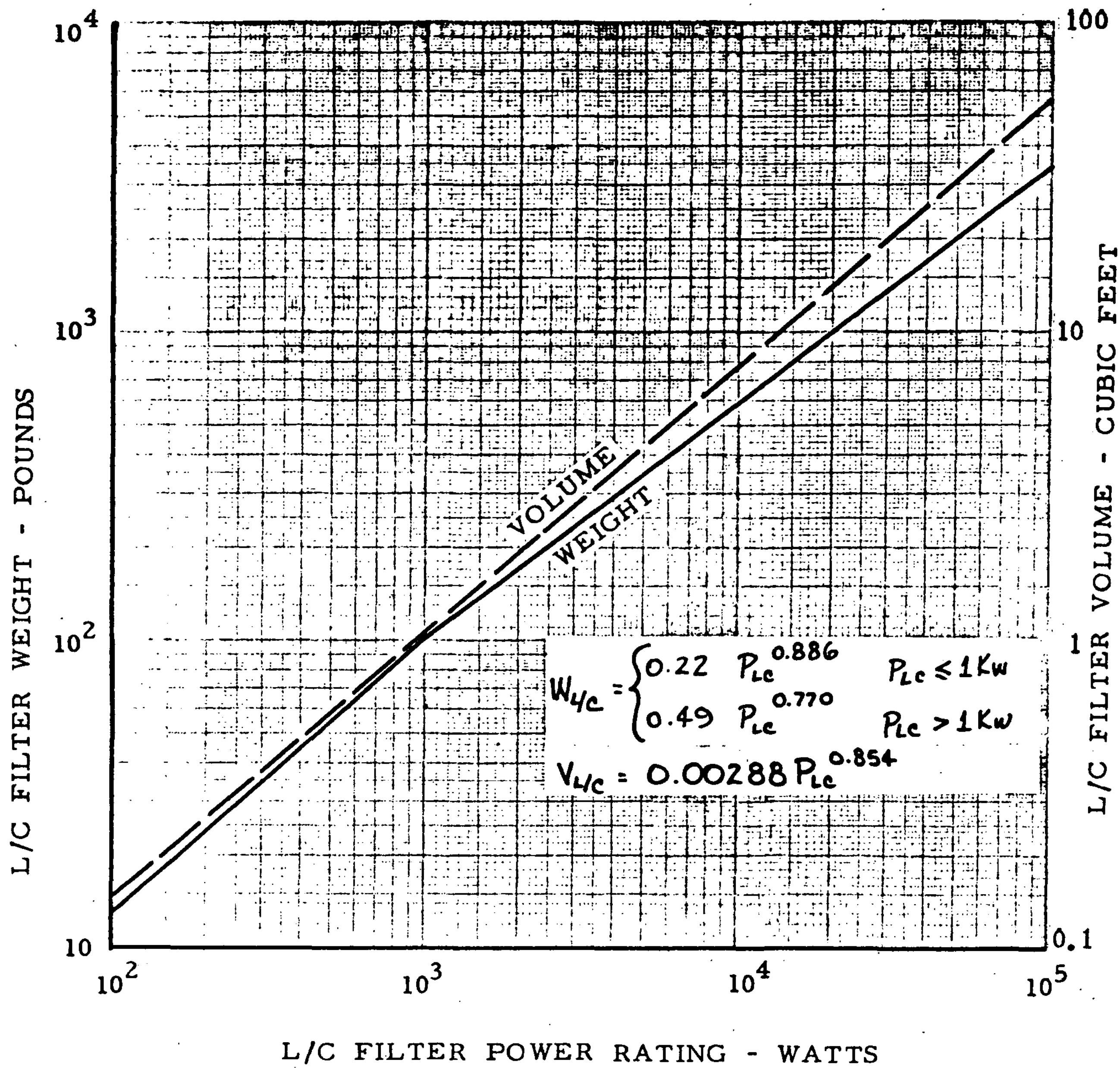

FIGURE 5-20. L/C FILTER WEIGHT AND VOLUME

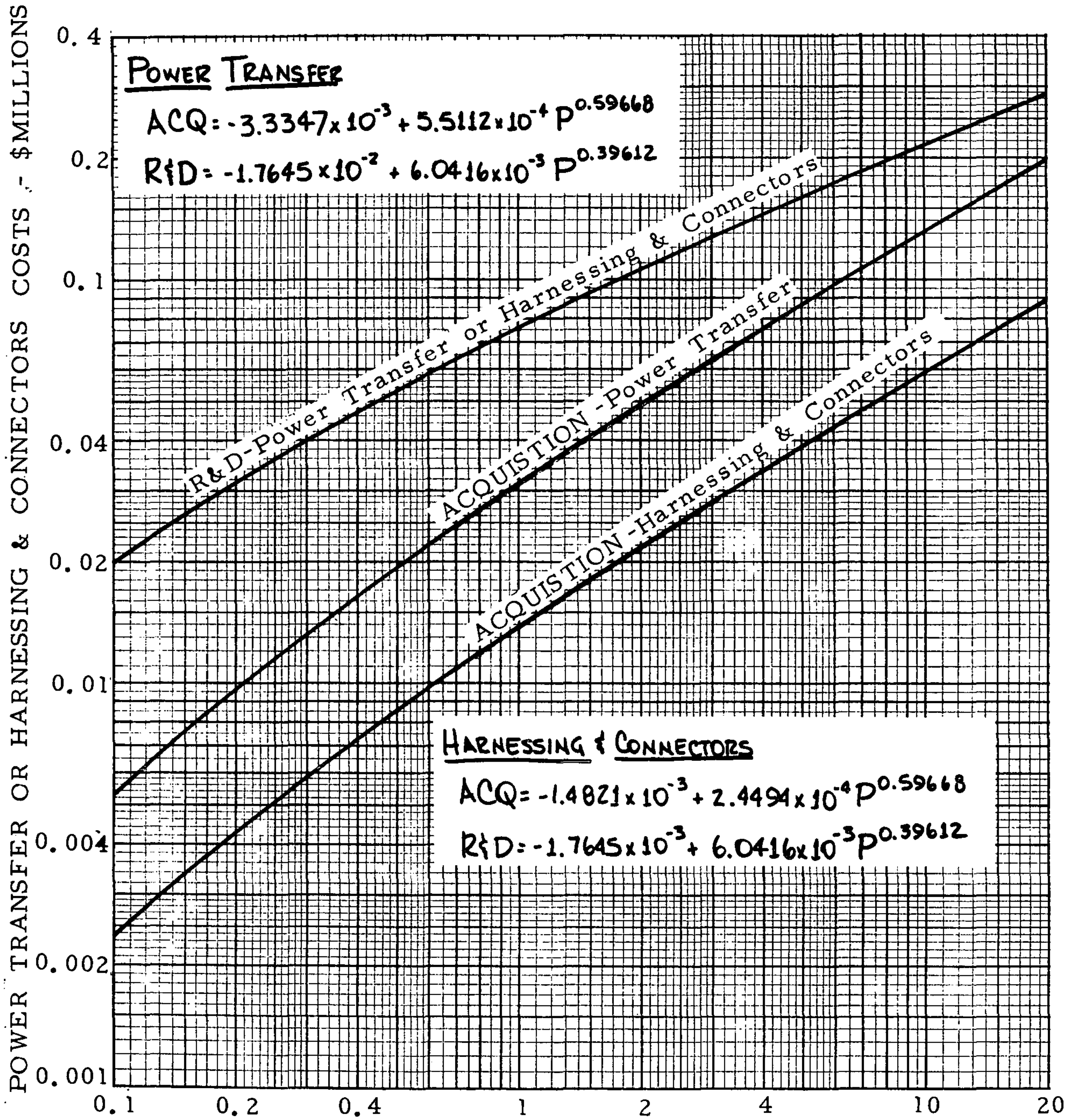

FIGURE 5-21. POWER TRANSFER AND HARNESSING COST

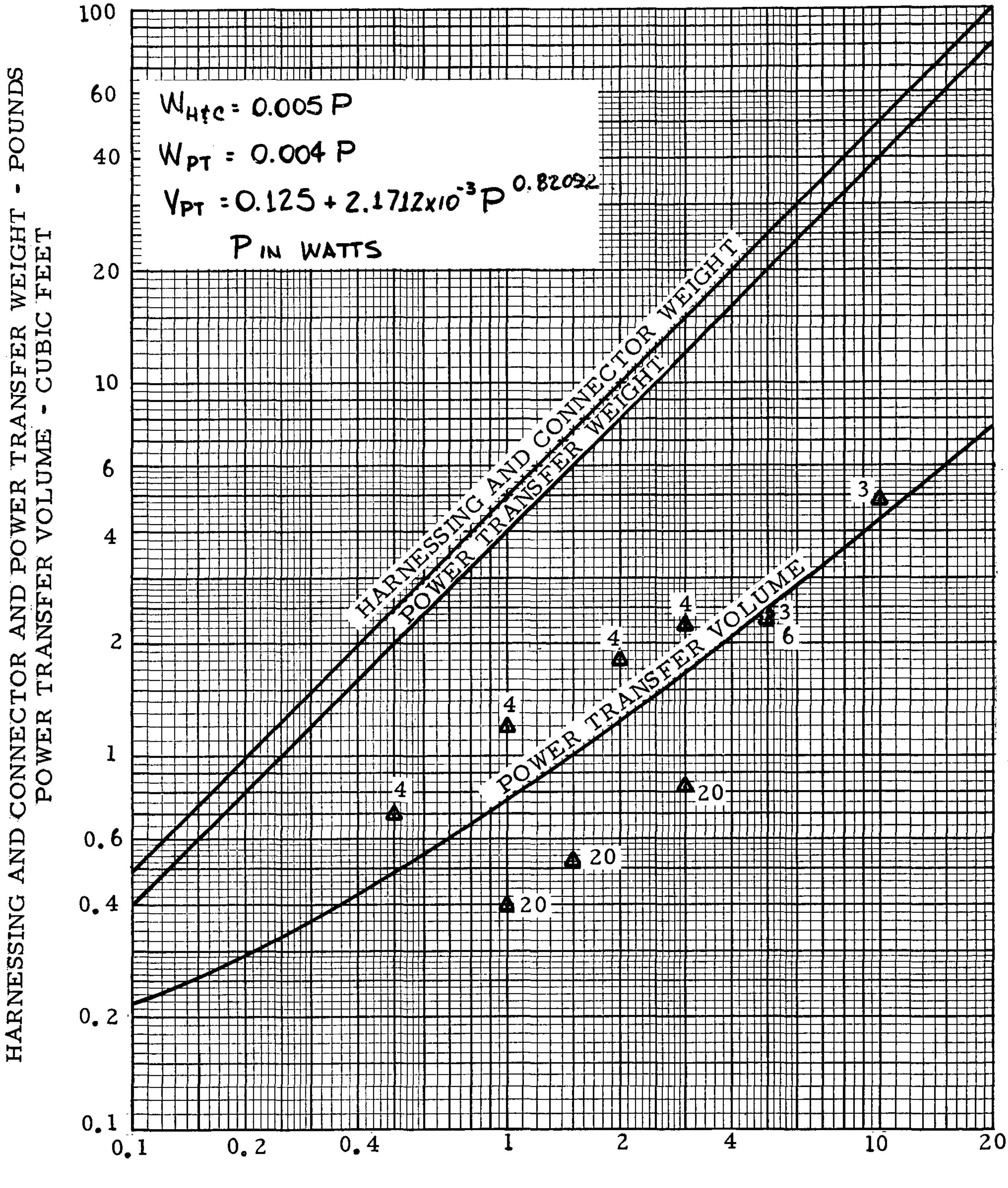

FIGURE 5-22. POWER DISTRIBUTION WEIGHT AND VOLUME

5.3.2 ANTENNA SUBSYSTEM. Satellite antennas will vary considerably according to coverage pattern required on earth. They will usually be of a reflector type (Dipole arrays and spirals will probably be used below S-band and horns may be used above X-band if high gain is not required). Satellite antennas may be assumed to be rigid if small and expandable if large (like Convair's PETA, "Parabolic Expandable Truss Antenna"). The line of demarcation between rigid and expandable can be set only when a specific booster payload volume is given. Convair has supplied the cost, weight and volume characteristics since the space application of antennas has been a continuing company interest. Figures 5-23, 5-24 and 5-25 display antenna costs, rigid and expandable (R&D and flight acquisition), weight and volume as a function of the effective antenna diameter. The parametric estimating relationships are inset in the figures.

5.3.3 TRANSMITTER SUBSYSTEM. Transmitter parametric relationships are greater in number than most other subsystems. Transmitters are differentiated into AM and FM classes. Each class may employ grid tube, TWT, cross field or solid state amplifiers. The cost of each of the above is dependent both upon frequency and power output level. The requirement for satellite operation results in different costs than would be the case for a similar transmitter at a ground facility. The information presented in the following curves is from the G.E. MKTS Report.[3] The parametric data are presented in:

1. Figure 5-26. AM Transmitter efficiency as a function of peak power output.
2. Figure 5-27. AM Transmitter costs as a function of peak power output.
3. Figure 5-28. AM Transmitter weight as a function of peak power output.
4. Figure 5-29. AM and FM Transmitter volume as a function of power output.
5. Figure 5-30. FM Transmitter efficiency as a function of average power output.

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[3] Ibid.

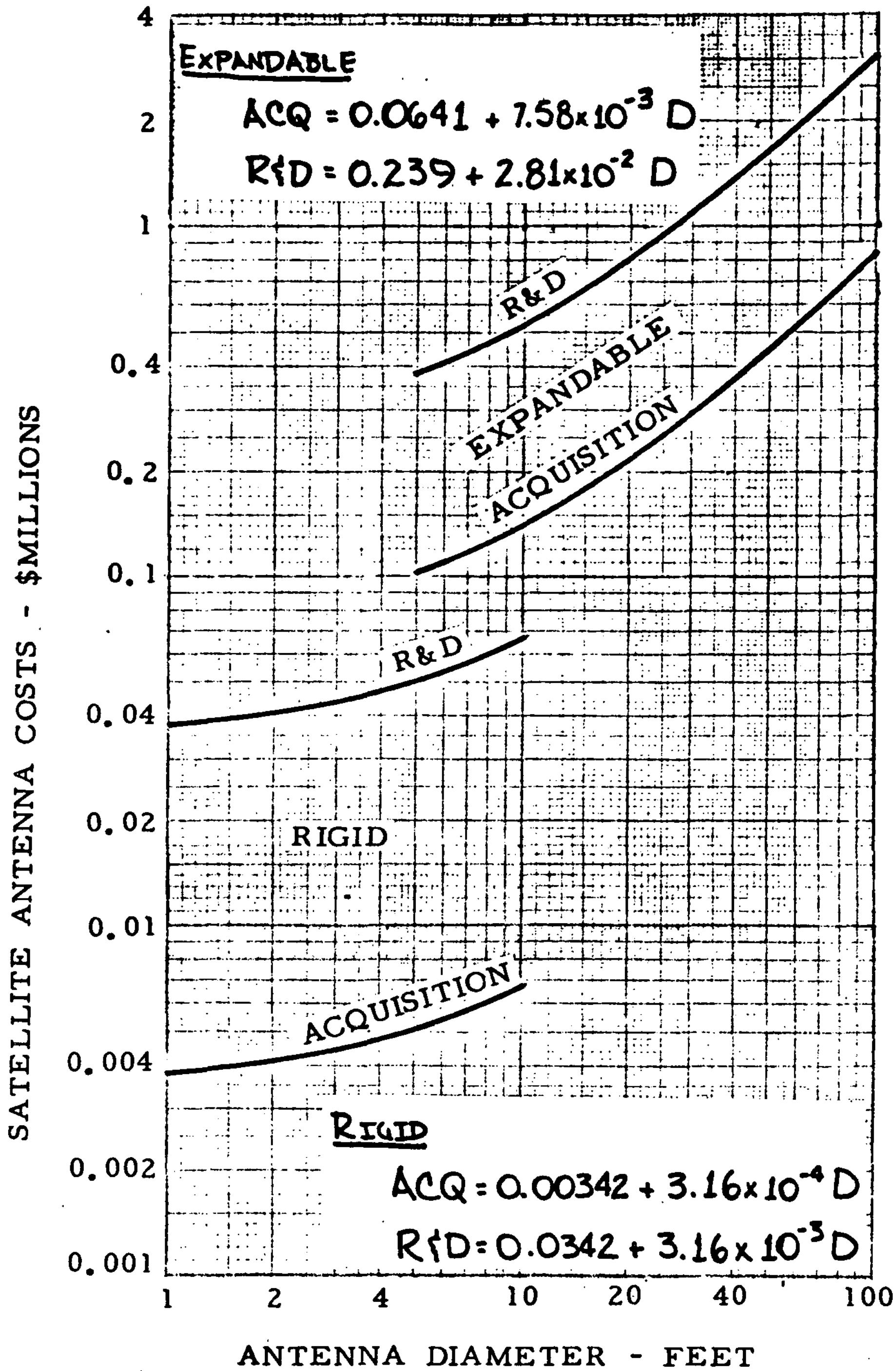


FIGURE 5-23. SATELLITE ANTENNA COST

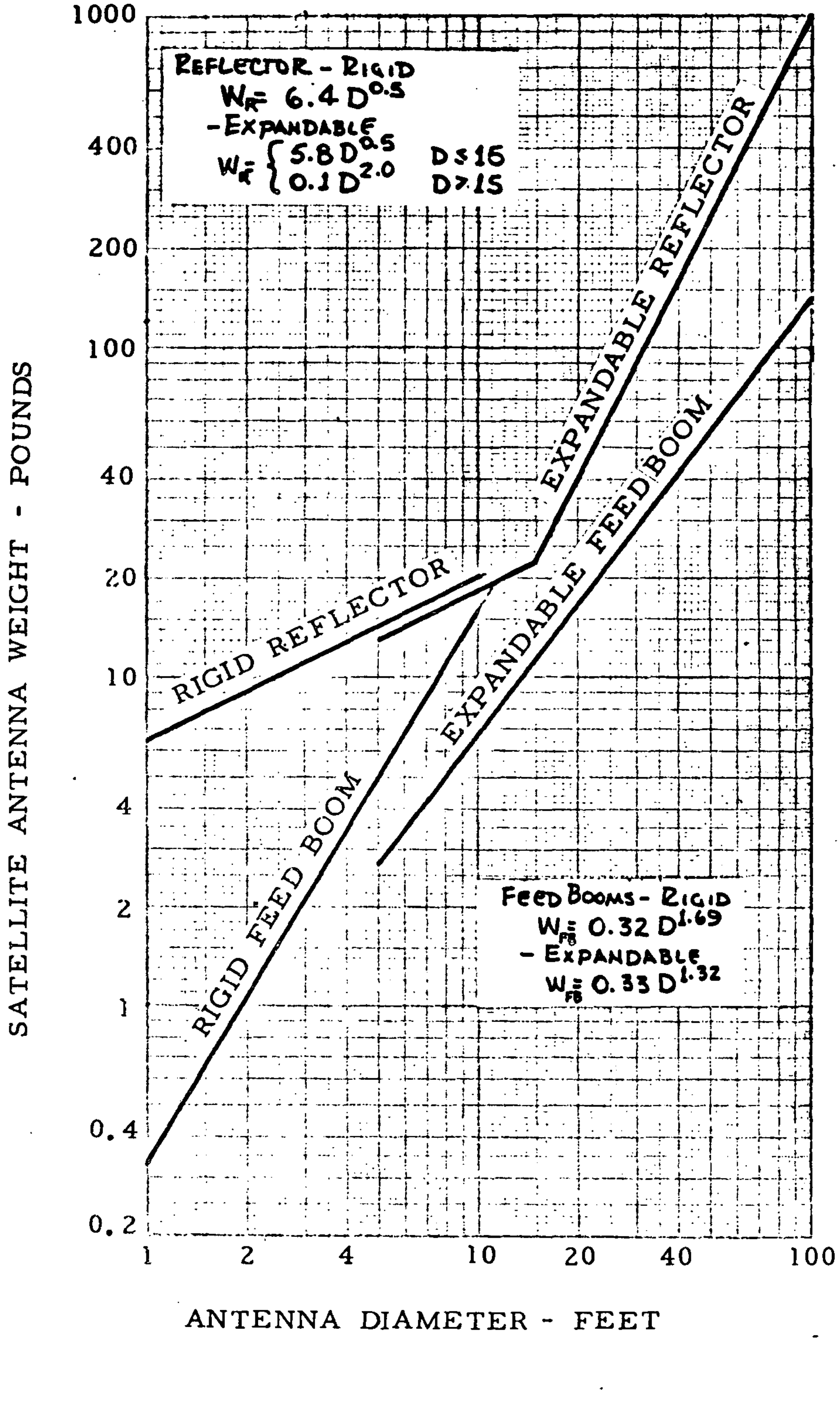


FIGURE 5-24. SATELLITE ANTENNA WEIGHT

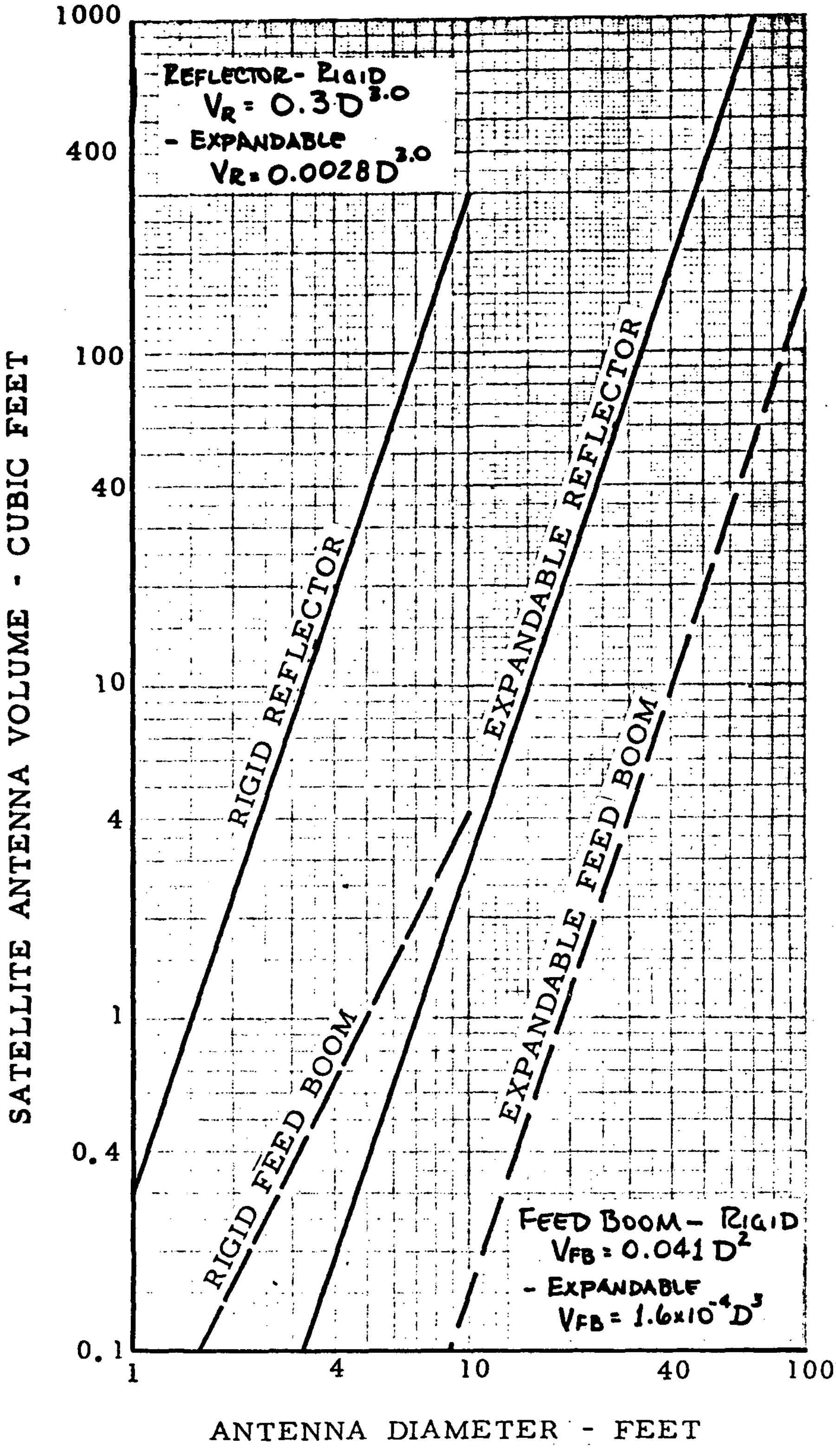


FIGURE 5-25. SATELLITE ANTENNA VOLUME

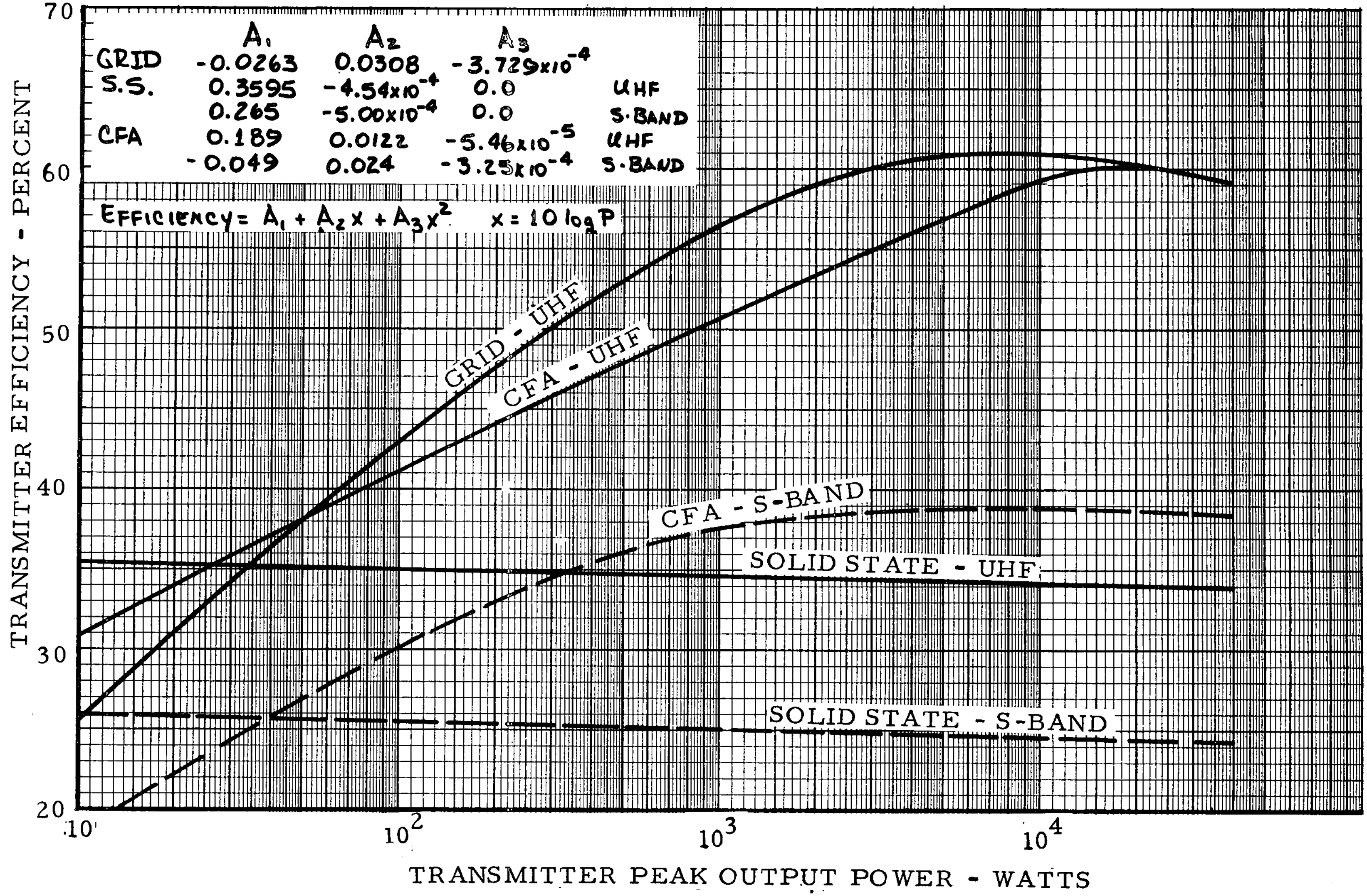


FIGURE 5-26. AM TRANSMITTER EFFICIENCY

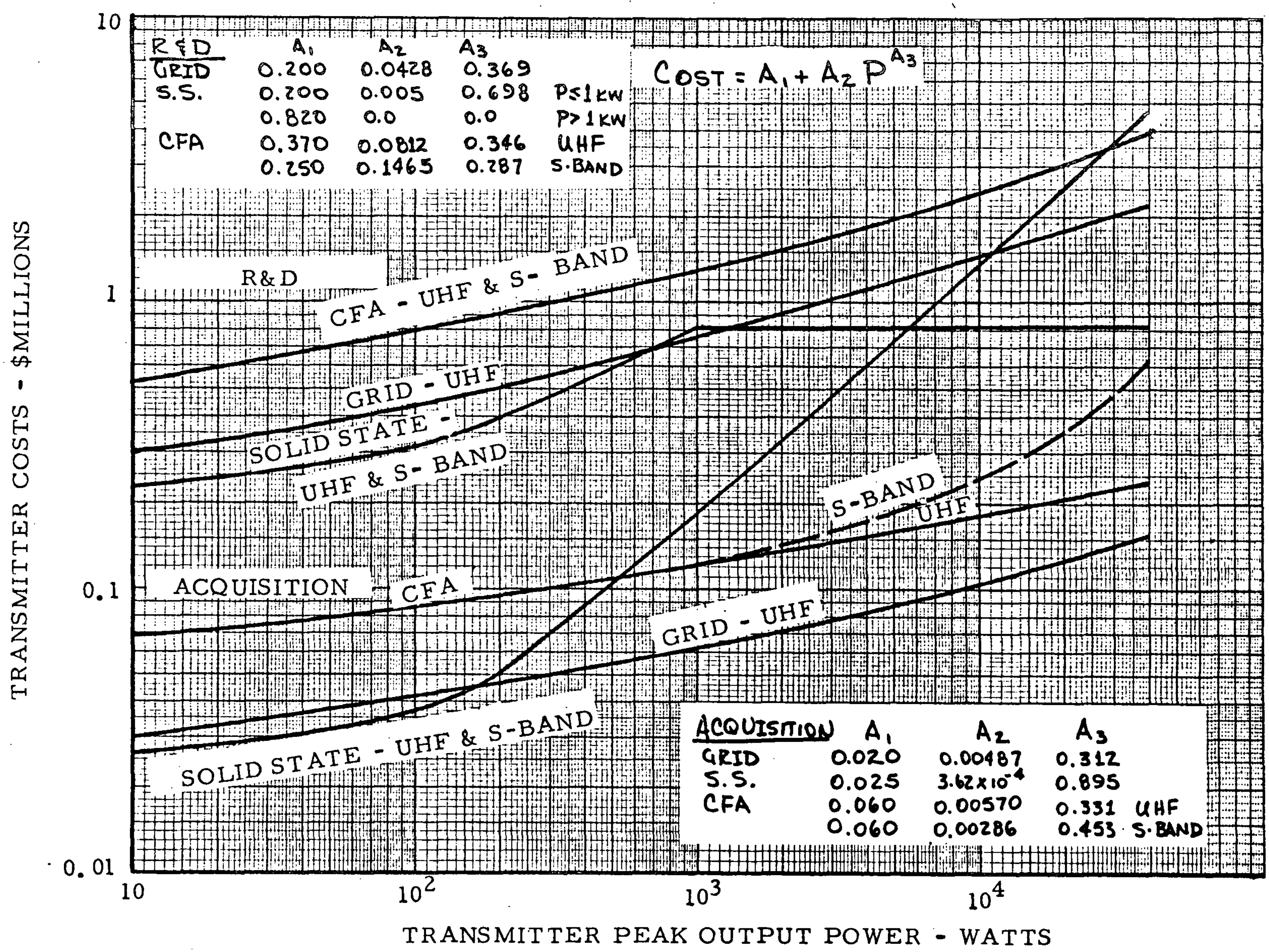


FIGURE 5-27. AM TRANSMITTER COST

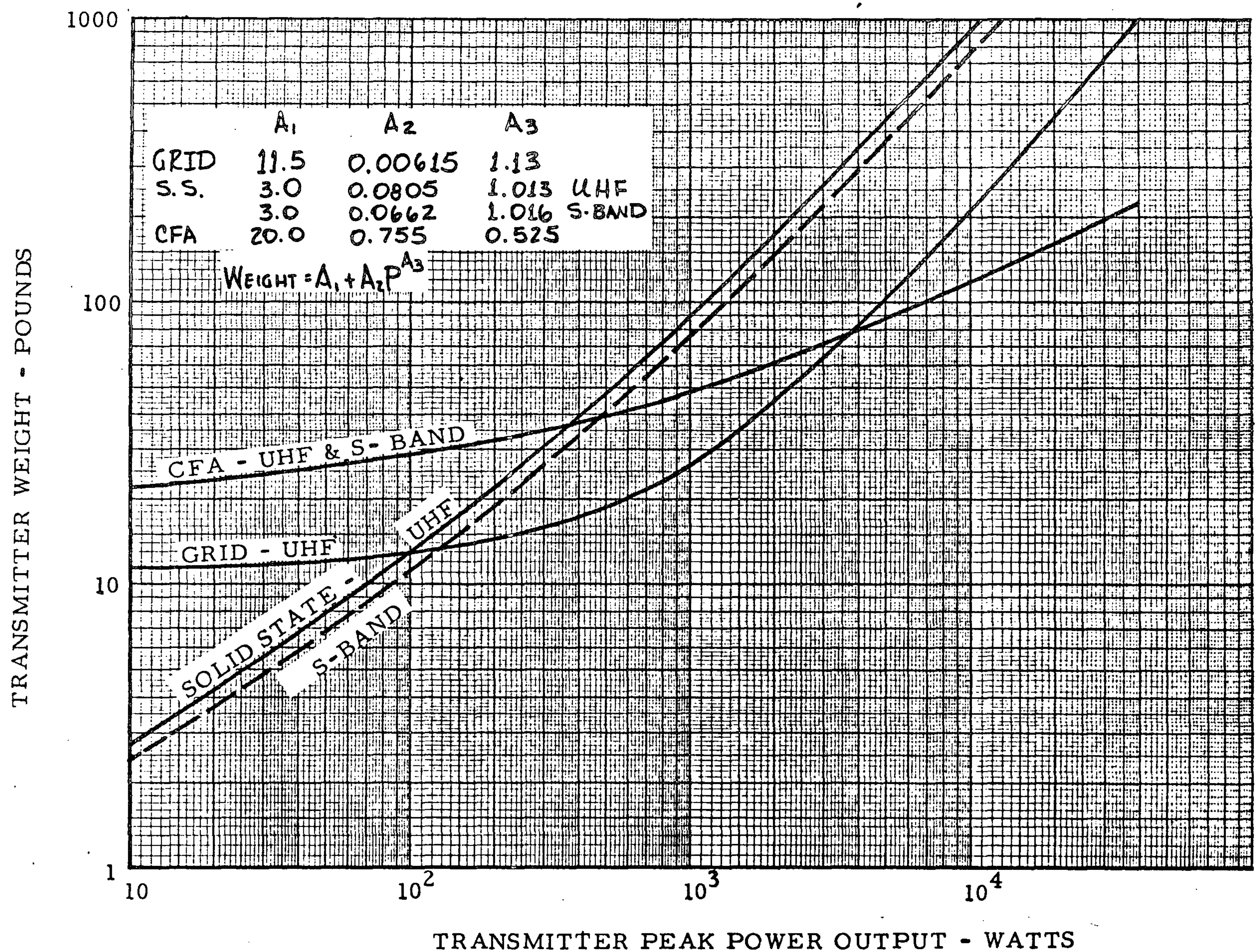


FIGURE 5-28. AM TRANSMITTER WEIGHT

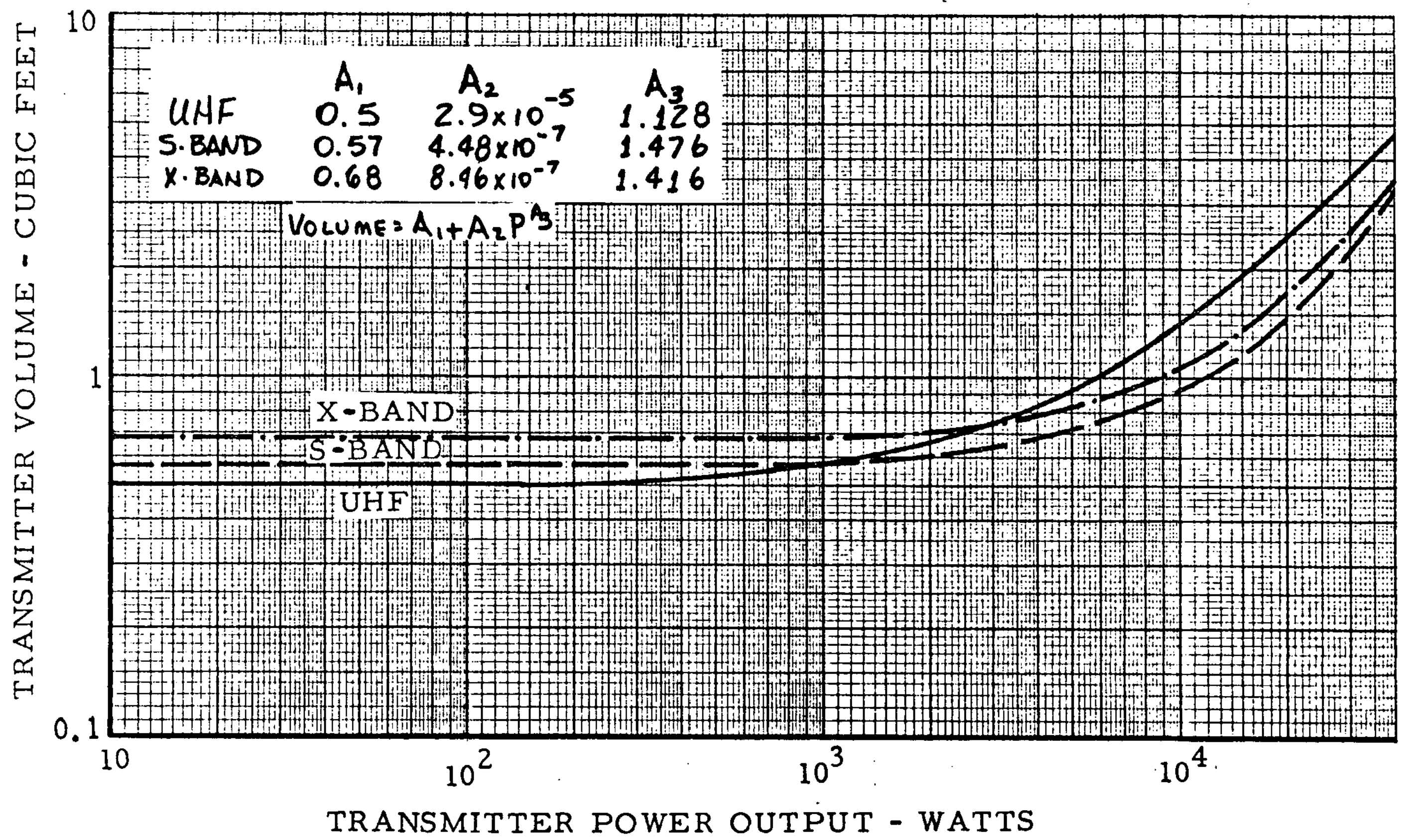
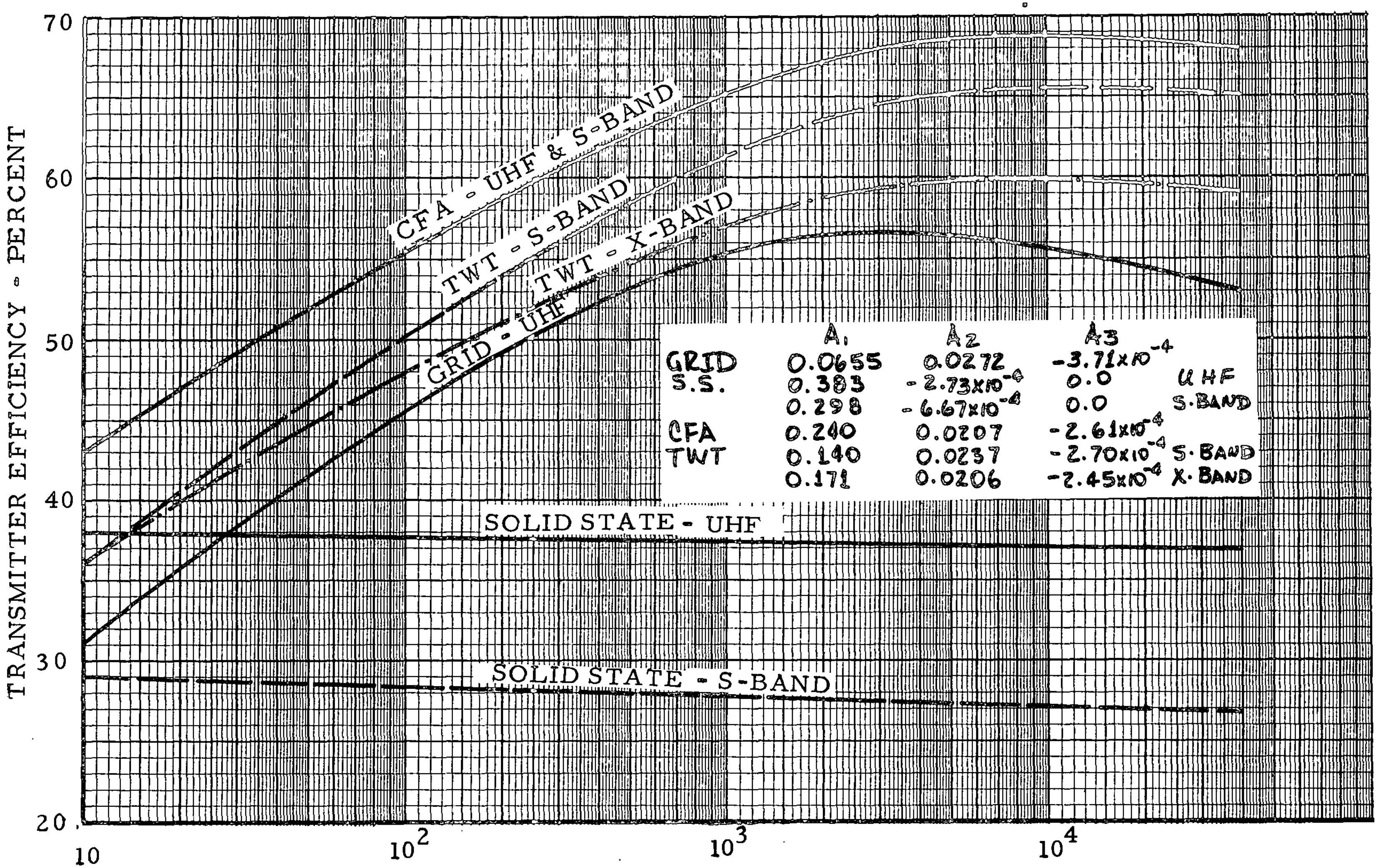


FIGURE 5-29. TRANSMITTER (AM & FM) VOLUME



TRANSMITTER POWER OUTPUT - WATTS

FIGURE 5-30. FM TRANSMITTER EFFICIENCY

6. Figure 5-31. FM Transmitter costs as a function of average power output.
7. Figure 5-32. FM Transmitter weight as a function of average power output.

5.3.4 MULTIPLEXER SUBSYSTEM. The multiplexer as used in this discussion refers to the r.f. power distribution whether combining the output of several transmitters to one antenna or the reverse process of distribution of a transmitter output to more than one antenna. Thus the multiplexer is an assembly of hybrids and coax or waveguide. The physical parameters and cost are related to number of channels and frequency. The information presented is from the G.E. MKTS Report.[4] Figures 5-33, 5-34 and 5-35 give insertion loss in dB, cost in millions of dollars and weight in pounds as a function of the number of carriers. A volume factor of 30 pounds per cubic foot has been used for multiplexers.

5.3.5 RECEIVER SUBSYSTEM. Several approaches are possible for the receiving portion of a satellite transponder. Each individual communication system requires study to determine the relative merits of the four receiver approaches shown in Figure 5-36. There will, in most applications, be a receiver for each carrier channel. Thus the receiver characteristics are useful when presented in terms of the number of receivers (G.E. MKTS Report[5]). Figure 5-37 shows receiver costs in mullions of dollars for quantities up to 16 units. Both R&D and flight article acquisition costs are shown. There is additional breakdown according to the receiver types of Figure 5-36. Weight, power and volume are given on Figure 5-38.

5.3.6 STRUCTURE SUBSYSTEM. Structure costs were readily estimated in view of the extent of experience with aerospace structures. The structure size is determined by the communications system elements it must carry. Size and availability of launch vehicles, of course, impose an upper bound

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[4] Ibid.
[5] Ibid.

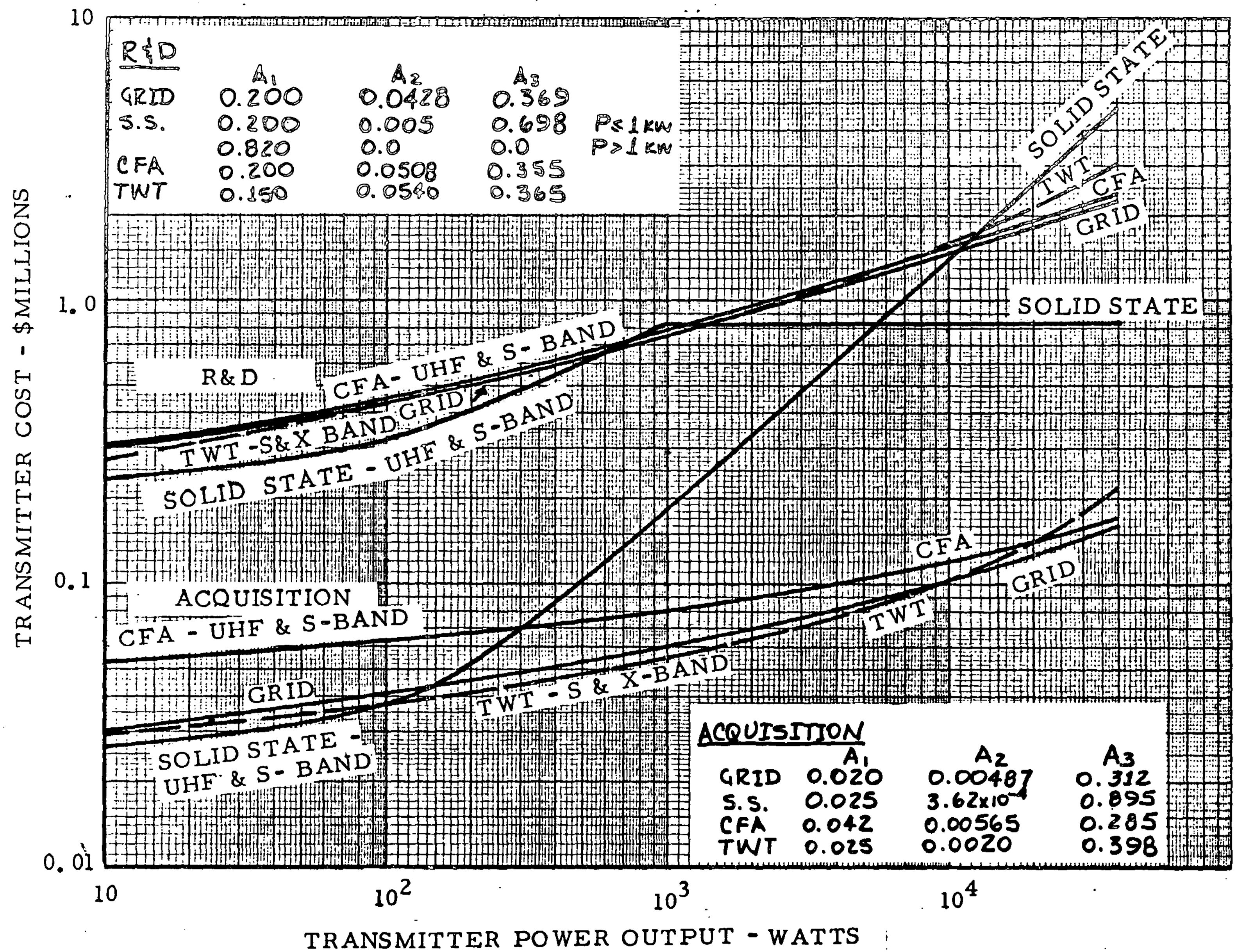


FIGURE 5-31. FM TRANSMITTER COST

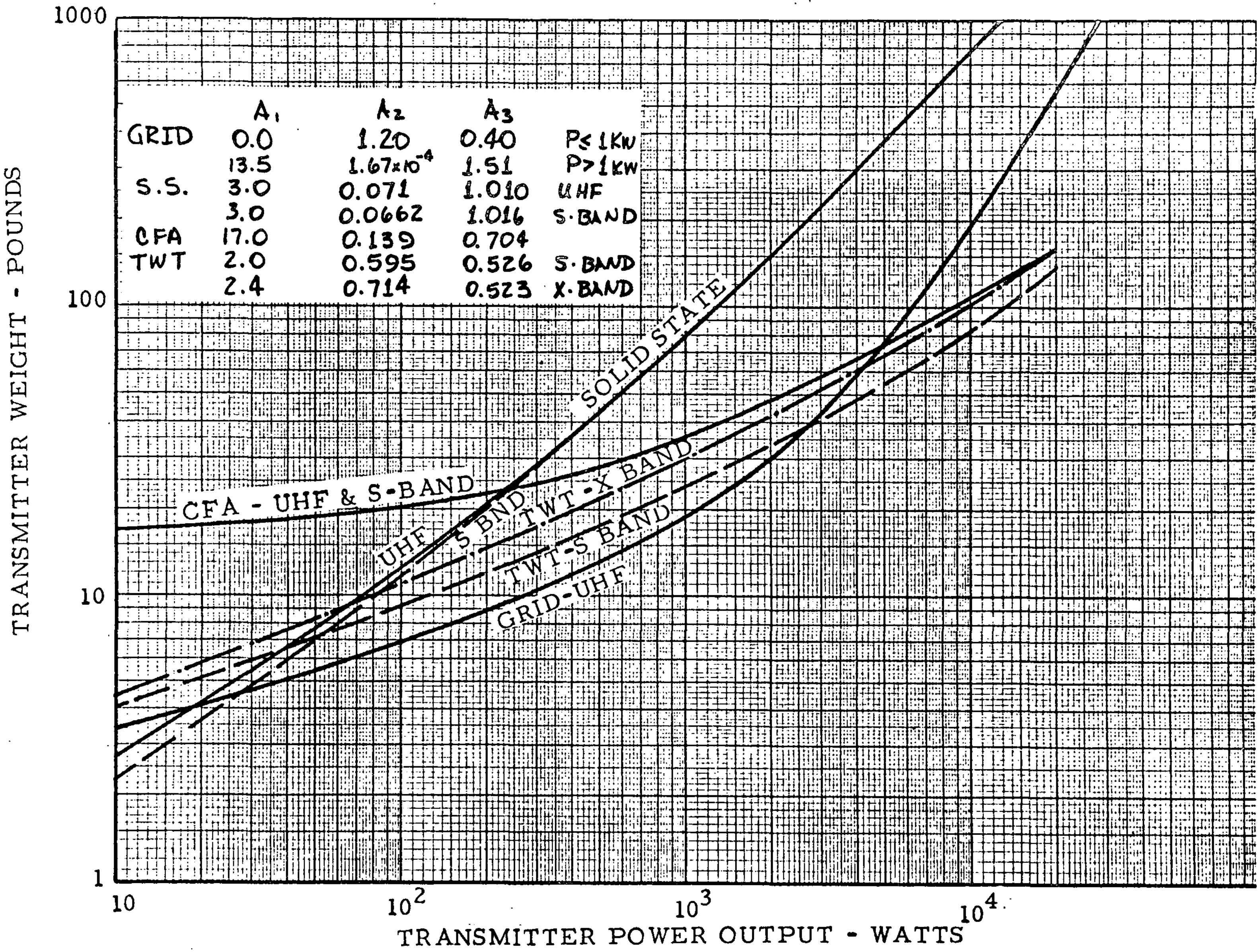


FIGURE 5-32. FM TRANSMITTER WEIGHT

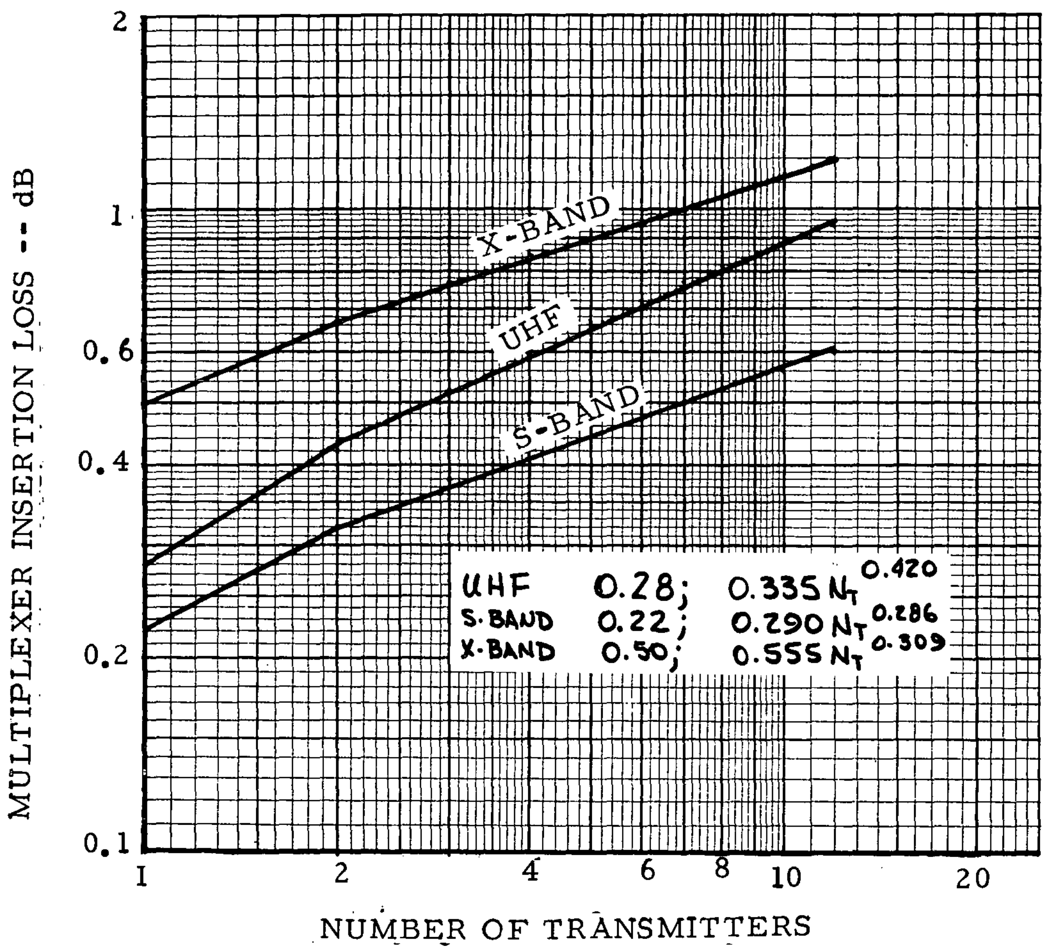


FIGURE 5-33. MULTIPLEXER INSERTION LOSS

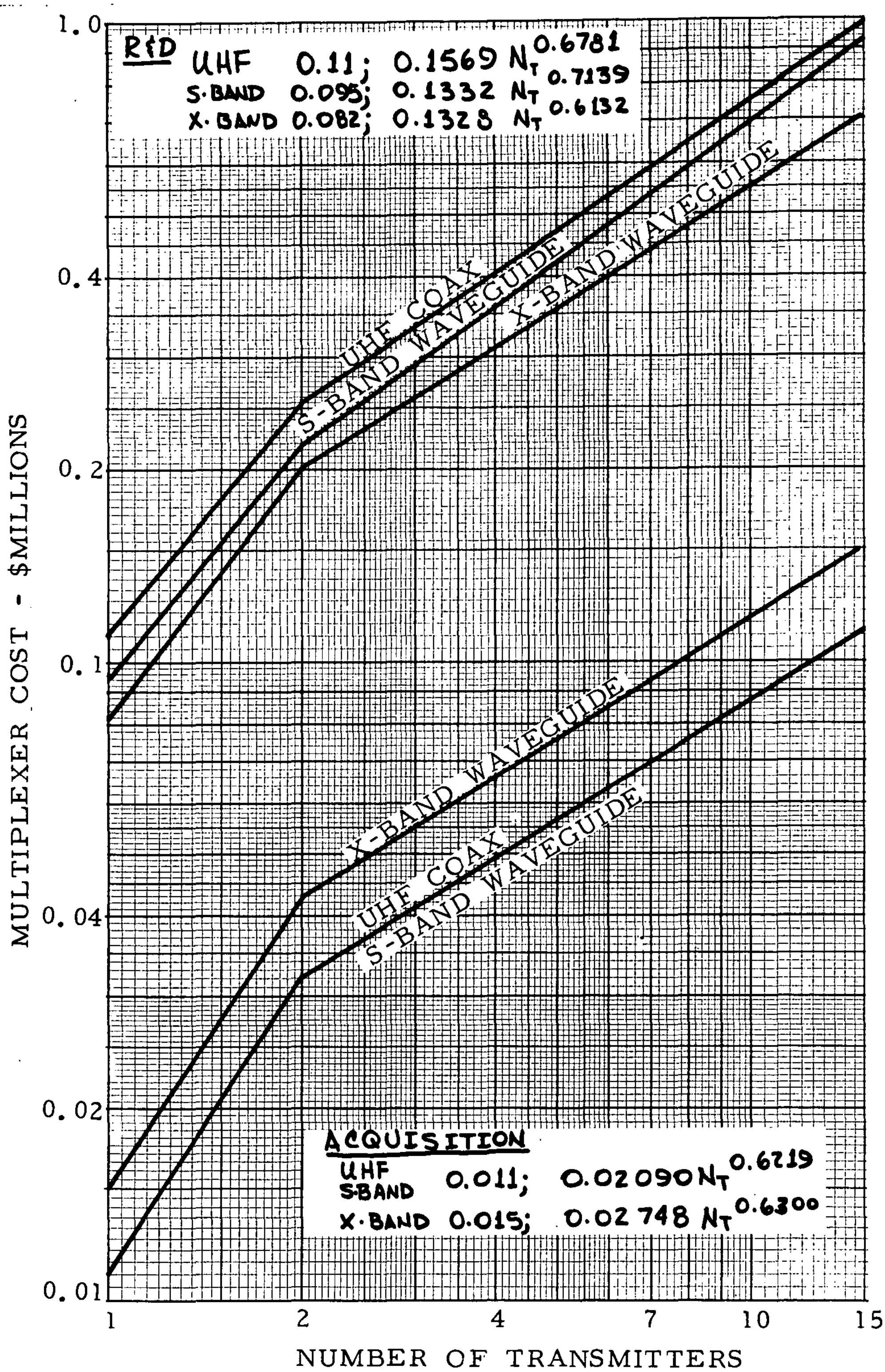


FIGURE 5-34. MULTIPLEXER COST

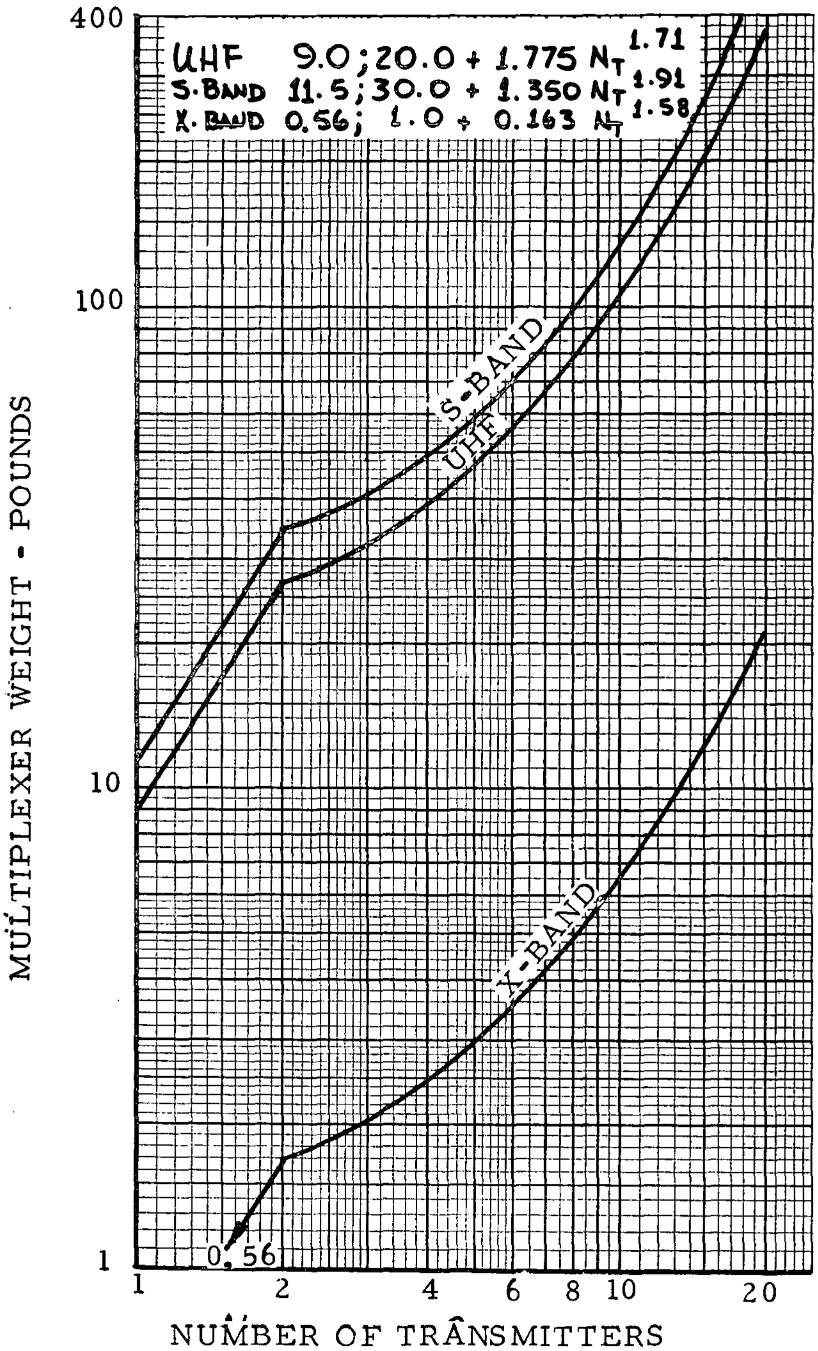


FIGURE 5-35. MULTIPLEXER WEIGHT

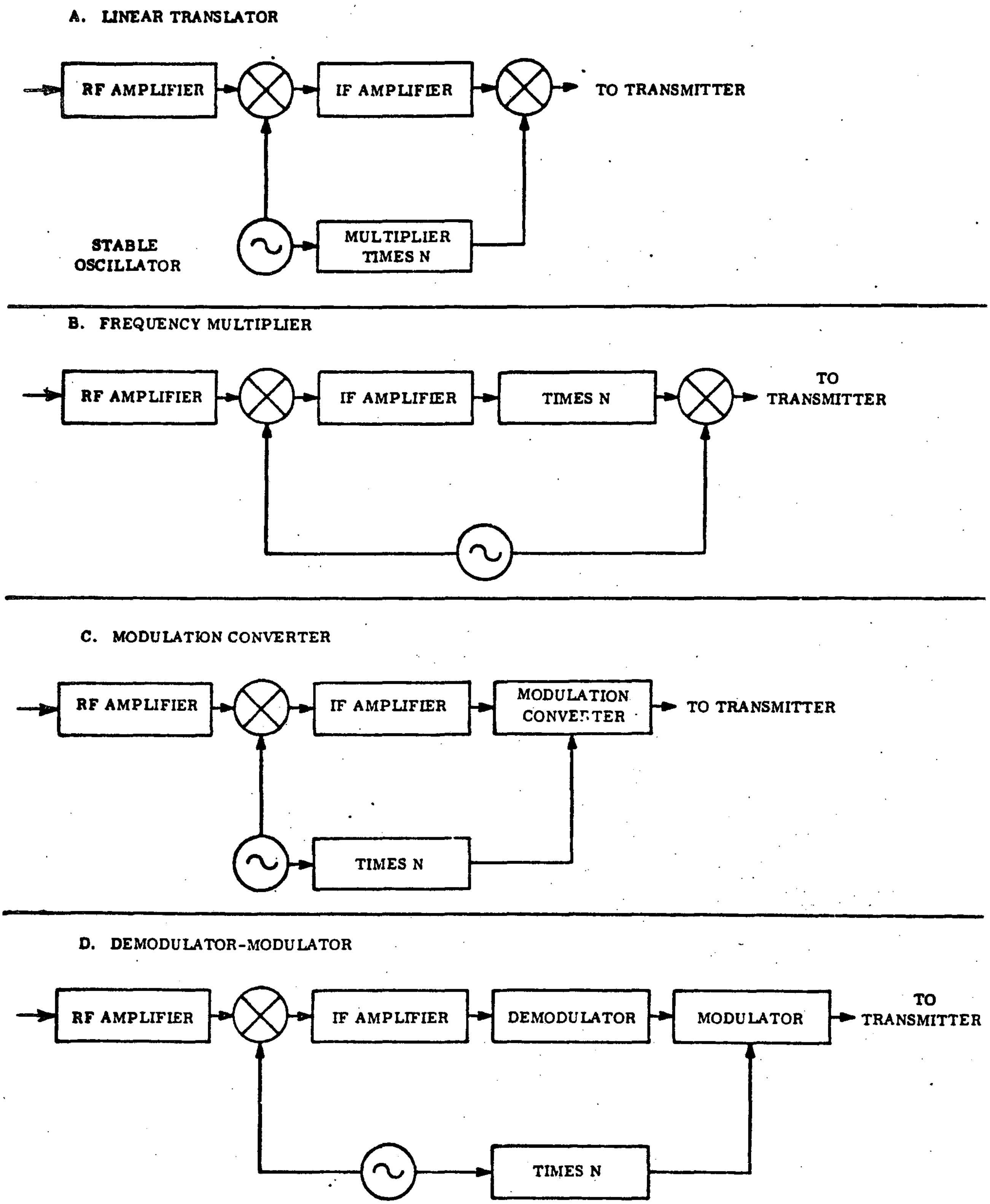


Figure 5-36. Types of Satellite Receivers

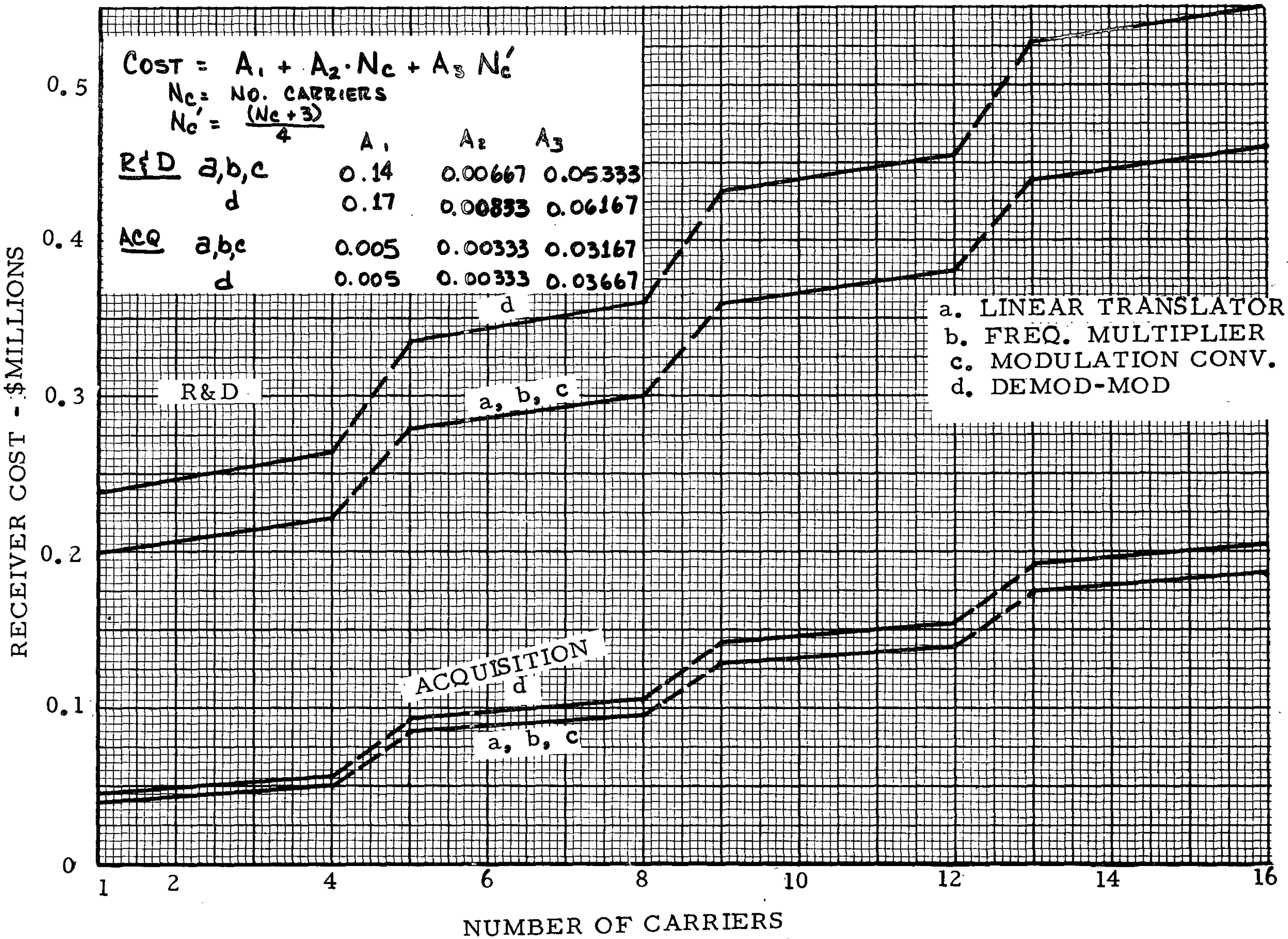


FIGURE 5-37. RECEIVER COST

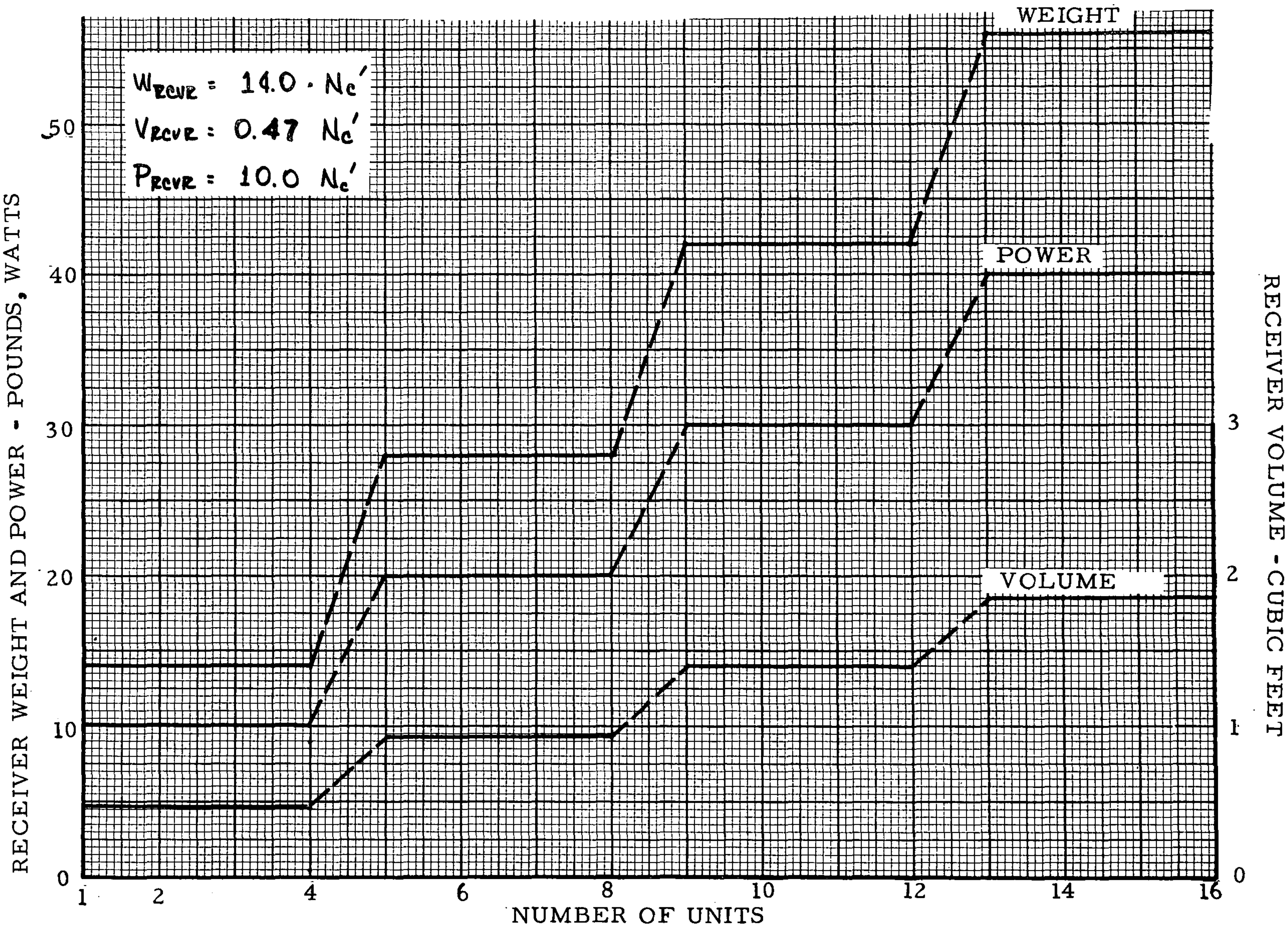


FIGURE 5-38. RECEIVER WEIGHT, POWER, AND VOLUME

upon weight and volume of the equipment module (EM). Figures 5-39 and 5-40 give structure cost (R&D and flight acquisition) in millions of dollars per pound and the structure weight in pounds as a function of volume in cubic feet.

5.3.7 THERMAL CONTROL SUBSYSTEM. Whenever feasible heat generating sources would be so mounted to permit passive radiation at the satellite surface. The large number of sources, however, does not permit exclusively this type of heat dissipation. In addition heat pipes are planned to conduct heat from larger sources to the radiating surface. Table 5-6 gives certain relationships used in analyzing thermal control systems. Figure 5-41 gives thermal control cost in millions of dollars for passive and heat pipe methods in terms of heat dissipation in watts (for both R&D and flight article). Figures 5-42 and 5-43 give weight in pounds and volume in cubic feet for the two cooling methods as functions of heat to be dissipated in kilowatts. This information was obtained from Convair's study of cooling and direct experience in thermal control on various space applications.

5.3.8 SATELLITE STABILITY. Satellite stability involves holding the intended position in synchronous orbit as well as maintaining pointing for antenna beam stability. Increased occupation of the synchronous orbit belt and increasing antenna gain impose more stringent requirements on stabilization. The communications satellite must maintain position and low angular rates for operational lifetime of five years or more. Initial positioning and stability are such that the satellite must be equipped with systems permitting both position and pointing corrections as perturbations become excessive. The parametric relations employed for the system synthesis were supplied by Convair flight dynamics personnel.

An overview is provided before considering the individual operations of stationkeeping and attitude control. Figure 5-44 illustrates numerous elements of a typical communication satellite system. The solar array panels are one possible deployment configuration. Table 5-7 gives comparative properties of several different thrust and torque devices. The resistojet and ion engine were selected for analysis providing a moderate weight relatively high specific impulse device and heavier but much higher specific impulse device (the ion engine).

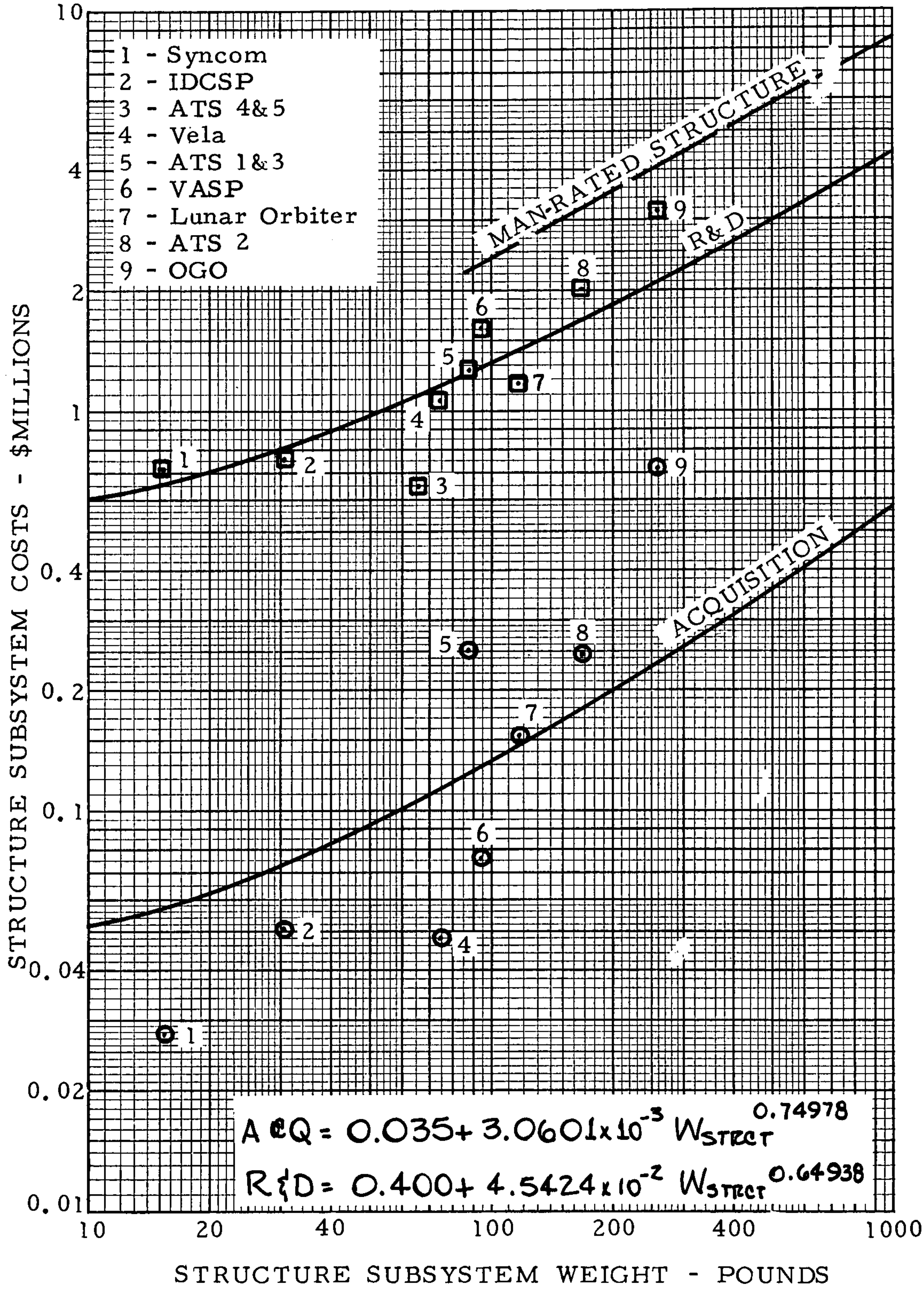


FIGURE 5-39. STRUCTURE COST

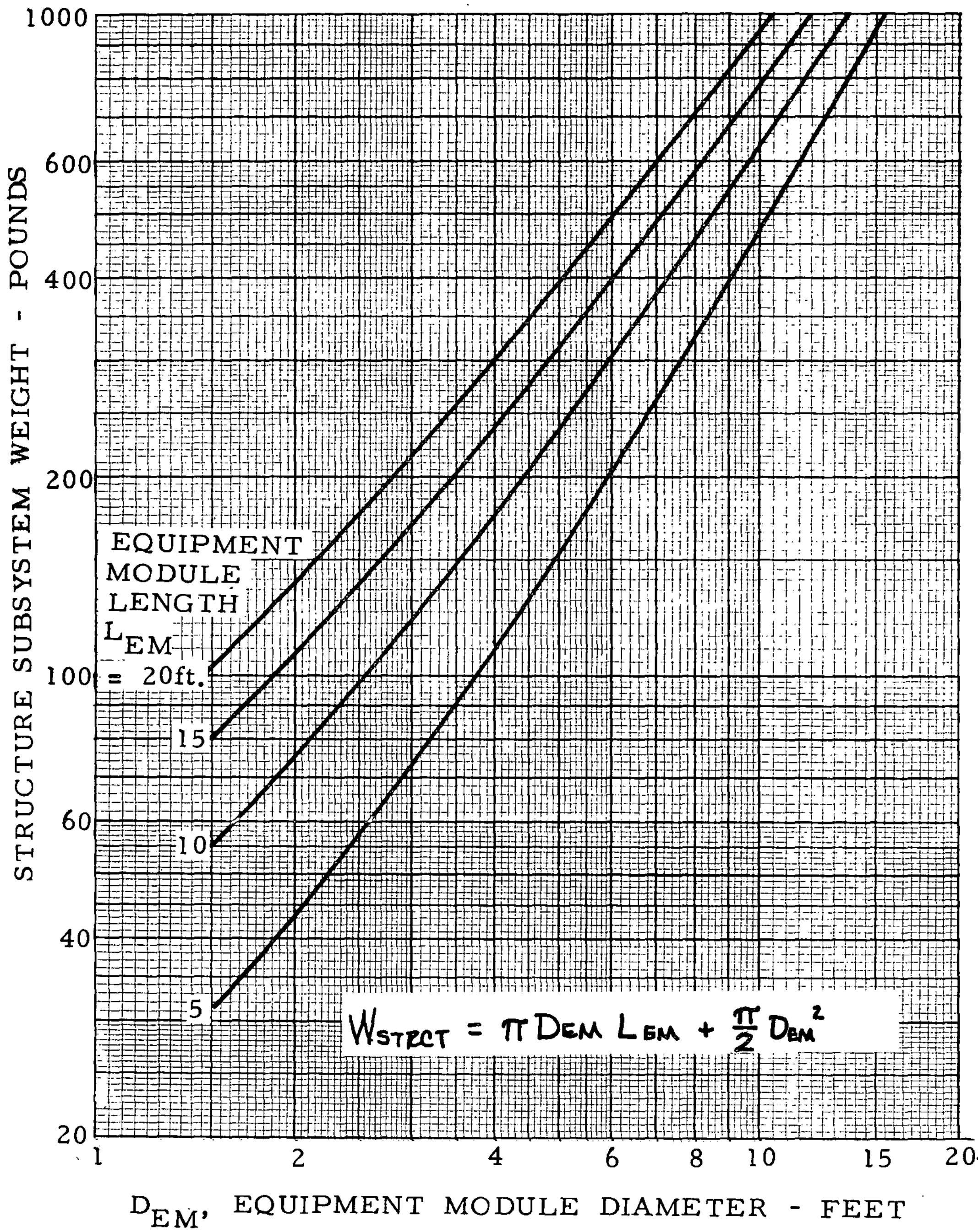


FIGURE 5-40. STRUCTURE WEIGHT

Table 5-6. Thermal Control Subsystem

1. **Passive Radiator For Total Spacecraft Heat Rejection**

P_{DIS} = Power to be dissipated by thermal control subsystem

P_{PRIME} = Prime power generated by power source

P_{XMTR} = Power transmitted by transmitter (RF)

V_{EM} = Volume of Equipment Module

P_{DIS}	$= P_{PRIME} - P_{XMTR}$	Watts
A_{TC}	$= 0.0548\ P_{DIS} - 2.5\ V_{EM}^{2/3}$	ft^2
W_{TC}	$= 0.0548\ P_{DIS} - 2.5\ V_{EM}^{2/3}$	lbs
V_{TC}	$= 0.0913\ P_{DIS} - 0.417\ V_{EM}^{2/3}$	ft^3

2. **Heat pipe for transmitter; passive radiator for other subsystems.**

P_{DIST} = Transmitter thermal power to be rejected

P_{DISS} = Heat to be rejected from other subsystems

η = Transmitter efficiency

a. Heat Pipe for Transmitter

P_{DIST}	$= \frac{1-\eta}{\eta}\ P_{XMTR}$	Watts
A_{HP}	$= 9 \times 10^{-3}\ P_{DIST}$	ft^2
W_{TC}	$= 0.01125\ P_{DIST}$	lbs
V_{TC}	$= 0.00225\ P_{DIST}$	ft^3

b. Passive System For Other Subsystems

P_{DISS}	$= P_{PRIME} - \frac{P_{XMTR}}{\eta}$	Watts
A_{PR}	$= 0.0548\ P_{DISS}$	ft^2
W_{PR}	$= 0.0548\ P_{DISS}$	lbs
V_{PR}	$= 9.13 \times 10^{-3}\ P_{DISS}$	ft^3

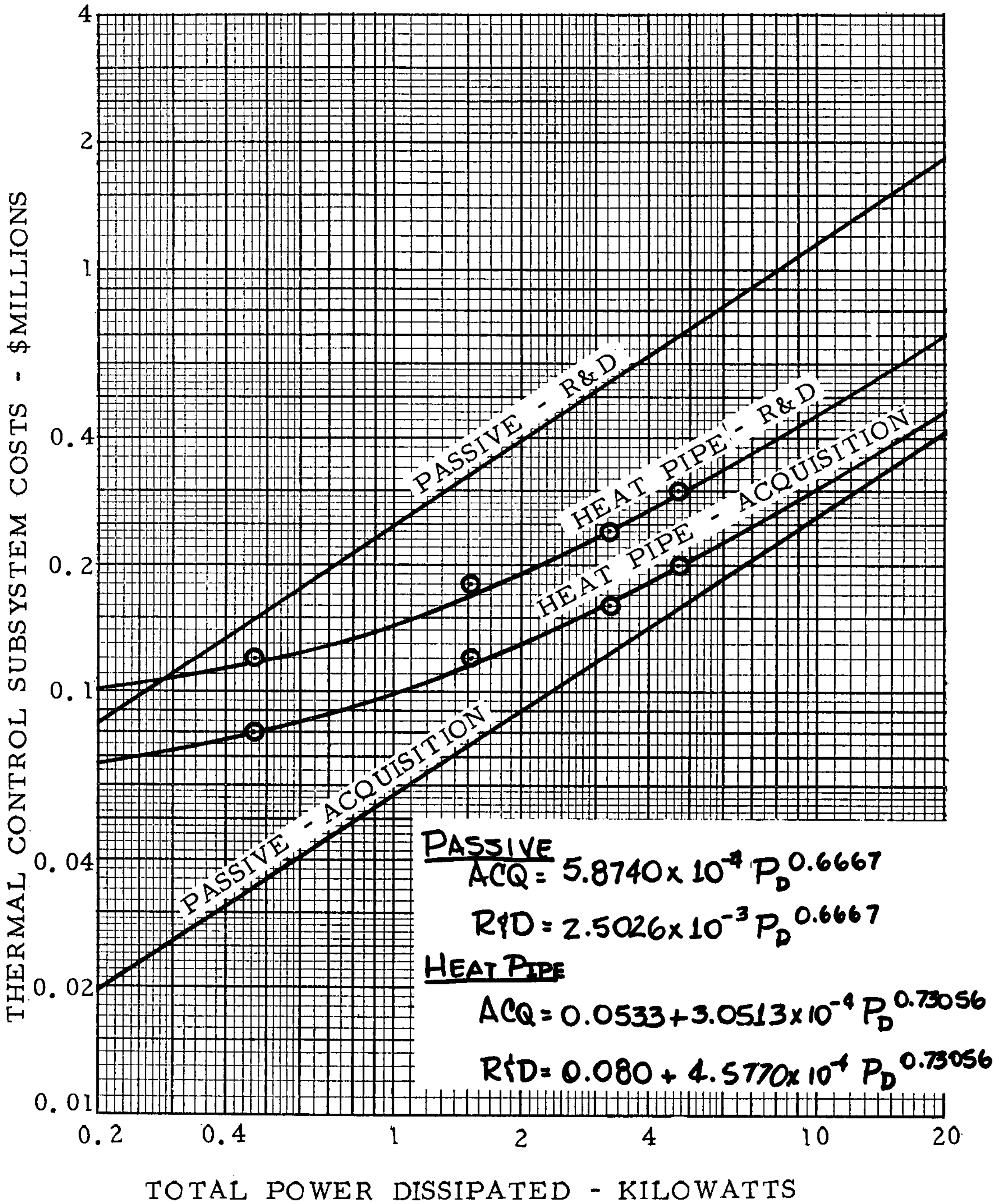


FIGURE 5-41. THERMAL CONTROL SYSTEM COST

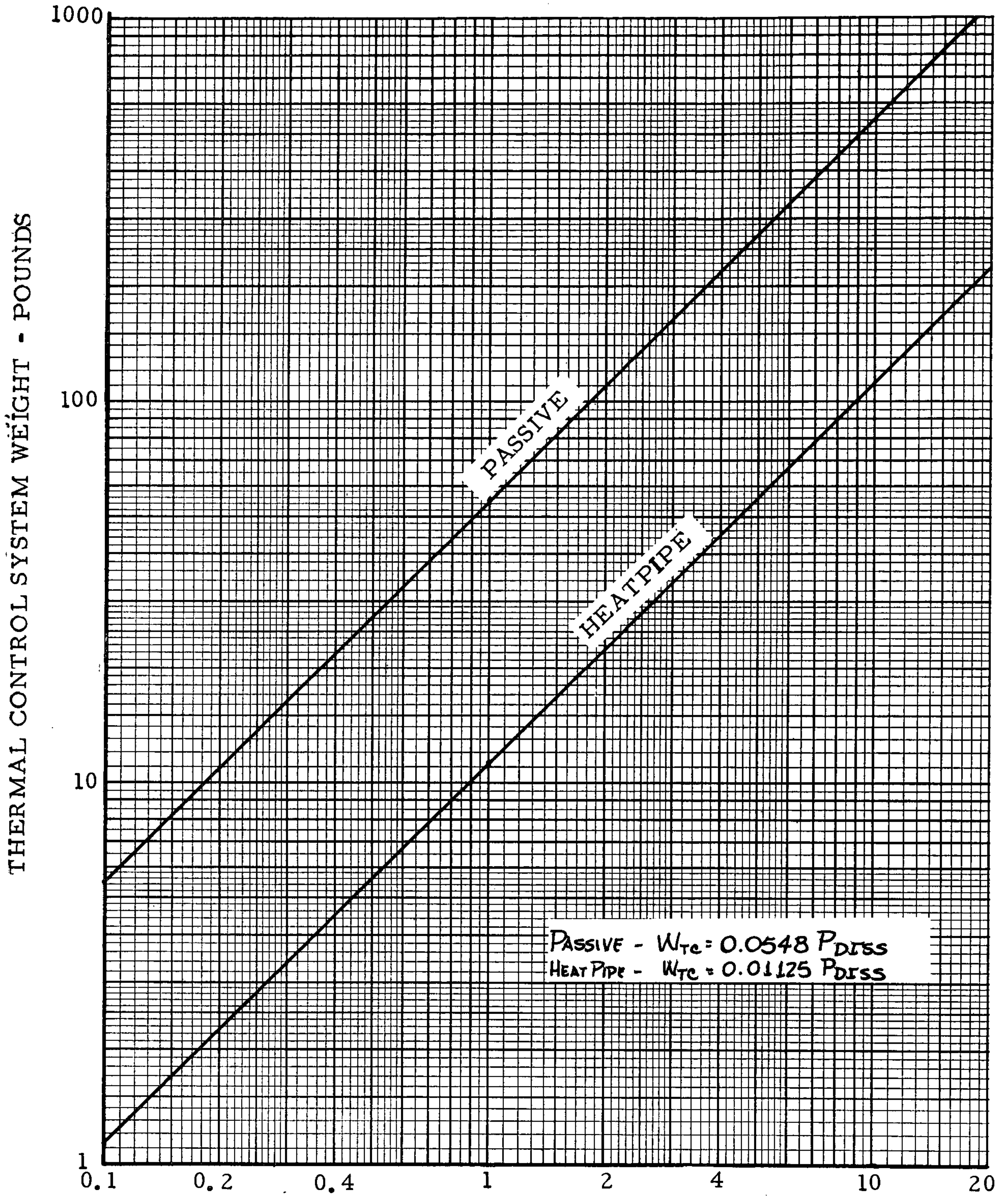


FIGURE 5-42. THERMAL CONTROL SYSTEM WEIGHT

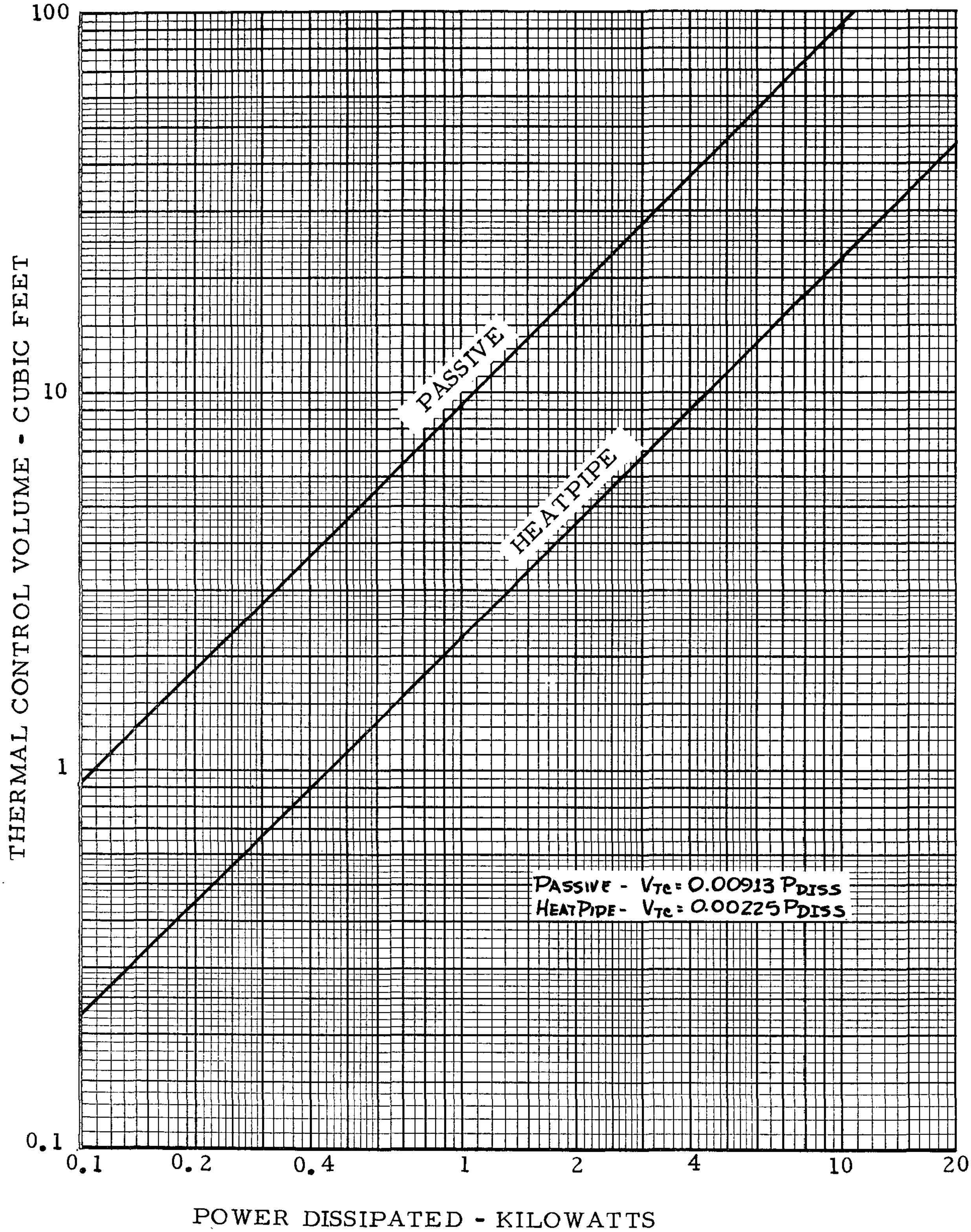
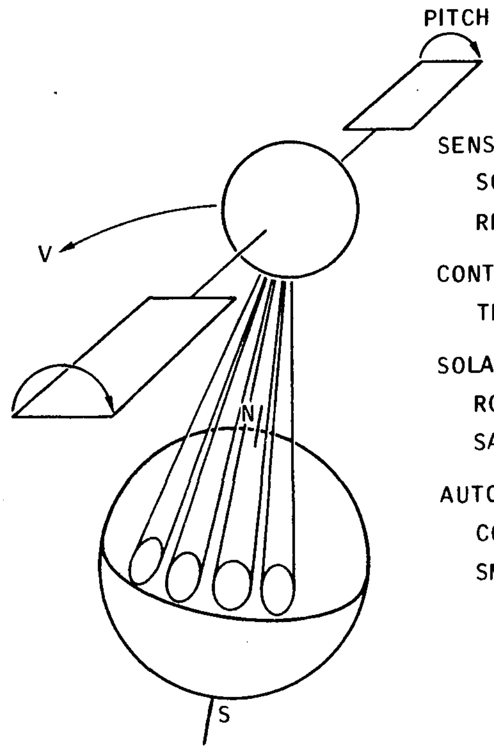


FIGURE 5-43. THERMAL CONTROL SYSTEM VOLUME



SENSORS

SOLAR & HORIZON SENSORS, RATE GYROS,
RF INTERFEROMETOR,* STAR TRACKER*.

CONTROL

TRANSLATION & ROTATION THRUSTERS, INERTIA WHEEL(S)*

SOLAR ARRAY ORIENTATION

ROTATION ABOUT PITCH AXIS, BY DIRECT LINEAR CONTROL
SATELLITE YAW ROTATION PROBABLE FOR UNI-BEAM CONCEPTS

AUTOPILOT

COMPENSATION FOR STRUCTURAL VIBRATION, DETERMINE
SMALL ANGULAR RATES OF ORDER $\left(\frac{1}{50}\right)$ EARTH RATE

*OPTIONAL

Figure 5-44. Typical System

Table 5-7. Active Control Devices

THRUSTERS	THRUST LEVEL (LB.)	WEIGHT	I_{SP} (SEC.)	POWER (W)	RELIABILITY
COLD GAS	> 0.02	HEAVIEST	60	1	BEST
HYDRAZINE	> 0.001	HEAVY	235	1	
HYDROGEN PEROXIDE	> 0.01	HEAVY	160	1	
RESISTOJET	0.01 – 0.00001	MODERATE	350	20	
WATER ELECTROLYSIS	10 – 0.1	MODERATE	360	20	?
ION PROPULSION	9.01 – 0.000001	HAS HIGH CONSTANT WT.	4,500 - 9,500	1,000	

MOMENTUM DEVICES - INERTIA WHEEL(S) - OPTIONAL

NO WEIGHT SAVING - LOW TORQUE CAUSES LESS VIBRATION EXCITEMENT
ONE WHEEL FOR PITCH OR THREE WHEELS
RELIABILITY FOR FIVE YEARS A PROBLEM
THRUSTERS SIZED FOR WHEEL DESATURATION, LARGER THAN DESIRABLE FOR ALL-JET CONTROL

5.3.8.1 Station Keeping Subsystem. The system synthesis allows a consideration of both the ion engine and resistojet in the cost minimization process. Figure 5-45 gives power expenditure requirement in watts as a function of effective satellite weight in pounds (actual less station keeping system). This allows the penalty of station keeping weight to be a part of the synthesis process. Figure 5-46 presents station keeping costs in millions of dollars for various effective satellite weights in points. R&D and acquisition costs are shown. In addition 10, 5 and 2 year lifetime systems are shown. Figures 5-47 and 5-48 give weight in pounds and volume in cubic feet for various satellite effective weights in pounds for both the ion and resistojet systems. The lifetimes of 10, 5 and 2 years are shown here also.

5.3.8.2 Attitude Control Subsystem. The ion and resistojet thrusters are again considered for the attitude control system model as pictured in Figure 5-49. L is the moment or "jet arm" for the torque created by the thruster. The "area moment," AM, is related to the inertial properties of the satellite due to the extended solar panels. The attitude control function is to keep the satellite and antenna pointed to the earth with a stability of ±0.1 degree or better and the solar panels rotated about an axis containing the panel surface and through the satellite permitting orientation to the sun within $\pm 10^0$ which will perfect efficient power generation. Figure 5-50 gives the power expenditure in watts with respect to the area moment to jet radius ratio in square feet.

Ion and resistojet thrusters are compared. Figure 5-51 gives the costs for the thrusters of various lifetimes, both R&D and acquisition. Figures 5-52 and 5-53 give the weight and volume relationships respectively.

5.3.9 TELEMETRY AND COMMAND SUBSYSTEMS. The telemetry and command subsystems are required to meet a specific performance specification and not submitted to parametric analysis. The cost, weight and volume contributions carried as constants ("through puts") in the total system. The information summarized briefly here is from Hughes Aircraft Company support to the television Broadcast Satellite Study.[6]

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[6] Appendix A to Fifth Monthly Report, "Television Broadcast Satellite," June 16 to July 30, 1969, MSFC contract with Convair, NAS8-21036.

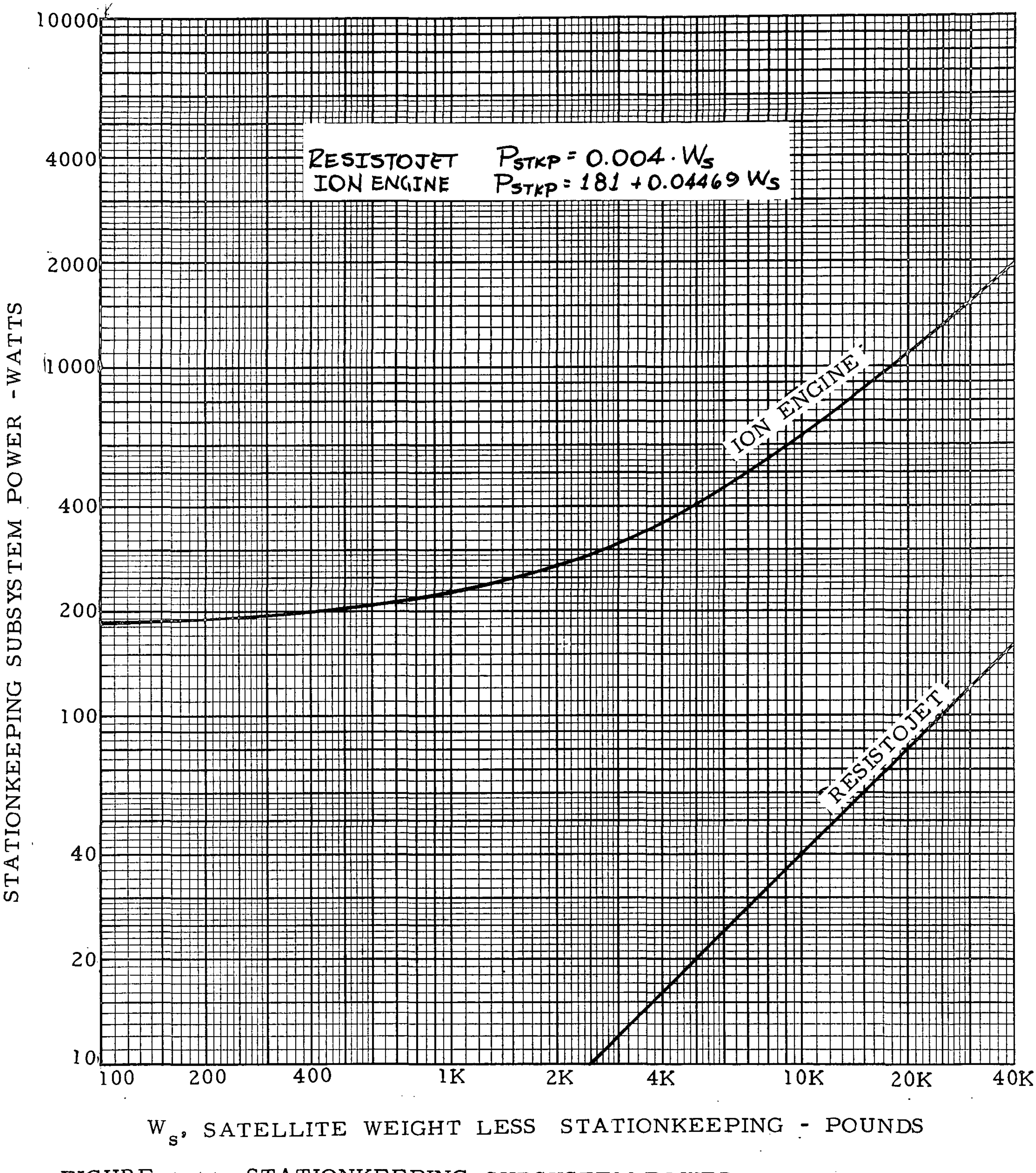


FIGURE 5-45. STATIONKEEPING SUBSYSTEM POWER

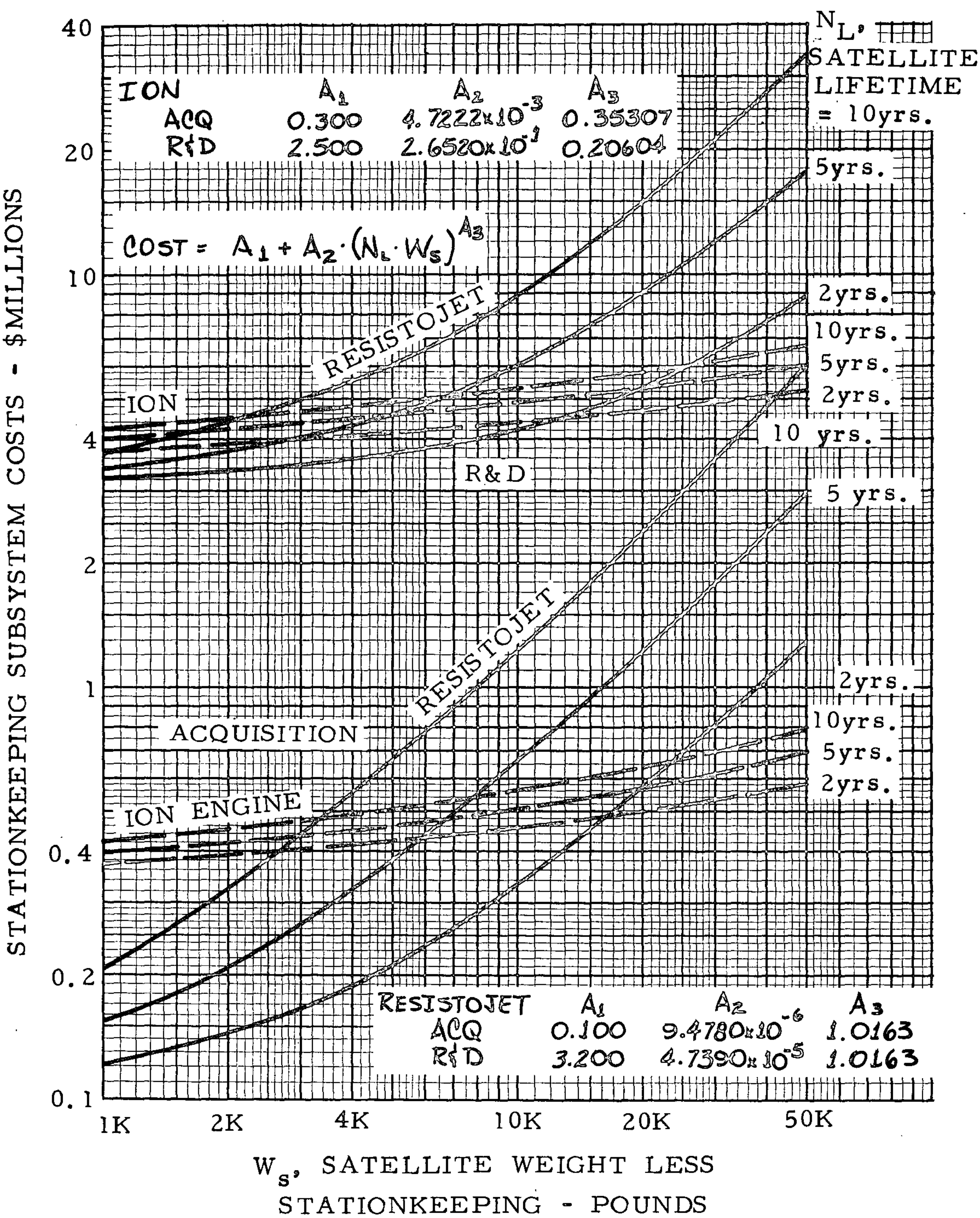


FIGURE 5-46. STATION KEEPING SUBSYSTEM COST

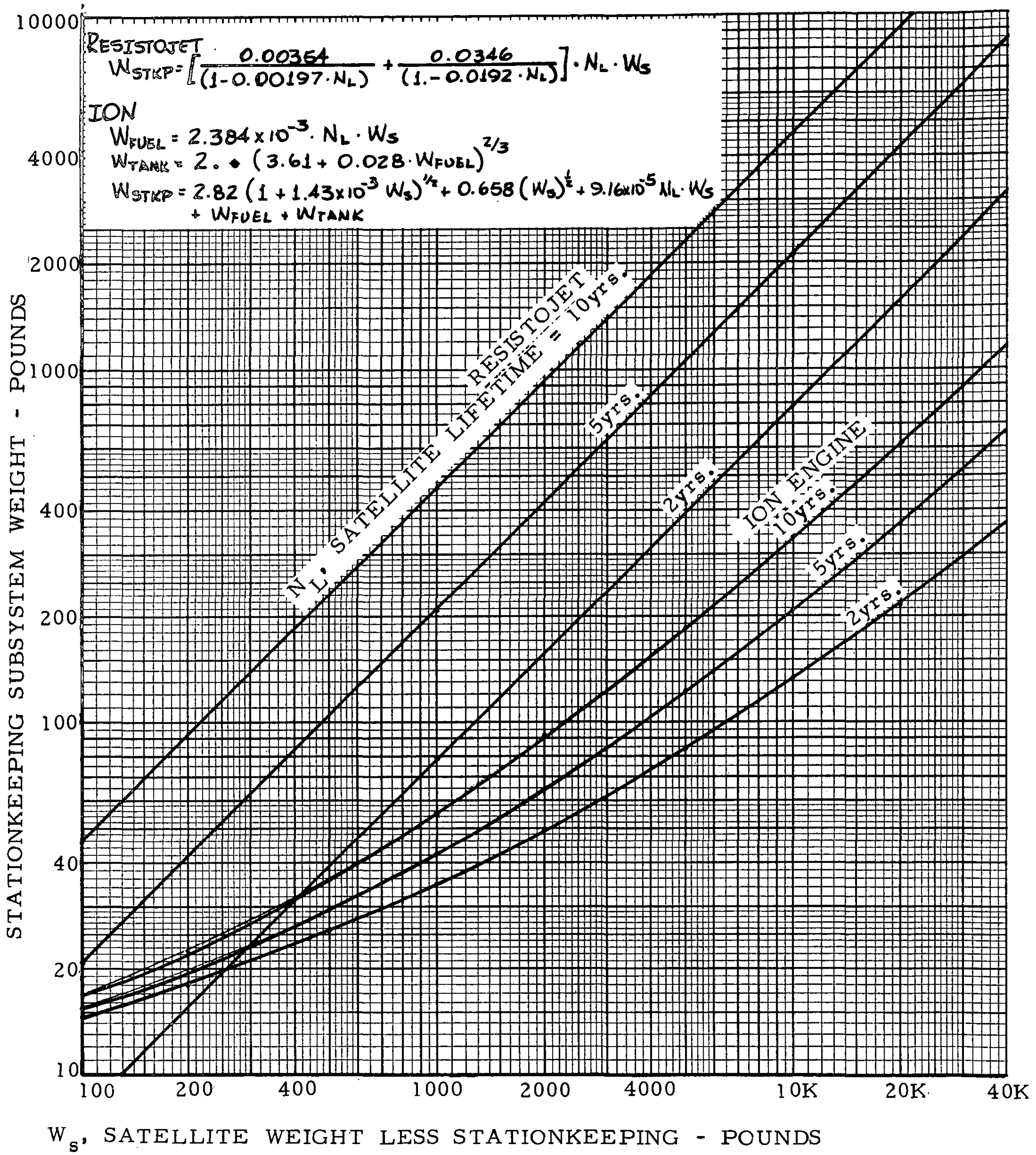


FIGURE 5-47. STATIONKEEPING SUBSYSTEM WEIGHT

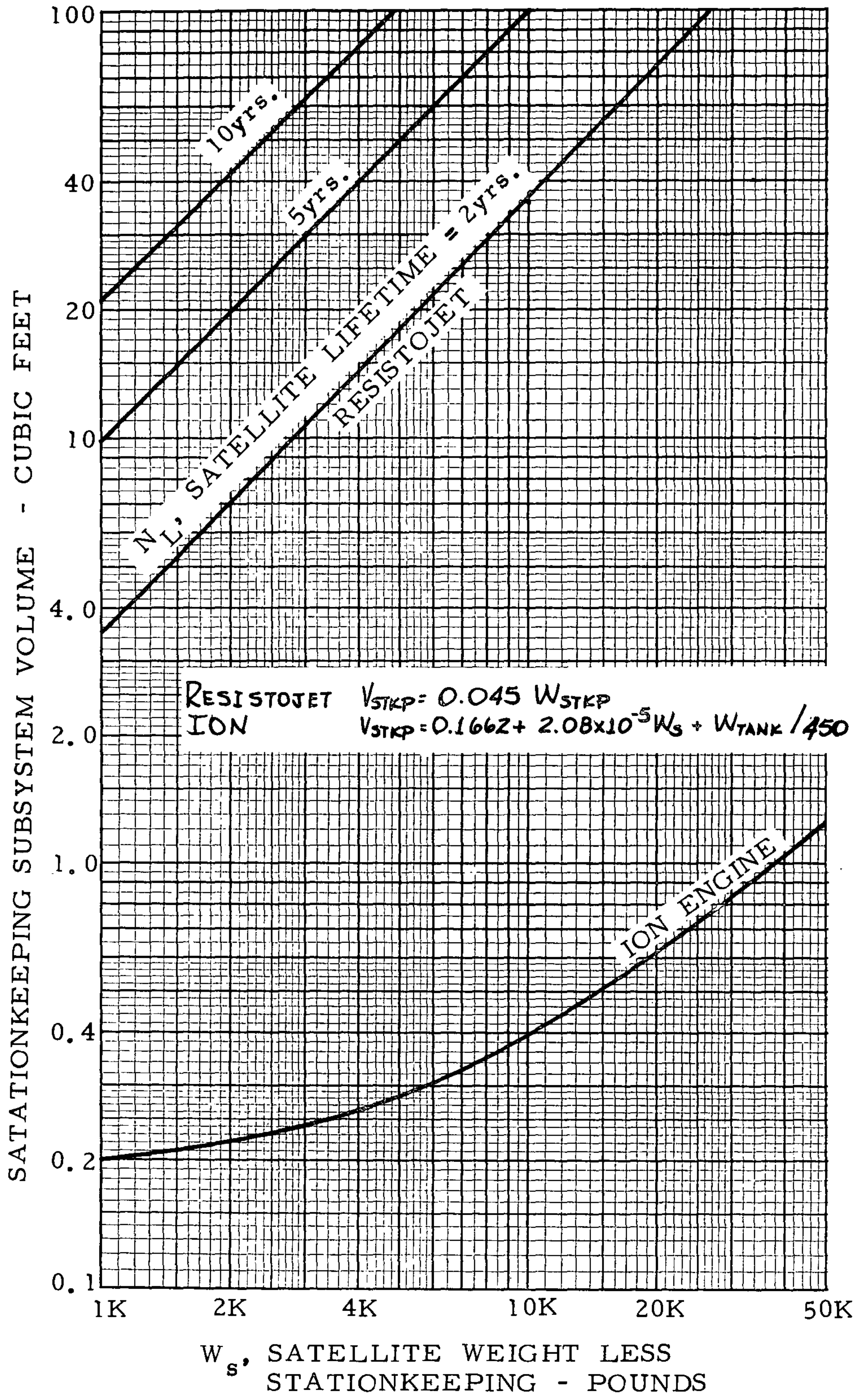


FIGURE 5-48. STATIONKEEPING SUBSYSTEM VOLUME

5.3.9.1 Telemetry Subsystem. A representative telemetry group consists of a redundant pair of central encoders and a number (approximately 70) of redundant remote multiplexers is shown in Figure 5-54. The central encoder addresses each of the remote multiplexers in sequence and processes the telemetry data returning from them. The remote multiplexers are located near the TM data sources thereby reducing the system harness weight. Performance of the telemetry group is summarized in Table 5-8.

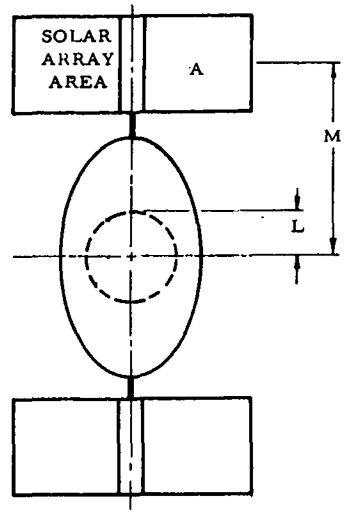


Figure 5-49. Attitude Control Subsystem Model

5.3.9.2 Command Subsystem. A representative command group consists of redundant command receivers, redundant demodulator/decoders, and eight sets of redundant remote decoders. The subsystem is capable of accepting a standard NASA Pulse Code Modulation (PCM) Instruction Command. The subsystem is completely redundant and capable of executing 512 pulse commands and 32 8-bit magnitude commands via redundant paths. Figure 5-55 is a block diagram of the command subsystem showing the interconnection between units. Table 5-9 summarizes performance.

5.3.9.3 Telemetry and Command Input to System Synthesis. The previously described system yielded the values for the communications satellite synthesis given in Table 5-10.

5.3.10 MANNED PROVISIONS. A satellite may be unmanned or provide for a life supporting environment permitting man to board for performance of service work. Several manned configurations have been considered in Convair's space module studies. The MDA (multiple docking adapter) provides a "shirt sleeve" environment up to 14 days duration. The BSM (basic submodule) is combining a living environment with the satellite permitting manning for an extended period. Table 5-11 gives the inputs to the total system synthesis to provide for either of the two alternatives for lift support. These are constants and do not have parametric expression.

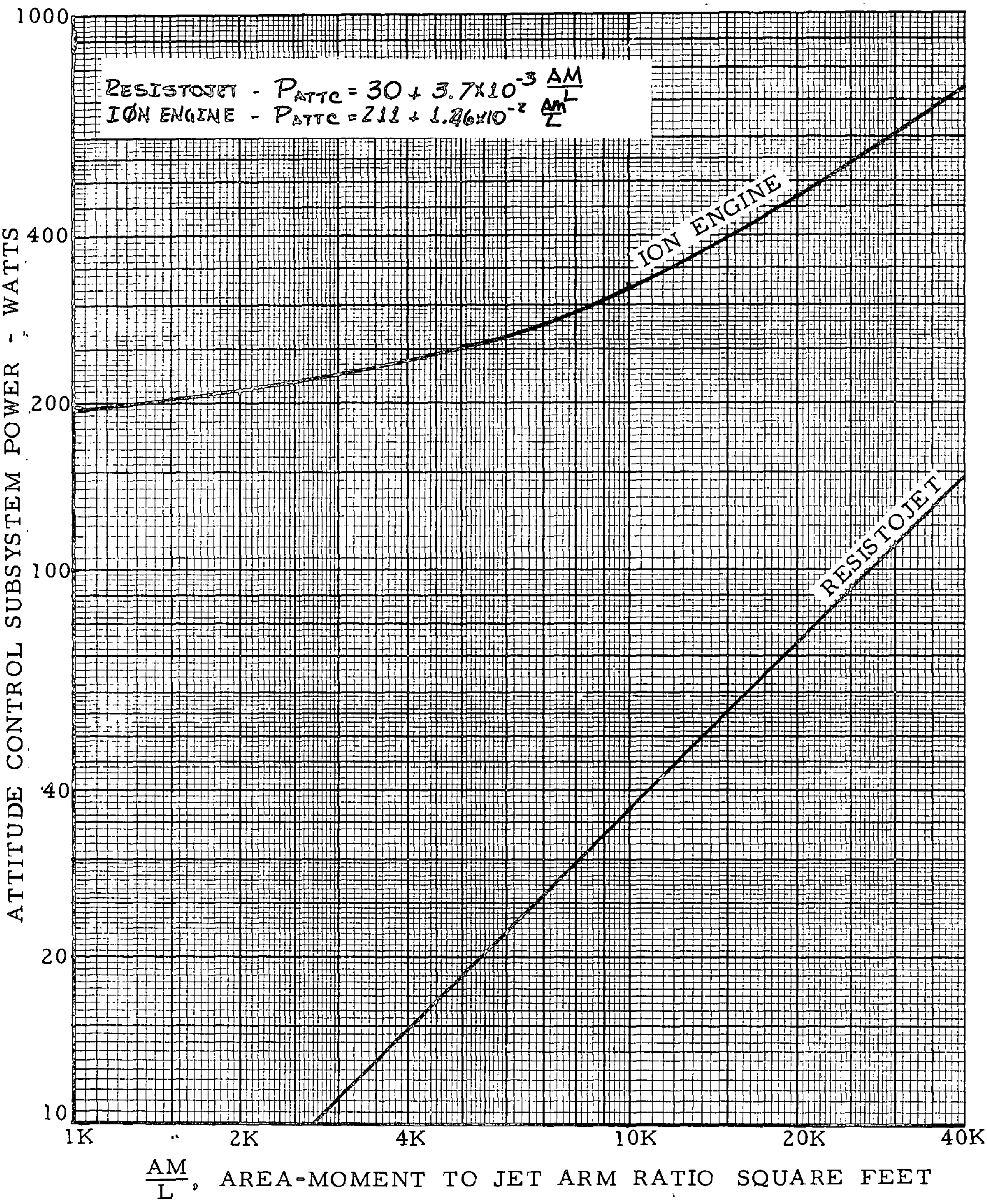
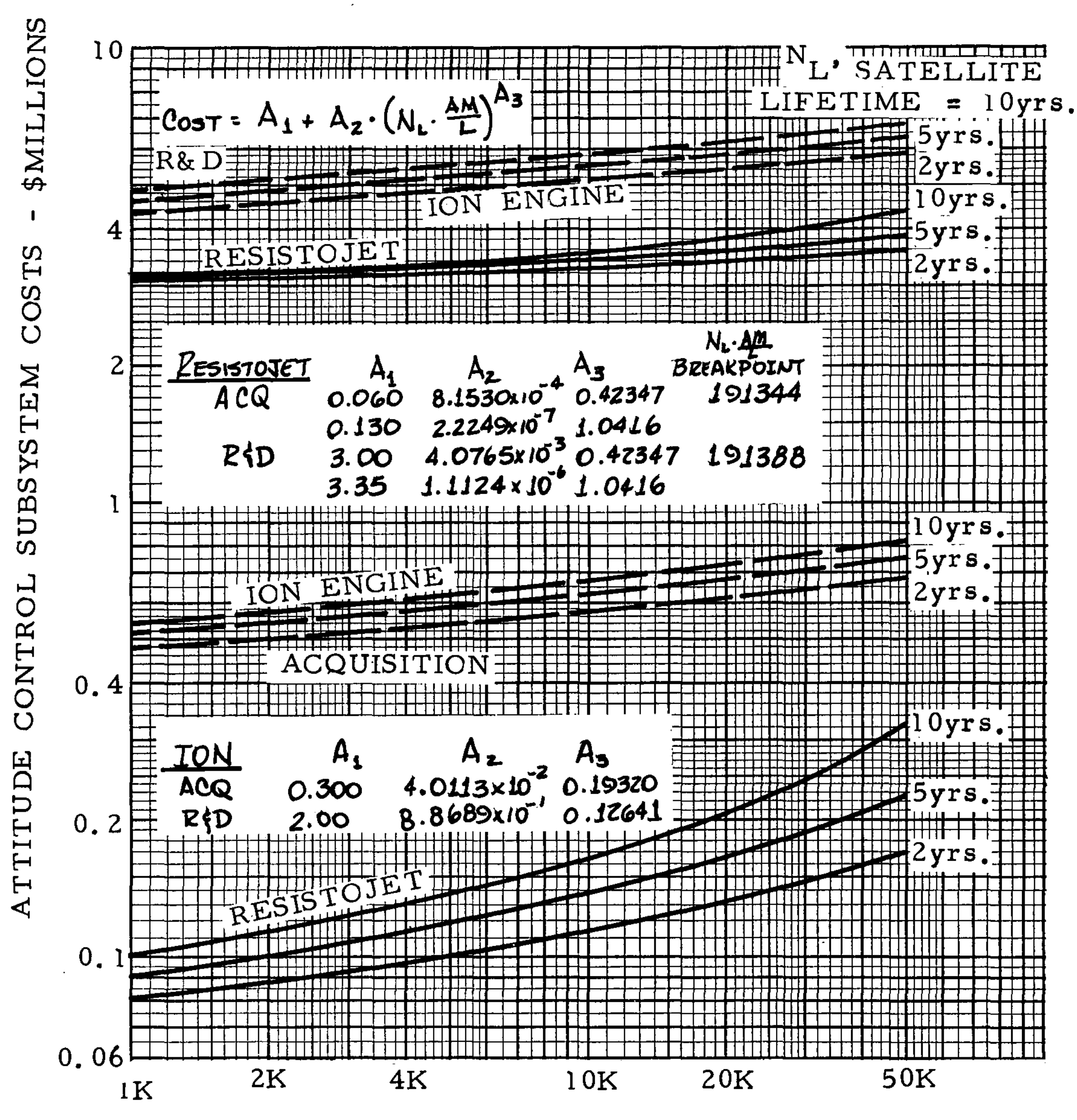


FIGURE 5-50. ATTITUDE CONTROL SUBSYSTEM POWER



$\frac{AM}{L}$, SATELLITE AREA-MOMENT TO JET ARM RATIO - SQUARE FEET

FIGURE 5-51 ATTITUDE CONTROL SUBSYSTEM COST

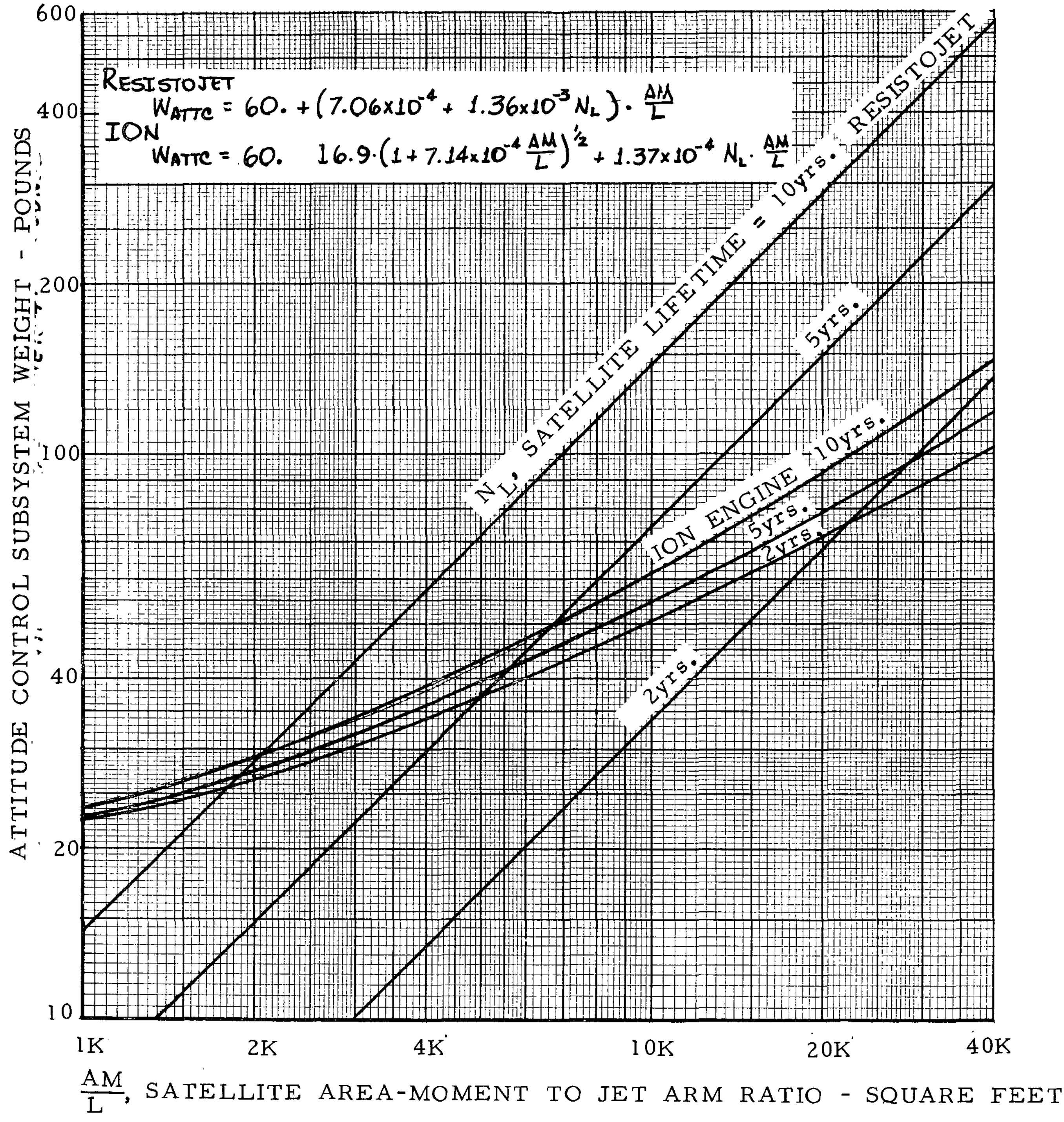


FIGURE 5-52. ATTITUDE CONTROL SUBSYSTEM WEIGHT

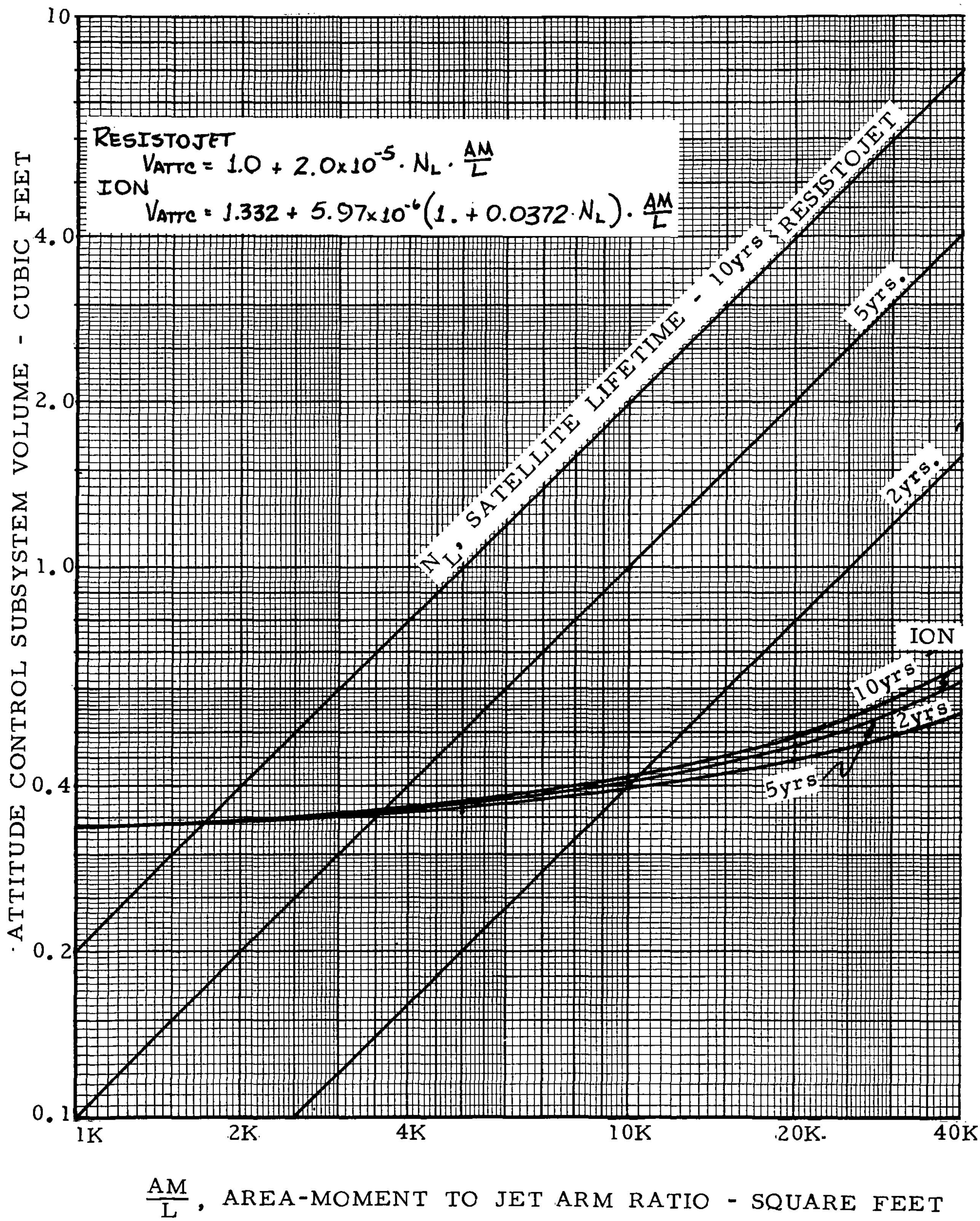


FIGURE 5-53. ATTITUDE CONTROL SUBSYSTEM VOLUME

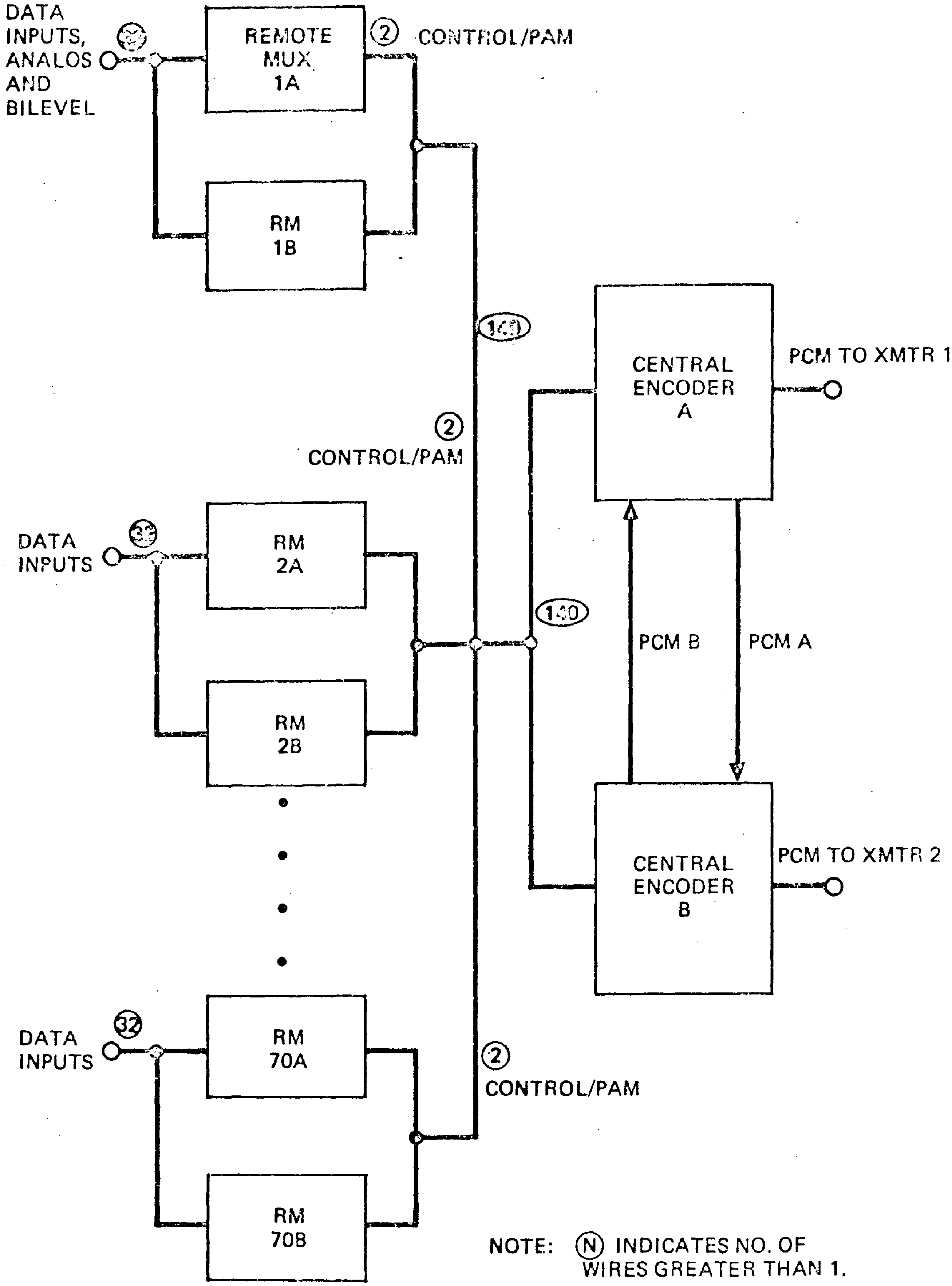


Figure 5-54. Telemetry Group Block Diagram

Table 5-8

SUMMARY OF TELEMETRY GROUP CHARACTERISTICS

Telemetry Transmitter		
Carrier Frequency	136 to 138 MHz	
Power Output	2 w	
Telemetry Encoder		
Circuit Type	Integrated Circuits	
Word Length	8 bits	
Frame Synchronization	32 bits	
Bit Rate	400 bits per second	
Code Type	PCM Code (NRZ-L)	
Number of Words	500	
Number of inputs		
Analog	250	
and		
Digital	2000 bits	
Number of units for full redundancy		
Transmitter	2	
Encoder	2	
Remote multiplexer (assumes either 32 analog inputs or 32 digital bits per unit)	140	
Unit Volume (per unit; non-redundant		
Transmitter	38 cu. in.	
Encoder	156 cu. in.	
Remote Multiplexer	15 cu. in.	
Unit Power Consumption (per unit; non-redundant)	Standby	Operate
Transmitter	0.4W	6.0W
Encoder	0.2W	1.0W
Remote Multiplexer	0.11W	1.0W
Unit Weight (per unit; non-redundant)		
Transmitter	1.0 lbs.	
Encoder	4 lbs.	
Remote Multiplexer	0.3 lbs.	

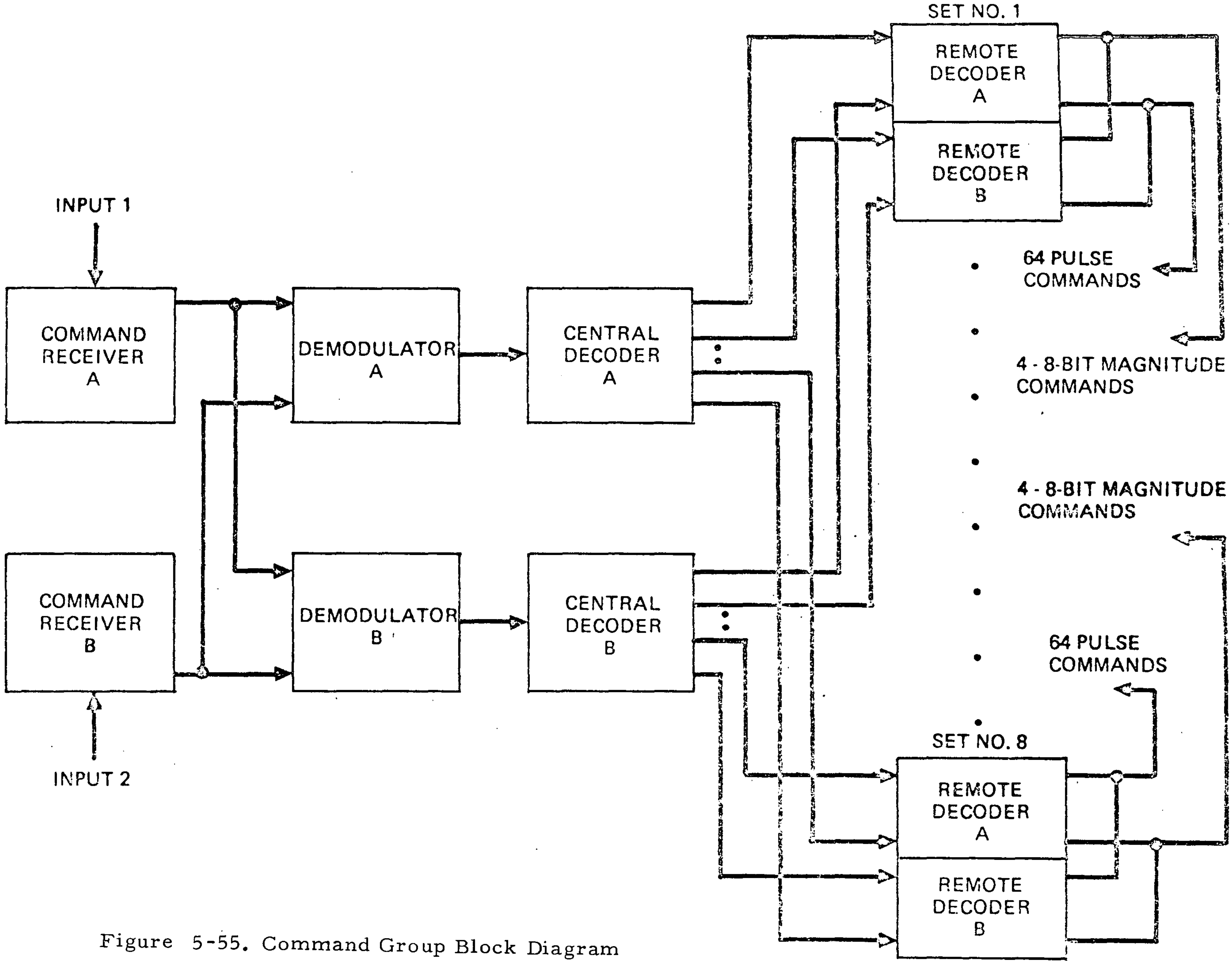


Figure 5-55. Command Group Block Diagram

Table 5-9

SUMMARY OF COMMAND GROUP CHARACTERISTICS

Command Receiver	
Carrier Frequency	148 to 154 MHz
Noise Figure	8 db
Sensitivity	-105 dbm
Modulation Type	AM/FSK
Command Demodulator/Decoder	
Circuit Type	Integrated Circuit
Bit Rate	128 bps
Word Length	64 bits
Preamble	14 bits
Spacecraft Address	7 bits
Remote Decoder Address	5 bits
Command	5 bits
Complement of Spacecraft Address, Remote Address, and Command	23 bits
Conclusion	4 bits
Code Type	PCM 1 and 0 plus clock
Number of outputs	
Pulse	512
and	
Magnitude	32
Number of Units for Full Redundancy	
Receiver	2
Demodulator/Decoder	2
Remote Decoder (assumes 64 pulse and 4 magnitude commands per unit)	16
Unit Volume (per unit; non-redundant)	
Receiver	35 cu. in.
Demodulator/Decoder	160 cu. in.
Remote Decoder	28 cu. in.
Unit Weight (per unit; non-redundant)	
Receiver	0.8 lbs.
Demodulator/Decoder	2.8 lbs.
Remote Decoder	0.7 lbs.

Unit Power (per unit; non-redundant	Standby	Operate
Receiver	N/A	0.5W
Demodulator/Decoder	N/A	2.5W
Remote Decoder	0.2W	1.0W

Table 5-10. Telemetry and Command Subsystems

	Telemetry	Command	Total
Cost Unit Recurring			0.85
($M) Non-recurring			0.17
Weight (pounds)	52	18	70
Volume (cu. ft.)	1.36	0.43	1.79
Power (watts)	77	11	88

Table 5-11. Manned Provisions

	MDA	BSM
Cost Unit Recurring	1.8	1.8
($M) Non-recurring	24.9	24.9
Weight (pounds)	6983	5500
Volume (cu. ft.)	740	740
Power (watts)	3000	3000

5.4 OTHER SIGNIFICANT COST ELEMENTS

Section 5.3 discussed the hardware subsystems which were modeled and expressed in parametric form for use in the synthesis program. In the design and acquisition of a satellite system, other cost elements must also be considered since they may affect the trade-offs between the satellite and ground systems The elements in the following paragraphs are related to the hardware subsystems costs by appropriate weighting factors. These factors were determined by the Economic Analysis Section of the Systems Analysis Group at Convair to be typical of those in use.

5.4.1 PROTOTYPE. This non-recurring cost provides for a complete satellite for test purposes. Since the solar cell array is typically a high cost item and may be simulated in the required tests, only 15% of the solar array cost is included in the prototype cost. To this is added the sum of all other hardware subsystem unit recurring costs.

5.4.2 INTEGRATION, ASSEMBLY AND CHECKOUT. This cost element is incurred for each flight article and is weighted at 7.5% of the sum of the recurring costs for all hardware subsystems.

5.4.3 DESIGN, INTEGRATION AND MANAGEMENT. This non-recurring cost element is assessed at 50% of the hardware subsystem non-recurring costs.

5.4.4 CENTER SUPPORT. This cost element is applied as both recurring and non-recurring costs. The unit recurring cost is 15% of the sum of the hardware unit recurring cost and the Integration, Assembly and Checkout cost. The non-recurring element is 5% of the sum of the hardware non-recurring and the Design, Integration and Management costs.

5.4.5 GROUND SUPPORT EQUIPMENT. This non-recurring cost is assessed at 50% of the satellite hardware subsystem unit recurring costs.

5.5 REFERENCES

5.5.1 NUCLEAR REACTOR REFERENCES

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5.5.2 SOLAR ARRAYS

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5.5.3 POWER CONDITIONING REFERENCES

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18. Extrapolated from existing deep-space probe technology.

19. Extrapolated from existing airborne electronics technology.
20. Extrapolated from existing ion engine power conditioning technology.
21. Extrapolated from existing communications satellite battery controller technology.
22. OV1 experience.

6

LAUNCH VEHICLE ANALYSIS

Analysis of the launch vehicles includes consideration of:

1. Performance - payload weight capability to synchronous, equatorial orbit.
2. Available payload volume.
3. System costs, both non-recurring and recurring.

Atlas and Titan families were considered as the standard launch vehicles.

Saturn V and Atlas/Delta were also considered as representing the extremes of payload capability of interest to this study.

The Space Shuttle (Recoverable Booster and Orbiter combination) is also a candidate launch vehicle but is insufficiently defined at this time for inclusion.

6.1 STANDARD LAUNCH VEHICLES

The Standard Launch Vehicles considered for the ITS Concept Study include the currently contracted Atlas and Titan families of boosters with appropriate upper stages. As shown in Figure 6-1 these include:

1. SLV-3A/Agena
2. SLV-3/Centaur, with and without Burner II kick stage.
3. Titan IIIC
4. Titan IIID/Centaur

These vehicles will be launched from the Eastern Test Range (ETR). Kennedy Space Center, for equatorial missions. Different configurations can be launched from the Western Test Range (WTR) for polar missions.

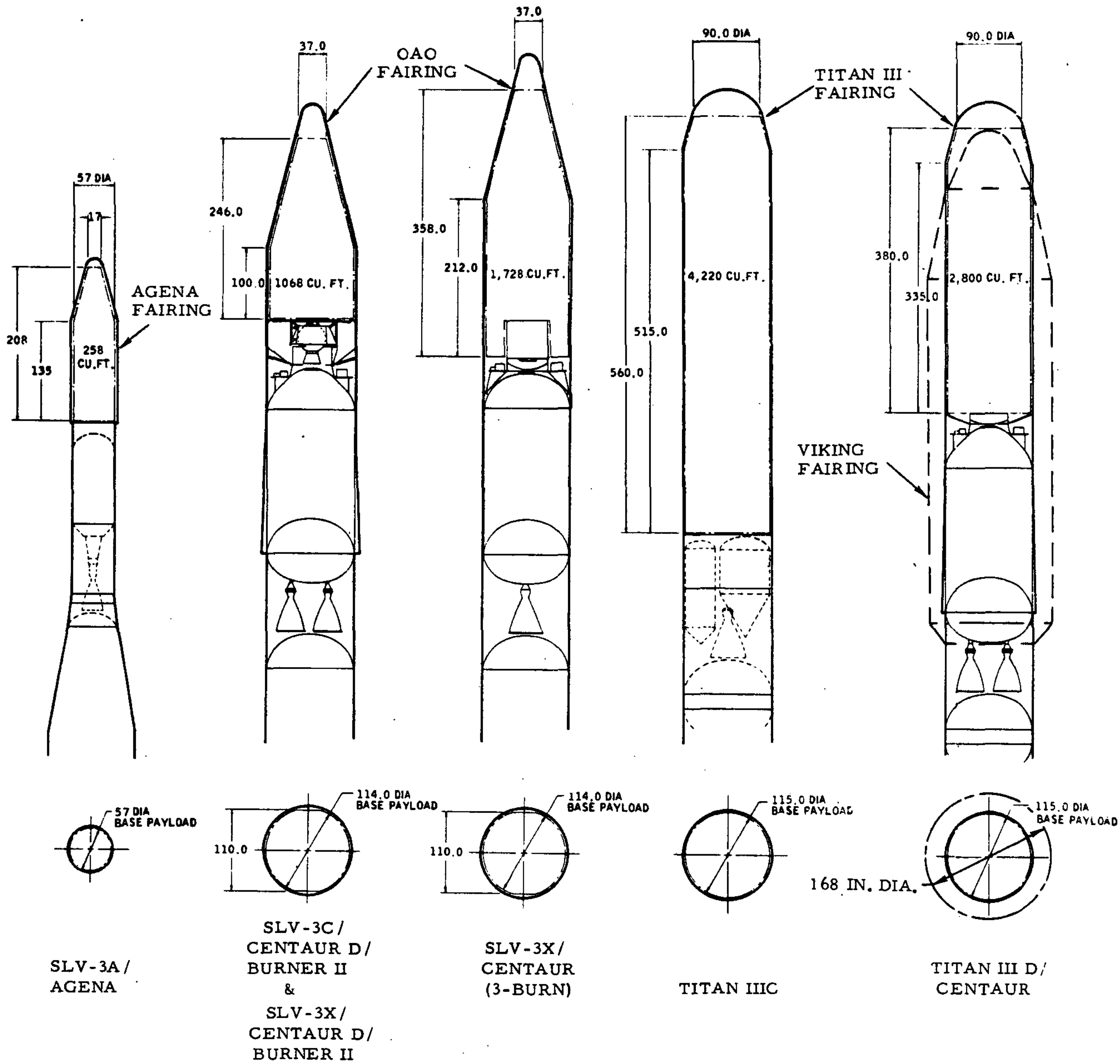


Figure 6-1. Standard launch vehicles and payload envelopes.

6.1.1 LAUNCH VEHICLE DESCRIPTIONS

1. Atlas Family of Space Launch Vehicles

Atlas Description

Table 6-1 summarizes the major Atlas characteristics. The engine thrusts shown are slightly higher than currently being used, reflecting the uprated engines which will be used in future production.

The Atlas is a stage-and-a-half configuration in which all engines are ignited on the ground. The booster section with its two thrust chambers and surrounding structure is jettisoned approximately 150 seconds after liftoff, when high thrust is no longer required. Atlas flight continues 90 seconds with the sustainer engine and vernier control engines. The booster section is considered only a half-stage because it contains no propellant tanks.

Table 6-1. Atlas SLV-3C Characteristics.

THRUST	411,000 lb. (sea level)
Booster -	350,000 lb.
Sustainer -	60,000 lb.
Verniers -	1,000 lb.
PROPELLANTS	266,000 lb.
LO_2 -	184,000 lb.
RP-1	82,000 lb.
JETTISON WT	7,480 lb. (Booster) 8,560 lb. (Sustainer)
TANK CONSTRUCTION -	Stainless steel
TANK DIAMETER -	10 ft.

The airframe structure consists of the tank section and the booster section. The propellant tanks are fabricated as a series of welded stainless steel bands, and are pressurized to react all loads without need for conventional stringers and frames. The booster section structure is primarily aluminum skin and stringer construction, as is the interstage adapter between Atlas and Centaur. The propulsion system is also divided into booster and sustainer sections, both furnished by Rocketdyne. Each section contains a gas generator and turbopump to supply high-pressure propellants to the thrust chambers. The sustainer engine mounts on the apex of the conical aft bulkhead of the fuel tank. Its propellant pumps and hydraulic system also serve the vernier engines.

Since its first launch in June 1957, the Atlas has been launched 387 times of which 142 were for scientific payloads. Ninety-eight of the last 100 launches were successful.

Agena Description

Table 6-2 summarizes the major Agena characteristics, as designed for use with the Atlas SLV-3.

The Agena D airframe is a cylindrical, semimonocoque structure divided into four major sections: forward, tank, aft, and SLV-3 adapter and extension. The forward section, constructed of beryllium and magnesium, houses most of the basic equipment and provides the mechanical and electrical interface for the spacecraft. The five-ft. diameter tank section is composed of two aluminum integral propellant cells with a sump below each cell for engine start and propellant feed. The aft section consists of the rocket engine and cone structure with associated equipment. The magnesium alloy, ring-stiffened adapter section supports the Agena/spacecraft combination and is jettisoned with the SLV-3 booster. Overall length of the stage is 23.2 ft.

Table 6-2. Agena D (SS01B) Vehicle Weights Dual-Burn Mission.

Agena Dry	1,175
Minimum Mission Optionals*	
Flight control patch panel kit	1
2-watt telemeter & adapter kit	2
760 watt-hr btry & adapter kits	32
Acquisition transmtr & " "	1
S-band beacon & decoder & adapter kit	18
Subtotal — Dry Weight	1,229
Residuals: Propellant @ 0% P_c	30
Helium	2
Flight Performance Reserve — 3σ	60
TOTAL — WET WT IN ORBIT	1,321

The Agena D receives its thrust from the Bell Aerosystems Model 8096 rocket engine or the optional Model 8247 multiple-restart engine. The engine system is a liquid bipropellant power package with a single regeneratively cooled combustion chamber mounted in a gimbal ring and swiveled by hydraulic actuators. Each engine model is designed for a nominal thrust duration of 240 sec. and uses unsymmetrical dimethylhydrazine (UDMH) as the fuel, and inhibited red fuming nitric acid (IRFNA) as the oxidizer, a hypergolic combination.

Vehicle attitude is sensed by a three-axis, strapped-down, inertial-reference package that is referenced to the earth by an infrared horizon sensor system. Attitude errors are converted to the required corrective torques which are applied to the vehicle through the control system.

Vehicle velocity is measured along the line of flight by an accelerometer unit known as the velocity meter. During powered flight operations, the velocity meter generates the engine cutoff signal when the required velocity increment is reached (preset according to mission requirements).

Centaur Description

Table 6-3 summarizes the major Centaur characteristics, as designed for use with the Intelsat IV. Centaur's two Pratt & Whitney engines are currently capable of two engine starts with up to 25 minutes coast duration between engine firings, allowed a second firing at the first equatorial crossing.

The centaur tank is of the same stainless steel construction as Atlas. Engine thrust is distributed into the aft bulkhead of the LO_2 tank by an internal thrust barrel. The LH_2 tank is located forward, with Centaur guidance and electrical equipment mounted on shelves above the forward bulkhead. A stub adapter has been added at the forward end of the tank for the Intelsat mission to support the longer nose fairing and new payload support truss, as discussed later.

Table 6-3. Centaur Characteristics.

Vacuum Thrust		30,000 lb.
Propellants		30,000 lb.
Liquid Oxygen	35,000 lb.	
Liquid Hydrogen	5,000 lb.	
Vacuum Specific Impulse		444 sec.
Centaur Jettison Weight (including payload truss)		4,366 lb.
Tank Construction	—	Stainless steel
Tank Diameter		10 ft.

Precision guidance is provided by a four-gimbal inertial platform system using a general-purpose digital computer. Primary flight control functions are provided by an autopilot system that controls the direction of main engine thrust or the pulsing of control engines during coast. Discrete signals are generated by the guidance computer, as well as by the autopilot programmer.

Since the first launch in May 1962, Centaur has been launched 21 times with 18 successes.

2. Titan Family of Space Launch Vehicles. The current Titan III family building blocks are the standard 2-stage core, the stretched core, the five-segment solid rocket motor, the Transtage, Agena and Centaur upper stages.

Titan IIIC

The Titan IIIC comprises the standard core, two 5-segment solids and a Transtage. The vehicle is operational at ETR.

The Titan IIIM program for a man-rated vehicle for MOL was essentially completed for WTR launch. Final development of the stretched core is in progress, and the 7-segment solids have been demonstration fixed.

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

Titan III/Centaur

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

Several payload fairings and stage shrouds are in use or under development for the Titan III programs. The Titan IIIC fairing (Figure 6-1) is currently used on all Titan IIIC vehicles. The sections of the fairing are joined along longitudinal seams that form separation joints permitting the fairing to be jettisoned in three separate trisectors. Silicon insulation protects the payload from ascent heating. Estimated jettison weight of the fairing is 2580 lb. A similar shroud may be used with Centaur. Reduced insulation and shorter separable length reduces the estimated jettison weight to 2485 lb.

The Viking shroud for Centaur is also shown in Figure 6-1. The combination payload fairing/stage shroud is jettisoned in two separate halves, and the estimated jettison weight is 4350 lb. Center segments can be added or removed from the IIIC type shroud and the length of the Viking shroud can be increased to accommodate payloads of various lengths.

6.1.2 PERFORMANCE. Performance for the standard launch vehicle groups is shown in Table 6-4. This table shows the payload capability to synchronous equatorial orbit. This payload ranges from 550 lb. to 7,100 lb.

Table 6-4. Standard Launch Vehicles Performance

PAYLOAD WEIGHT CAPABILITY TO SYNCHRONOUS ORBIT	
LAUNCH VEHICLE	PAYLOAD WEIGHT (LB)
SLV-3A/AGENA	550
SLV-3C/CENTAUR D1-A/B-II	1,650
SLV-3X/CENTAUR D1-A/B-II	2,700
SLV-3X/CENTAUR (3-BURN)	1,800
TITAN III C(UPRATE)	2,600
TITAN III D/CENTAUR D-1T	7,100

6.1.3 COST. Costs for the different booster/upper stage versions are shown in Table 6-5. These costs are given for both Non-recurring and Recurring elements, within these elements costs are further broken down for the booster/stage combination, fairing and adapter, launch services and spares.

These costs are further based on the concurrencies shown in Table 6-6 - based on current contracted requirements.

Table 6-5. Standard Launch Vehicles Cost Summary ($M)

	SLV-3A/ AGENA	SLV-3C/ CENTAUR D/B-II	SLV-3X/ CENTAUR D/B-II	SLV-3X/ CENTAUR (3-BURN)	TITAN III C	TITAN III D/ CENTAUR
A. NON-RECURRING:						
LV DEVELOPMENT			23.0	23.0		
FAIRING & ADAPTER						
MISSION INTEGRATION	1.5	2.5	2.5	2.5	4.3	4.6
SUBTOTAL	1.5	2.5	25.5	25.5	4.3	4.6
B. RECURRING:						
LAUNCH VEHICLE	6.8	9.0	9.2	8.6	15.3	15.4
FAIRING & ADAPTER	0.2	0.5	0.5	0.6	1.0	1.2
LAUNCH SERVICES	2.1	2.3	2.3	2.1	3.2	3.4
SPARES, ETC.	0.7	1.1	1.1	1.0	1.5	1.6
SUBTOTAL	9.8	12.9	13.1	12.3	21.0	21.6
TOTAL	11.3	15.4	38.6	37.8	25.3	26.2

Table 6-6. Standard Launch Vehicles Concurrency

VEHICLE	PRODUCTION RATE 73 - 74	PRODUCTION RATE 75 - 79	LAUNCH RATE 73 - 74	LAUNCH RATE 75 - 79	SITE
SLV-3A	2	2	2	2	CX-13
AGENA-D	2	2	2	2	CX-13
SLV-3C	4	3	4	3	CX-36
CENTAUR D-1A	4	3	4	3	CX-36
CENTAUR D-1T	0	4	0	4	CX-41
TITAN III D	0	4	0	4	CX-41
TITAN III C	2	2	2	2	CX-40
ATLAS E/F MOD.	4	4	4	4	ABRES
BURNER II	4	4	4	4	ABRES
TITAN III B	4	4	4	4	SLC-4W
AGENA D	4	4	4	4	SLC-4W
TITAN III D	3	3	3	3	SLC-4E

6.2 SATURN V (Figure 6-2)

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

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

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

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

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

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

Saturn fairings are available to protect the payload from aerodynamic loads and temperatures while in flight. They may also be used for payload thermal conditioning on the launch pad. A typical fairing configuration suitable for a S-IVB/ Centaur is shown in Figure 6-3.

In a manned configuration, the payload volume (Figure 6-2) is that available when the LEM is not used. A payload volume of 3,230 cu.ft. and a weight of 29,500 lb. can be accommodated in this space.

For unmanned launches of the Saturn V, a large fairing was developed for the Voyager spacecraft. It provided a volume of approximately 2,900 cu. ft. Approximate weight of the fairing is 2,500 lb. (Aluminum honeycomb configuration). The Voyager fairing is essentially the structure forward of Station 3386.6. With the addition of an S-IVB forward skirt, as shown in Figure 6-3, the volume increases to approximately 6,000 cu.ft. and shroud weight is approximately 3,600 lb.

Table 6-7 summarizes the performance capability of the Saturn V to synchronous equatorial orbit. Depending on the particular manned version being used the payload may be as low as 10,000 lb. In the unmanned version, the payload is 52,500 lb.

Nominal costs for the Saturn V are shown in Table 6-8. These costs - $25M R&D and $188.2M recurring - are contingent upon a concurrent production of 4 Saturn V's. Present NASA planning does not maintain this production status beyond 1972. Significant cost increases would then be experienced to restart Saturn V production. It is unlikely that the present configuration would be maintained. Several advanced versions have been proposed and it is probable that, if a new requirement is established and accommodated, one or more of these proposals would be implemented.

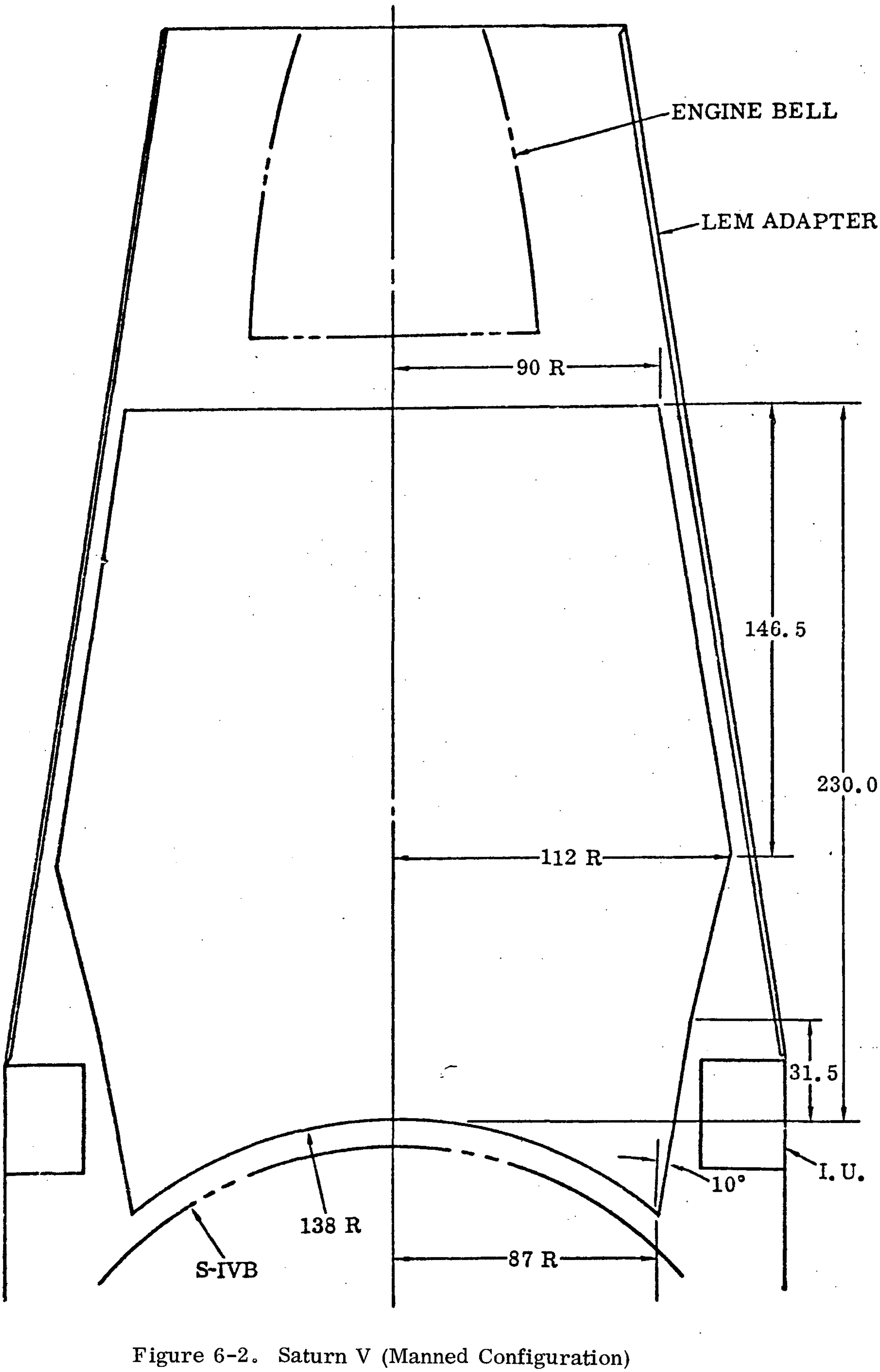


Figure 6-2. Saturn V (Manned Configuration)

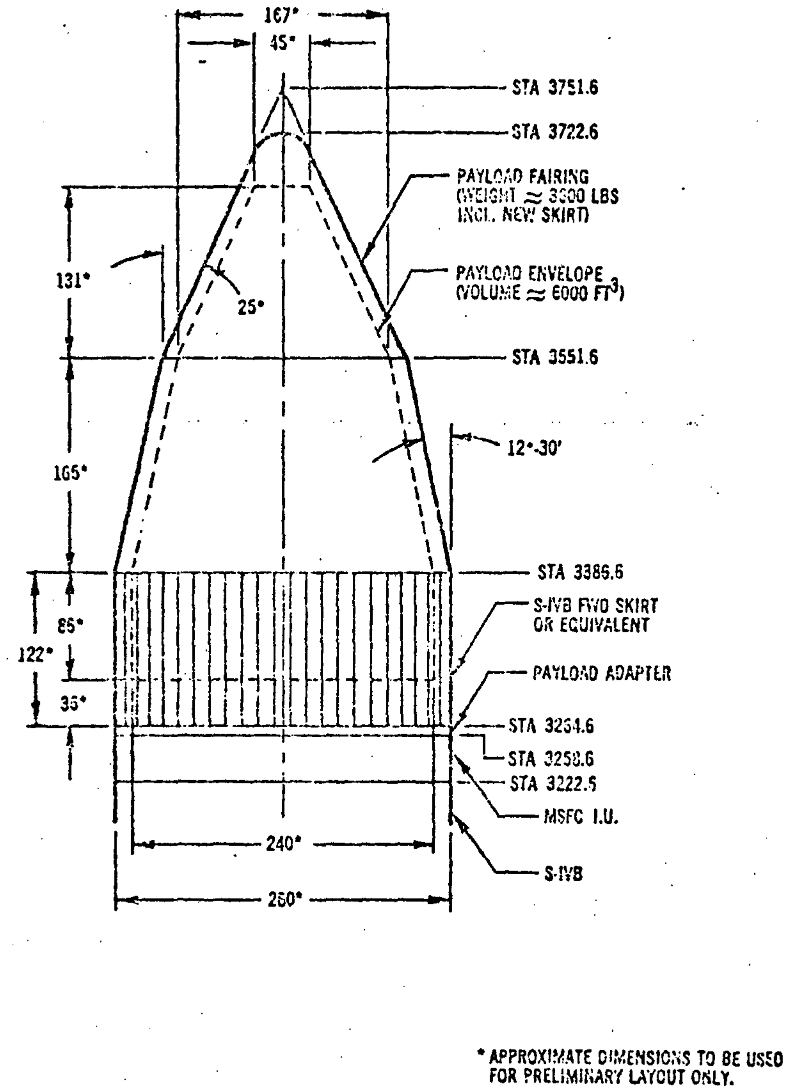


Figure 6-3. Saturn V (Unmanned Configuration)

Table 6-7. Saturn V Payload to Synchronous Orbit

Saturn V Configuration		Payload Installation			Payload Weight (lb.)
		Diameter (in.)	Length (in.)	Volume[1] (Cu. Ft.)	
1.	Unmanned Saturn V (Topless)	224	230	6,000	52,500
2.	With CSM	224	198	4,500	12,150
3.	With SSESM	190	200	4,000	44,000
4.	With CSM and Half-Rack	215	150	3,000	10,000

(1) Volume increases can be accommodated by means of a cylindrical spacer added to the fairing assembly.

Table 6-8. Saturn V Cost Summary

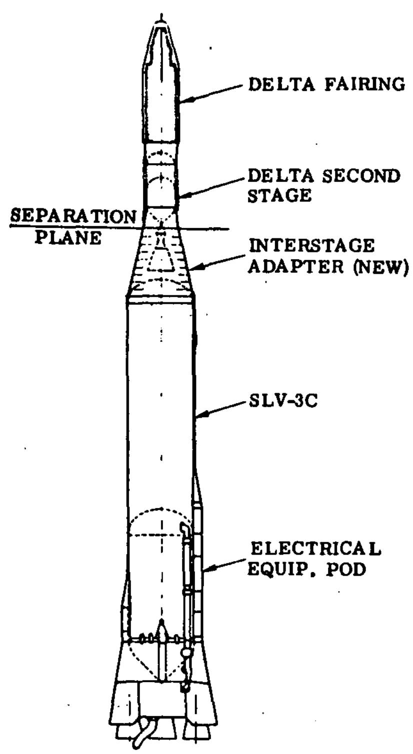
● NON RECURRING:		$25.0M
LAUNCH VEHICLE DEVELOPMENT	$10.0M	
FAIRING AND ADAPTER	5.0	
MISSION INTEGRATION	10.0	
● RECURRING:		$188.2M
VEHICLE	$99.4M	
FAIRING AND ADAPTER	1.5	
LAUNCH SERVICES	37.0	
SPARES, ETC.	50.3	
	TOTAL	$213.2M
● PRODUCTION CONCURRENCY	4 SATURN V	

6.3 ATLAS SLV-3C/DELTA

This launch vehicle has been proposed as a replacement for the Thor/Delta in order to:

- Reduce number of vehicles/stages
- Consolidate launch sites
- Reduce number of contractors/support activities
- Minimize further expendable vehicle development and
- Improvement costs during interim until shuttle

This change also addresses the need in the current program for increased performance capability and for larger payload envelope. Using the Atlas SLV-3C booster will nearly double the current Delta capability to low earth orbit and increase by 70% the payload to synchronous transfer. The standard Delta payload fairing (65 in. dia.) can be used as can the OV1 all-metal fairing (84in.dia.) and the OAO/Intelsat IV fairing (120 in.dia.). These latter fairings allow the volume to increase by factors of 1.7 and 3 respectively. The basic configuration proposed for the SLV-3C/ Delta is shown in Figure 6-4.

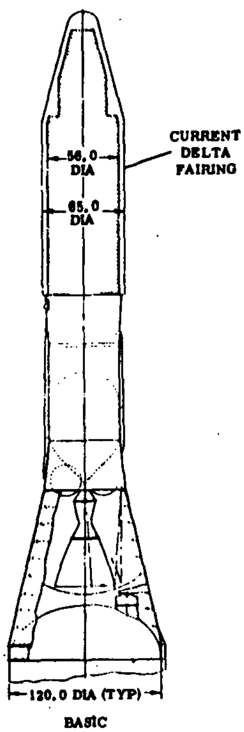


FEATURES

- STANDARD DELTA CONFIGURATION FORWARD OF SEPARATION PLANE:
  - ▲ DELTA SECOND STAGE
  - ▲ DELTA INERTIAL GUIDANCE SYSTEM (DIGS)
  - ▲ TRANSTAGE ENGINE THRUST CHAMBER ASSEMBLY
- BASELINE SLV-3C COMMON FOR DELTA AND CENTAUR, WITH KITS FOR:
  - ▲ TELEMETRY
  - ▲ RATE GYRO UNIT (RGU)
  - ▲ SERVO INVERTER UNIT (SIU)
  - ▲ INTERSTAGE ADAPTER
- LAUNCH SITE CAPABILITY FOR CONVERSION OF SLV-3C TO EITHER CENTAUR OR DELTA

Figure 6-4. Atlas SLV-3C/Delta Basic Configuration

Performance and cost data are summarized in Figure 6-5. These systems would be launched from the Eastern Test Range (ETR), Complex 36.



- PERFORMANCE (TO SYNCHRONOUS ORBIT):

	65 IN. SHROUD	84 IN. SHROUD	120 IN. SHROUD
WITH B-II	720	570	520

- COST:

NON-RECURRING	$6M
RECURRING	$6.4M
LAUNCH SERVICES	$1.6M
TOTAL	$14.0M

(ASSUMES ATLAS REPLACES THOR)

Figure 6-5. Atlas SLV-3C/Delta

6.4 SPACE SHUTTLE

The space shuttle is the key element for future space operations in earth orbit. In the post-1977 period, the shuttle will provide economical transportation for unmanned and manned payloads for both NASA and DOD. The shuttle will also provide the ability to accomplish substantial reductions in payload costs through the relaxation of payload weight requirements, the more benign payload environment, the ability to return payloads for repair or refurbishment prior to redeployment, and the provision of intact abort capability, which precludes the loss of payloads due to malfunction of the launch vehicle. The vehicle will be a two-stage, vertical takeoff, horizontal landing, fully reusable system in which maximum use will be made of aircraft design and operations procedures. The first stage is referred to as the booster and the second stage as the orbiter (Figure 6-6). Booster propulsion is supplied by 12 main rocket engines with a thrust of 550,000 pounds at sea level. The orbiter uses two

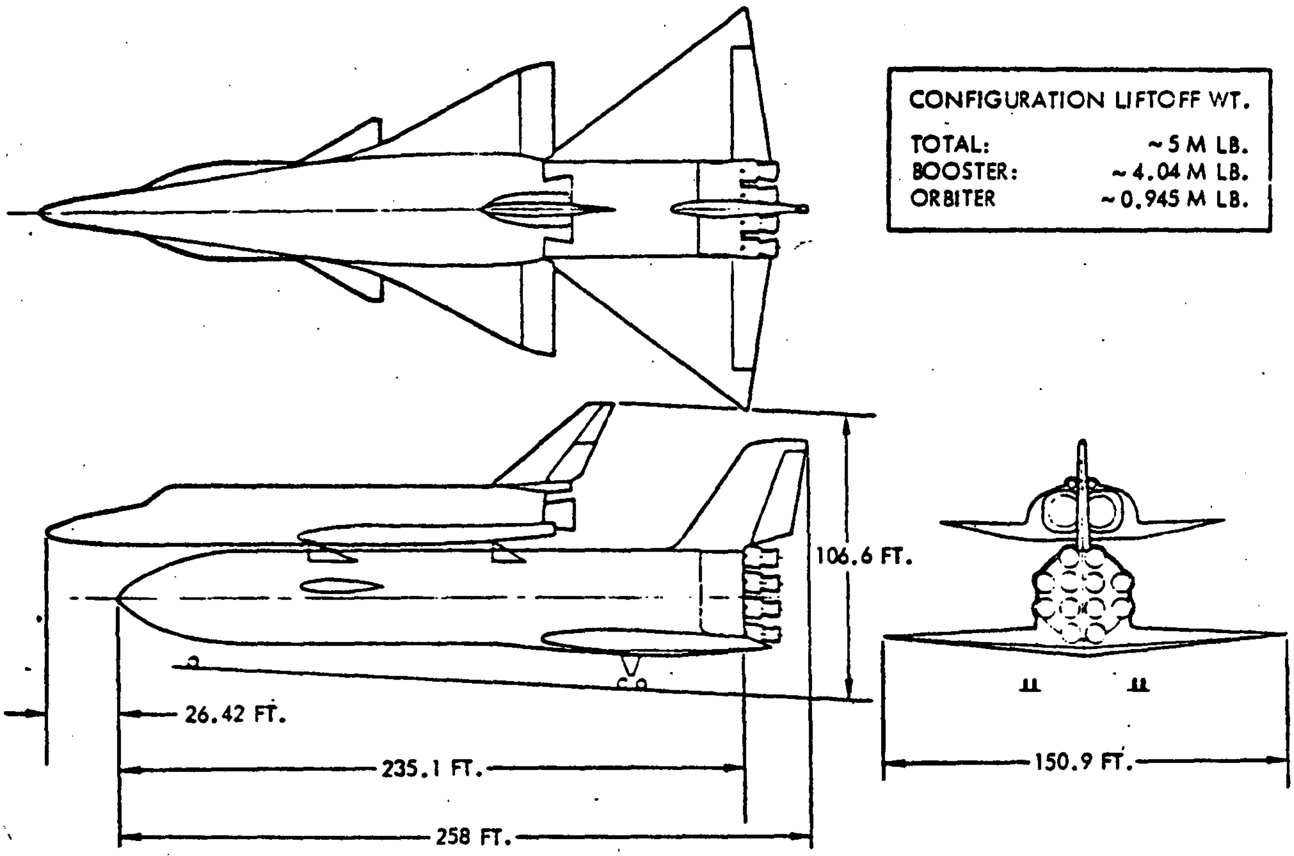


Figure 6-6. Space Shuttle, Booster and Orbiter.

similar engines modified for greater expansion ratio nozzles. Each stage is manned by a crew of two. In addition, the orbiter may carry two cargo masters and eight passengers. Recent NASA direction has changed the primary design mission from space station re-supply (25,000 lb. payload to 270 n.mi. at 55° inclination) to a requirement for 65,000 lb. payload in a 100 n.mi. orbit, due east.

A cylindrical volume, 15 ft. in diameter and 60 ft. long, is provided for the payloads.

Use of the Space Shuttle for high altitude orbital, translunar and/or deep space missions will require the use of the Space Tug for transfer operations. Large payloads will not be compatible with the single-stage reusable vehicles currently envisaged. Such payloads may have to wait for the development of the Nuclear Translunar Shuttle (circa 1982).

7

MISSION ANALYSIS

The function of mission analysis in the ITS Concept Study is to determine the feasibility and desirability of using satellites to satisfy the information transfer demands of the future and to identify viable satellite concepts which are most appropriate for further analysis. Both single purpose and multiple purpose missions were considered:

1. Single Purpose Mission. A single purpose mission is one designed to accommodate a single set of requirements for a single user. The "set of requirements" may conisder only one mode of information transfer (e.g., TV) or may include TV, voice, facsimile and digital data.
2. Multiple Purpose Mission. A multiple purpose mission is one designed to accommodate several sets of requirements for one or more users.

   Under this definition a single user can require a multiple purpose mission where his requirements are for separable purposes, especially when an incremental implementation is envisaged. A typical mission in this category is the Biomedical Communications Network Services where the user is the entire medical community (physicians, dentists, nurses, paramedics, administrators, etc.) in which different segments have different needs.

   The rationale for combining the requirements of several users into one mission includes:

   a. Similar modes of information transfer (e.g., digital data).
   b. Similar bandwidth requirements (e.g., same data rates).
   c. Compatible duty cycles.
   d. Similar modes of operation (e.g., inquiry/response through control center).

Descriptive and background materials for the missions are contained in Technical Appendix E (Vol. III).

7.1 SYSTEM SYNTHESIS

System synthesis was accomplished by means of the Communications System Synthesis Program developed for use on the CDC 6400. It is readily adaptable to the IBM 360. For each system a set of inputs is defined, as shown in Table 7-1. These are processed through the program to develop minimum-cost solutions. System sensitivities to variations in different parameters are derived by perturbing the inputs over the range of interest and developing a solution at each perturbation.

Systems were synthesized, as shown in Table 7-2. These systems are discussed in Sections 7.2 and 7.3.

7.2 SINGLE PURPOSE MISSIONS

7.2.1 TELEVISION SERVICES. This mission group covers all aspects of distribution of commercial (advertisement-supported) and non-commercial (tax and/or private endowment-supported) television programming to the viewing audience of the U.S. Both Direct and Redistribution modes are included. Over 90% of the population can be reached in 224 primary, secondary and tertiary marketing areas of the U.S.

7.2.1.1 Commercial TV Distribution. Several satellite proposals have been submitted by the networks for distribution of their TV programming (commercial).

Their general requirements are listed in Table 7-3. This system was synthesized at 12 GHz to provide adequate bandwidth for the required number of channels. Synthesis of this system yielded a Total System cost of $94.54M/year with $80.25M/year attributed to the ground re-distribution stations (219 ea.). Some details of the system are presented in Table 7-4. Two satellites are provided (1 active and 1 in-orbit spare) at a cost of $72.48M, including development. Each satellite weighs 7,100 lb. and requires a Titan III/Centaur launch vehicle. The unit originating facility cost is $4.61M including 1 Video Tape Recorder (VTR) per channel (6 channels), operations, maintenance and structure for the 10-year system life. This amortizes to $461K/year. The corresponding cost for the receiving facility, including the same elements, is $366K/year.

Table 7-1. Synthesis Program Inputs

TITLE(6)	60H	Title
UDESCR(6)	60H	User Description
NOUSER		User Number
ICASE		Case Identification
BBAUD	*	Base-Band per Audio
ISER	*	Service Identification
BBVID	*	Base-Band per Video
BVEST	*	Vestigial Base Band
NAPV	*	No. of Audio Channels per Video
IBCST	*	Broadcast Service type -- Direct, Redistribution
FAXHEI	*	Facsimile Size -- Height
FAXWID	*	Facsimile Size -- Width
FDNSTY	*	Facsimile Density
FXTIME	*	Facsimile Transmission Time
DRATE	*	Data Rate
NBMS		Number of Beams per Satellite
IFCAP		Facility Capability -- Class 1, 2 or 3
BMWU(2, 6)		Beamwidth, Up
BMWD(2, 6)		Beamwidth, Down
XLAT(6)	*	Beam Center -- Latitude
XLONG(6)	*	Beam Center -- Longitude
XLNGS		Satellite Center - Longitude

* Data Required From Users.

Table 7-1. Synthesis Program Inputs (Continued)

NCHCAU(4)	*	Number of Channels per Carrier -- Up
NCHCAD(4)	*	Number of Channels per Carrier -- Down
NCBUG1(4, 6)	*	Number of Channels per Beam - Ground Up, Class 1
NCATU1(4, 6)	*	Number of Carriers per Transmitter -- Up, Class 1
NCBDG1(4, 6)	*	Number of Channels per Beam -- Ground Down, Class 1
NCBUG2(4, 6)	*	Number of Channels per Beam - Ground Up, Class 2
NCATU2(4, 6)	*	Number of Carriers per Transmitter -- Up, Class 2
NCBDG2(4, 6)	*	Number of Channels per Beam -- Ground Down, Class 2
NCBDG3(4, 6)	*	Number of Channels per Beam -- Ground Down, Class 3
NCBMUS(4, 6)	*	Number of Channels per Beam -- Up, Satellite
NCBMDS(4, 6)	*	Number of Channels per Beam -- Satellite, Down
NCATRD(4, 6)	*	Number of Carriers per Transmitter - Down
SNRG1I(4, 4)	*	Signal-to-Noise Ratio -- Ground, Class 1
SNRG2I(4, 4)	*	Signal-to-Noise Ratio -- Ground, Class 2
SNRG3I(4, 4)	*	Signal-to-Noise Ratio -- Ground, Class 3
ISNRGI (4)	*	Identify Signal-to-Noise Ratio -- Ground
XNGF1(6, 4)	*	Number of Ground Facilities -- Class 1
XNGF2(6, 4)	*	Number of Ground Facilities -- Class 2
XNGF3(6, 4)	*	Number of Ground Facilities -- Class 3
INGR(4)	*	Identify Number of Ground Receivers
IANTG(2)		Identify Ground Antenna Type

Table 7-1. Synthesis Program Inputs (Continued)

IFBND1(4)		Identify Frequency Band -- Uplink
IFBND2(4)		Identify Frequency Band -- Downlink
IMOD1(4)		Identify Modulation Type -- Uplink
IMOD2(4)		Identify Modulation Type -- Downlink
IENVI(4)		Identify Ground Noise Environment
ILIFE(6)		Identify Satellite Life
ICNFIG(8)		Identify Satellite Configuration
ISTRCT		Identify Sturcture Type
IPTYPE(2)		Identify Power Subsystem Type
IBATT(3)		Identify Battery Type
IXMTR(4)		Identify Transmitter Type
ITHRML(2)		Identify Thermal Control System Type
ISTKP(3)		Identify Stationkeeping System Type
IATTCN(4)		Identify Attitude Control System Type
NSAT		Number of Satellites
NSL(8)		Number of Satellites per Launch Vehicle
LSYS	*	System Life
MPFLG		Manned-Provisions Flag
IDATA		Operational -- End of Data Decks
ITMAX		Maximum Number of Iterations
XI(4)		Initial Design Point
ISATT		Operational Re-Read Flags

Table 7-2. Systems Synthesized

MISSION GROUP	SERVICES
1. TELEVISION SERVICES	A. COMMERICAL TV DISTRIBUTION B. CATV DISTRIBUTION
2. REMOTE AREA TELECOMMUNICATIONS	A. ALASKA AND MOUNTAIN STATES B. ALASKA
3. EDUCATIONAL AND INSTRUCTIONAL SERVICES	A. LIBRARY NETWORK B. U.N. MEETINGS C. EDUCATIONAL TELEVISION DISTRIBUTION D. INSTRUCTIONAL TELEVISION 1. PUBLIC SCHOOLS 2. PAROCHIAL SCHOOLS
4. DATA COLLECTION AND DISTRIBUTION	A. NATIONAL DATA BUOY SYSTEMS B. HYDROLOGY C. WEATHER STATION D. OCEAN FISHING E. WILD ANIMAL MIGRATION
5. CIVIC SERVICES	A. CIVIL DEFENSE B. LAW ENFORCEMENT - VIDEO C. LAW ENFORCEMENT - DATA
6. TRAVEL & RECREATIONAL SERVICES	
7. MOBILE SERVICES	A. AIRCRAFT BUSINESS SERVICES/ARINC B. SHIP COMMUNICATIONS
8. MEDICAL NETWORK SERVICES	A. MEDICAL DATA B. MEDICAL VIDEO C. BIOMEDICAL
9. BUSINESS MANAGEMENT SERVICES	A. STOCK QUOTATION B. FEDERAL RESERVE SYSTEM C. CREDIT CARDS
10. DOMESTIC WIDEBAND SERVICES	A. COMPUTER SERVICES B. NASA CENTER-TO-CENTER TELECONFERENCING

Table 7-3. Commercial TV Distribution Requirements

SOURCE LOCATIONS	DESTINATIONS
• New York • Chicago • Denver • Los Angeles	• Each of 223 major metropolitan areas

SYSTEM DESCRIPTION

- 1 Full U.S. Coverage Beam (3^{o} x 7^{o})
- 6 Video Channels per Time Zone (24 total)
- CCIR Relay Quality Signal (S/N = 54 dB)
- 10-Year System Life

Table 7-4. Commercial TV Distribution System Results

• ORIGINATION FACILITIES		
EIRP	73.6 dBW	
G/T	28.0 dB/^{o}K	
ACQUISITION COST		\$ 1.66M
ANNUAL OPERATING COST		1.85
ANNUAL MAINTENANCE COST		1.10
TOTAL (10 YEARS)		\$ 4.61M
• DESTINATION FACILITIES		
G/T	28.0 dB/^{o}K	
ACQUISITION COST		\$ 1.22M
ANNAUL OPERATING COST		1.61
ANNUAL MAINTENANCE COST		.83
TOTAL (10 YEARS)		\$ 3.66M
• SATELLITE (2 REQUIRED)		
EIRP	48.7 dBW	
G/T	2.82 dB/^{o}K	
WEIGHT	7,100 LB.	
ACQUISITION COST		\$31.13M
NON-RECURRING COST		41.35
TOTAL		\$72.48M
• LAUNCH VEHICLE (TITAN III/CENTAUR, 2 REQUIRED)		
ACQUISITION COST		\$42.00M
NON-RECURRING COST		5.40M
TOTAL		\$47.40M

This system was not exercised further as an independent system but was incorporated with other missions in this mission group.

7.2.1.2 CATV Distribution. Discussions with representatives of the National Cable TV Association (NCTA) show this to be a very promising application for a satellite system. Under present FCC rulings CATV systems systems (with more than 3500 are subscribers required to originate programming. While this is probably prohibitive on a local level, a national system is reasonable but would then require a mechanism for distributing the programming. The present CATV market consists of 2,350 systems with 4.5×10^6 subscribers. This market is expected to grow to 5000 systems with as many as 60 x 10 subscribers before 1980.

A satellite system was synthesized for CATV distribution using the requirements shown in Table 7-5. Results for this system are shown in Figure 7-1 and Table 7-6. From these it can be seen that the Total Systen Annual costs are on the order of $600M to $1B depending on the number of TV channels provided. Space Segment Costs (or Implementation costs consisting of the Satellite plus Launch Vehicle) is nominally $30M/year. The difference between this and the Total System Cost is attributable to the Ground Facilities @ $200 - $250K/yr. and 5000 ea. CATV headers @ $100 - $200K/yr.). Each of these ground facilities includes Video Tape Recorders to the extent of approximately $450,000 (including Acquisition, Installation, Operations and Maintenance).

Table 7-5. 1980 CATV Requirements

● 4 ORIGINATING FACILITIES		
	NEW YORK	LOS ANGELES
	CHICAGO	DENVER
6 CHANNELS PER ORIGINATING STATION		
● 5000 DESTINATION FACILITIES		
24 CHANNELS PER SYSTEM		
RELAY QUALITY SIGNAL		
● U.S. COVERAGE SATELLITE ANTENNA (3° x 7°)		
10 YEAR SATELLITE LIFETIME		
12 GIGAHERTZ OPERATION		

The resulting satellite is large. It weighs 26,250 lbs., generates 51 KW initial prime power and is orbited by a Saturn V launch vehicle.

Figure 7-2 shows the effect on this system of varying the number of ground facilities. The Total System Cost for 2,350 CATV headers (1970-71) is

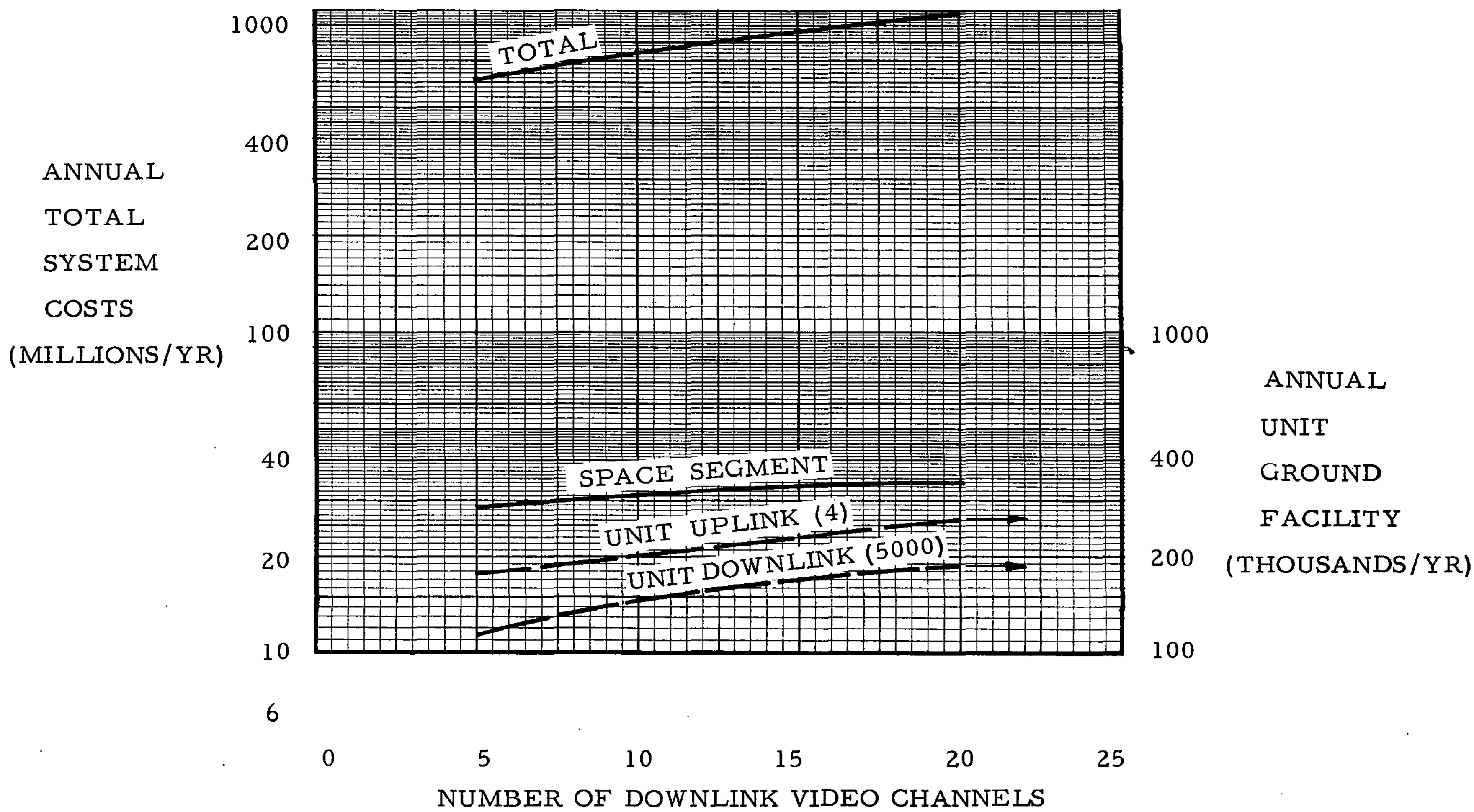


Figure 7-1. CATV System Costs (5000 Ground Facilities)

Table 7-6. CATV System Results (20 TV Channels)

• ORIGINATING FACILITIES		
EIRP	73.6 dBW	
G/T	17.9 dB/^{o}K	
ACQUISITION		1.01 M
ANNUAL OPERATING		0.97 M
ANNUAL MAINTENANCE		0.06 M
TOTAL (10 YRS)		\$2.90 M
• DESTINATION SYSTEMS		
G/T	17.9 dB/^{o}K	
ACQUISITION		\$0.51 M
ANNUAL OPERATING		0.10 M
ANNUAL MAINTENANCE		0.02 M
TOTAL		\$1.87 M
• SATELLITE		
EIRP	58.8 dBW	
G/T	2.8 dB/^{o}K	
WEIGHT	26,250 LBS	
ACQUISITION		\$ 60.3 M
NON-RECURRING		61.4 M
TOTAL		\$121.7 M
• LAUNCH VEHICLE (SATURN V)		
ACQUISITION		\$188.2 M
NON-RECURRING		25.0 M
TOTAL		\$213.2 M

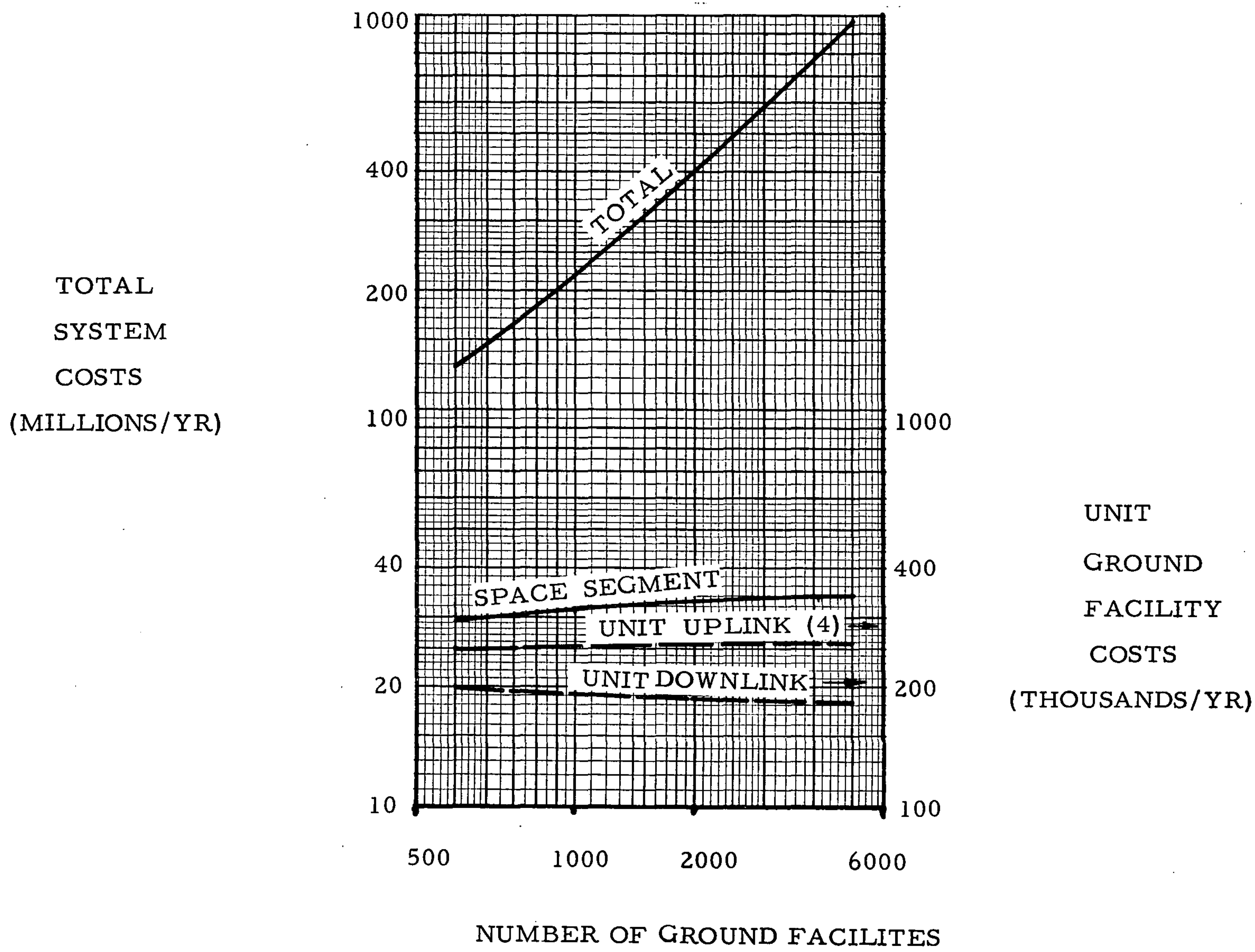


Figure 7-2. CATV System Costs (20 Downlink Channels)

$460M/year - approximately 50% of the previously stated cost. Other costs remain relatively unchanged because of no change in service requirements.

7.2.1.3 TV Network Distribution. This mission is well-defined and substantiated by the previous LMSC and SRI studies in terms of the scope, topology and channel requirements. It is similar to the Commercial TV system discussed previously (Section 7.2.1.1) but differs to the extent that both commercial and noncommercial TV programming is included here. As shown in Table 7-7 the system distribution 12 channels of TV to each of the 4 time zones of the CONUS in 1980. Other areas of the U.S. (Alaska, Hawaii, etc.) can be accommodated by switching beams.

Table 7-7. U.S. TV Network Requirements

SOURCE LOCATIONS

- NEW YORK
- CHICAGO
- DENVER
- LOS ANGELES

DESTINATIONS

- EACH OF 223 MAJOR METROPOLITAN AREAS

SYSTEM DESCRIPTION

- 4 DOWNLINK BEAMS (ONE PER TIME ZONE)
- 12 CHANNELS PER TIME ZONE
  - COMMERCIAL - 6
  - INSTRUCTIONAL - 4
  - CULTURAL - 1
  - RESERVE - 1
- CCIR RELAY QUALITY (S/N = 54 dB)
- 10 YEAR SYSTEM LIFE

Results for this system are shown in Figures 7-3 and 7-4.

Figure 7-3 shows only a slight improvement for using a 2.5 GHz downlink despite the exaggerated Total Cost scale. This is typical of those systems where the ground system costs dominate the total costs to the extent of dampening any trade-off advantages. Here a Video Tape Recorder (VTR) is postulated for each channel. Deleting the VTR's, thereby reducing the Unit Ground Receiver Facility cost to $234K/year, nominal, results in a Total Cost reduction of approximately $160M/yr. to $63.38M/yr.

Figure 7-4 shows the increasing systems costs with increasing numbers of channels.

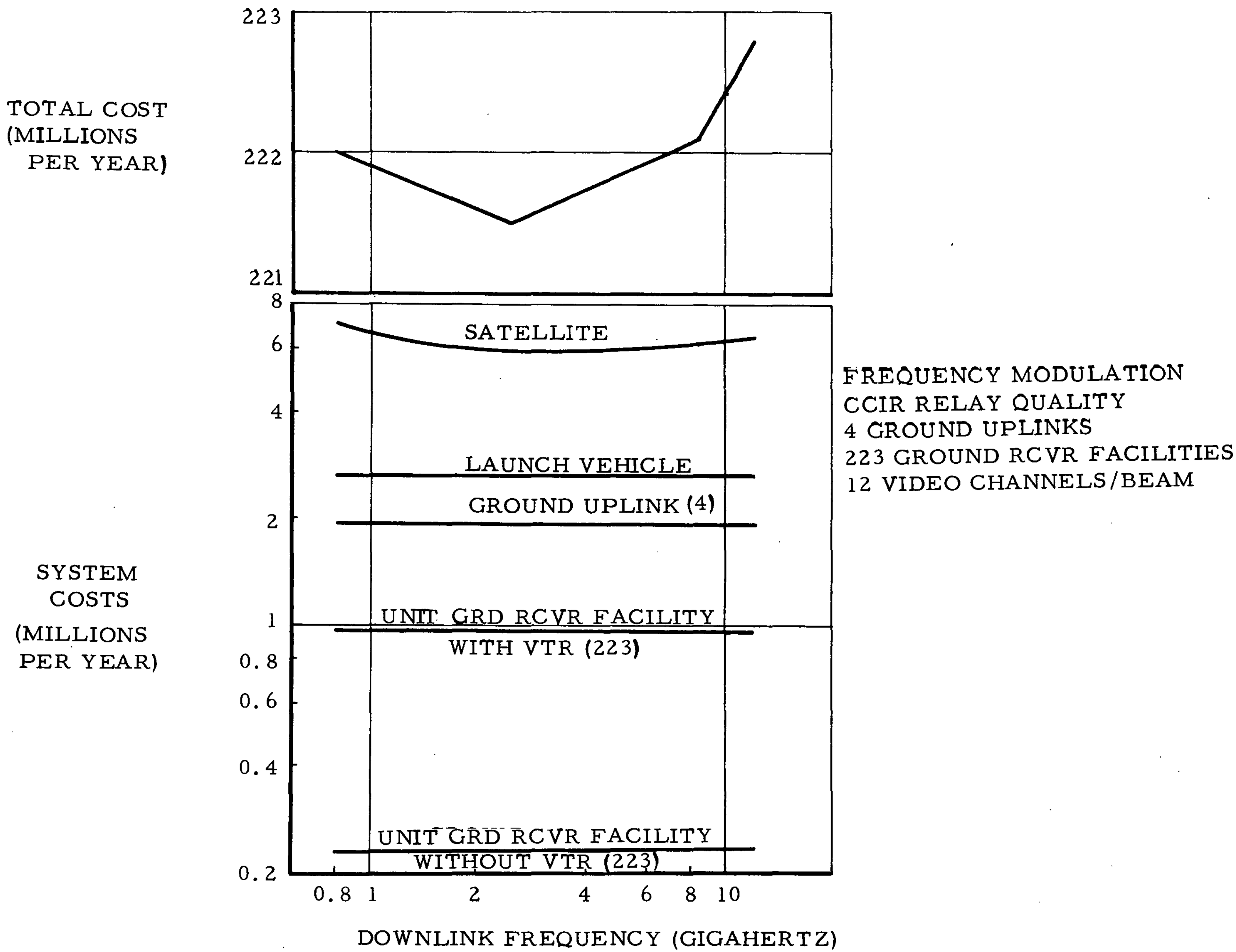


Figure 7-3. U.S. Television Network - System Cost Sensitivity to Frequency

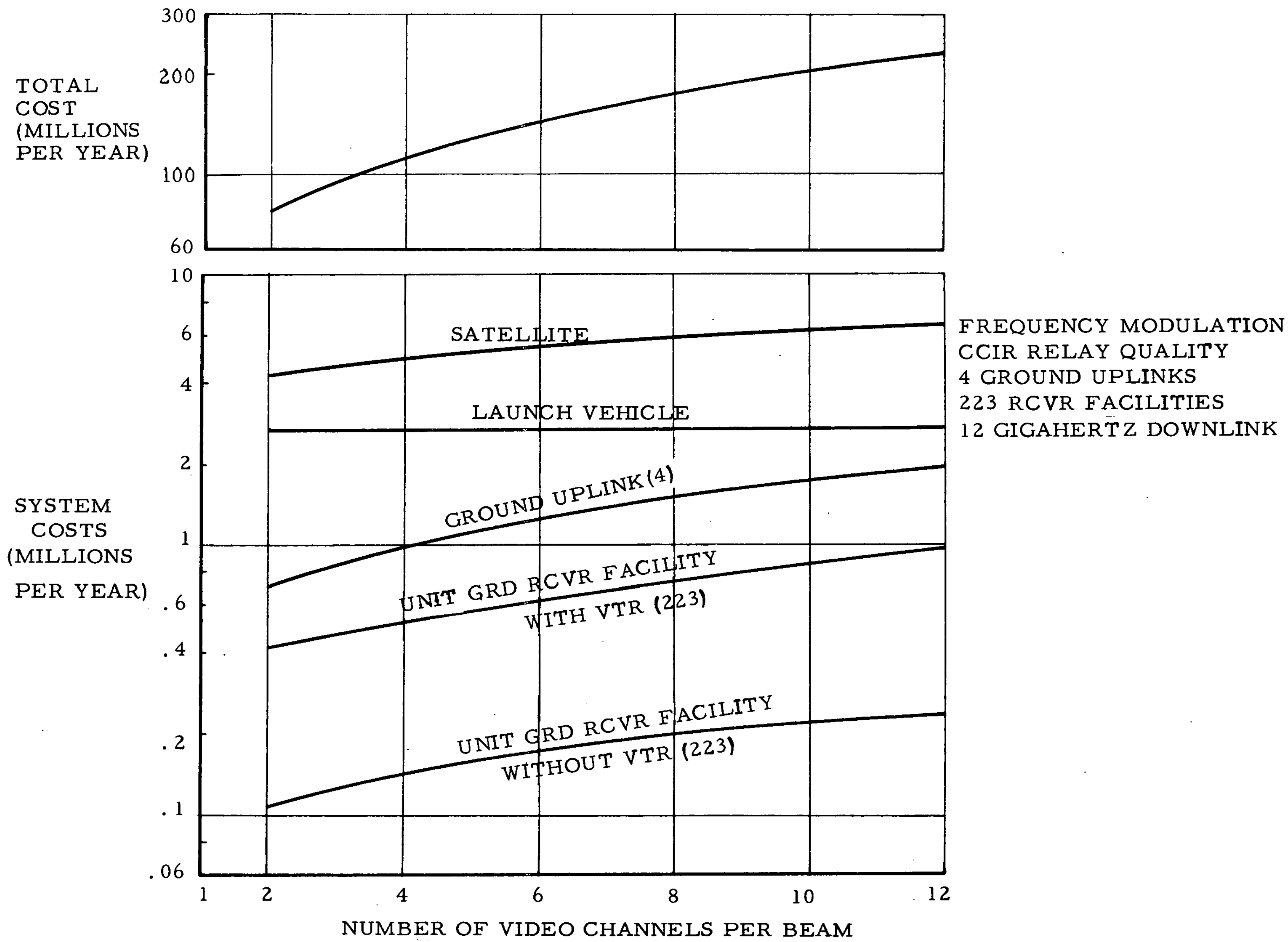


Figure 7-4. U.S. Television Network - System Cost sensitivity to Number of Channels

7.2.2 REMOTE AREA TELECOMMUNICATIONS. The objective of this mission group is to provide general utility and entertainment communications services to remote areas which are not adequately served by terrestrial systems. While intuitively clear for Developing Nations this situation is also ture for parts of Developed Nations where by reason of low population density, rugged terrain and adverse climate, terrestrial systems are not economically viable. Such areas are Alaska and parts of the western states in the U.S. and the Outback of Australia.

7.2.2.1 Alaska and the Western States. This system developed from the growing awareness of the inadequate services in Alaska. Initial emphasis was placed on the lack of TV coverage for Alaska and the western states (New Mexico, Arizona, Nevada, Utah, Colorado, Wyoming, Idaho and Montana). As the system was defined it became equally clear that extensive telephony is also needed for the Alaska interior. The system analyzed was based on the requirements shown in Table 7-8. This constitutes a fairly elaborate system reaching all of the communities in Alaska with populations greater than 100 and close to 3,000 communities in the western states. Eleven channels of TV were provided, as shown. 1,200 telephony channels were included for Alaska. This system was synthesized for four frequency

Table 7-8. Alaska and Mountain States Requirements

SOURCE LOCATIONS		DESTINATIONS	
• VIDEO	- 2 IN ALASKA	• VIDEO	- 438 IN ALASKA
	- 8 IN MOUNTAIN STATES		- 2,978 IN MOUNTAIN STATES
• VOICE GRADE	- 438 IN ALASKA	• VOICE	- 438 IN ALASKA

SYSTEM DESCRIPTION

- 2 DOWNLINK BEAMS
- 11 VIDEO CHANNELS/BEAM
  - 8 INSTRUCTIONAL/EDUCATIONAL
  - 3 ENTERTAINMENT
- 1,200 VOICE GRADE CIRCUITS FOR ALASKA
- CCIR RELAY QUALITY
- COMMUNITY RECEIVERS FOR LESS THAN 100 POPULATION
- REDISTRIBUTION FOR GREATER THAN 100

bands: 0.8, 2.5, 8.4 and 12.2 GHz and results are shown in Figure 7-5. The system shown assumed that each community in Alaska has its own telephony uplink/downlink facility. The major uplink/downlink facilities costs represent Alaskan communities with populations greater than 100 with redistribution capability to individual homes. The minor uplink/downlink facilities offer community receivers without distribution for communities of population less than 100. Similarly, the Mountain States major distribution facilities are for greater than 100 populations and the minor facilities are for community receivers, less than 100. Since the ground transmission/reception facilities are such a large portion of the total system cost, the minimum system cost minimizes at the frequency where the ground receivers are least expensive -- 0.8 GHz. The satellite cost at 8.4 and 12.2 GHz levels off at $7 million per year, since the satellite is bounded by the launch vehicle payload capability of 7,100 pounds.

Further synthesis runs were made for Alaska TV only. Essentially the same TV coverage was provided as before namely 11 channels of TV to 438 communities. The effect of varying the number of communities served is shown in Figure 7-6. With all other factors remaining essentially constant the Total System cost increases from $100M/year for 100 communities to $800M/year for 1000 communities to reflect the additional ground facility costs. Holding the number of communities constant at 438 and varying the number of TV channels provided from 1 to 11 results in a Total System cost increase from $100M/year to $400M/year (as previously) as shown in Figure 7-7. The The increases in ground facility costs directly reflect the additional equipment, operations and maintenance for the increased number of channels.

7.2.2.2 Alaska. Further consideration was given to providing a satellite system for Alaska only. This analysis was undertaken in support of the Public Service Commission hearings (June 1970) and was based on inputs provided by the Department of Commerce (Table 7-9). As shown, three cases were considered. The first and second cases differ both in the station arrangement and in the telephony and TV services offered. Case 3 was the same as Case 2 except it was constrained to use Intelsat type ground stations with 42-ft. diameter antennas. Results for these cases are shown in Tables 7-10, 7-11 and 7-12. Table 7-10 shows a Total System Cost of $186.2M as compared to $114.4M for the Case 2 reduced service and rearranged topology.

Table 7-9. Alaska Telecommunications System Requirements

STATION CLASS	NO. TELEPHONY CIRCUITS		NO. VIDEO CHANNELS				NUMBER OF STATIONS	
	CASE 1	CASE 2	CASE 1		CASE 2		CASE 1	CASE 2
			R	T	R	T		
1	240	120	1-3	1-3	1	1	3	1
2	120	48	1-3	-	1	-	8	4
3	24	24	1-3	-	1	-	50	5
4	1	1	1	-	1	-	200	250

NOTE: CASE 3 — SAME AS CASE 2 EXCEPT CONSTRAINED TO INTELSAT TYPE GROUND STATIONS

The antenna diameter for Class I, Class II and Class III stations optimized at 15.5 ft. Table 7-12 shows these diameters constrained to 42 ft. with an increase in Total System cost to $185.7M. The corresponding changes in the satellite systems are noted. In each case 2 satellites were provided (1 active plus 1 in-orbit spare).

An overall summary of system costs is shown in Figure 7-8. It shows the effect of varying the number of TV channels provided for two arrangements of ground stations.

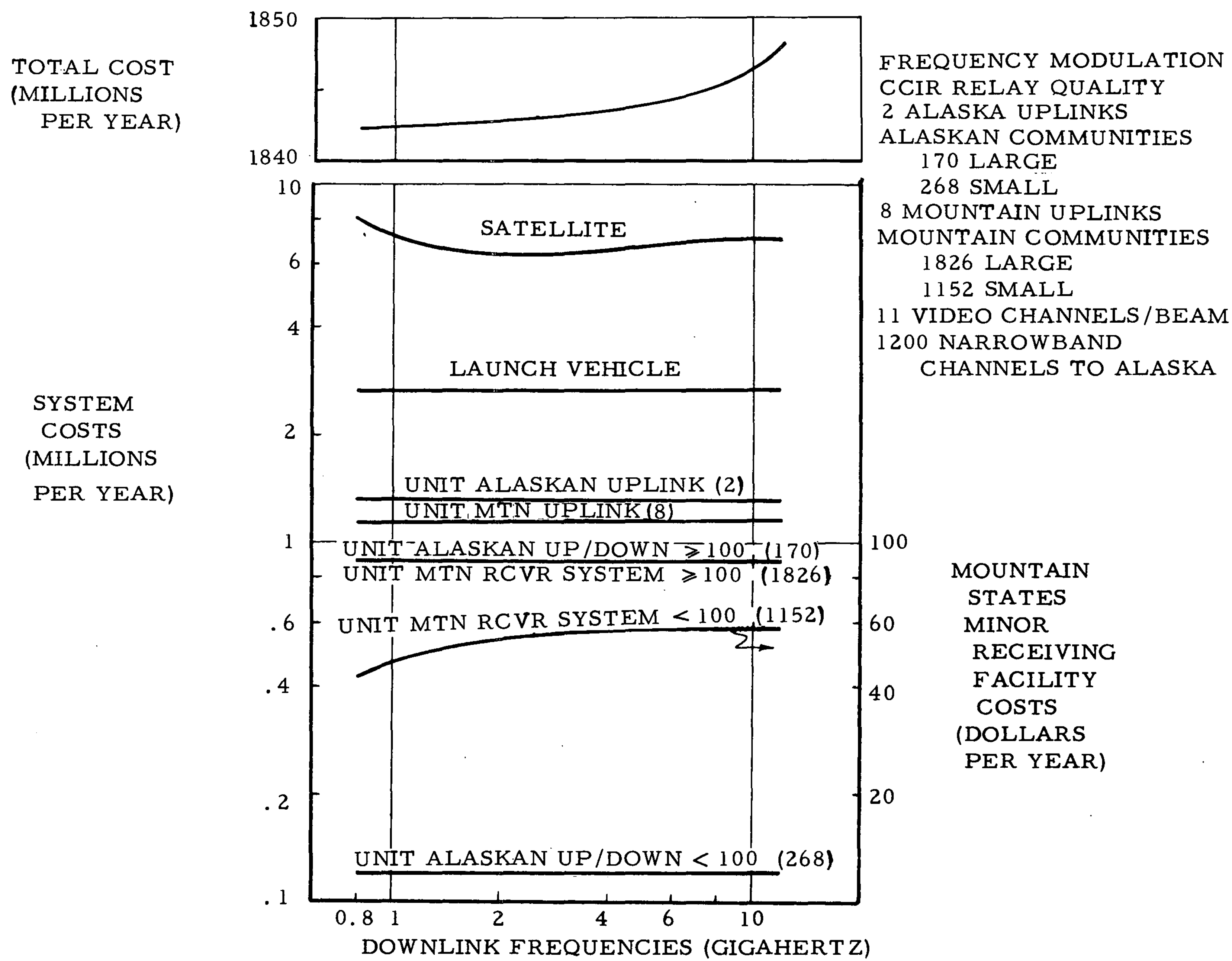


Figure 7-5. Alaska and Mountain States Communications Service - System Cost Sensitivity to Frequency

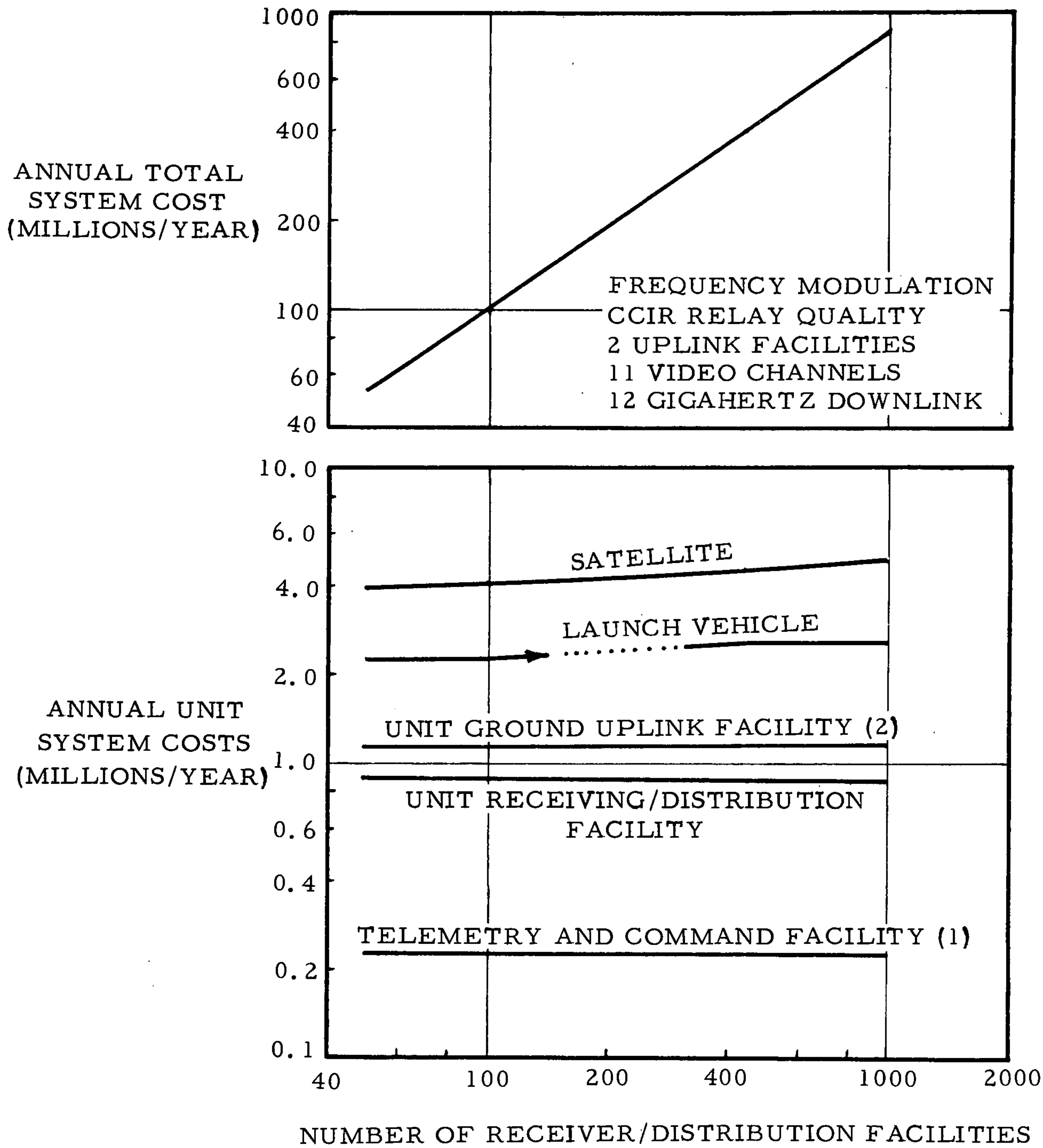


Figure 7-6. Alaska ETV/ITV System - System Cost Sensitivity to Number of Facilities

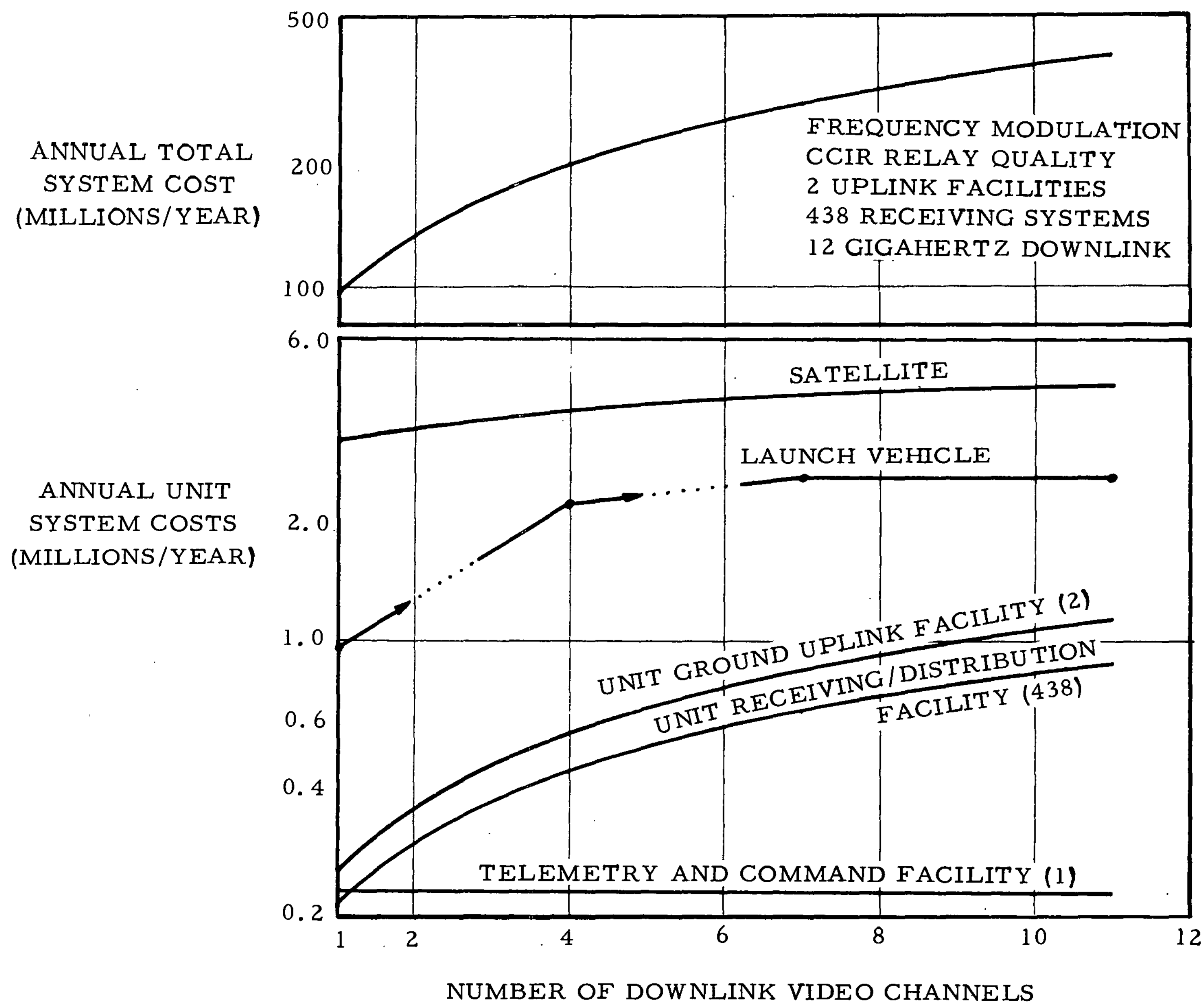


Figure 7-7. Alaska ETV/ITV System - System Cost Sensitivity to Number of Video Channels

Table 7-10. Alaska, Case 1 Results

	Class 1	Class 2	Class 3	Class 4	Satellite	Launch Vehicle	Total
No. of Stations	3	8	50	200			
Unit Costs:							
Initial	$ 8.43M	$758K	$157K	$ 68K	$15.6M	$21.0M	
Annual	.72M	73K	18K	7K	38.1M	5.4M	
Total/Station (10 years)	$15.64M	$ 1.49M	$338K	$141K	$53.6M	$26.4M	
Total System (10 years)	$46.92M	$11.78M	$16.95M	$28.20M	$53.6M	$26.4M	$186.2M*

*Includes $2.29M Telemetry/Command Subsystems in one class 1 station.

Table 7-11. Alaska, Case 2 (Unconstrained) Results

	Units	Class I	Class II	Class III	Bush	Satellite	Launch Vehicle
EIRP	DBW	54.1 Voice	54.1	54.1	42.4	60.4 (Video + Voice)	
		29.4 Bush 75.4 Video				45.0 (Voice)	
G/T	dB/^oK	13.2	13.2	13.2	8.3	5.7	
Antenna Diameter	ft	15.5	15.5	15.5	8.7	6.1	
RCVR Noise Figure	dB	7.1	7.1	7.1	7.1	6.0	
Costs-Initial	$	1.24M	370K	180K	76K	7.0M(Unit Sat)	21.0M
Annual	$/yr	218K	32K	19K	9K	25.7M (R&D)	5.4M
Weight	Lbs	——				1530 /Sat)	
Total Unit Costs (10 Years)	$M	3.42	0.69	0.37	0.16	39.71	26.4
No. of Stations		1	4	5	250	2	1
Total Costs (10 Years)	$M	3.42	2.77	1.86	40.25	39.71	26.40
Total System Costs (10 Years)	$M	114.41					

Figure 7-12. Alaska, Case 3 (Constrained) Results

	Units	Class I	Class II	Class III	Bush	Satellite	Launch Vehicle
EIRP	dBW	56.6 Voice	56.6	56.6	44.9	41.9 (Video + Voice)	
		47.6 Bush 77.9 Video				26.5 (Voice)	
G/T	dB/^{o}K	31.7	31.7	31.7	26.7	2.5	
Antenna Diameter	Ft	42	42	42	23	3.3	
RCVR Noise Figure	dB	0.7	0.7	0.7	0.7	6.0	
Costs-Initial	$	1.78M	710K	440K	190K	6.2M (/Sat)	11.40M
Annual	$/yr	292K	73K	50K	23K	22,5M (R&D)	18.5M
Weight	Lbs					890 /Sat	
Total Unit Costs (10 Years)	$M	4.70	1.44	0.94	0.42	34.9	29.90M
No. of Stations		1	4	5	250	2	1
Total Costs (10 Years)	$M	4.70	5.74	4.72	105.7	34.9	29.90
Total System Costs (10 Years)	$M	185.7					

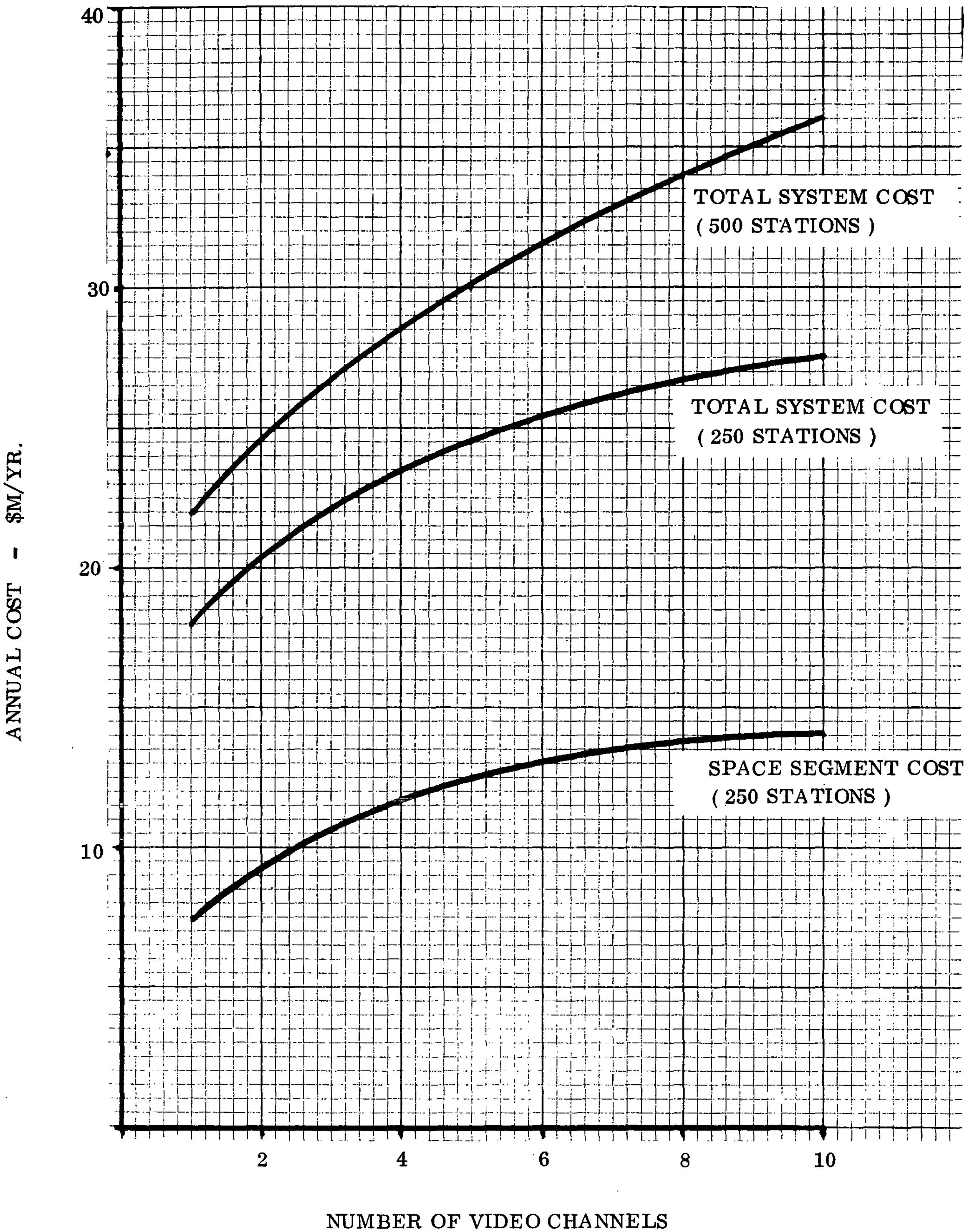


Figure 7-8. Alaska Communications Results

7.2.3 EDUCATIONAL AND INSTRUCTIONAL SERVICES. The intent of this mission group is to provide the multi-mode (audio, video, facsimile, digital data) telecommunications services needed for educational and instructional purposes. In this context "instructional" is applied to formal classroom training and "educational" is applied to informal activities such as enrichment cultural courses, public interest affairs and adult/professional continuing education. Television is emphasized only because it represents the larger, more demanding requirements.

7.2.3.1 Library Network (03A). This system is derived from the LMSC study — Demand db 065. Table 7-13 shows the system requirements taken from the LMSC Demand Profile. It shows an all-digital data system to interconnect 70 major library centers. Under the LMSC designation these would be Business Libraries.

Table 7-13. Library Network requirements

GROUND FACILITIES
● 70 Library Centers
● 20 Circuits/Library
● 4.8 K-Baud/Circuit
SYSTEM DESCRIPTION
● CONUS Coverage Beam (3° × 7°)
● 10 Year System Life
● 600 Circuits Through the Satellite
● 10 Year Satellite Life

Results for this system are presented in Table 7-14. Each of the ground facilities is identical with the others and has the capability to transmit and receive 20 digital data channels. Unit acquisition costs for each facility is $237.7K, but when operations and maintenance for the system life are included the cost of each facility becomes $717.4K.

Two satellites are used to support this system — 1 active and 1 in-orbit spare. Costs of these satellites is $27.06M including acquisition and R&D. Each satellite weighs 1,136 lb and can be orbited by an SLV-3X/Centaur launch vehicle. Cost for two launch vehicles is $39.90M.

Total cost for this system, including all of the above elements, is $122M, or $12.2M/Year.

Table 7-14. Library Network Results

● GROUND FACILITIES		
EIRP	45.8 dBW	
G/T	20.1 dB/°K	
ACQUISITION COST		$ 237.7K
ANNUAL OPERATING COST		374.6
ANNUAL MAINTENANCE COST		105.1
	TOTAL (10 YEARS)	$ 717.4K
● SATELLITE (2 REQUIRED)		
EIRP	45.3 dBW	
G/T	2.82 dB/°K	
WEIGHT	1,136 LB	
ACQUISITION COST		$ 6.99M
NON-RECURRING COST		20.07
	TOTAL	$ 27.06M
● LAUNCH VEHICLE (SLV-3X/CENTAUR: 2 REQUIRED)		
ACQUISITION COST		$ 24.40M
NON-RECURRING COST		15.50
	TOTAL	$ 29.90M

7.2.3.2 United Nations Meetings (03B). This system was also derived from the LMSC study — Demand No. 114. Table 7-15 shows the system requirements taken from the LMSC Demand Profile. It reflects the need for 1 TV channel broadcast directly to 1 million viewers. Results for this system are summarized in Table 7-16.

Table 7-15. U. N. Meetings Requirements

SOURCE	DESTINATIONS
● New York City	● 1×10^6 TV Receivers (direct-to-home)
	● TASO 1 Quality (S/N = 44.5 dB)

SYSTEM DESCRIPTION

● CONUS Coverage Beam (3° × 7°)	● 1 Video Channel
● 10 Year System Life	● 10 Year Satellite Life

Table 7-16. U. N. Meetings Results

● ORIGINATING FACILITY			
	EIRP	39.7 dBW	
	G/T	--	
	ACQUISITION COST		$ 440.52K
	ANNUAL OPERATING COST		490.6
	ANNUAL MAINTENANCE COST		271.8
		TOTAL (10 YEARS)	$ 1.2M
● DIRECT RECEIVER			
	G/T	-10.49 dB/°K	
	ACQUISITION COST		$ 107.8
	ANTENNA	$57.5	
	RECEIVER	$50.3	
	MAINTENANCE/YEAR		$ 4.77
● SATELLITE			
	EIRP	56.9 dBW	
	G/T	3.49 dB/°K	
	WEIGHT	1,690 LB	
	ACQUISITION COST		$ 4.24M
	NON-RECURRING COST		24.43
		TOTAL	$ 28.67M
● LAUNCH VEHICLE (SLV-3X/CENTAUR)			
	ACQUISITION COST		$ 12.2M
	NON-RECURRING COST		15.5
		TOTAL	$ 27.7M

The transmitting facility in New York costs $440.52K to acquire. Including operations and maintenance this cost grows to $1.2M over the 10 year lifetime. Direct reception of the viewer's home requires augmentation of his TV set to the extent of an antenna and a pre-amplifier/modulation converter at a cost of $107.8, including installation. Ten per cent of the "purchase price" is attributed to the maintenance of this equipment each year.

A reasonably small satellite,at 1,690 lb., can accommodate this mission. Acquisition (recurring) cost for this satellite is $4.24M. $24.43M R&D is required bringing the total satellite cost to $28.67M. This satellite can be orbited by the SLV-3X/Centaur launch vehicle for a total cost of $27.7M. A high non-recurring cost is shown for the vehicle pending the development of flight history.

7.2.3.3 ITV for Parochial Schools (03C). Considerable interest has been expressed by the parochial schools in the extension of their diocesan systems to a national system. Two cases were examined. The first provides 2 channels of TV to each of the 4 CONUS time zones. Reception is at the diocese level — 174 dioceses. In the second case reception was at the school level — 14,000 schools. System requirements are presented in Table 7-17.

Table 7-17. ITV Requirements for Parochial Schools

SOURCE	DESTINATIONS CASE 1	DESTINATIONS CASE 2
● New York	● 174 Dioceses	● 14,000 Parochial Schools

SYSTEM DESCRIPTION

1 U. S. Coverage Beam (3° × 7°)
2 TV Channels/Time Zone (8 Total)
10 Year System Life
10 Year Satellite Life

Results for these systems are summarized in Table 7-18. As expected, the direct transmission to the schools is an order of magnitude greater than the transmission to the dioceses ($6520M compared to $225M) because of the increased number of ground facilities — even though, on a unit to unit comparison, the parochial school receiving system is half the price of the diocesan receiving system. The satellite in Case 2 assumes a larger share of the communications function but still remains within the payload capability of the Titan 3/Centaur launch vehicle.

Total system cost for these systems make them too prohibitive for consideration. A shared system is discussed in Section 7.3.3.

7.2.3.4 ITV for Public Schools (03D). Many systems have been discussed for this mission. As shown in Table 7-19, this particular set of requirements has been arranged to provide a full 8-grade curriculum for public schools throughout the U. S.

Table 7-18. ITV/Parochial Schools, Results

	CASE 1	CASE 2
● ORIGINATING FACILITIES		
EIRP (dBW)	64.4	64.4
G/T	--	--
ACQUISITION COST	$761K	$606K
ANNUAL OPERATING COST	$1.04M	$860K
ANNUAL MAINTENANCE COST	$423K	$311K
TOTAL (10 YEARS)	$2.22M	$1.78M
● DESTINATION FACILITIES		
G/T (dB/°K)	24.8	14.2
ACQUISITION COST	$301K	$124K
ANNUAL OPERATING COST	$484K	$301K
ANNUAL MAINTENANCE COST	$168K	$ 36K
TOTAL (10 YEARS)	$953K	$461K
● SATELLITE		
EIRP (dBW)	45.7	56.3
G/T (dB/°K)	2.82	2.82
WEIGHT (LB)	1,853	7,100
ACQUISITION COST	$5.42M	$10.88M
NON-RECURRING COST	$23.61M	$34.60M
TOTAL	$29.03M	$45.48M
● LAUNCH VEHICLE (TITAN 3/CENTAUR)		
ACQUISITION COST	$21.0M	$21.0M
NON-RECURRING COST	$5.4M	$5.4M
TOTAL	$26.4M	$26.4M

Table 7-19. ITV Requirements for Public Schools

SOURCES	DESTINATIONS: CASE 1	DESTINATIONS: CASE 2
● 1 Per CONUS State, plus Washington, D.C.	30,000 School Districts	300,000 Schools

SYSTEM DESCRIPTION

- 4 Beams (1/Time Zone)
- 8 TV Channels/Time Zone (32 Total)
- 10 Year Satellite Life
- 10 Year System Life

It was postulated to establish a preliminary estimate of where a future operational system might locate itself economically. Results are summarized in Table 7-20.

Table 7-20. ITV/Public Schools, Results

	CASE 1	CASE 2
● ORIGINATING FACILITIES		
EIRP (dBW)	68.6	68.6
G/T (dB/°K)	17.3	13.4
ACQUISITION COST	$495K	$350K
ANNUAL OPERATING COST	$627K	$446K
ANNUAL MAINTENANCE COST	$276K	$166K
TOTAL (10 YEARS)	$1.4M	$962K
● DESTINATION FACILITIES		
G/T (dB/°K)	10.5	6.6
ACQUISITION COST	$423K	$200K
ANNUAL OPERATING COST	$782K	$601K
ANNUAL MAINTENANCE COST	$176K	$ 56K
TOTAL (10 YEARS)	$1.4M	$857K
● SATELLITE		
EIRP (dBW)	59.7	63.6
G/T (dB/°K)	8.24	8.24
WEIGHT (LB)	17,430	34,642
ACQUISITION COST	$26.14M	$40.27M
NON-RECURRING COST	$55.04M	$73.94M
TOTAL	$81.18M	$114.21M
● LAUNCH VEHICLE (SATURN V)		
ACQUISITION COST	$188.2M	$188.2M
NON-RECURRING COST	$25.0M	$25.0M
TOTAL	$213M	$213M

The elements shown accumulate to a total system cost of $40B for Case 1 and $257B for Case 2. This large increase reflects the order of magnitude increase in receiving systems. These values indicate the dominance of the ground systems. They would be prohibitive at this time.

7.2.3.5 ETV Distribution (03E). Table 7-21 shows the system requirements for this mission which is designed to distribute ETV to the existing ETV stations throughout the U. S.

Table 7-21. ETV Distribution Requirements

SOURCES	DESTINATIONS
● New York ● Los Angeles	● 221 ETV Stations (Present "on the Air" & Applications)

SYSTEM DESCRIPTION

- 1 CONUS Coverage Beam (3° × 7°)
- 3 Video Channels per Time Zone (12 Total)
- 10 Year System Life
- 10 Year Satellite Life

Total system cost for this mission is $317M. Details are summarized in Table 7-22.

7.2.4 DATA COLLECTION AND DISTRIBUTION. The objective of this mission group is to provide the communications services required for the collection of data from remote sensing platforms of all types, such as ocean buoys, hydrological monitors and weather stations.

7.2.4.1 National Data Buoy System. The large expanse of ocean area poses a particularly difficult task for obtaining synoptic oceanographic and near surface meteorological data. Weather satellites provide a large quantity of data not heretofore available. These data, however, are not synoptic over a major ocean region nor are sensors available to permit satellite collection of all data of interest. The method that presently seems feasible to survey conditions virtually over the earth within a short period (an hour or less) is a system of instrumental buoys interrogated by and responding to a central station via geostationary relay satellites. The system to be described may employ full earth coverage or northern hemisphere satellite antennas. The buoy deployment proposed over northern hemisphere oceans may be expanded to cover southern ocean areas if full earth coverage antennas are used.

1. Baseline System Description. The buoy system is envisioned to contain three buoy types. A high capability (HCB) moored buoy collects up to 8000 bits of information responding upon address at a rate of 2000 bps. A low capability moored buoy (LCBM) collecting 2000 bits and responding at 200 bps. A low capability drifting buoy (LCBD) collecting 1000 bits and responding at 200 bps. Table 7-23

Table 7-22. ETV Distribution Results

● ORIGINATING FACILITIES		
EIRP	73.6 dBW	
G/T	25.5 dB/°K	
ACQUISITION COST		$633K
ANNUAL OPERATING COST		$732K
ANNUAL MAINTENANCE COST		$372K
	TOTAL (10 YEARS)	$1.7M
● DESTINATION FACILITIES		
G/T	25.5 dB/°K	
ACQUISITION COST		$343K
ANNUAL OPERATING COST		$555K
ANNUAL MAINTENANCE COST		$195K
	TOTAL (10 YEARS)	$1.1M
● SATELLITE		
EIRP	51.2 dBW	
G/T	2.82 dB/°K	
WEIGHT	5,046 LB	
ACQUISITION COST		$10.17M
NON-RECURRING COST		$37.94M
	TOTAL	$43.11M
● LAUNCH VEHICLE (TITAN 3/CENTAUR)		
ACQUISITION COST		$21.0M
NON-RECURRING COST		$5.4M
	TOTAL	$26.4M

describes a complete ensemble of buoys and the interrogation, readout and prescribed error rates. The distribution of drifting buoys is shown equal in the North Atlantic and Pacific. However, this is a user's operational decision to plan use of drifting buoys.

The shared satellite/dedicated transponder was also selected for growth capability. The transponder will relay two channels of data, one for the HCB data and one for LCB data. The satellites are positioned over the respective regions of coverage such that one ground facility may view both satellites. Figure 7-9 shows the ocean coverage resulting for northern hemisphere use only.

Table 7-23. Baseline Systems

NUMBER OF BUOYS:	
HIGH CAPABILITY (HCB)	300
LOW CAPABILITY — MOORED (LCB-M)	100
LOW CAPABILITY — DRIFTING (LCB-D)	100
250 — NORTH ATLANTIC	
250 — NORTH PACIFIC	
DATA REQUIREMENTS AND RATES:	
HCB DATA 8000 BITS AT	2000 BITS/SEC
LCB-M DATA 2000 BITS AT	200 BITS/SEC
LCB-D DATA 1000 BITS AT	200 BITS/SEC
BIT ERROR RATES:	
HCB — GROUND (RESPONSE)	1 BIT/10^5 BITS
LCB — GROUND (READOUT)	1 BIT/10^4 BITS
GROUND — HCB (INTERROGATION)	1 BIT/10^6 BITS
LINK MARGINS	6 db
TOTAL INTERROGATION/READOUT TIMES:	
4.8 SECONDS PER HCB 15 MINUTES TOTAL	
5.3 SECONDS PER LCB 23 MINUTES TOTAL	
(INCLUDES 8.5 SECOND TIMING ERROR)	
SATELLITE (CONSIDERING SHARED SATELLITE/DEDICATED TRANSPONDER-ANTENNA)	
2 CHANNELS PER TRANSPONDER	
2 SATELLITES PLUS 2 BACKUP SATELLITES	
FULL EARTH COVERAGE BEAMS	

2. Synthesized Baseline Systems. Frequency control and allocation prohibits use of frequency as an independent variable. Systems were synthesized for the VHF, UHF, L and S-bands. An additional system (designated L-band/S-band cross-strapped system) operated in S-band for uplinks and L-band for downlinks. The systems synthesis led to selecting the UHF-band as the most desirable for the system mission at low costs. From the point of view of frequency availability for allocation, the S-band was selected as a secondary system.

3. Cost Sensitivities Resulting from Synthesis. The system costs are strongly dependent upon frequency. It has been mentioned that frequency allocation may prevent selecting the frequency for lowest costs. In addition, cost of the buoy communications equipment for high data rate capability is 4 to 5 times that for

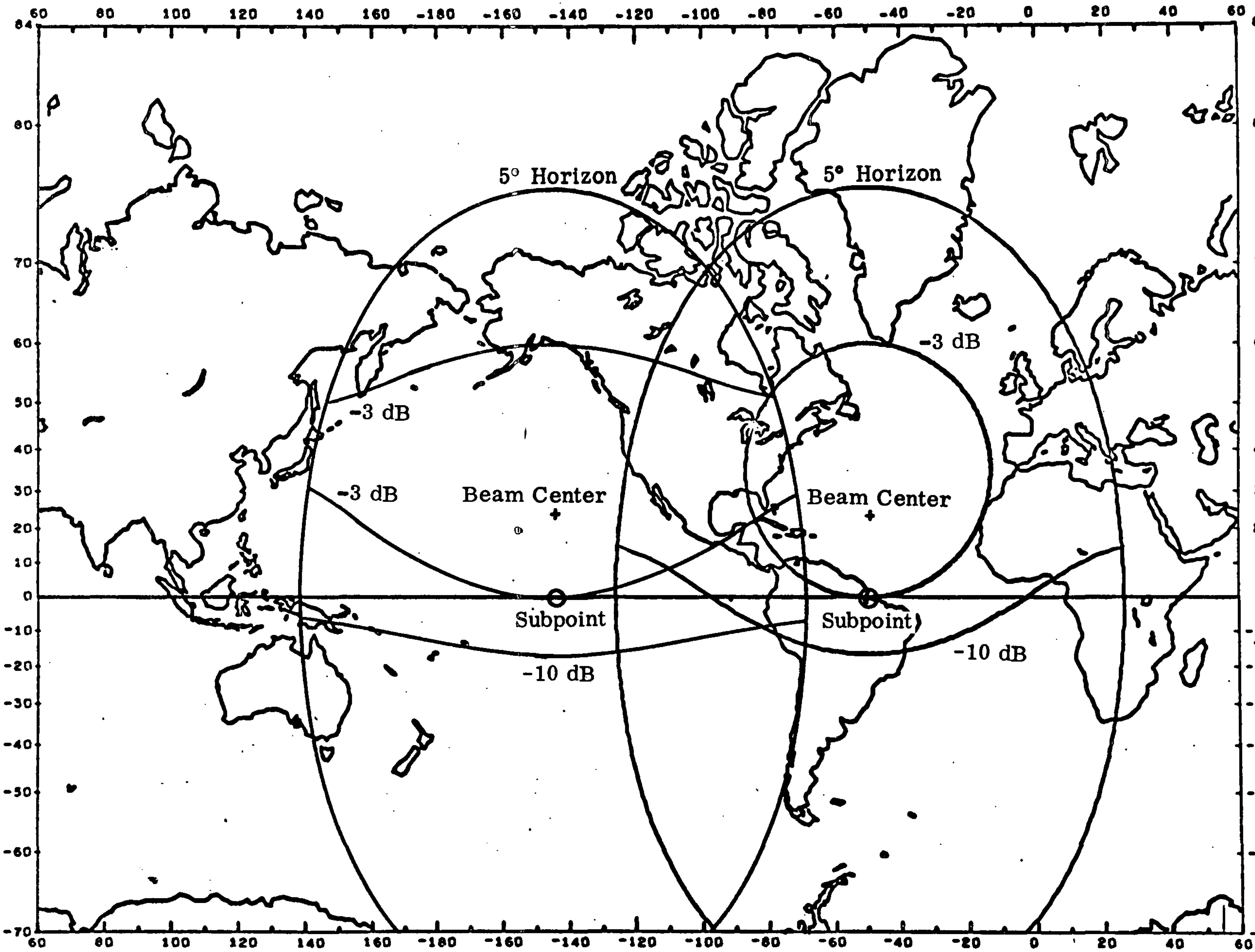


Figure 7-9. Ocean Area Coverage

the low rate buoy. Figure 7-10 shows total system, satellite and ground central station costs as a function of frequency. Figure 7-11 shows buoy communication system costs for both high and low capability as functions of frequency. These cost data are for the full earth coverage satellite antennas.

7.2.4.2 Hydrological Data (04A). This mission was derived from the LMSC study — Demand 152. Table 7-24 shows the system requirements taken from the LMSC Demand Profile. The remote sensing stations shown are located in watershed areas, streams,

Table 7-24. Hydrological Data Requirements

SOURCES	DESTINATION
● 25,000 Remote Hydrological Sensing Stations	● 1 Data Collection Center

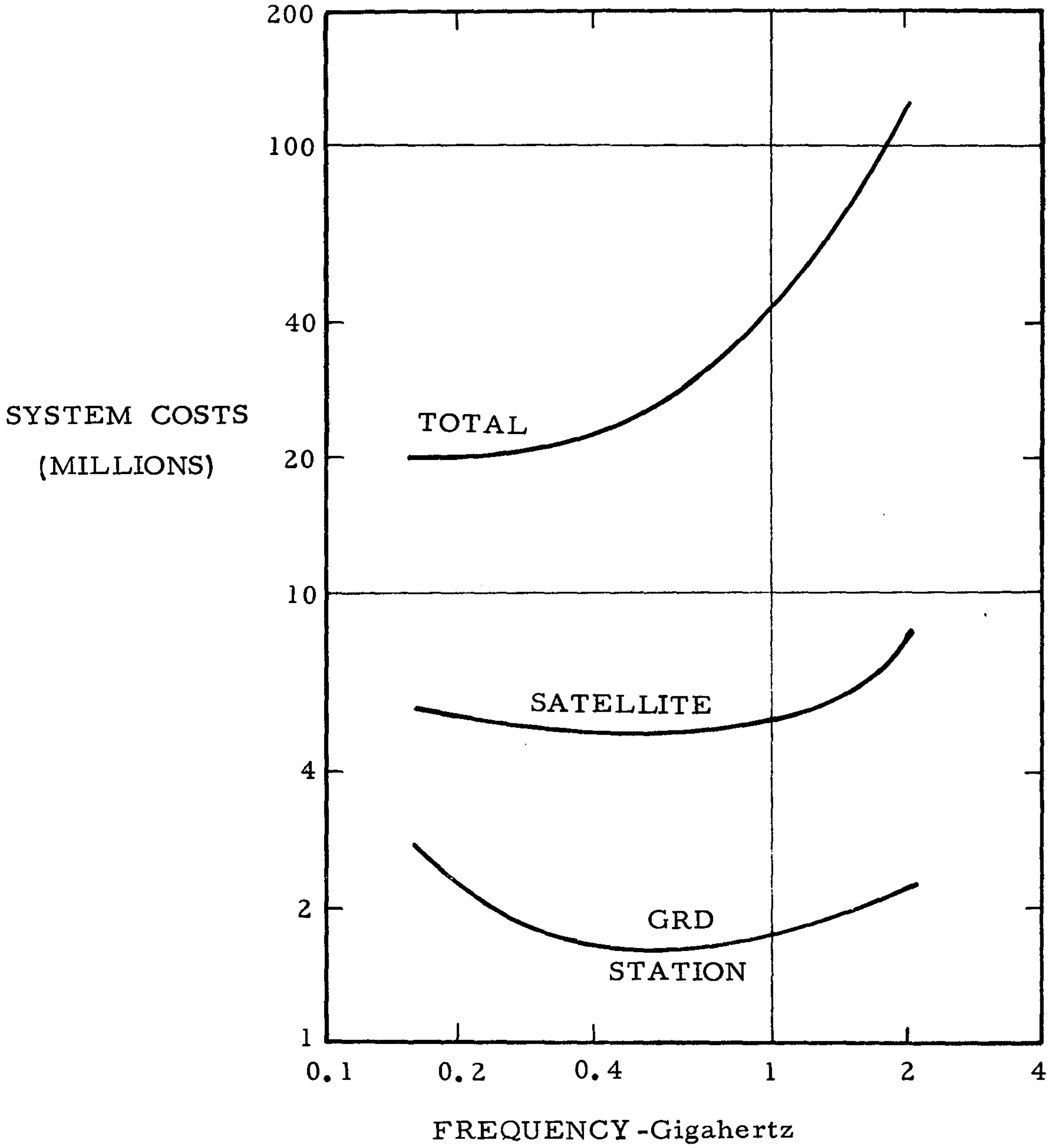
SYSTEM DESCRIPTION

- Full Earth Coverage Beam (17°)
- 3 Data Channels (2,500 BPS)
- Timed Readout
- 10 Year System Life
- 10 Year Satellite Life

lakes, rivers and tide waters of the U. S. This data will be ultimately used in a national water management system having responsibility for such items as flood control, hydroelectric power generation and irrigation.

Results for this system are summarized in Table 7-25 which shows the detailed elements of the overall \$71M/Year system. From this table it can be seen that the individual elements are reasonably inexpensive. Some operational means to be developed to permit a system of this type to be implemented.

7.2.4.3 Weather Station Data (04B). This system was derived from LMSC — Demand 081. System requirements are shown in Table 7-26. Results for the system are summarized in Table 7-27. The Data Collection Center, including operations and maintenance for 10 years, costs \$1.3M. The communications system for each weather station costs \$36.5K (\$146.4M for the entire network of 4,100 stations). A \$6M satellite weighing 910 lb can accommodate these requirements. It can be orbited by a Titan 3/Centaur launch vehicle.



- Shared satellite system.
- Satellite costs include only communications subsystems and increment in power subsystem.

Figure 7-10. Total System Costs

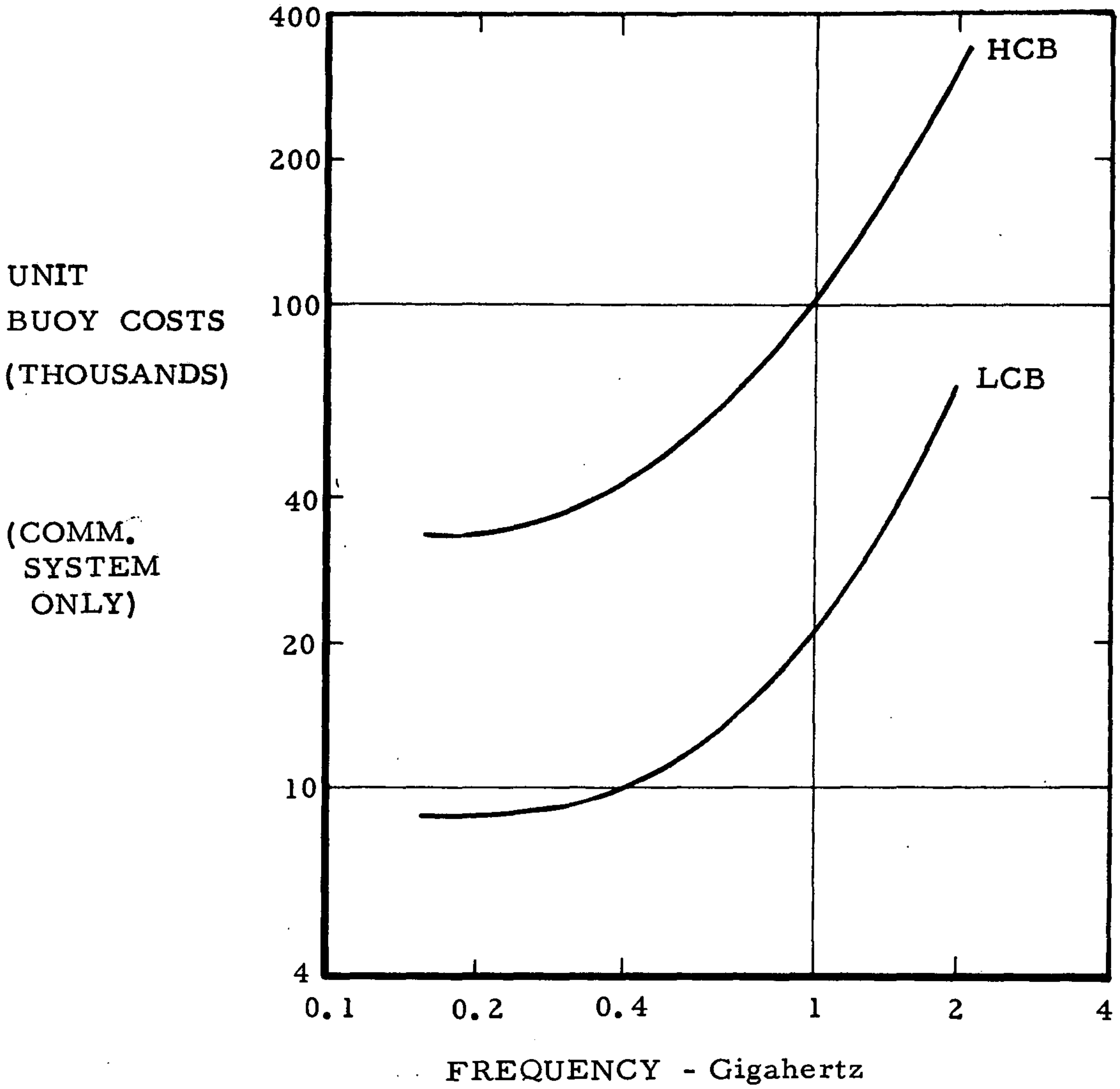


Figure 7-11. Buoy Equipment Costs

Table 7-25. Hydrological Data Results

● COLLECTION CENTER		
EIRP	19.2 dBW	
G/T	-14.9 dB/°K	
ACQUISITION COST		$68K
ANNUAL OPERATING COST		--
ANNUAL MAINTENANCE COST		$42K
	TOTAL (10 YEARS)	$110K
● SENSING PLATFORM (COMMUNICATION SYSTEM ONLY)		
G/T	-4.4 dB/°K	
ACQUISITION COST		$10.5K
ANNUAL OPERATING COST		--
ANNUAL MAINTENANCE COST		$16K
	TOTAL (10 YEARS)	$26.5K
● SATELLITE		
EIRP	21.6 dBW	
G/T	-10.8 dB/°K	
WEIGHT	913 LB	
ACQUISITION COST		$6.2M
NON-RECURRING COST		$22.9M
	TOTAL	$29.1M
● LAUNCH VEHICLE (TITAN 3/CENTAUR)		
ACQUISITION COST		$21.0M
NON-RECURRING COST		$5.4M
	TOTAL	$26.9M

Table 7-26. Weather Station Requirements

SOURCES	DESTINATIONS
4,100 Remote Weather Stations	1 Data Collection Center

SYSTEM DESCRIPTION

- Full Earth Coverage Beam (17°)
- 1 Data Channel (300 BPS)
- Interrogation/Response Operations
- 10 Year System Life
- 10 Year Satellite Life

Table 7-27. Weather Station Results

● DATA COLLECTION CENTER		
EIRP	11.0 dBW	
G/T	-25.5 dB/°K	
ACQUISITION COST		$140K
ANNUAL OPERATING COST		$1023K
ANNUAL MAINTENANCE COST		$94K
	TOTAL (10 YEARS)	$1.3M
● WEATHER STATION (COMMUNICATIONS ONLY)		
G/T	-16.3 dB/°K	
ACQUISITION COST		$15K
ANNUAL OPERATING COST		--
ANNUAL MAINTENANCE COST		$21.5K
	TOTAL (10 YEARS)	$36.5K
● SATELLITE		
EIRP	18.4 dBW	
G/T	-10.8 dB/°K	
WEIGHT	910 LB	
ACQUISITION COST		$6.16M
NON-RECURRING COST		$22.93M
	TOTAL	$29.1M
● LAUNCH VEHICLE (TITAN 3/CENTAUR)		
ACQUISITION COST		$21.0M
NON-RECURRING COST		$5.4M
	TOTAL	$26.4M

7.2.4.4 Ocean Fisheries (04C). This is another of the systems taken directly from the LMSC study (Demand 105). System requirements are shown in Table 7-28 and the results of the system synthesis are summarized in Table 7-29.

Table 7-28. Ocean Fishery Requirements

SOURCE	DESTINATIONS
1 Broadcast Station	15,000 Ships at Sea

SYSTEM DESCRIPTION

- 1 Earth Coverage Beam (17°)
- 30 Audio Channels
- 10 Year System Life
- 10 Year Satellite Life

Table 7-29. Ocean Fishery Results

● ORIGINATING FACILITIES		
EIRP	35.6 dBW	
G/T	--	
ACQUISITION COST		$334K
ANNUAL OPERATING COST		$482K
ANNUAL MAINTENANCE COST		$155K
	TOTAL (10 YEARS)	$971K
● DESTINATION FACILITIES		
G/T	-4.59 dB/°K	
ACQUISITION COST		$189.15
ANNUAL MAINTENANCE COST		$ 92.1
	TOTAL (10 YEARS)	$281.25
● SATELLITE (3 REQUIRED)		
EIRP	35.5 dBW	
G/T	-7.89 dB/°K	
WEIGHT	1,207 LB	
ACQUISITION COST		$10.64M
NON-RECURRING COST		$20.28M
	TOTAL	$30.92M
● LAUNCH VEHICLE (SLV-3A/AGENA; 3 REQUIRED)		
ACQUISITION COST		$24.00M
NON-RECURRING COST		$ 1.50M
	TOTAL	$25.50M

The total system cost for this system is $68.46M ($6.85M/Year). The radio transmission station costs $971K while the individual shipboard antenna and receiver cost $281.25, installed. Three satellites are used to provide global coverage.

7.2.4.5 Wild Animal Migration (04D). This system was defined by LMSC (Demands 162 and 163). The system requirements are shown in Table 7-30 and results of the system synthesis are given in Table 7-31. Total system cost is $57.53M.

Table 7-30. Wild Animal Migration Requirements

SOURCES	DESTINATION
50 Animals	1 Data Collection Center

SYSTEM DESCRIPTION

- Earth Coverage Beam (17°)
- 1 Data Channel (100 BPS)
- 10 Year System Life
- 10 Year Satellite Life

Table 7-31. Wild Animal Migration Results

● DATA COLLECTION CENTER		
EIRP	20.2 dBW	
G/T	-29 dB/°K	
ACQUISITION COST		$64K
ANNUAL OPERATING COST		--
ANNUAL MAINTENANCE COST		$36K
TOTAL (10 YEARS)		$100K
● TRANSMISSION SYSTEM		
EIRP	14.4 dBW	
G/T	-34.7 dB/°K	
ACQUISITION COST		$15.5K
ANNUAL OPERATING COST		--
ANNUAL MAINTENANCE COST		$23.5K
TOTAL (10 YEARS)		$39K
● SATELLITE		
EIRP	17.5 dBW	
G/T	-10.8 dB/°K	
WEIGHT	909 LB	
ACQUISITION COST		$6.16M
NON-RECURRING COST		$22.92M
TOTAL		$29.08M
● LAUNCH VEHICLE (TITAN 3/CENTAUR)		
ACQUISITION COST		$21.00M
NON-RECURRING COST		$5.4M
TOTAL		$26.4M

7.2.5 CIVIC SERVICES. This mission group is intended to include all those communications services associated with the public interest. It includes civil defense, law enforcement and emergency warnings and recovery communications. Search and rescue communications may also be included.

7.2.5.1 Civil Defense Audio Network (05A). This system derived from the LMSC study (Demand 154) is summarized in Table 7-32. It provides a 15-channel radio interconnection of 60 major metropolitan areas in the U.S. Results of the synthesis are presented in Table 7-33. The total system cost of $113.25M includes provision for an in-orbit spare satellite.

Table 7-32. Civil Defense Requirements

SOURCES/DESTINATIONS	SYSTEM DESCRIPTION
	● U.S. Coverage Beam (3°×7°)
● 60 Cities Within CONUS	● 15 Audio Channels
	● 10 Year System Life
	● 10 Year Satellite Life

Table 7-33. Civil Defense Results

● GROUND FACILITIES			
EIRP	42.9 dBW		
G/T	18.0 dB/°K		
ACQUISITION COST			$223K
ANNUAL OPERATING COST			$361K
ANNUAL MAINTENANCE COST			$ 94K
		TOTAL (10 YEARS)	$678K
● SATELLITE (2 REQUIRED)			
EIRP	44.4 dBW		
G/T	2.82 dB/°K		
WEIGHT	1,199 LB		
ACQUISITION COST			$ 7.53M
NON-RECURRING COST			$20.56M
		TOTAL	$28.09M
● LAUNCH VEHICLE (SLV-3X/CENTAUR: 2 REQUIRED)			
ACQUISITION COST			$24.40M
NON-RECURRING COST			$15.50M
		TOTAL	$39.90M

7.2.5.2 Law Enforcement, Video System (05B). The requirements for this system, derived from LMSC Demand 004, are shown in Table 7-34. It provides a TV relay interconnection between the state capitals, Washington, D. C. and Montreal, Canada. Results of the analysis are summarized in Table 7-35. The total system cost of \$256.47M includes the elements shown and a spare in-orbit satellite.

Table 7-34. Law Enforcement Video Requirements

GROUND FACILITIES	SYSTEM DESCRIPTION
	● U.S. Coverage Beam (3°×7°)
● 52 Major Cities	● 3 Video Channels
	● Relay Quality
	● 10 Year System Life
	● 10 Year Satellite Life

Table 7-35. Law Enforcement Video Results

● ORIGINATING FACILITIES			
EIRP	73.6 dBW		
G/T	38.3 dB/°K		
ACQUISITION COST			\$1.22M
ANNUAL OPERATING COST			\$1.16M
ANNUAL MAINTENANCE COST			\$ .84M
		TOTAL (10 YEARS)	\$3.22M
● SATELLITE (2 REQUIRED)			
EIRP	38.4 dBW		
G/T	2.82 dB/°K		
WEIGHT	2,100 LB		
ACQUISITION COST			\$16.32M
NON-RECURRING COST			\$27.59M
		TOTAL	\$43.91M
● LAUNCH VEHICLE (TITAN 3; 2 REQUIRED)			
ACQUISITION COST			\$35.40M
NON-RECURRING COST			\$ 5.10M
		TOTAL	\$40.50M

7.2.5.3 Law Enforcement Data (05C). This is the second part of LMSC Demand 004. The system requirements are similar to those shown in Table 7-34 except the TV channel is replaced by 100 digital data channels, each capable of accommodating

2,400 bands. Results of the synthesis are shown in Table 7-36. This system has a total system cost of $106M including the elements shown in Table 7-36 and an in-orbit spare satellite.

Table 7-36. Law Enforcement Data Results

● ORIGINATING FACILITIES		
EIRP	29.2 dBW	
G/T	5.9 dB/°K	
ACQUISITION COST		$188K
ANNUAL OPERATING COST		$322K
ANNUAL MAINTENANCE COST		$ 68K
	TOTAL (10 YEARS)	$578K
● SATELLITE (2 REQUIRED)		
EIRP	46.3 dBW	
G/T	2.82 dB/°K	
WEIGHT	1,526 LB	
ACQUISITION COST		$ 8.89M
NON-RECURRING COST		$21.73M
	TOTAL	$30.62M
● LAUNCH VEHICLE (TITAN 3; 2 REQUIRED)		
ACQUISITION COST		$35.40M
NON-RECURRING COST		$ 5.10M
	TOTAL	$40.50M

7.2.5.4 Law Enforcement Network. The statistics of communications in support of law enforcement present an eye opening example of staggering growth. The present volume of law enforcement related communications, rate of growth of crime and cost of present communication methods are sufficient to create an interest in the potential of a nationwide law enforcement communications network. Table 7-37 illustrates volume of business currently handled by the National Crime Information Center (NCIC, FBI, Washington, D.C.). Figure 7-12 shows that even this is partial coverage. NCIC is handled by land lines except for one satellite link with Hawaii. Figure 7-13 shows a crime rate of increase in excess of 20% per year for 1966 - 1969. On this basis the 52,900 average daily transactions by NCIC could conceivably increase by a factor approaching 2.5 in five years by virtue of the compounding effect of a constant rate of increase.

Table 7-37. NCIC File Statistics as of June, 1970

● RECORDS ON FILE		
	WANTED PERSONS	60,902
	VEHICLES	487,780
	LICENSE PLATES	160,220
	SECURITIES	619,077
	ARTICLES	385,156
	GUNS	317,507
	BOATS	1,508
	TOTAL RECORDS ON FILE	2,032,150
● TOTAL TRANSACTIONS FOR JUNE		1,587,000
● DAILY AVERAGE TRANSACTIONS		52,900

1. Law Enforcement System Requirements. A communication system was defined with a capacity over fourteen times the present NCIC daily volume. This system would be via geostationary data relay satellite to direct receiving stations. Additional cable distribution around the major receiving areas is a possibility but not included in this system synthesis. Table 7-38 tabulates the coverage, system description, data rate and total capacity of this proposed law enforcement network. The cost data following extends the daily transaction capacity.

2. Costs Resulting from Synthesis of Law Enforcement System. The system synthesis is based upon the cost of all subsystems in ground and satellite stations. However, only total system and station costs are presented. Figure 7-14 shows cost dependence upon daily volume for the total system, central and city stations, and space segment (satellite and launch vehicle) with and without a facsimile capability. The central station and city costs shown are totaled for a ten year life system. Figure 7-15 shows annual costs with a television channel added and the cost per transaction as functions of number of transactions. The total system cost is increased by one-third with television added. However, the central and city unit costs (Figure 7-15 is for one year) are doubled. Comparison of Figures 7-15 and 7-16 shows the cost per transaction is approximately doubled through having the television capability.

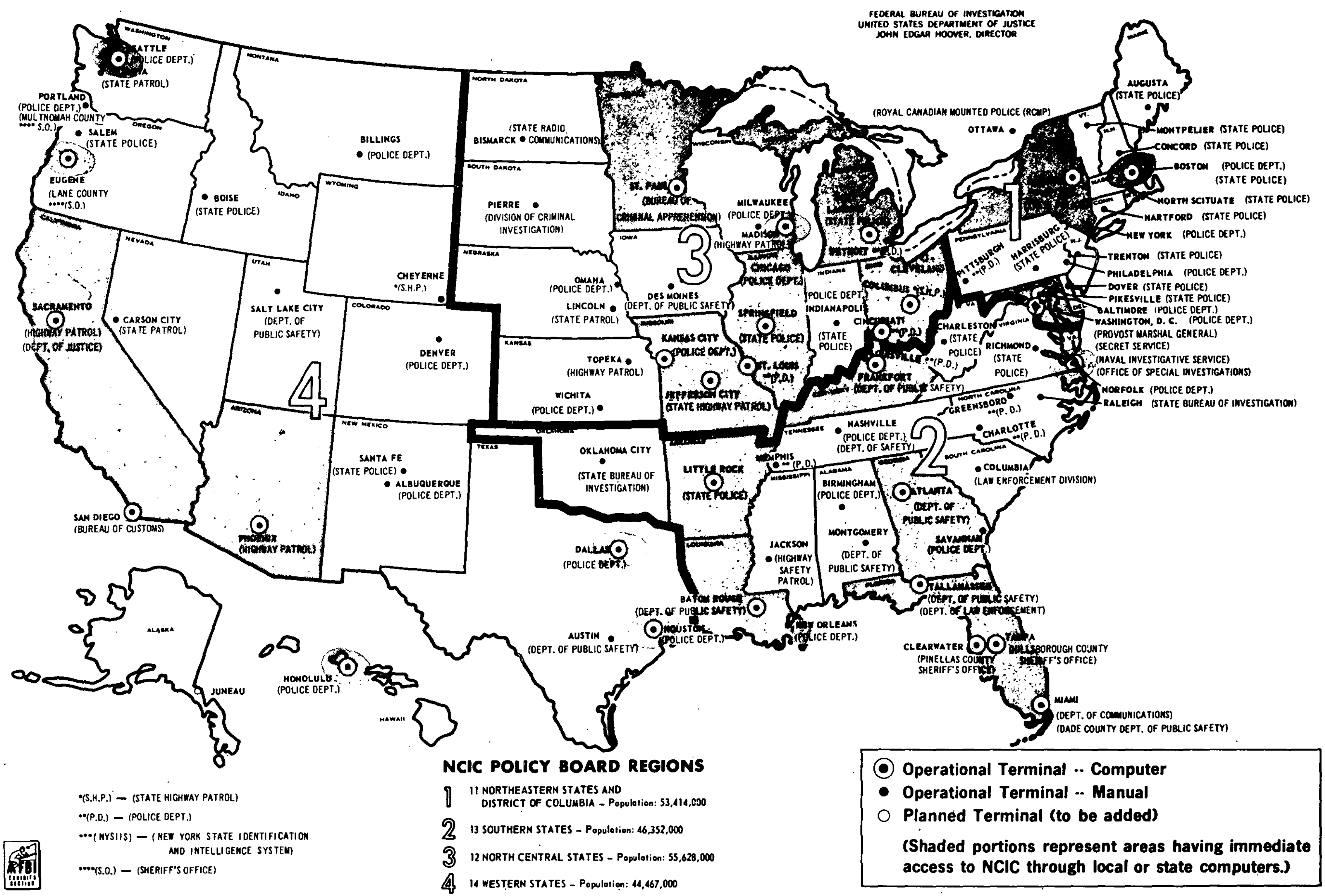


Figure 7-12. NCIC Network (April, 1970)

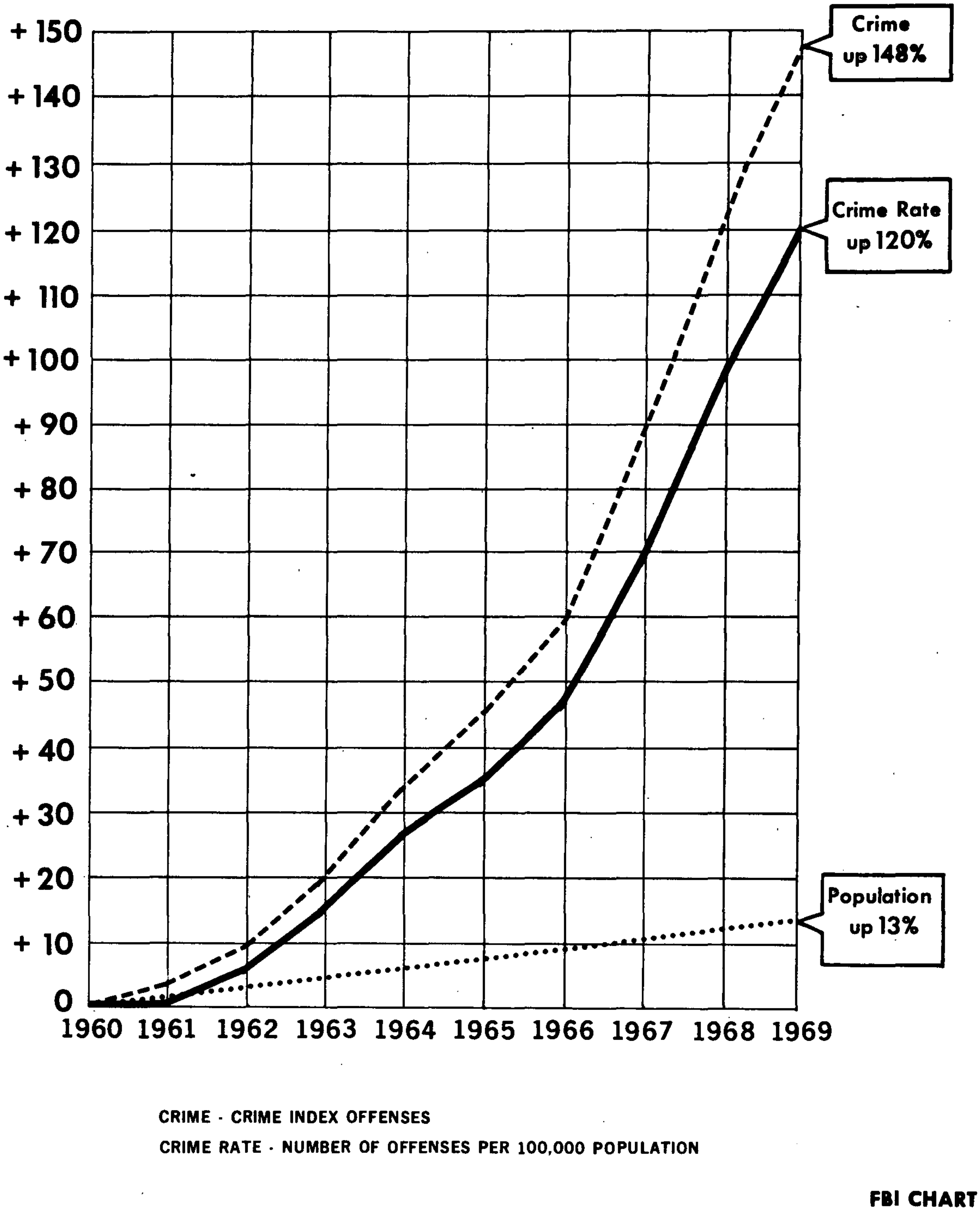


Figure 7-13. Crime and Population (1960-1969)

Table 7-38. Law Enforcement Network

ACCESS TECHNIQUE — INTERROGATION/RESPONSE
WITH POLLING BY CENTRAL FACILITY

- CHANNEL ALLOCATION
  - 2 CHANNELS FOR POLLING
  - 14 CHANNELS FOR INTERROGATION/RESPONSE
  - 1 ORDER WIRE FOR WIDEBAND CHANNEL
  - 1 WIDEBAND CHANNEL
- GROUND NETWORK FOR TRAFFIC TO SATELLITE TERMINALS
  - 750,000 TRANSACTIONS/DAY (2 MESSAGES = 1 TRANSACTION)
- 2400 BAUD CHANNELS
- 1 CENTRAL FACILITY
- 203 CITY FACILITIES

48 STATE CAPITALS	@	5,000 TRANS/DAY	240,000
58 CITIES > 250K	@	2,300	133,400
97 CITIES > 100K	@	1,500	145,500
• GOVERNMENT	@	10,000	
• MILITARY	@	5,000	16,000
• CANADA/MEXICO	@	1,000	
TOTAL			534,900
• ADDITIONAL 40% FOR STATE-TO-STATE DIRECT			215,000
			750,000

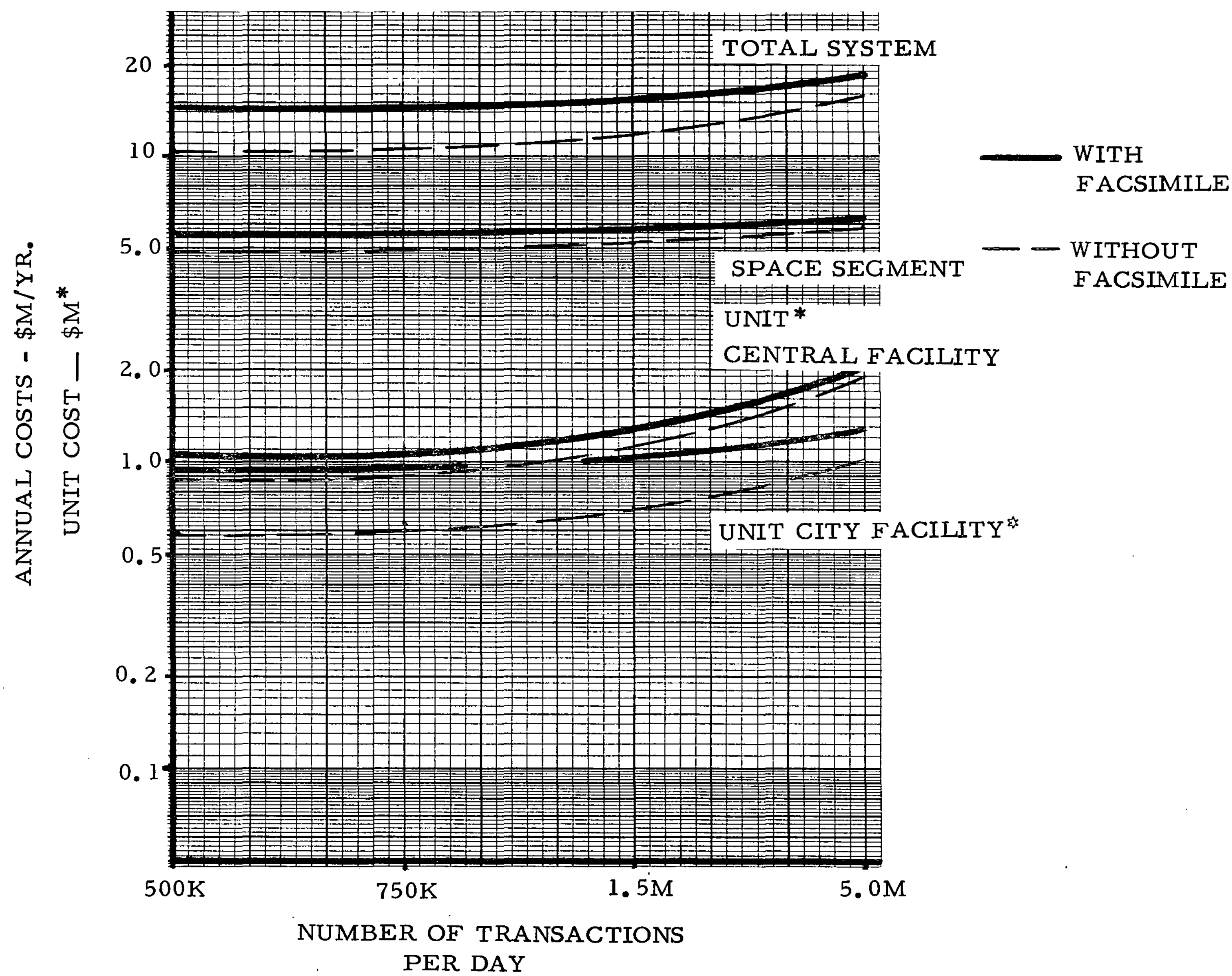


Figure 7-14. Law Enforcement Results

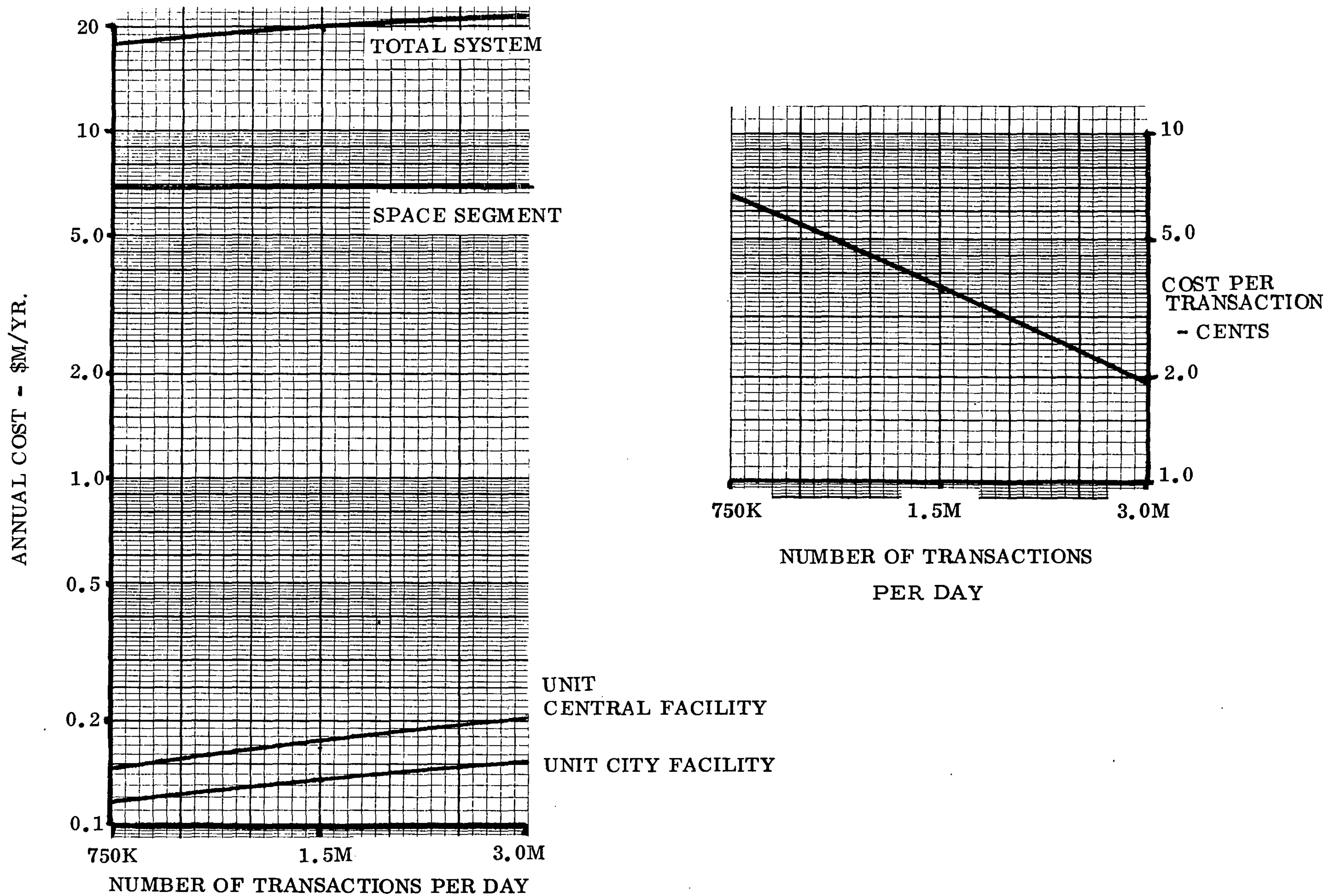


Figure 7-15. Law Enforcement Results (with TV Channel)

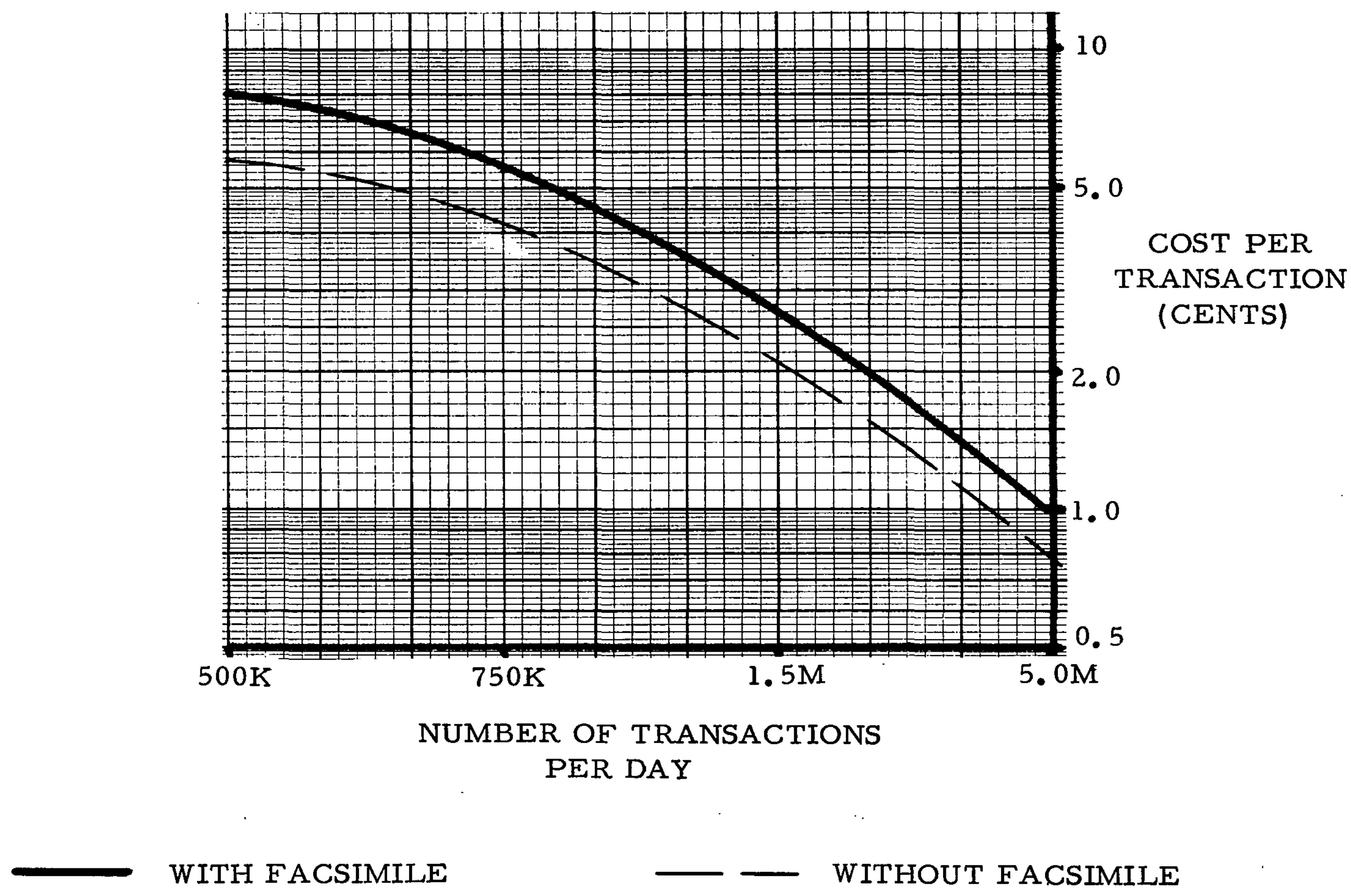


Figure 7-16. Law Enforcement Results Per Transaction

7.2.6 TRAVEL AND RECREATIONAL SERVICES. The objective of this mission group is to provide a computer access network for inquiry, acknowledgment and confirmation of reservations of all kinds associated with travel and recreation. These include airline, car rental, hotel/motel, campsite and theater reservations. Several systems are being established in these areas (Holidex for Holiday Inn, Reservations World, Am-Ex Space Bank and all the airline systems). The most readily definable are the airline reservations where the passenger enplanements are carefully recorded.

System requirements are shown in Table 7-39. This arrangement is based on a growth in reservations from 160×10^6 per year in 1970 to 510×10^6 per year in 1980. During this same period airline passenger enplanements are projected to increase from 110×10^6 per year to 350×10^6 per year (Note: corresponding data from the SRI report show approximately double these values). A polling technique is envisaged to enable the control center to manage the system.

Table 7-39. Travel and Recreation Services Requirements

SOURCES	DESTINATION
• 2000 Inquiry Centers around the U.S. (Major Airports and Cities)	• 1 Data Storage, Processing and Control Center

SYSTEM DESCRIPTION

- 1 U. S. Coverage Beam (3° × 7°)
- 1200 Data Channels (3,100 BPS)
- Polling System
- 10 Year System Life
- 10 Year Satellite Life

Results for this system are summarized in Table 7-40. As anticipated, the Data Center total cost is quite high at $11.91M or $1.19M/Year. The individual terminals are also quite expensive at $565K. The total system cost is $1.23B or $123.117M/Year. This translates into a 77¢/transaction cost in 1970 and 24¢/transaction in 1980.

Table 7-40. Travel and Recreational Services Results

● DATA CENTER (COMMUNICATIONS ONLY)			
EIRP	77.5 dBW		
G/T	16.2 dB/°K		
ACQUISITION COST			\$4.36M
ANNUAL OPERATING COST			\$4.42M
ANNUAL MAINTENANCE COST			\$3.13M
		TOTAL (10 YEARS)	\$11.91M
● INQUIRY STATIONS			
EIRP	51.5 dBW		
G/T	18.6 dB/°K		
ACQUISITION COST			\$166K
ANNUAL OPERATING COST			\$330K
ANNUAL MAINTENANCE COST			\$ 69K
		TOTAL (10 YEARS)	\$565K
● SATELLITE (2 REQUIRED)			
EIRP	54.4 dBW		
G/T	2.82 dB/°K		
WEIGHT	2,928 LB		
ACQUISITION COST			\$11.52M
NON-RECURRING COST			\$25.50M
		TOTAL	\$37.02M
● LAUNCH VEHICLE (TITAN 3/CENTAUR; 2 REQUIRED)			
ACQUISITION COST			\$42.0M
NON-RECURRING COST			\$ 5.4M
		TOTAL	\$47.4M

7.2.7 MOBILE COMMUNICATIONS SERVICES. The intent of this service is to provide a central source(s) with information on the identification, status and location of mobile equipments — aircraft, ships, trucks and railway cars. It also can include routine business communications with these vehicles.

7.2.7.1 Domestic Airlines, Business Communications (07A). As presented here, this system represents a third-generation system to meet this requirement. Currently, the Aeronautical Radio Incorporated (ARINC) is providing these services through the use of TELPAK wireline services. The next step is to develop the ARINC Intercity Network — a dedicated microwave system depicted in Figure 7-17.

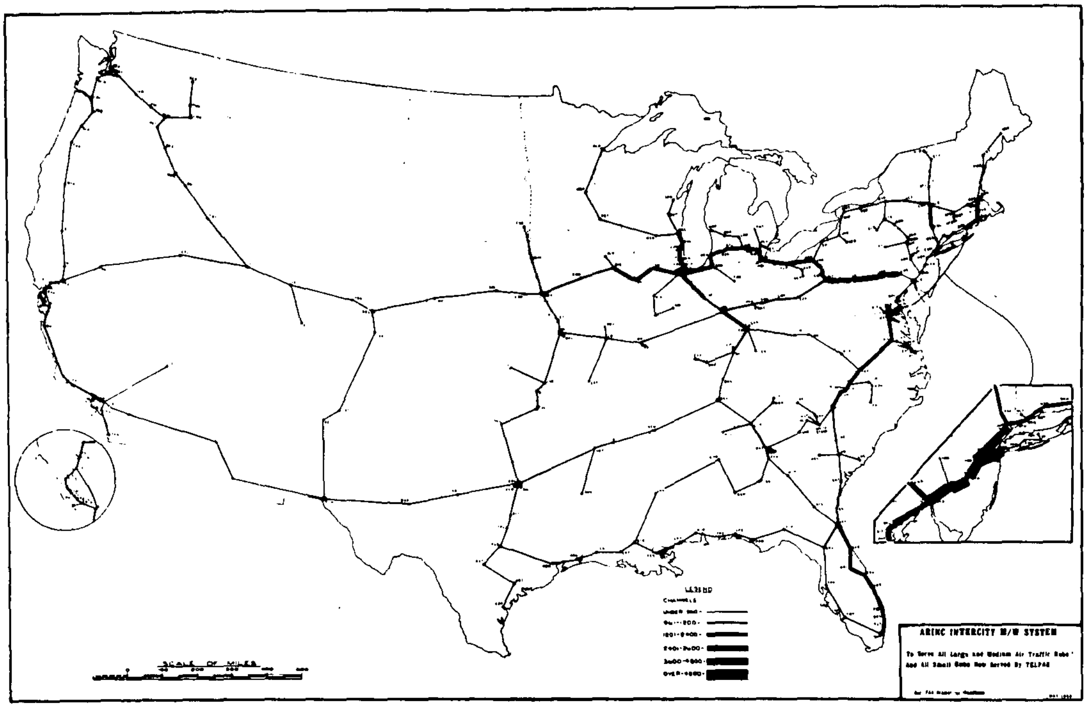


Figure 7-17. ARINC Intercity M/W System

This system provides two major east-west trunks with a major north-south network on the eastern seaboard and lesser north-south trunks in the midwest and on the west coast. This system has the following characteristics:

- NUMBER OF STATIONS — 730
- NUMBER OF SERVICE POINTS — 282
- PATH MILES — 22,200
- AVERAGE STATION SPACING, MILES — 30
- FREQUENCY BANDS
  - 6.7 GHz (OPEN COUNTRY)
  - 12 GHz (CONGESTED AREAS)
- ULTIMATE CAPABILITY — 87,200 4 KHz CHANNEL ENDS
- TYPES OF INFORMATION
  - TELETYPEWRITER
  - HIGH SPEED DATA
  - VOICE
- LIFESPAN — 20 YEARS

With an initial capital investment of $165M, the annual costs of the ARINC Intercity M/W Network are estimated to be $25,243,000.

A satellite system has been considered for the third-generation approach to replace the microwave network but also to serve most of the additional points not connected by wireline. The validity of this approach depends greatly on still undetermined aspects of the off-microwave traffic. If the wireline traffic is mostly short haul, satellite utilization may not be economical. However, if there is much long-haul traffic the satellite advantage would improve. Another factor is the additional operational possibilities made possible by a satellite system. Referring back to the Microwave System map (Figure 7-17) it is obvious that the inclusion of a central control station is not practical because of the series arrangement of the system. With a satellite system, however, a central control station is entirely feasible.

Requirements for the ARINC system, shown in Table 7-41, are:

Table 7-41. ARINC System Requirements

SOURCE/DESTINATIONS
• 271 SECONDARY FACILITIES
• 16 GATEWAY FACILITIES
SYSTEM DESCRIPTION
• VOICE GRADE CIRCUITS 60 - GATEWAY FACILITIES 15 - SECONDARY FACILITIES
• NORTH AMERICAN COVERAGE PLUS NORTH ATLANTIC AND PACIFIC (4°×8° BEAM)
• 10 YEAR SYSTEM LIFE
• CCIR RELAY QUALITY

1. Sources and Destinations — Sources and destinations for this system are:

   a. Major Facilities — These correspond to gateway (international) or large hub airports — San Juan, Miami, Atlanta, Washington, New York, Boston, Montreal, Toronto, Chicago, Denver, Seattle, Vancouver, San Francisco, Los Angeles, Dallas/Fort Worth, and New Orleans. Beam coverage is such that Mexico City, Bermuda, and others could be included.

   b. Minor Facilities — These correspond to the remainder of the 282 service points on the intercity microwave interconnection system.

2. Description — A total of 75 voice channels are provided, with 60 serving the major facilities and 15 serving the minor facilities. Coverage of these systems extends beyond the limits of the continental United States so that incoming traffic in the Atlantic and Pacific areas can be served as well as border areas of Mexico and Canada.

Total system cost is $257.6M ($25.76M/Year) with the system elements shown in Table 7-42. These results compare favorably to those projected for the Intercity M/W Network.

Table 7-42. ARINC System Results

● GATEWAY FACILITIES			
EIRP	60.1 dBW		
G/T	19.9 dB/°K		
ACQUISITION COST			$420K
ANNUAL OPERATING COST			$512K
ANNUAL MAINTENANCE COST			$238K
		TOTAL (10 YEARS)	$1.17M
● SECONDARY FACILITIES			
EIRP	46.2 dBW		
G/T	20.0 dB/°K		
ACQUISITION COST			$185.7K
ANNUAL OPERATING COST			$349K
ANNUAL MAINTENANCE COST			$ 84.6K
		TOTAL (10 YEARS)	$619K
● SATELLITE			
EIRP	44.0 dBW		
G/T	0.99 dB/°K		
WEIGHT	3,698 LB		
ACQUISITION COST			$10.17M
NON-RECURRING COST			$32.16M
		TOTAL	$42.33M
● LAUNCH VEHICLE (TITAL 3/CENTAUR)			
ACQUISITION COST			$21.00M
NON-RECURRING COST			$ 5.40M
		TOTAL	$26.4M

7.2.7.2 Ship Communications. This system was defined in LMSC Demand 090, as shown in Table 7-43, to provide voice communications to ships on the high seas. As such, 2 satellites are required. Synthesis of the system results in a total system cost of $102.87M. Details are summarized in Table 7-44. At a cost of $18.76K for the 10-year system lifetime, a large number of shipboard terminals can be added to the system without significant impact on total costs.

Table 7-43. Ship Communication

SOURCE/DESTINATIONS
- 1200 Ships

SYSTEM DESCRIPTION
- Ocean Coverage (Full 17° Beam)
- 2 Satellite System (Atlantic & Pacific)
- 100 Voice Channels
- 10 Year System
- 10 Year Satellite

Table 7-44. Ship Communications Results

● SHIPBOARD FACILITIES			
EIRP	21.2 dBW		
G/T	-5.1 dB/°K		
ACQUISITION COST			$10.26K
ANNUAL OPERATING COST			$ 0.1K
ANNUAL MAINTENANCE COST			$ 8.4K
		TOTAL (10 YEARS)	$18.76K
● SATELLITE (2 REQUIRED)			
EIRP	37.6 dBW		
G/T	-7.89 dB/°K		
WEIGHT	2,100 LB		
ACQUISITION COST			$11.20M
NON-RECURRING COST			$24.10M
		TOTAL	$35.3M
● LAUNCH VEHICLE (TITAN 3; 2 REQUIRED)			
ACQUISITION COST			$35.40M
NON-RECURRING COST			$ 5.10M
		TOTAL	$40.50M

7.2.8 MEDICAL NETWORK SERVICES. This service addresses itself to providing communications for all members of the medical community — physicians, nurses, technicians, administrators and supporting functionaries. The intent is to provide all modes of information transfer to accommodate demands in the areas of dial access to data banks, library browsing, remote diagnosis, instructional and educational services.

7.2.8.1 Medical Diagnostic Video (08A). The requirements for this system were derived from LMSC Demand 032 and are summarized in Table 7-45. Fifty medical centers are interconnected on a high quality color TV system. Results for this system show a total system cost of $143M for the 10-year lifetime. Detailed elements are summarized in Table 7-46. Two satellites are provided, one as the operating unit and the second as an in-orbit spare to prevent disruption of service.

Table 7-45. Medical Diagnostic Video Requirements

GROUND FACILITIES
- 50 Medical Centers

SYSTEM DESCRIPTION
- U. S. Coverage (3° × 7°)
- 1 Video Channel (Color)
- Relay Quality (S/N = 54.0 dB)
- 10 Year Satellite
- 10 Year System

Table 7-46. Medical Diagnostic Video Results

● ORIGINATING FACILITIES			
EIRP	73.6 dBW		
G/T	32.4 dB/°K		
ACQUISITION COST			$454K
ANNUAL OPERATING COST			$504K
ANNUAL MAINTENANCE COST			$267K
		TOTAL (10 YEARS)	$1.2M
● SATELLITE (2 REQUIRED)			
EIRP	44.3 dBW		
G/T	2.82 dB/°K		
WEIGHT	1946 LB		
ACQUISITION COST			$12.02M
NON-RECURRING COST			$24.52M
		TOTAL	$36.54M
● LAUNCH VEHICLE (TITAN 3; 2 REQUIRED)			
ACQUISITION COST			$35.40M
NON-RECURRING COST			$ 5.10M
		TOTAL	$40.50M

7.2.8.2 Medical Data (08B). Requirements for this system, derived from LMSC Demands 028, 030 and 032, are summarized in Table 7-47. This table shows an increased number of centers being served, but with digital data only. Results for the system show a total system cost of $192M. Detailed elements are summarized in Table 7-48. At $54.9K per year, most medical centers could afford to participate in this type of system.

Table 7-47. Medical Data Requirements

GROUND FACILITIES
- 209 Medical Centers

SYSTEM DESCRIPTION
- U. S. Coverage (3° × 7° Beam)
- 100 Data Channels (4800 Band per Channel)
- 10 Year System
- 10 Year Satellite

Table 7-48. Medical Data Results

● ORIGINATING FACILITIES			
EIRP	32.2 dBW		
G/T	6.6 dB/°K		
ACQUISITION COST			$175K
ANNUAL OPERATING COST			$317K
ANNUAL MAINTENANCE COST			$ 57K
		TOTAL (10 YEARS)	$549K
● SATELLITE (2 REQUIRED)			
EIRP	48.6 dBW		
G/T	2.82 dB/°K		
WEIGHT	1,830 LB		
ACQUISITION COST			$9.66M
NON-RECURRING COST			$22.79M
		TOTAL	$32.45M
● LAUNCH VEHICLE (TITAN 3; 2 REQUIRED)			
ACQUISITION COST			$35.40M
NON-RECURRING COST			$ 5.10M
		TOTAL	$40.50M

7.2.8.3 Medical Video Plus Data (08AB). Results of combining the two previous cases are shown in Table 7-49. Total system cost is $277M compared to $335M, the sum of the previous 2 cases. It shows a savings of $58M by combining the systems.

7.2.9 BUSINESS MANAGEMENT SERVICES. This service provides full information transfer capabilities for business management functions. It includes data processing for accounting and stock/inventory control, telecomferencing and support functions such as credit verification and stock quotations.

Table 7-49. Medical Video Plus Data Results

	VIDEO	DATA		
● ORIGINATING FACILITIES				
EIRP (dBW)	64.4	44.0		
G/T (dB/°K)	19.7	19.7		
ACQUISITION COST				$485K
ANNUAL OPERATING COST				$675K
ANNUAL MAINTENANCE COST				$271K
		TOTAL (10 YEARS)		$1.4M
● DESTINATION FACILITIES				
EIRP (dBW)	----	43.9		
G/T (dB/°K)	19.7	19.7		
ACQUISITION COST				$189K
ANNUAL OPERATING COST				$351K
ANNUAL MAINTENANCE COST				$ 87K
		TOTAL (10 YEARS)		$627K
● SATELLITE (2 REQUIRED)				
EIRP (dBW)	47.8	43.8		
G/T (dB/°K)	2.82	2.82		
WEIGHT	3,865 LB			
ACQUISITION COST				$20.71M
NON-RECURRING COST				$32.68M
		TOTAL		$53.39M
● LAUNCH VEHICLE (TITAN 3/CENTAUR; 2 REQUIRED)				
ACQUISITION COST				$42.0M
NON-RECURRING COST				$ 5.4M
		TOTAL		$47.4M

7.2.9.1 Stock Quotations (09A). Table 7-50 presents the system requirements derived from LMSC Demand 075. The system is designed to provide status information of the New York Stock Exchange to 29,000 monitoring terminals. System synthesis shows a total system cost of $44.5M for the 10-year lifetime. Cost elements are summarized in Table 7-51.

7.2.9.2 Federal Reserve System (09B). The Federal Reserve System (FRS) instituted by Congress in 1913 performs the functions of 1) Fiscal agent of U. S. Government, 2) Custodian of reserve accounts of commercial banks, 3) Loans to commercial bands,

Table 7-50. Stock Quotation Network Requirements

SOURCES	DESTINATIONS
1 - New York City	25,000 Receiving Stations

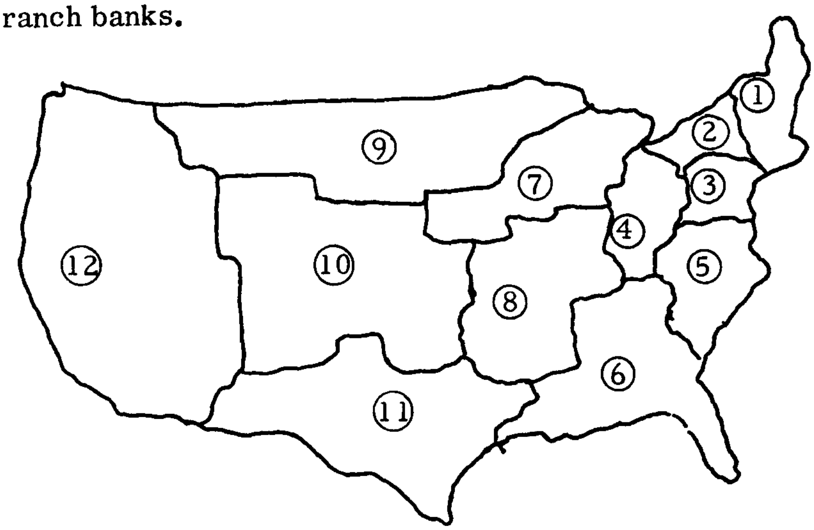
SYSTEM DESCRIPTION
- U. S. Coverage (3°×7° Beam)
- 1 Data Channel (360 K-Band)
- 10 Year System
- 10 Year Satellite

Table 7-51. Stock Quotations Results

● ORIGINATING FACILITIES			
EIRP	51.1 dBW		
G/T	---		
ACQUISITION COST			$175K
ANNUAL OPERATING COST			$312K
ANNUAL MAINTENANCE COST			$ 61K
		TOTAL (10 YEARS)	$548K
● DESTINATION FACILITIES			
G/T	6.45 dB/°K		
ACQUISITION COST			$226K
ANNUAL OPERATING COST			---
ANNUAL MAINTENANCE COST			$158K
		TOTAL (10 YEARS)	$384K
● SATELLITE			
EIRP	51.7 dBW		
G/T	2.82 dB/°K		
WEIGHT	1,114 LB		
ACQUISITION COST			$ 3.08M
NON-RECURRING COST			$19.51M
		TOTAL	$22.59M
● LAUNCH VEHICLE (SLV-3A/AGENA)			
ACQUISITION COST			$8.00M
NON-RECURRING COST			$1.50M
		TOTAL	$9.50M

and 4) Issues Federal Reserve notes. FRS is made up of a Federal Reserve Board, 12 Federal Reserve District Banks and 24 additional Federal Reserve Branch Banks as

part of the 12 districts. A telegraphic wire service was initiated in 1922. A new communication network is in preparation now. This is a land wire served system connecting a central control facility at Culpeper, Virginia with the U. S. Treasury, the Federal Reserve Board and all 36 Federal Reserve Banks. Figure 7-18 shows the location of the districts and the current traffic load which is as high as 3500 transactions per hour in mid afternoon EST. Alaska and Hawaii are part of the 12th district and currently have no FRS branch banks.



FEDERAL RESERVE DISTRICTS

DISTRICT NO.	TRAFFIC-MESSAGES/MO	PERCENT
1	10,000	4.2
2	50,000	21.0
3	10,500	4.4
4	15,000	6.3
5	19,000	8.0
6	25,000	10.5
7	30,000	12.7
8	12,000	5.0
9	8,500	3.6
10	14,000	5.9
11	21,500	9.2
12	22,000	9.2
TOTAL	237,500	

Figure 7-18. Federal Reserve System Geographical Distribution

1. <u>Description of Current Communications Requirements.</u> The communications load may be further defined as shown in Table 7-52. The Culpeper system links the various stations as shown in Figure 7-19.

Table 7-52. System Details

3500 TRANSACTIONS PER HOUR (3500 IN, 3500 OUT).

AVERAGE MESSAGE LENGTH:

125 CHARACTERS FOR WIRE TRANSFERS OR SECURITY TRANSFERS.

225 CHARACTERS FOR GENERAL ADMINISTRATION.

BREAKDOWN BY CATEGORY

WIRE TRANSFERS	65 PER CENT
SECURITY TRANSFERS	10 PER CENT
GENERAL ADMINISTRATION	25 PER CENT

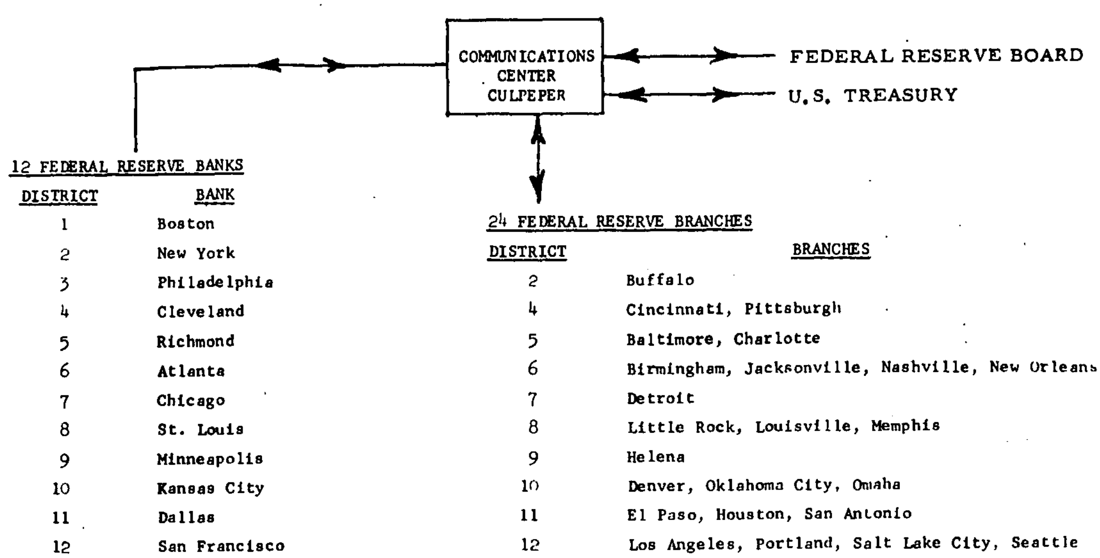


Figure 7-19. The Communications Center at Culpeper, Virginia Stores and Forwards Traffic Between 38 Locations

2. <u>Proposed Satellite Linked FRS Communication System.</u> The system shown in Figure 7-19 was the basis for defining an FRS communications system employing satellite relay between Culpeper, Virginia and all 38 stations in the system. This system, of course, is analyzed for increased message load (up to twelve-fold growth). The satellite in use would be accompanied by a second backup

satellite to give added assurance of uninterrupted service for a ten year satellite lifetime. Table 7-53 tabulates the channel and data capacity as well as the type of service.

Table 7-53. Federal Reserve System Configuration for Present Load

(1970)

USAGE	NO. OF CHANNELS *	DATA RATE	REMARKS
WIRE TRANSFERS SECURITY TRANSFERS GENERAL ADM.	12 DUPLEX	150 BAUD	1 DEDICATED DUPLEX PATH TO EACH FRS DISTRICT. TIME SHARED WITHIN DISTRICT.
CHANNEL POLLING	1 ONEWAY	150 BAUD	SERVES ALL BANKS
SERVICE AND MAINTENANCE	4 HALF DUPLEX	150 BAUD	EACH CHANNEL TIME SHARED BY 3 DISTRICTS
RESERVE	1 DUPLEX	150 BAUD	FOR TEMPORARY OVERLOAD OR DOWN CHANNEL SUB.
HIGH SPEED DATA EXCHANGE (STATISTICS)	4 HALF DUPLEX	2400 BAUD	EACH CHANNEL TIME SHARED BY 3 DISTRICTS

* GROWTH RATE ———— 6%/YR.

3. Costs Resulting from System Synthesis. The major cost segments are central facility, space (satellites and launch vehicles), and branch facilities. Figure 7-20 shows these costs as related to the number of daily transactions. The total system and space segment are annual costs. The central facility and bank facility costs are total for the ten year life. The only cost strongly related to number of transactions is the central facility. Figure 7-20 also shows remit transaction costs which reduce from $2.50 at the current rate to $0.40 at an expanded rate of 48,000 transactions per day.

7.2.9.3 Credit Card Verification (09C). There are approximately a quarter of a million credit cards in use throughout the U. S. as shown in Table 7-54. The vast

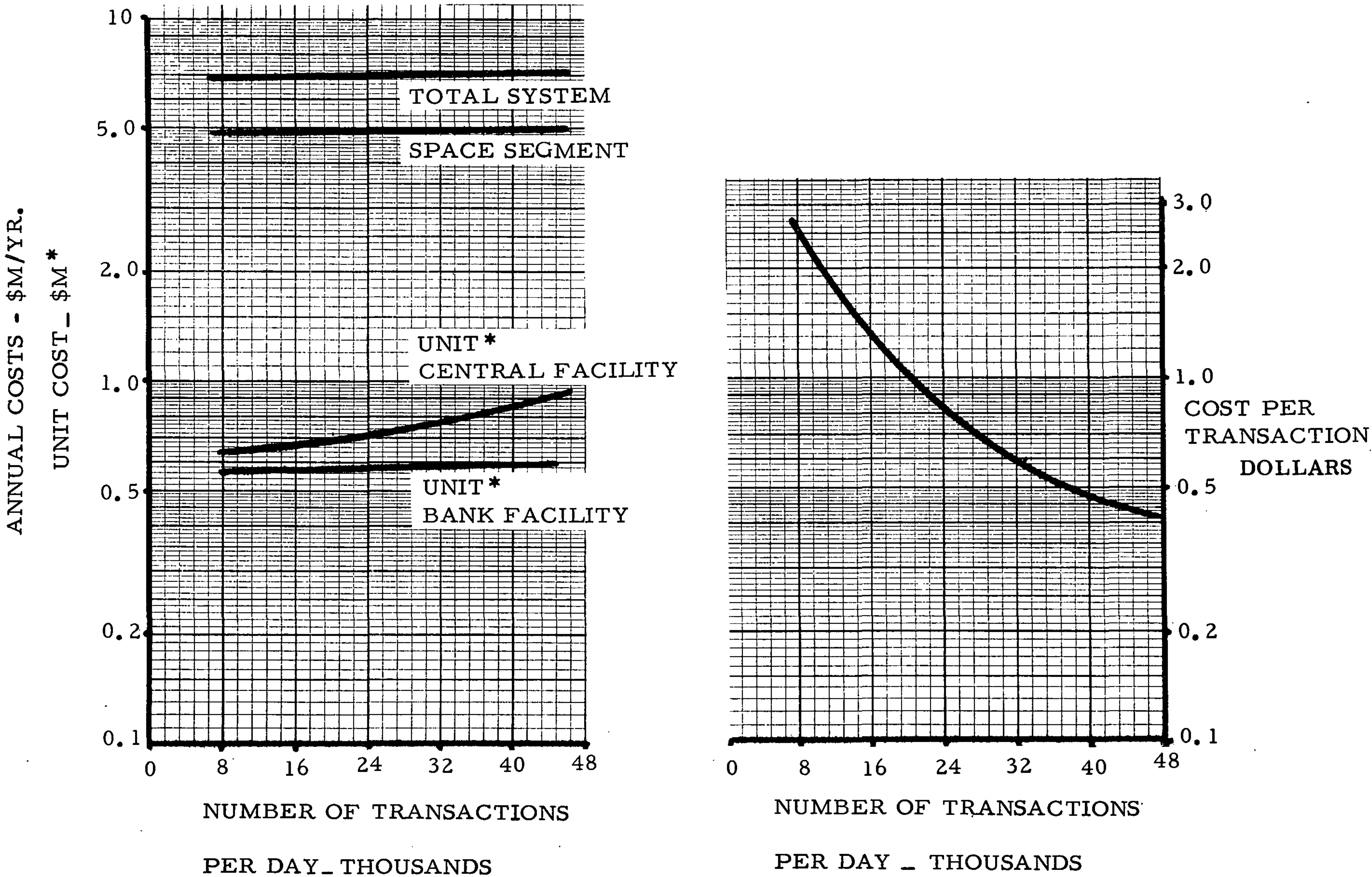


Figure 7-20. Federal Reserve System Results

majority are for retail activities (general merchandising and gasoline stations) which require local confirmation. Of interest to the ITS study are the 50 million bank cards that frequently require long distance configuration.

Table 7-54. Credit Cards in Circulation

TYPE		QUANTITY (M)
TRAVEL AND ENTERTAINMENT		6
AIR TRAVEL		3
OIL COMPANY		90
RETAIL STORE		100
* BANK CARDS		50
	TOTAL	~ 250

* MAJOR INTEREST

The bank cards are almost equally divided between the Interbank and BankAmericard series. Each has more than 20 million cards in circulation. Each also has approximately 3,000 franchises and 450,000 merchant members scattered throughout the nation. In effect, there are then close to a million inquiry sources with 6,000 information centers or response sources. Requirements for the system are summarized in Table 7-55. Synthesis of this system resulted in total system costs in excess of $200M/Year. Details of one case (4M transactions/day) are presented in Table 7-56. Costs of this system as a function of the number of transactions is shown in Figure 7-21.

Table 7-55. Credit Card Authorization Requirements

- MODEL - BANKERS TRUST OF NEW YORK
  - 50,000 INQUIRIES/MONTH
  - EACH INQUIRY ≡ 2-MIN. PHONE CALL
  - 10% LONG DISTANCE
- SYSTEM
  - SOURCE/DESTINATIONS
    - 6000 BANKS IN 3000 CITIES
    - 150 CHARACTER INQUIRY (2 MESSAGES/INQUIRY)
    - 4800 BAND CHANNELS
  - SATELLITE
    - 10 YEAR LIFETIME
    - FULL U.S. COVERAGE ANTENNA BEAM

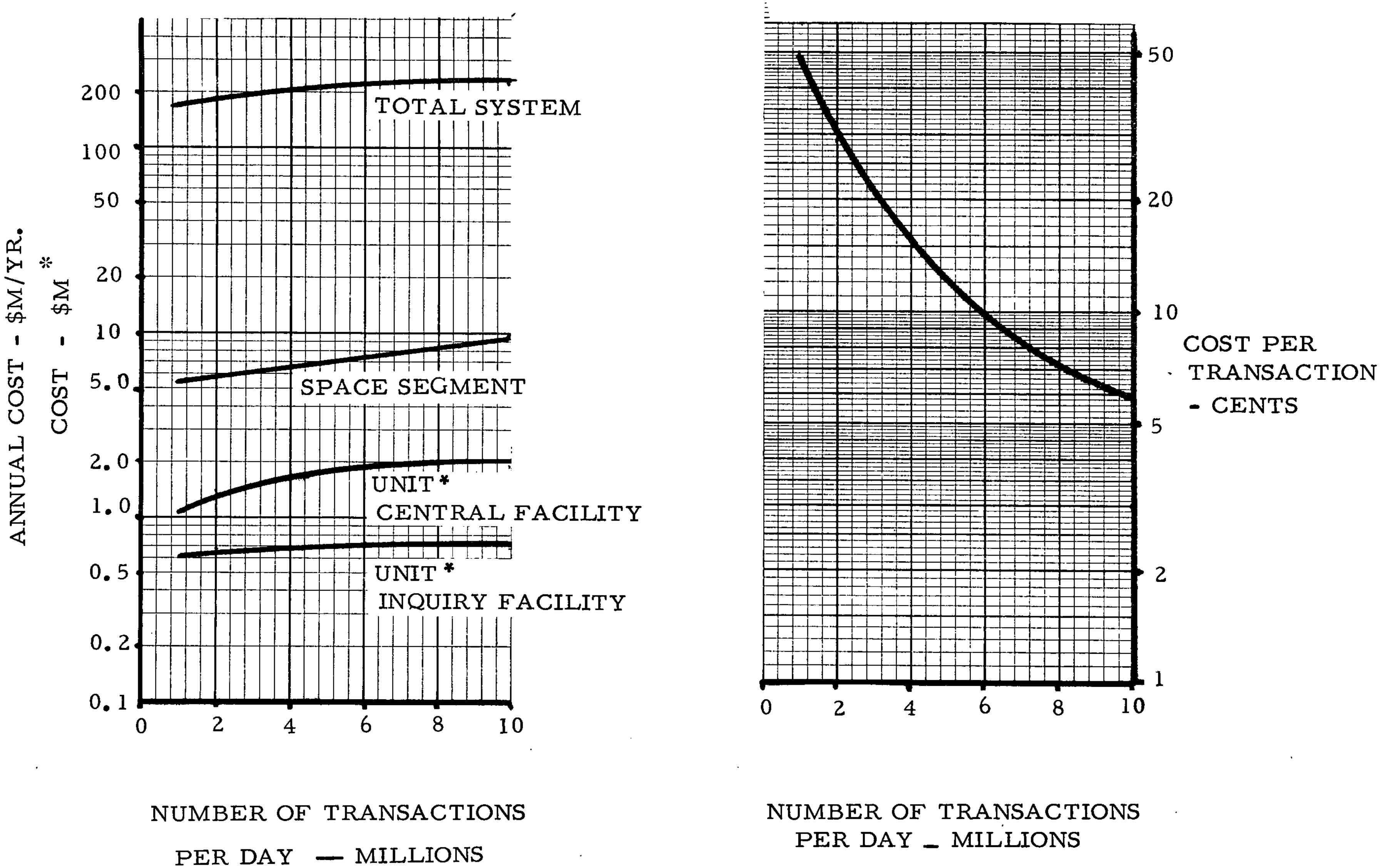


Figure 7-21. Credit Card Authorization Results

Figure 7-56. Credit Card Verification Results

● ORIGINATING FACILITIES			
EIRP	53.5 dBW		
G/T	3.1 dB/°K		
ACQUISITION COST			$447K
ANNUAL OPERATING COST			$414K
ANNUAL MAINTENANCE COST			$253K
		TOTAL (10 YEARS)	$1.1M
● DESTINATION FACILITIES			
EIRP	37.7 dBW		
G/T	2.3 dB/°K		
ACQUISITION COST			$190K
ANNUAL OPERATING COST			$333K
ANNUAL MAINTENANCE COST			$ 81K
		TOTAL (10 YEARS)	$604K
● SATELLITE (2 REQUIRED)			
EIRP	56.7 dBW		
G/T	2.82 dB/°K		
WEIGHT	1,583 LB		
ACQUISITION COST			$ 7.09M
NON-RECURRING COST			$20.22M
		TOTAL	$27.31M

7.2.10 DOMESTIC WIDEBAND SERVICES. This is a wideband (high-rate) digital data system to implement or supplement some of the proposed microwave services for such functions as computer time-sharing, computer-to-computer interconnection and remote publishing.

7.2.10.1 Computer Services (10A). The requirements for this system derived from LMSC Demand 169, are shown in Table 7-57. This system is designed to interconnect one major computer center in each state with each other. The total system cost, for the 10-year lifetime, is $85.1M. System details are presented in Table 7-58.

A tradeoff was performed on systems costs versus the number of channels provided (Figure 7-22). While costs increase with increasing service, the rate is not large — 9% for a factor of 2 on service.

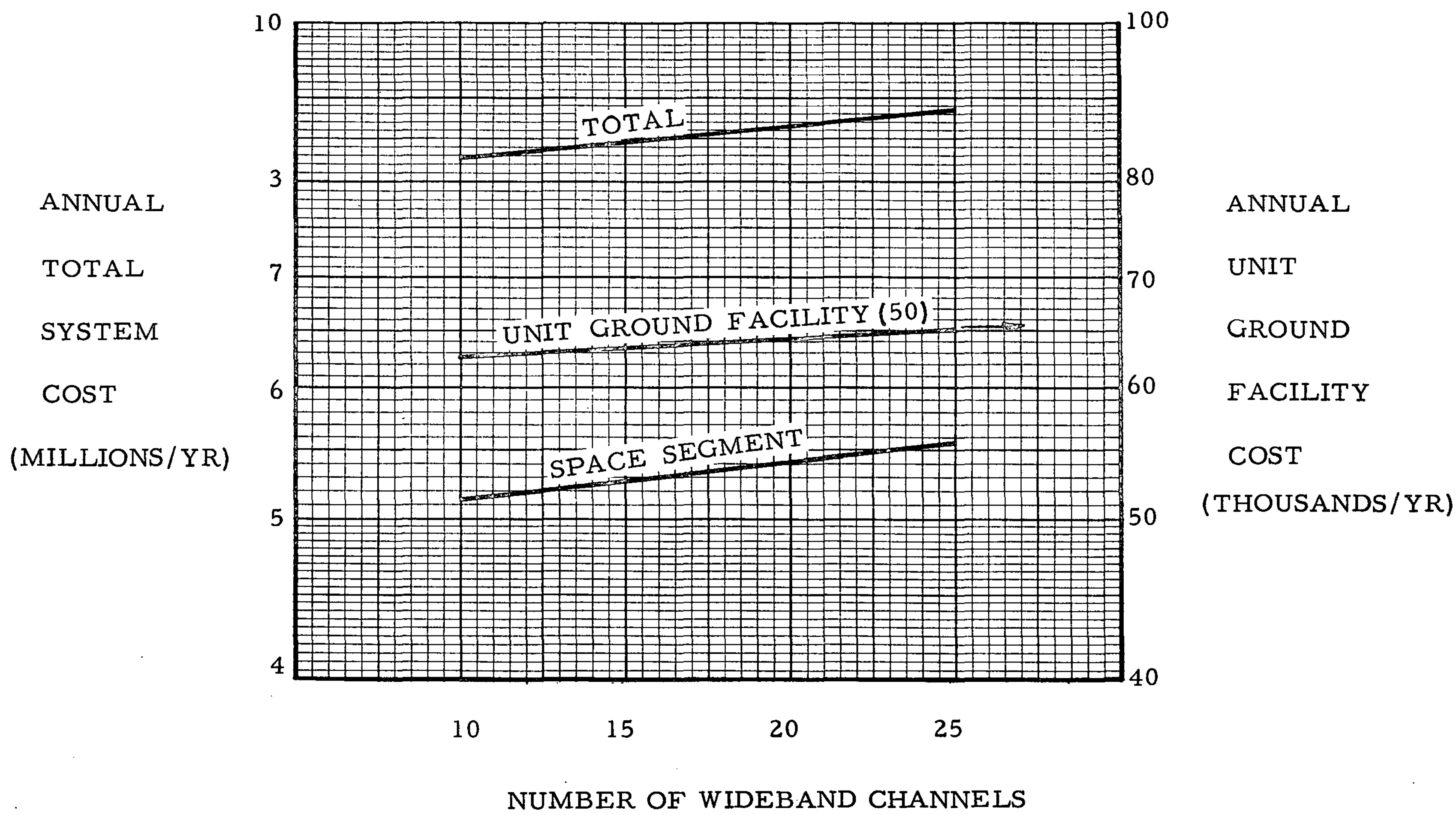


Figure 7-22. Computer Services System Costs

Table 7-57. Computer Services Requirements

- INTERCONNECTION OF COMPUTER TERMINALS WITH WIDEBAND CIRCUITS

- GROUND TERMINALS -50
  - DISTRIBUTION - CONTINENTAL U.S.
  - DATA RATE - 280 kilobits/second

- SATELLITE
  - FULL U.S. COVERAGE $(3^\circ \times 7^\circ)$
  - 10 YEAR SYSTEM LIFETIME
  - OPERATING FREQUENCY — 12 GHz
  - 20 CHANNELS

Table 7-58. Computer Services Results

- GROUND TERMINAL CHARACTERISTICS

EIRP	57.8 dBw
G/T	28.4 dB/°K
ACQUISITION COST	\$224K
ANNUAL OPERATION	32K
ANNUAL MAINTENANCE	10K
TOTAL	\$644K

- SATELLITE CHARACTERISTICS

EIRP	46.4 dBw
G/T	2.8 dB/°K
WEIGHT	1300 pounds
ACQUISITION	\$3.8M
NON-RECURRING	20.0M
TOTAL	27.6M

- LAUNCH VEHICLE

TITAN III	
ACQUISITION	\$21.0M
NON-RECURRING	4.3M
TOTAL	\$25.3 M

7.2.10.2 NASA Center Interconnection Requirements for this system are shown in Table 7-59. The aim is to provide 20 wideband channels for teleconferencing between the centers. A TV capability is provided. Results are summarized in Figures 7-23 and 7-24. Figure 7-23 shows a slight minimum at a 2.5 GHz operating frequency. Usual cost increase with frequency above this value is also shown. Figure 7-24 shows the effect of varying the number of channels provided. An overall cost increase of 50% occurs when the number of channels is doubled from 10 to 20.

Table 7-59. NASA Center Interconnection Requirements

SOURCE/DESTINATION

- 12 NASA CENTERS

SYSTEM DESCRIPTION

- 20 WIDEBAND CHANNELS
- NORTH AMERICAN COVERAGE
- CCIR RELAY QUALITY
- 10 YEAR SYSTEM LIFE

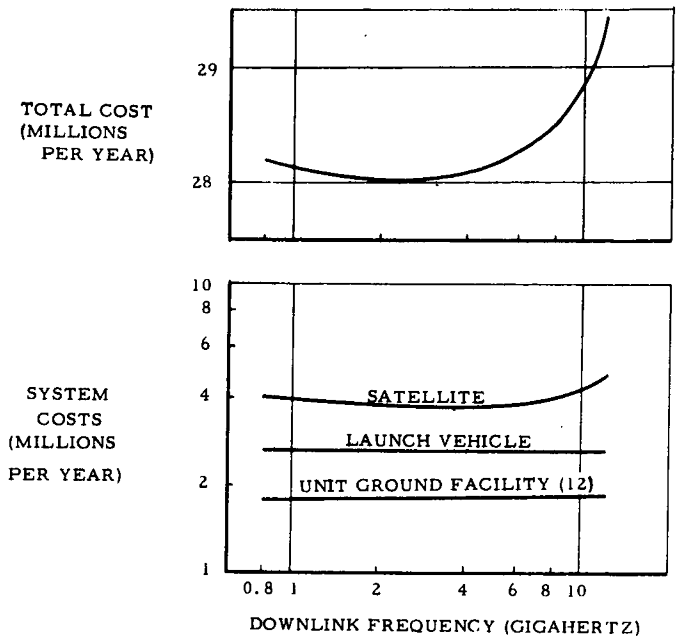


Figure 7-23. NASA Network System Cost Sensitivity to Frequency

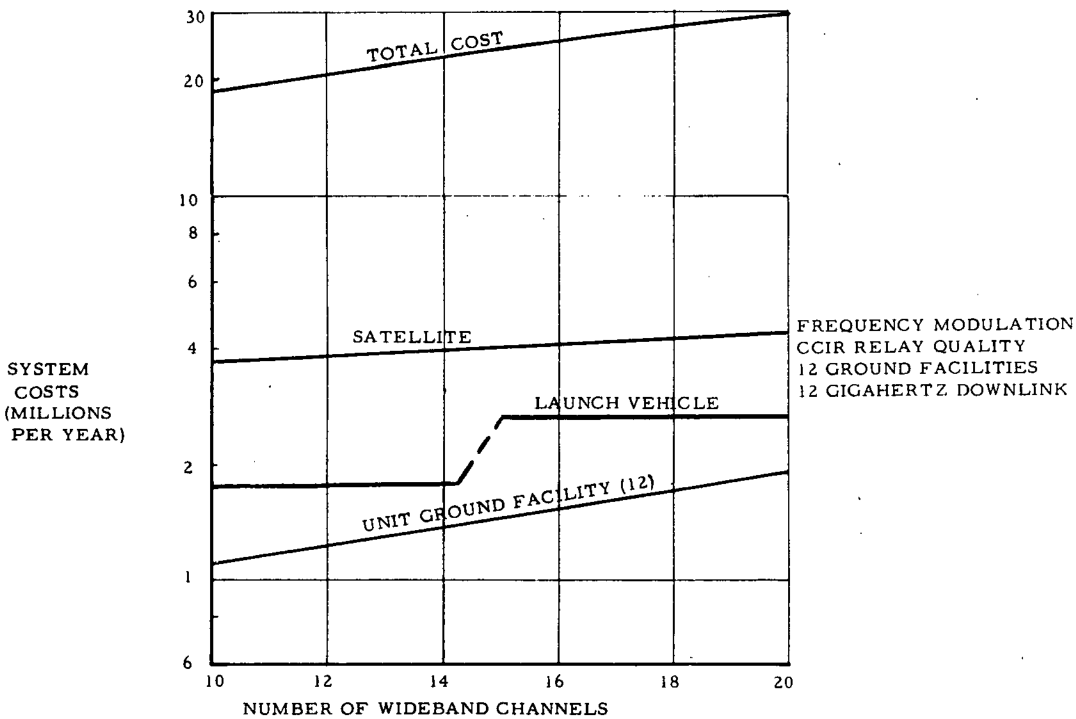


Figure 7-24. NASA Network System Cost Sensitivity to Number of Channels

7.3 MULTIPLE PURPOSE MISSIONS

7.3.1 INQUIRY/RESPONSE SYSTEM. This system combines three single purpose missions previously discussed:

1. LAW ENFORCEMENT (Section 7.2.5.4)

   93 Cities with 1 Central Control
   1 Facsimile Channel with Orderwire
   1 Data Channel at 4800 Band
   750,000 Transactions per Day

2. CREDIT CARD (Section 7.2.9.3)

   3000 Cities with 1 Central Control
   1 Data Channel
   1,000,000 Transactions/Day

3. FEDERAL RESERVE (Section 7.2.9.4)

   38 Banks with 1 Central Control
   1 Data Channel
   11,800 Transactions/Day

They are combined here because of the similarity in the mode of their operations (inquiry/response through a central control facility) and their narrowband, digital data characteristics. Results of this combination are summarized in Table 7-60.

Table 7-60. Multi-Purpose Mission Results

	TRANSACTIONS		TOTAL SYSTEM COST $M/YR		SPACE SEGMENT COST $M/YR		COST PER TRANSACTION	
	PER DAY	PER YR.	MULTI -	SINGLE	MULTI -	SINGLE	MULTI -	SINGLE
LAW ENFORCEMENT	750K	274 M	8.15	10.9	2.3	4.9	3¢	4¢
CREDIT CARDS	1M	360 M	197.0	186.8	3.7	5.4	55¢	50¢
FEDERAL RESERVE SYSTEM	10K	3.8 M	2.3	6.9	0.27	4.8	60¢	$1.82
TOTALS	1.76M	638 M	207	204.6	6.27	15.1	32¢	31.8¢

As shown, the combined system is only slightly more expensive than the sum of the separate systems. Correspondingly, the average cost per transaction is relatively unchanged. However, the individual cost/transaction for the Federal Reserve System shows a reduction to one-third of the original cost — a viable price level that would enable the FRS to consider a satellite system.

7.3.2 TV SERVICES — MULTIPLE PURPOSE. Due to their similar operational characteristics, the various television systems from Mission Group 1/Television Services and Mission Group 3/Educational Services were combined into a number of multiple-purpose mission cases. The various combinations are listed in Table 7-61. The number of channels received per ground station for each service is as follows:

EDUCATIONAL TELEVISION	3
PUBLIC SCHOOL ITV	8
PAROCHIAL SCHOOL ITV	2
COMMERCIAL-REBROADCAST	6
CABLE	20

The results of these runs are itemized in Tables 7-62 through 7-66. The unit facility costs in all cases include the building, a VTR/film chain for the program redistribution, standby power and operating personnel. Since, in some cases, these items may not be required, they may be deleted without change in the minimum cost solution. The costs do not include the means for redistributing the program material beyond the receiving facility.

The costs of each service, as synthesized in single purpose missions, is included on the tables. In all cases, except one, the multiple purpose configuration resulted in a cost savings over the single purpose mission. The only exception was for the parochial system case number 7. This case represented a bounded solution, 2 beam satellite. The decrease in gain realized from a 4 beam satellite drove the prime power requirement to its constraint and further savings were not realizable.

Table 7-61. Case Combinations for TV Services

Case	Downlink Frequency (GHz)	Number of Beams	Number of Stations							
			ETV		ITV		Parochial ITV		Commercial	
			Source	Receive	Source	Receive	Source	Receive	Source	Receive
1	0.8	4	2	200	49	30,000	-	-	-	-
2	2.5	4	2	200	49	30,000	-	-	-	-
3	8.4	4	2	200	49	30,000	-	-	-	-
4	12.2	4	2	200	49	30,000	-	-	-	-
5	12.2	2	2	200	49	30,000	-	-	-	-
6	12.2	4	2	200	49	30,000	1	174	-	-
7	12.2	2	2	200	49	30,000	1	174	-	-
8	12.2	2	2	200	49	30,000	1	174	4	219 (1)
9	12.2	2	-	---	49	30,000	1	174	4	5000 (2)
10	12.2	4	2	200	49	300,000	-	-	-	-
11	12.2	4	2	200	49	300,000	1	14,000	-	-
12	12.2	2	-	-	49	300,000	1	14,000	4	5000 (2)

(1) Commercial Rebroadcast

(2) Commercial Cable

Table 7-62. ETV Cost Summary

Case	Number of Stations		System Costs (Millions of Dollars)					Single Purpose Mission Cost ($M)
	Source	Receive	Unit Source	Unit Receive	Satellite	Launch Vehicle	Total System	
1	2	200	1.938	1.003	22.40	58.10	285.08	316.9
2	2	200	1.977	1.005	18.63	58.10	281.74	
3	2	200	1.992	1.006	22.69	58.10	285.95	
4	2	200	2.028	1.007	26.35	58.15	289.89	
5	2	200	2.129	1.007	31.28	58.15	295.08	
6	2	200	2.041	1.007	24.66	49.20	279.29	
7	2	200	2.126	1.007	29.00	49.20	283.87	
8	2	200	1.269	0.687	15.83	33.66	189.34	
9	-	-	-	-	-	-	-	
10	2	200	2.049	1.005	33.80	58.15	297.08	
11	2	200	2.058	1.005	30.00	49.20	284.36	
12	-	-	-	-	-	-	-	

Table 7-63. Public School ITV Cost Summary

Case	Number of Stations		System Costs (Millions of Dollars)					Single Purpose Mission Cost ($M)
	Source	Receive	Unit Source	Unit Receive	Satellite	Launch Vehicle	Total System	
1	49	30,000	1.306	1.313	59.75	155.05	39,634.8	39,998
2	49	30,000	1.335	1.317	49.81	155.05	39,781.8	
3	49	30,000	1.346	1.319	60.51	155.05	39,847.3	
4	49	30,000	1.369	1.321	70.25	155.05	39,929.3	
5	49	30,000	1.405	1.322	83.40	155.05	39,953.5	
6	49	30,000	1.370	1.321	65.77	131.20	39,903.4	
7	49	30,000	1.405	1.322	77.34	131.20	39,927.5	
8	49	30,000	1.574	1.315	42.41	89.77	39,658.8	
9	49	30,000	1.578	1.315	70.09	113.71	39,695.5	
10	49	300,000	1.342	0.856	90.12	155.05	257,162	257,197
11	49	300,000	1.369	0.856	80.00	131.20	257,150	
12	49	300,000	1.577	0.849	72.21	113.71	254,975	

Table 7-64. Parochial School ITV Cost Summary

Case	Number of Stations		System Costs (Millions of Dollars)					Single Purpose Mission Cost ($M)
	Source	Receive	Unit Source	Unit Receive	Satellite	Launch Vehicle	Total System	
1	-	-	-	-	-	-	-	
2	-	-	-	-	-	-	-	
3	-	-	-	-	-	-	-	
4	-	-	-	-	-	-	-	
5	-	-	-	-	-	-	-	
6	1	174	2.308	0.920	16.44	32.80	211.69	225.4
7	1	174	2.126	1.007	19.33	32.80	229.49	
8	1	174	2.873	0.914	10.55	22.44	194.89	
9	1	174	2.848	0.914	17.52	28.43	207.83	
10	-	-	-	-	-	-	-	
11	1	14,000	2.330	0.457	20.00	32.80	6455.09	6519.7
12	1	14,000	2.863	0.450	18.05	28.43	6359.70	

Table 7-65. Commercial TV Cost Summary

Case	Number of Stations		System Costs (Millions of Dollars)					Single Purpose Mission Cost ($M)
	Source	Receive	Unit Source	Unit Receive	Satellite	Launch Vehicle	Total System	
1	-	-	-	-	-	-	-	
2	-	-	-	-	-	-	-	
3	-	-	-	-	-	-	-	
4	-	-	-	-	-	-	-	
5	-	-	-	-	-	-	-	
6	-	-	-	-	-	-	-	
7	-	-	-	-	-	-	-	
8	2* 2	200* 19	2.307 2.493	1.142 1.367	31.66	67.33	362.99	945.40
9	4	5000	2.526	1.838	43.81	71.07	9316.83	9721.00
10	-	-	-	-	-	-	-	
11	-	-	-	-	-	-	-	
12	4	5000	2.535	1.830	45.13	71.07	9278.74	

* Shares 2 source and 200 receive stations with ETV. Costs are prorated on channel requirements.

Table 7-66. Multipurpose Space Segment Cost Summary

Case	Satellite Costs					Launch Vehicle Costs				
	ETV	ITV	Parochial	Commercial	TOTAL	ETV	ITV	Parochial	Commercial	TOTAL
1	22.40	59.75	-	-	82.15	58.15	155.05	-	-	213.2
2	18.68	49.81	-	-	68.49	58.15	155.05	-	-	213.2
3	22.69	60.51	-	-	83.20	58.15	115.05	-	-	213.2
4	26.35	70.25	-	-	96.60	58.15	115.05	-	-	213.2
5	31.28	83.40	-	-	114.68	58.15	115.05	-	-	213.2
6	24.66	65.77	16.44	-	106.88	49.20	131.20	32.80	-	213.2
7	29.00	77.34	19.33	-	125.67	49.20	131.20	32.80	-	213.2
8	15.83	42.21	10.55	31.66	100.26	33.66	87.77	22.44	67.33	213.2
9	-	70.09	17.52	43.81	131.42	-	113.71	28.43	71.07	213.2
10	33.80	90.12	-	-	123.92	58.15	155.05	-	-	213.2
11	30.00	80.00	20.00	-	130.00	49.20	131.20	32.80	-	213.2
12	-	72.21	18.05	45.13	135.39	-	113.71	28.43	71.07	213.2

7.3.3 <u>BIOMEDICAL NETWORK</u>. Individual medical video and data services were discussed in Section 7.2.8. The intent of this section is to elaborate on a multi-service mission in which the following modes of information transfer are considered:

1. Digital Data. This mode includes dial access for computer-assisted diagnoses, and data bank inquiry, records transfer and some library browsing. While this can be implemented near term in some areas through telephone networks, long term applications will need a dedicated microwave network to accommodate their traffic requirements. A satellite can then be used.

2. Television. The optical features of zooming and magnification are exploited for medical ETV where operations and experiments can be observed "close up". Several applications have included the TV optics at a microscope view plane for observing smears and pathological samples. A high-quality color system is required for these applications. Television is also used for remote diagnoses. The experience at Massachusetts General Hospital, Boston, shows that 2-way TV is required to maintain the patient's interest and cooperation. Finally, TV is used to support library browsing activities. The general requirements for these systems are summarized in Table 7-67.

The requirements shown in Table 7-67 were combined to illustrate cost increments as a function of service. The cases considered are itemized in Table 7-68 and the results of the synthesized systems are given in Table 7-69 and Figure 7-25. Case numbers 2, 3 and 4 considered a system topology composed of 8 regional centers and 1 national center while the other cases utilized only the national center. The unexpected drop in central facility cost in case 3 is due to the decrease in equivalent voice/data channel multiplex equipment (180 data channels as compared to 500 voice channels of case 2).

Table 7-67. Biomed System Inputs

4 TIME ZONE SYSTEM

EACH T.Z. CONNECTED TO
NATIONAL DATA CENTER — WASHINGTON

		NO. OF DIGITAL CH.			NO. TV CH.		
TIME ZONE	NO. HOSPITALS	COMPT. DIAGN.	BROWSING & RECORDS	DATA BANK INQUIRY	LIBRARY BROWSING	REMOTE DIAGNOSIS	MED ETV
EAST	3450	180	90	360	6	6/OR 3-DUPLEX	5
CENTRAL	2075	84	40	168	—	—	5 AUDIO OUT
MOUNTAIN	400	10	7	23	—	—	500 AUDIO IN.
WEST	1200	40	20	80	—	—	—
	7,125	100%	100%	100%	6	6 3-DUPLEX	5

Table 7-68. Requirements Combinations for Biomedical Network

CASE	NUMBER OF CHANNELS				
	DIGITAL DATA	LIBRARY BROWSING VIDEO	REMOTE DIAGNOSIS VIDEO	ETV	
				VIDEO	AUDIO[1]
1	1100	-	-	-	-
2[2]	-	-	-	5	500
3[2]	180	6	-	-	-
4[2]	1100	-	-	-	500
5	1100	6	-	5	500
6	1100	6	6	5	-
7	1100	6	6	5	500

(1) For talkback capability.

(2) System uses 9 regional centers.

Table 7-69. Biomedical Network Cost Summary

CASE	NUMBER OF STATIONS		SYSTEM COSTS (MILLIONS OF COLLARS)				
	CENTRAL	HOSPITAL	UNIT CENTRAL	UNIT HOSPITAL	SATELLITE	LAUNCH VEHICLE	TOTAL SYSTEM
1	1	7125	12.12	0.53	42.31	26.4	3857
2	9	7119	3.94	1.047	60.50	213.2	7763
3	9	7119	2.50	1.051	61.49	213.2	7781
4	9	7119	13.84	1.048	66.20	213.2	7865
5	1	7125	14.68	1.49	103.37	213.2	10948
6	1	7125	15.78	1.51	106.32	213.2	11094
7	1	7125	17.41	1.52	108.71	213.2	11169

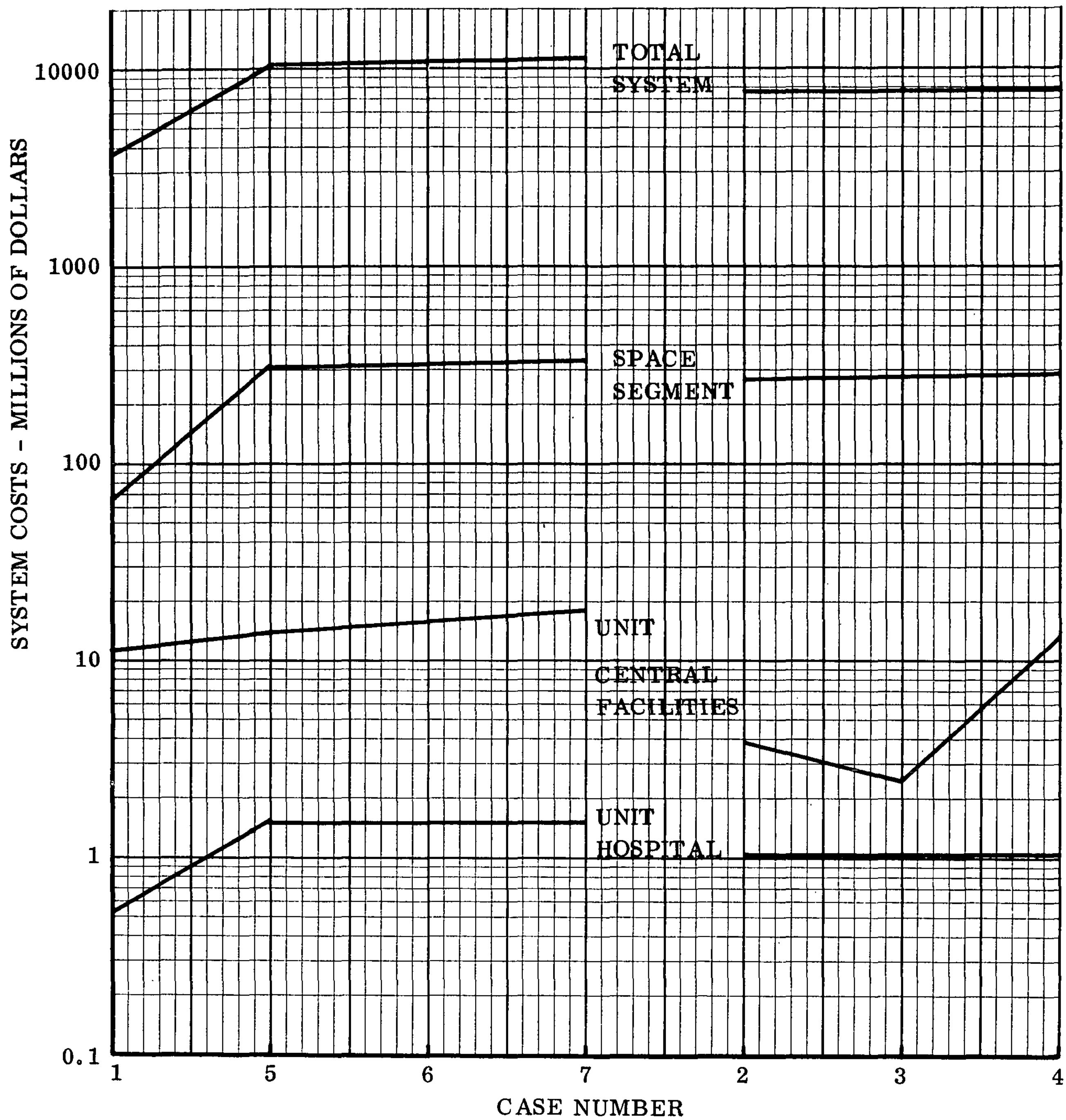


Figure 7-25. Biomedical Network System Costs

8

COMPUTER PROGRAMS

The sole function of a communications system is to transfer information between two or more users. Typical terrestrial systems are composed of serial combinations of increasingly higher density lines. Dedicated satellite communications systems utilize a parallel combination of "lines." Since it is not always feasible to install a satellite terminal at each source or destination, a hybrid terrestrial/satellite system is indicated.

In keeping with the total system approach, two computer programs were developed by Convair Aerospace to synthesize such hybrid systems. One program — Satellite Telecommunications Analysis and Modeling Program (STAMP) — considers the satellite/ground facility system while the other — Ground Network Model — treats a terrestrial network.

The programs are structured such that they may define alternative or complementary communications systems.

8.1 SATELLITE TELECOMMUNICATIONS ANALYSIS AND MODELING PROGRAM (STAMP)

STAMP provides the systems analyst with a flexible tool for the analysis of satellite communications system requirements. The program utilizes a total system approach in which ground facilities, the satellite and the launch vehicle in a complex system topology are simultaneously synthesized. This approach provides insight into the multiple interrelationships among the system parameters and aids in identifying potential problem areas requiring further study and development.

The approach followed in developing the program was to minimize the total system cost consistent with constraints of satellite size, power levels, antenna diameters and receiver noise figures while satisfying the user requirements of area of coverage and type and grade of service. A cost effective satellite communications system will provide a balance of expenditures between the space and the ground segments. To achieve this balance a steepest-descent search technique was implemented to locate the system parameters yielding the minimum total cost.

The program also provides the capability to consider a wide range of system configurations and subsystem options. Minimum cost solutions for each configuration may then be compared. The input parameters may also be perturbed from their nominal values to assess the impact and sensitivities to those system parameters.

8.1.1 PROGRAM APPROACH. STAMP was developed with four basic objectives in mind: 1) a total system approach in which the ground facilities, satellite and launch vehicle are simultaneously synthesized; 2) a modular program structure for both program and parameter data; 3) flexible input of user requirements, system configurations and subsystem options; and 4) compatibility with CDC 6400 FORTRAN IV and IBM 360 FORTRAN IV.

Figure 8-1 illustrates the total system concept as utilized in STAMP. The ground facility system is made up of three classes of stations. The class 1 and 2 stations may differ in number, signal quality, channel capacity and transmit/receive capability. The class 3, or direct station, may receive only, at different signal quality than either of the former classes. This capability will be explained in depth in the following section on program structure. The satellite may have up to six antenna beams pointed at various locations within its visibility contour on the earth. Each of these beams, which have any mix of ground station classes, are treated separately in deriving the system parameters.

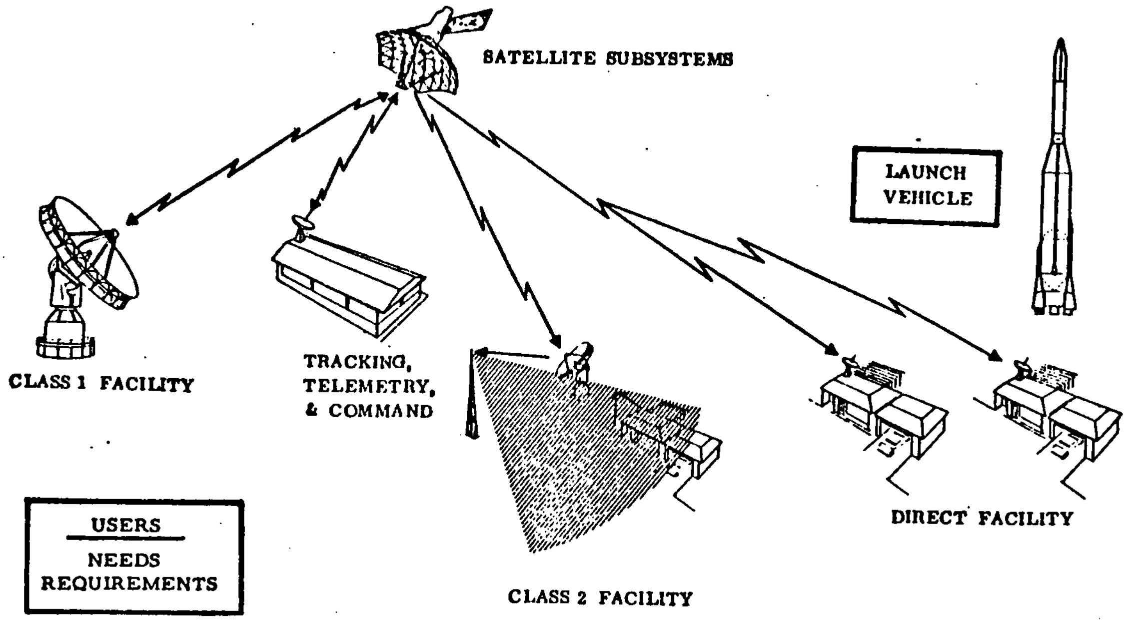


Figure 8-1. Total System Approach.

Due to the multiple interrelationships among the system parameters, the total system approach is mandatory. Any change in one parameter in one of the systems will be reflected into all systems. For example, a decrease in transmitter power on the satellite would lower the satellite prime power requirements, the satellite size and satellite cost. However to maintain the same signal quality at the ground receiving system, the characteristics of the ground stations must be changed — i.e. the receiving antenna gain must increase, the receiver noise figure must decrease, or the ground transmitter EIRP must increase. Either of these perturbations will increase the cost of the ground stations. The total system cost however, may increase or decrease depending upon the topology of the total system. STAMP automatically performs these perturbations in the system parameters but only in the direction to reduce the system cost.

STAMP was developed in modular form to increase its flexibility. The program is composed of numerous subroutines roughly corresponding to the subsystems of a communications system. Each subroutine is as independent as possible allowing inclusion or exclusion with little or no modification to the other subroutines. The parametric data defining the characteristics of each subsystem were curve fit with one of three forms. As new data are derived, the new coefficients may be input with no change in the program.

The FORTRAN Namelist feature was utilized for data input to the program to simplify specification of the input parameters. With this feature, data does not have to follow a rigid format and, after an initial input operation, only those parameters to be changed need be input.

STAMP is compatible with both CDC 6400 FORTRAN IV and IBM 360 FORTRAN IV. Features unique to either machine are avoided, however the short word length on the 360 requires double precision variables in the 360 version. The program occupies 30,200 words of storage on the CDC 6400 and approximately 37,500 words with overlay on the 360.

8.1.2 PROGRAM STRUCTURE. The basic program structure is shown in Figure 8-2. STAMP is divided into five major sections: 1) the driver routine; 2) the ground facility models; 3) the satellite and launch vehicle models; 4) the convergence process; and 5) miscellaneous models. Each section is divided into several subroutines which, as mentioned previously, may be modified with little or no change in the remaining subroutines.

Since the program utilizes a search technique to determine the minimum cost solution, the system must be described by a number of independent parameters. All other system characteristics, including cost, are dependent upon these parameters.

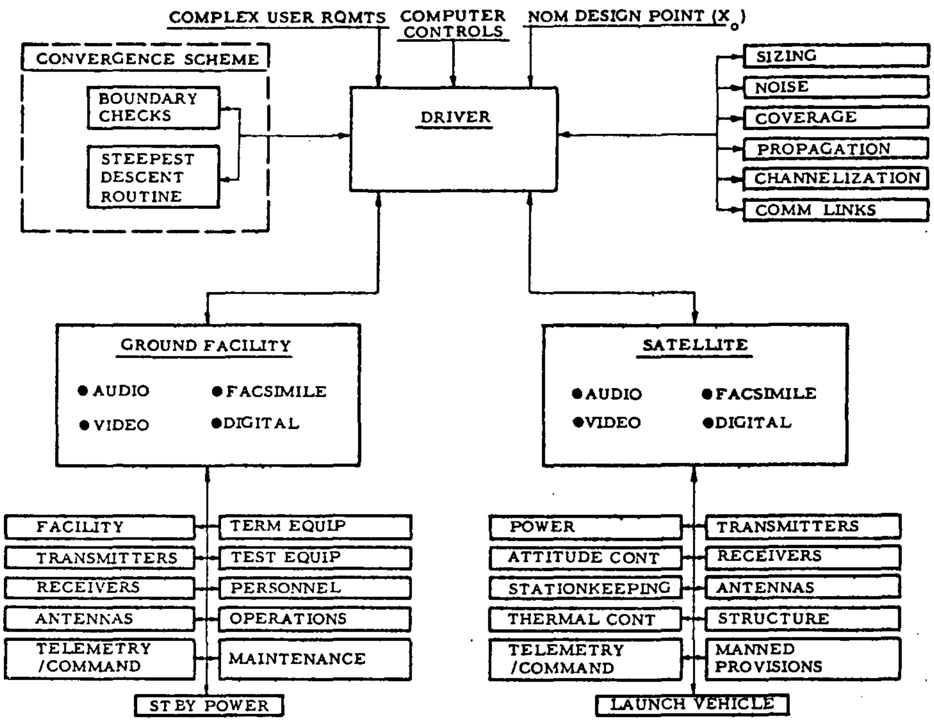


Figure 8-2. Synthesis Program Block Diagram.

The link equations in section 3.1.1 describe the communications characteristics. From these, a set of independent parameters are drawn, the number varying from 2 to 4. These parameters define up to 78 constrained dependent parameters and hundreds of unbounded dependent parameters. In most cases, ground facility antenna diameters and receiver noise figures are independent with ground facility transmitter powers, satellite transmitter powers, and satellite weight, volume and prime power as constrained dependent parameters.

A simplified block diagram for the program operation is shown in Figure 8-3. An initial set of values for the independent parameters is input. The ground and space subsystems are sized and their costs computed. The dependent parameters are then tested for boundary violations and the partial derivatives of the cost with respect to the independent parameters are computed. The convergence algorithm then computes a set of perturbations in the Xs to reduce the system cost. If the perturbations are sufficiently small as to indicate convergence, the program exits, prints a detailed listing of the minimum cost solution and inputs

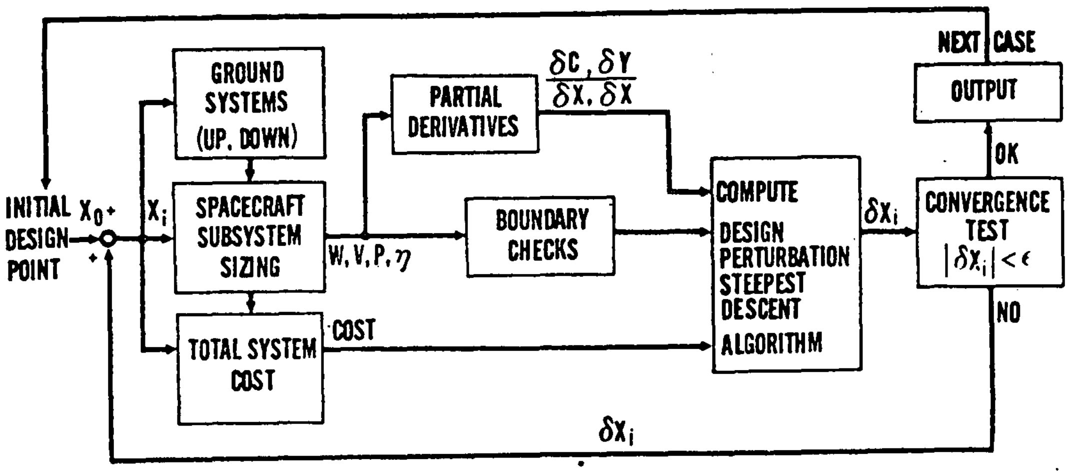


Figure 8-3. Program Operation.

another case. If convergence has not been achieved, an intermediate listing of the parameters is printed and the process is repeated until convergence.

8.1.3 <u>CONVERGENCE TECHNIQUE</u>. STAMP considers a wide range of communications confgurations ranging from a direct broadcast mode to a complex system of multiple uplinks and downlinks. The cost function is just as varied. In some cases, the system exhibits only one, well-defined minimum while in others the function is very complex with multiple local minima. For some system configurations, the system cost is more sensitive to a particular parameter than in other configurations. In addition, in most cases the cost contours are oblique to the parameter axes. The convergence technique should then be general enough to treat this wide range of systems but should not be so sophisticated as to require a disproportionate amount of computer time or storage.

Due to the complexity of the system, numerical partial derivatives are necessary. At each iteration, the cost gradient is calculated by perturbing each independent parameter by some small value. This requires from 2 to 4 additional passes through a major portion of the program for each iteration. A quadratic search would allow faster convergence, however the second partial derivatives would be required, necessitating from 6 to 20 additional passes through the program.

It was felt the faster convergence would be more than offset by the increase in computation time of a quadratic search.

The steepest-descent technique was chosen since it requires only first order derivatives and is much more efficient than less sophisticated, one dimensional searches. An adaptive step size control was employed to speed up convergence and to avoid local minima far from the minimum cost solution. Also a second term was added to reduce constraint violations that occur.

The operation of the steepest-descent technique is shown in Figure 8-4. In the plane of two independent parameters, X_1 and X_2, the constant cost contours appear as shown with the minimum system cost denoted by point D. A constraint boundary in this plane is shown as the dotted line such that solutions to the right are acceptable and solutions to the left are unacceptable. From some initial design point, A, the program perturbs the Xs in the direction of steepest-descent until the boundary is encountered (point B). The perturbations are then made parallel with the boundary in the direction of the steepest-descent until the minimum cost is achieved consistent with the boundary (point C). An example of the process is shown in Figure 8-5. In this case the independent parameters are ground receiver noise temperature and receiving antenna diameter and the constraint encountered is the solar array volume (170 cubic feet). The initial design point (2', 300°K) violated the volume constraint and resulted in an annual cost of $80 million per year. The results per iteration are shown is the right figure. As the perturbations in the Xs are made the volume decreases until at the seventh iteration, it encounters the boundary. The perturbations are then made along the boundary until the minimum constrained cost is realized at iteration 15. This cost is the constrained minimum system cost. However, the cost at iteration 3 is a factor of three less than the constrained solution but the solar array volume required is between 2,000 and 3,000 cubic feet. In this case, a larger launch vehicle may allow a lower cost system.

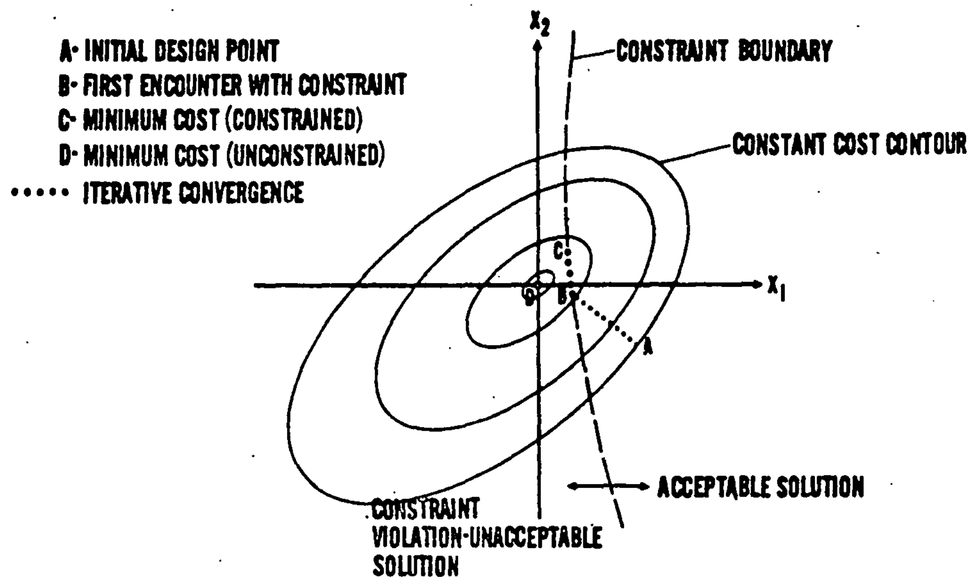


Figure 8-4. Steepest Descent Iterative Process.

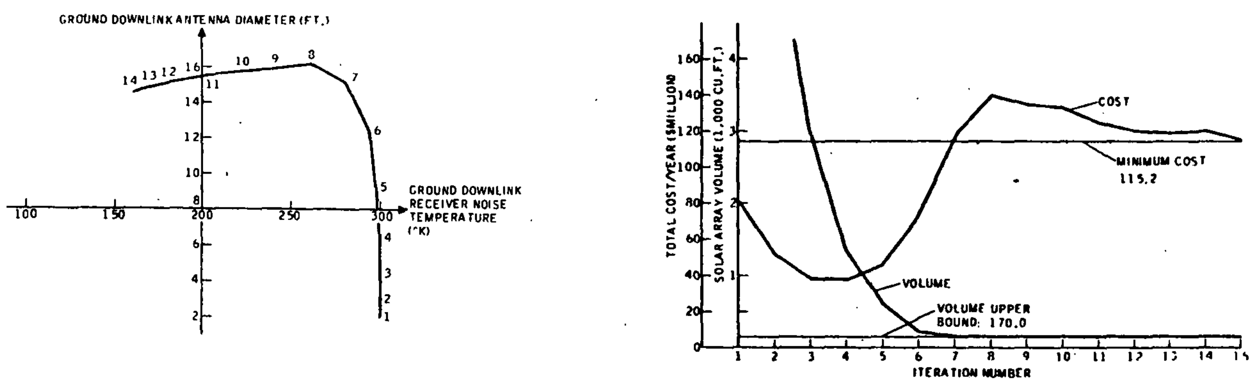


Figure 8-5. Convergence Example.

The convergence algorithm accepts the cost gradients with respect to the independent parameters and computes the perturbations as in the following equations. If Δy_j is the amount by which the j^{th} boundary is violated and $\bar{g}$ represents the gradient of the total system cost, then the perturbation in $\bar{X}$, the vector of independent parameters, is given by

$$\Delta X = K_c Hg - K_y F \Delta y_j \qquad (8-1)$$

where

$$F = \Phi(\Phi^T \Phi)^{-1}$$

$$H = (I - F\Phi^T)$$

and Φ is the gradient of the maximum constraint. The first term of equation (8-1) represents the component of the cost gradient parallel to the constraint boundary and in the direction of minimum cost. For small ΔX this term contributes nothing to the reduction of the constraint violation. The second term of equation (8-1) represents, for K_y equal to unity, the X perturbation required to reduce Δy_j to zero.

Since a first order technique produces no step size information, the value of Kc in the above equation is an arbitrary vector. A step size vector, $(S)_i$, where the i subscript represents the iteration index, has been added to the algorithm. The relationship for K_c is derived in Appendix of Volume 4. The k^{th} element of the vector is

$$K_{c_k} = \left[\frac{(S_k)_i^2 - K_y^2 \Delta y_j^T (\Phi^T \Phi)^{-1} \Delta y_j)^{1/2}}{(Hg)^T (Hg)} \right] \qquad (8-2)$$

If no constraints are violated, the terms Δy_j and Φ are zero. Equation (8-2) then becomes simply

$$K_{c_k} = \frac{(S_k)_i}{|g|}$$

and equation (8-1) reduces to

$$\Delta X_k = K_{ck} g_k. \qquad (8-4)$$

The rationale for varying the step size is straight-forward. If successive steps of one of the independent parameters has been in the same direction, it is desirable to increase the step size to speed up convergence. On the other hand, if the perturbations are changing signs, the parameter is oscillating about the minimum and a decrease in step size is desirable. The program examines the three previous iterations and if all three perturbations are in the same direction, the step size is doubled. If the perturbations between the third and second previous iteration changed size with no change between second and first previous iterations the step size remains unchanged. However if the perturbation changed sizes between the two previous iterations with no change before, the step size is halved.

This technique helps to avoid local minima far from the desired solution since the step size is course enough to follow the envelope of the response surface. However, as is the case with most convergence techniques, local minima may be selected giving the appearance of a true minimum. Experience and sound engineering judgement reduce the possibility of the acceptance of such a solution. The vast majority of local minima encountered to date were easily recognizable. The printout at each iteration should be consulted to determine if the convergence path bypassed a more reasonable, lower cost system configuration. In addition, the cost balance between the independent parameters can be examined. If the costs for the antenna, transmitter and receiver subsystems in a ground station differ widely or do not appear to be balanced in an unconstrained solution there is the possibility of the solution being a local minimum. If there is any doubt as to the validity of a solution, the program may be restarted at a significantly different initial point to see if the program converges to the same solution. The region in the vicinity of the questionable solution may also be investigated by running the program in the single iteration mode at selected points about this minimum.

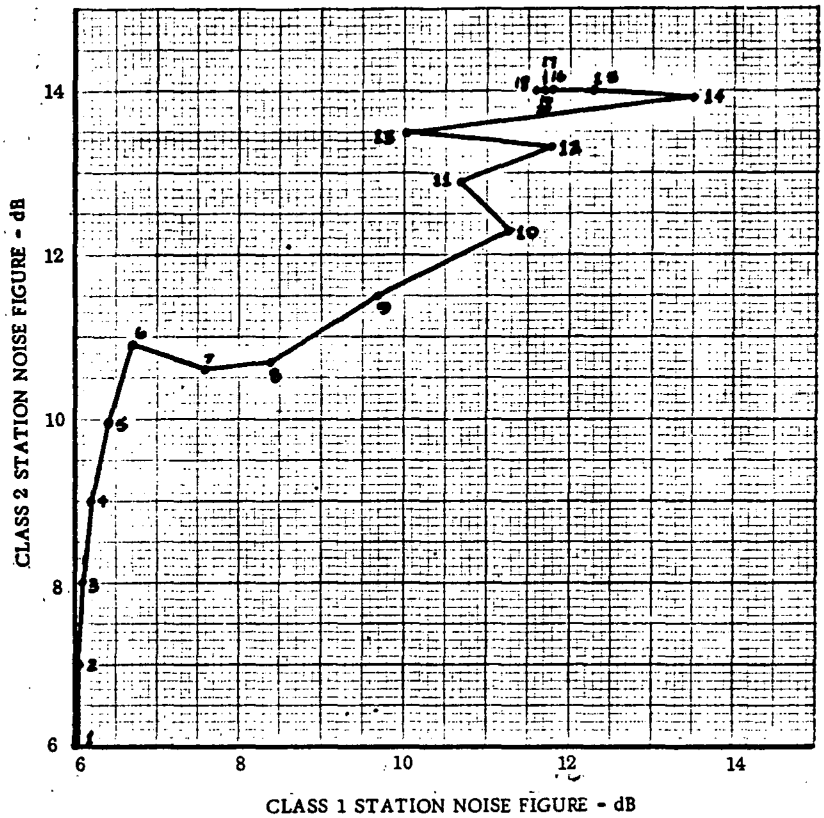
8.1.4 EXAMPLE CASE. Educational/Instructional Television for the U.S.- The baseline system description for this example is given in Table 8-1. The system was synthesized with STAMP and the solution followed the convergence path shown in Figure 8-6. Although the change in cost was slight from the initial design point, the independent parameters, receiver noise figures, increased significantly. The small cost change is due to the large number of constant cost items in the system, e.g. operations personnel and video recording and playback equipment. The system characteristics are given in Table 8-2.

Table 8-1. U.S. Educational/Instructional Television System Baseline Description

SOURCE LOCATIONS	DESTINATIONS
• ETV-2 FACILITIES	• ETV-200 METROPOLITAN AREAS
• ITV-49 FACILITIES	• ITV-30,000 SCHOOL DISTRICTS

SYSTEM DESCRIPTION

- 4 DOWNLINK BEAMS
- 11 VIDEO CHANNELS PER BEAM
  - 8 INSTRUCTIONAL
  - 3 EDUCATIONAL
- CCIR RELAY QUALITY $\frac{S}{N} = 54$ dB
- 10 YEAR SYSTEM LIFE
- DOWNLINK FREQUENCY - 12 GHz



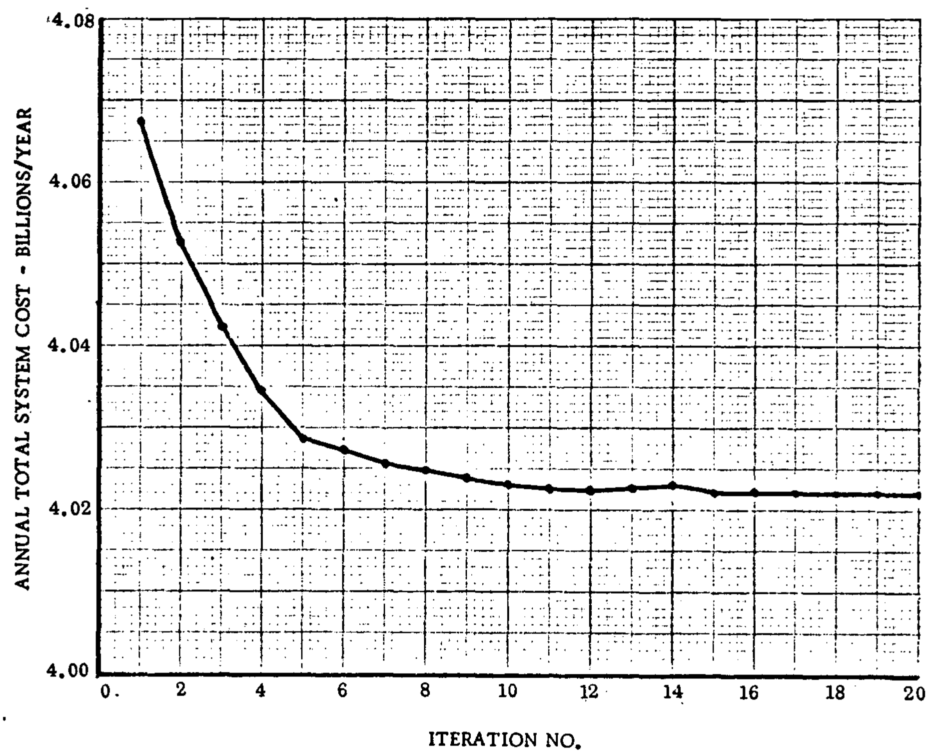


Figure 8-6. U.S. ETV/ITV Iterations

Table 8-2 System Characteristics (ETV/ITV)

	ETV		ITV		Satellite	Launch Vehicle
	Source	Destination	Source	Destination		
No. of Stations	2	200	49	30,000	1	1
EIRP - dBW	68.7	—	68.7	—	59.1	—
G/T - dB/°K	18.0	11.1	18.0	11.1	8.2	—
ANT Diameter - ft	18.2	10.6	18.2	10.6	1.9 2.8	—
RCVR Noise Fig - dB	11.7	14.0	11.7	14.0	3.0	—
XMTR Power - W	60	—	60	—	300	—
Costs:						
Initial	\$706K	\$299K	\$477K	\$363K	\$32.7M(Unit)	\$188.2M
Annual	132K	70K	89K	96K	63.9M(R&D)	25.0M
Unit Station Costs (10 Years)	\$2.03M	\$1.01M	\$1.37M	\$1.32M	\$96.6M	\$213.2M
Total Costs (10 Years)	\$4.05M	#201.3M	\$67.1M	\$39.6B	\$96.6M	\$213.2M
Total System Cost (10 Years)	\$40.22B					

8.2 GROUND NETWORK PROGRAM

A ground network modeling program has been developed which computes upper and lower bounds on the cost of installation and maintenance of a terrestrial network. A typical satellite ground terminal provides a service to an area. If more than one user is located in the area, some ground network capability is required for collection and distribution of the information within the area. Trades exist between the number, location and cost of the satellite terminals and the associated size and costs of the terrestrial distribution systems. The ground system modeling program is designed to assist in these trade studies. It is not intended to optimize a ground system network for a specific set of input data, but only to generate realistic, parametric cost data for the ground links so more nearly optimum overall systems can be derived.

The cost of a terrestrial link is a function of length and capacity and the cost of a network is the sum of the individual links and terminals. The ground system modelling problem is the identification of the necessary links to meet a set of user requirements. Two independent methods are used to generate the networks and the associated costs. The first generates a non-realizable system -- but one useful for establishing a lower bound on cost. The second generates a network having sufficient capacity to meet the demand requirements. It is a realizable system -- but not necessarily optimum. It establishes an upper bound on the network cost. The two methods generate cost data for acquisition and maintenance and the cost of leasing equivalent service from a common carrier.

The network analysis requires that each user be characterized as a terminal or node with a specified communication requirement and location. The program is dimensioned to process as many as 60 points, and input decks have been prepared and used for the state capitols, 50 major cities and 50 major marketing areas. One input deck lists 30 major communications users in Alaska, another, the 35 Datran terminals. Each card has the geographical location of the user, and, if demand matrix is to be generated internally, population or some other measure of user communication requirement.

The demand matrix establishes the number of channels of a specified capacity (typically 4KHz voice) which meet the communication requirements of the users within the network. If the demand matrix is known it can be input directly. Alternatively, if user population is input, the demand matrix can be computed as a function of population at each node. The distances are computed from the latitude and longitude of each point pair.

Great circle distance normally is computed, however, the plane surface model (airline miles) can be used instead for particular applications.

The remaining input data are the cost constants. Linear cost functions are used for acquisition and maintenance costs. These are essentially a fixed cost per mile (independent of the number of channels), and a channel cost per mile.

While linear functions are used, the program can be generalized to any cost function of capacity. Specifically a cost model could be used which selects between hardwire, microwave relay or coaxial cable, for example, depending on link length and capacity required.

8.2.1 LOWER BOUND COMPUTATION. Calculation of the lower bound on cost is based on an approach suggested by E. N. Gilbert in the Bell System Journal, November 1967. His method uses a "Steiner" minimal tree to establish the shortest possible interconnecting path between the nodal points. Graphic methods are available for constructing this tree, however, an inexpensive computerized analogy is not apparent. For this reason, a "minimal ordinary weighted spanning tree" is substituted. This path is usually slightly longer than the "Steiner" and never shorter. An algorithm for computing the spanning tree is credited to D. R. Fulkerson of Rand Corporation. This tree is the shortest path connecting the nodes directly without use of intermediate branch points.

Use of the minimal tree provides a lower bound on the ditch length required if, for example, a buried coaxial cable system is proposed. The tree is generated by connecting points to the nearest unconnected neighbor until N-1 branches are generated between N points. The cost of this ditch and channel capacity independent equipment costs are computed on a straight cost-per-mile basis. It is the lowest possible cost for a minimum interconnecting system (without intermediate branches) but its use does not necessarily lead to lowest system cost when the additional costs of increased capacity are considered.

In Gilbert's method, the additional cost for capacity needed to meet the demand matrix requirements is estimated by computing channel miles on the basis of direct paths between nodes. Essentially, the cables are not constrained to follow the ditches. The combination of cost for the shortest ditch, and cost for shortest cables (the complete graph) is the lower bound on system cost.

The process of increasing cable length to drop it into the ditch, and rearranging and adding branches to the tree to minimize cable length increases cost but leads to a realizable network which is the basis of the upper bound on cost.

Terminal costs are based on a fixed cost plus an additional cost per channel connected. The complete graph is used to establish the number of channels at each terminal (e.g., no through traffic or switching is accommodated). This is the minimum capacity which would meet the requirements at each terminal, therefore, it is the lower bound on terminal cost.

Computation of maintenance and operation costs on the branches and terminals is similar. Leasing costs are based on channel mile requirements and station connection requirements, again representing minimum values.

8.2.2 <u>UPPER BOUND COMPUTATION.</u> This subroutine formulates a credible network which meets the requirements and for which costs can readily be computed. The process involves the assumption that the entire graph is installed (i.e., all direct branches exist between nodes with sufficient capacity to meet the demand requirements).

All branches are then tested, proceeding from longest to shortest, to determine if a saving can be made by eliminating a specific branch and rerouting the capacity assigned to this branch over a combination of other existing channels. This test can be accomplished very rapidly because only the shortest alternate path is considered. If the cost of adding the needed capacity to the alternate path exceeds the cost of the branch being tested, no change is made. If the alternate path is less expensive the channels are transferred, the demand for the test branch is set to zero, and the length of the deleted branch is set to an extremely high value to preclude its later selection as part of an alternate shortest path.

The network generated by the above series of tests appears to be surprisingly close to optimum for connecting points (without intermediate branch points). The shortcoming to the method is that after many branches have been deleted there are times when alternate 2-hop paths do not exist. In this case, the branch is kept even through alternate paths of 3 or more links may yield a lower overall cost. While the additional complexity is not warranted here, this condition could be noted and a search made for an alternate 3- or 4-hop path.

The program has other less significant idiosyncracies which prevent an optimum result. The study objective, however, it not to derive optimum networks but only to provide useful bounds on cost. The present algorithm meets the objective.

After the network is established, the installation and maintenance cost is computed. Terminal costs are computed as before except that all channels passing through the node are assumed to be terminated at the node. Provision is therefore made for the cost of any switching which may be required. Since no terminal is deleted, and all demands are met, all terminals are at least as expensive as in the lower bound calculation. The additional cost of through traffic along trunk routes raises the cost estimate of these terminals. These are the upper bound estimates of terminal costs.

8.2.3 TEST – GILBERT'S EXAMPLE. In Gilbert's paper, an example of four cities was made. Figure 8-7 shows schematically the input data. Distances along each branch are indicated in airline miles as used by Gilbert, and in parenthesis, great circle distances used by the Convair program. On the lines, the demand is shown. The value "X" was varied from 30 to 5000 to examine the effect of increased channel capacity on cost.

Gilbert's paper listed the predicted minimum bound and a graphically (hand methods) computed optimum value. The latter process is time consuming, restricting the analysis to a few nodes. The ground system modelling program repeated cases for X = 30, 100, 500, and 5000. Results are summarized in Table 8-3 .

In this example, branch cost was set at $17,000 plus $7 per channel for each mile of branch length. We are interested in whether Gilbert's computed "actual" cost lies within the range set by the upper and lower bounds of the ground system modelling program.

Gilbert's "actual" cost is based on a weighted Steiner tree. In case "X = 30," the primary cost per mile is capacity independent, i.e., $17,000 versus $350 to $3500 for the 30 to 300 channels required. Under these circumstances the actual case approaches the computed lower bound -- and in this case has actually dropped below it as a result of the use of the more efficient Steiner tree. Through the middle range of values, the actual falls within the computer predicted range. In the last case, the actual cost computed by Gilbert is higher than the computed upper bound. This results from the fact that Gilbert's process results in a "relatively minimal" tree for which small perturbations do not reduce cost. There is no guarantee, however, that a large perturbation will not lead to a lower absolute minimum. This was the case with the Convair upper bound being more nearly the correct minimum value, and Gilbert's (with the network not having the Houston/New York branch) resulting in a higher "relative minimum."

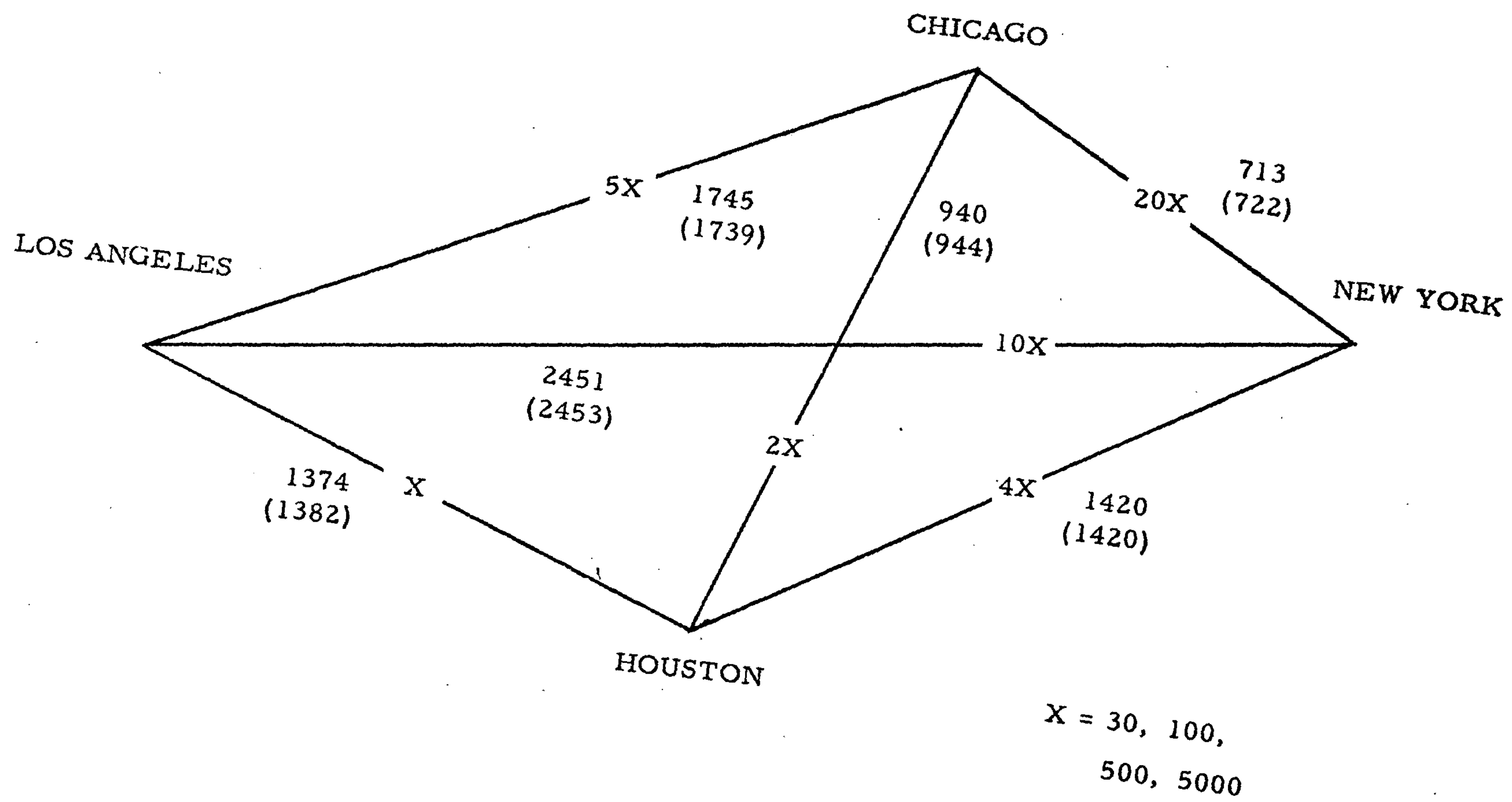
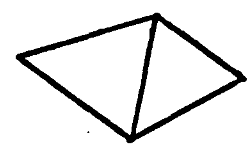


Figure 8-7. Gilbert's 4-City Example

Table 8-3. Results for Gilberts' Example

(COST IN $ MILLIONS)

	GILBERT'S		GSM PROGRAM		
X	LOWER BOUND	MINIMUM COST	LOWER BOUND	UPPER BOUND	NETWORK
30	62.5	63.2	63.7	65.8	
100	90.1	93.2	91.5	98.4	
500	247.9	260.4	250.0	264.4	
5000	2022.7	2096.0	2033.7	2090.4	

This simple test case illustrates the accuracy to which the modelling program can place bounds on a network cost.

8.2.4 TERRESTRIAL LONG HAUL COMMUNICATION SYSTEM COSTS. In order to develop parametric cost data input to the ground system modelling program, various types of transmission systems have been considered. Construction costs and annual costs for different kinds of transmission systems have been analyzed by several sources.[1,2,3,4]

Construction costs and recurring annual costs per channel mile for different communication media are shown in Figures 8-8 to 8-13. These figures were plotted from data published in Reference 3. In estimating system costs hypothetical systems were assumed. For the line-of-sight microwave relay system a length of 3,000 miles was assumed and an operating frequency of 7125-8400 MHz was utilized. The capital recovery is based on a useful life of 20 years and an interest rate of four percent.

Leased facilities were considered by Cosgrove and Chipp in Reference 3. Data published in Reference 3 is plotted in Figure 8-14. It was noted that the cost for a 60-channel system for 1000 miles would be $1,200,000 per year while the commercial leased rate for similar service would be $1,290,000 per year.

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1. DCS Applications Engineering Manual-Volume I: System Planning and Performance Criteria, Defense Communication Agency, January 1968.
2. R.D. Chipp and T. Cosgrove, "Economic Analysis of Communication Systems", IRE Trans. Communication Systems, Vol. CS-10, pp. 416-421, December 1962.
3. T. Cosgrove and R.D. Chipp, "Economic Considerations for Communication Systems", IEEE Trans. Communications Technology, Vol. COM-16, No. 4, August 1968.
4. D.H. Homsher, Ed., Communication System Engineering Handbook, McGraw-Hill, 1967.

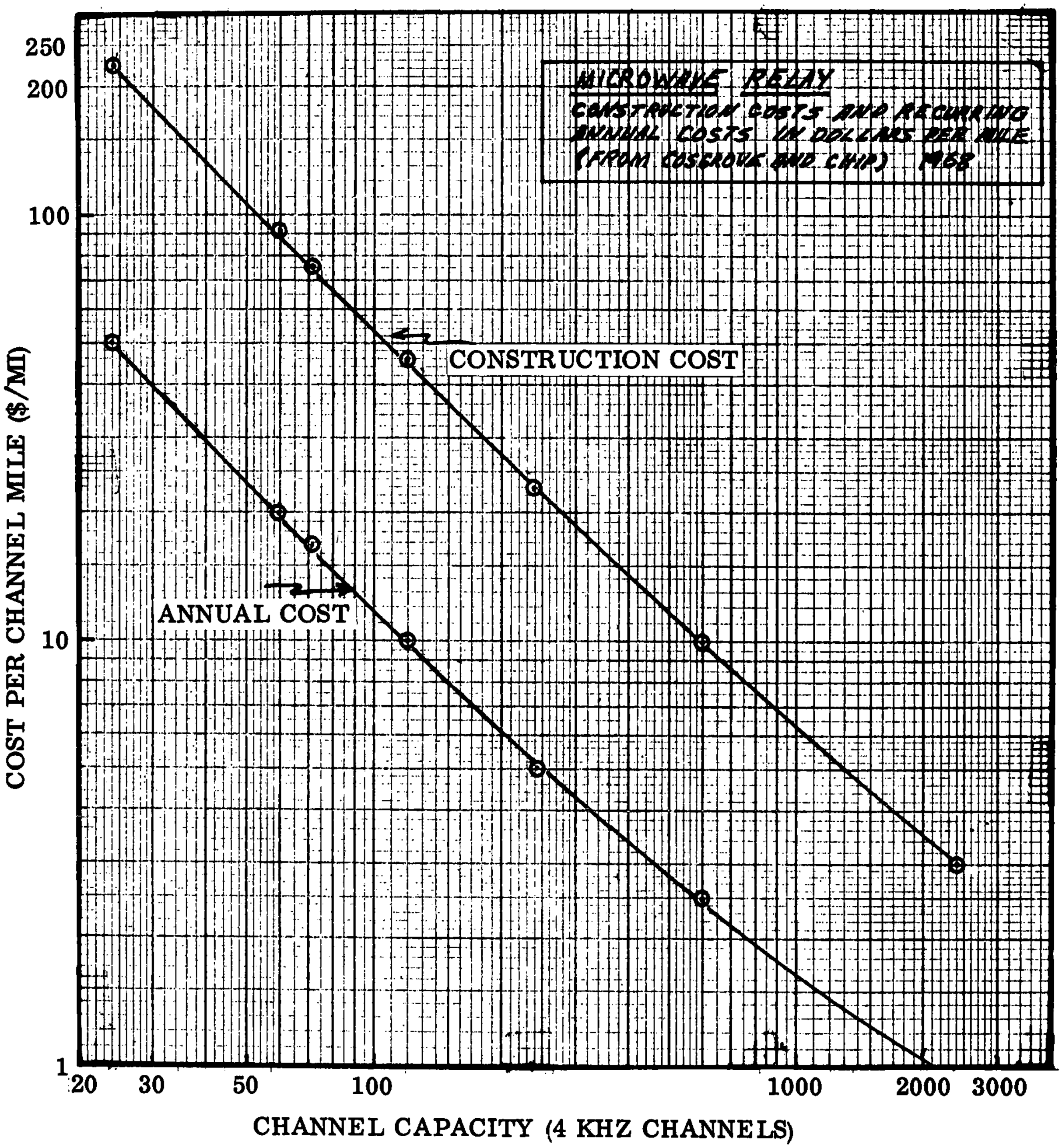


Figure 8-8. Microwave Relay Costs

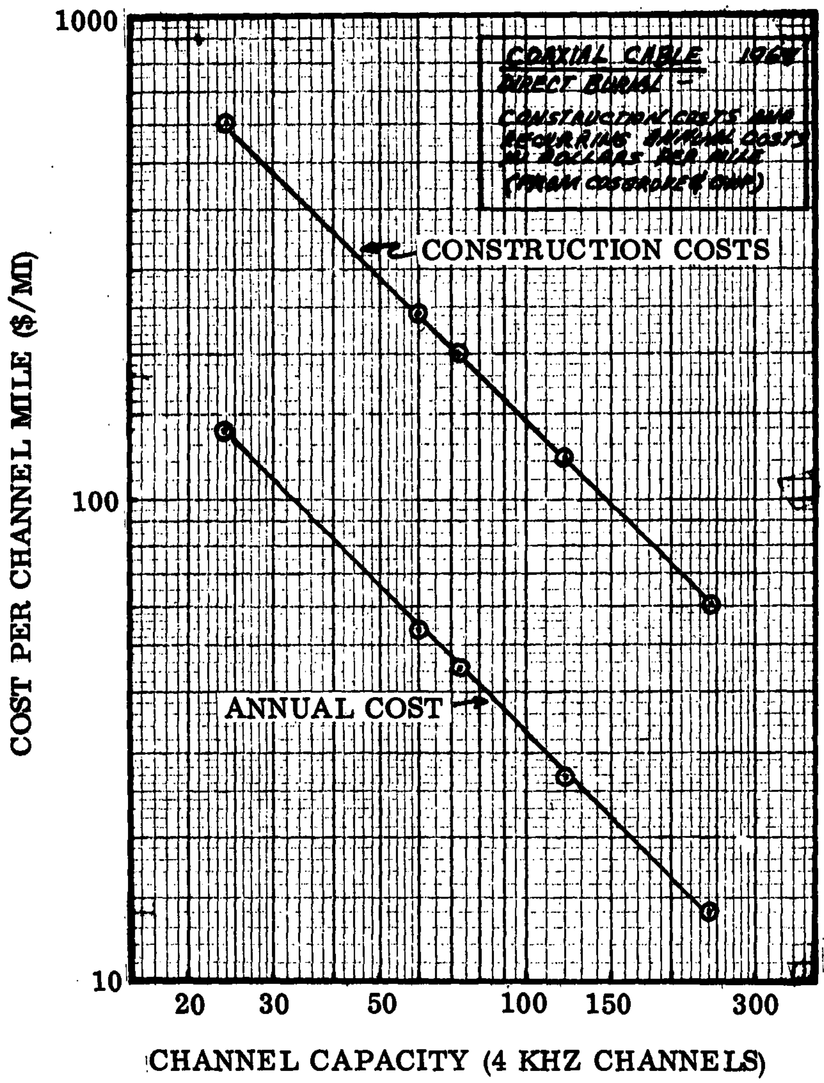


Figure 8-9. Coaxial Cable Costs

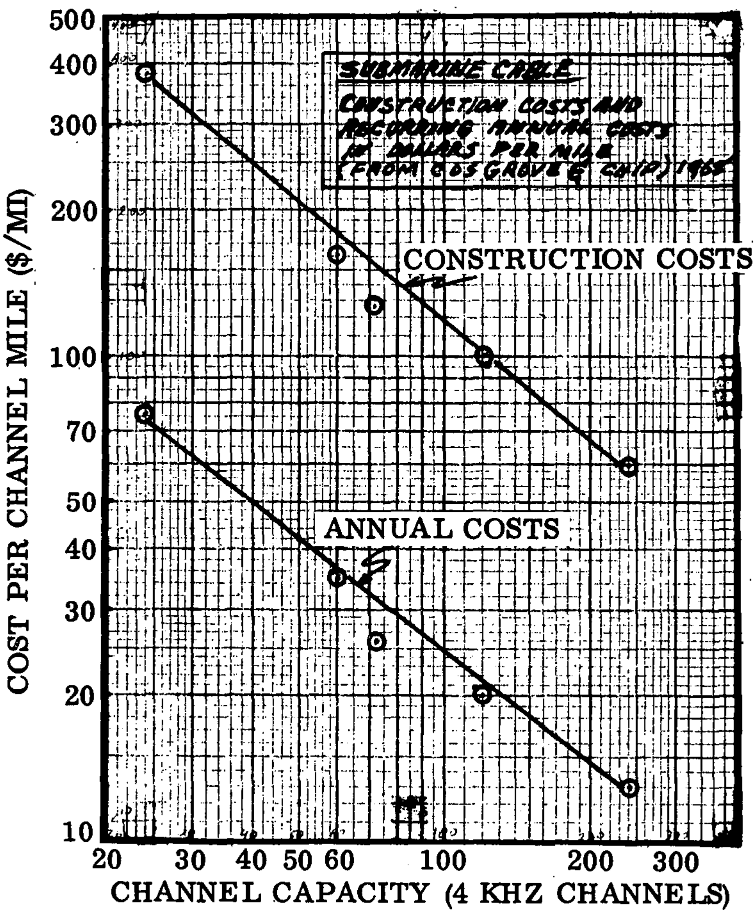


Figure 8-10. Submarine Cable Costs

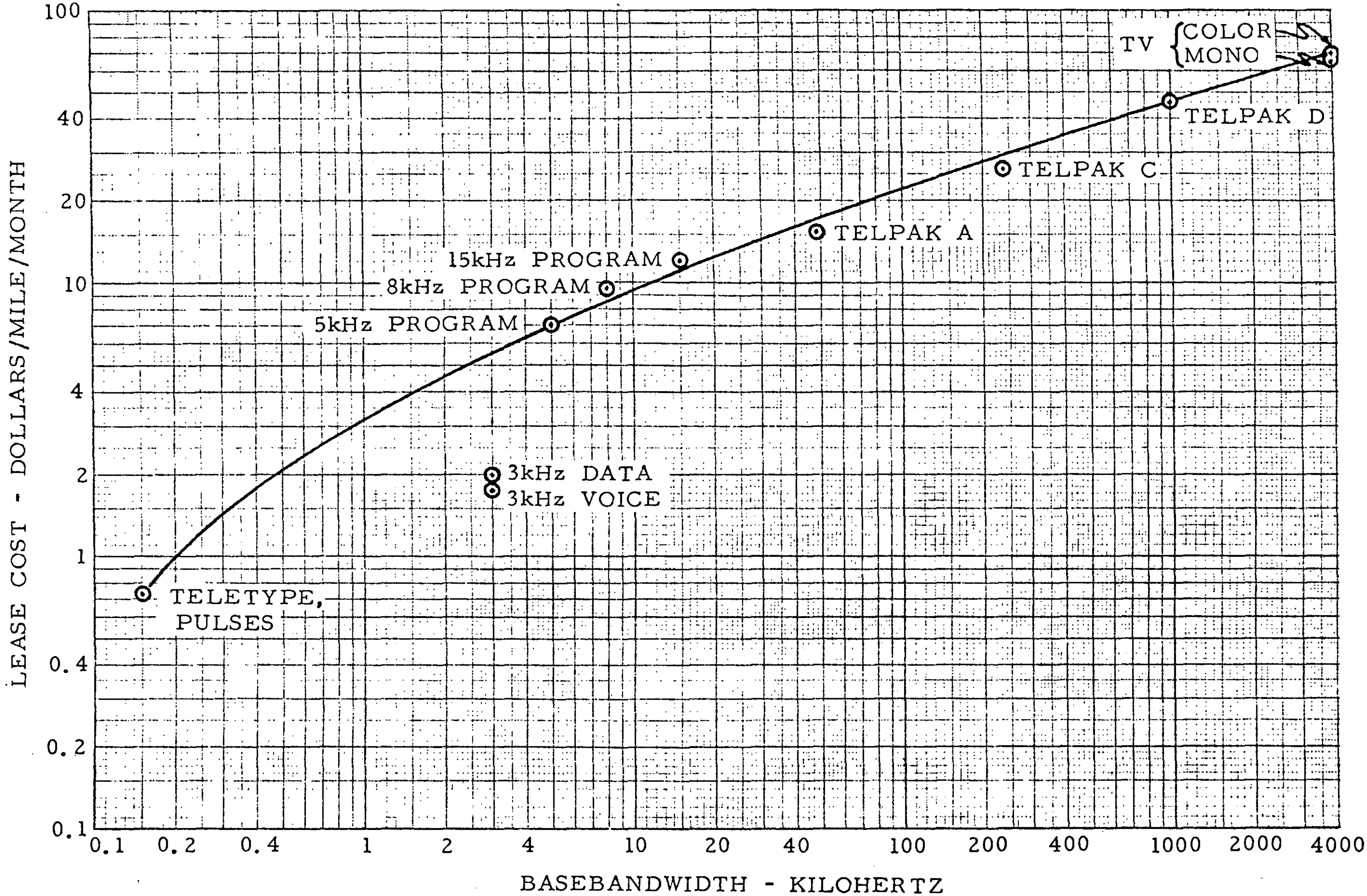


Figure 8-14. Monthly Leased Cost of Full Period Channels

6(A)

In using the cost data for systems to be installed in various geographic areas a "location factor" should be used to account for price variation due to varying equipment costs and transportation and labor rates. Typical location factors are listed in Table 8-4.[5]

Table 8-4. Typical Location Cost Factor

Location	Factor
Alaska	
Adak	3.0
Anchorage	1.7
Fairbanks	1.9
Nome	2.3
Hawaii	
Coastal	1.4
Mountainous	1.6
Alabama	.9
Washington, D. C.	1.0
Colorado	1.05

The data plotted in the figures apply to present-day equipment. These numbers are representative of present-day transmission system costs but these systems may be outmoded by new developments in long distance waveguide or surface wave transmission. Waveguides, usually of rectangular cross-section, are commonly used for antenna feed lines. The configuration most likely to be used for longer distance transmission employs a very low loss mode of propagation in circular cross-section guide. The design of economical repeaters and guide components is a problem which requires consideration.

The G-Line or surface wave transmission line consists of a single wire with coaxial-to-surface wave transitions mounted at appropriate intervals. An estimate of the comparative costs of three hypothetical systems in the same situation is shown in Table 8-5.[6]

5. DCA Cost Manual, Volume I, Communication Costs.

6. T. Hafner, "Surface Wave Corridors" - Communications for High Speed Ground Transportation Systems. IEEE International Conference on Communications, June 9-11, 1969. CAT No. 69C29-Com.

Table 8-5. Transmission Media Comparative Cost

Coaxial Cable	Microwave Relay	G-Line
2.5	3	1

Guided wave transmission media have a significant advantage over radiated wave systems in that the frequency spectrum is conserved. The frequency spectrum of coaxial cable, waveguide or surface wave transmission lines is iterative in that an arbitary number of guided wave transmission lines can be operated on the same frequency.

In order to utilize available cost data properly a knowledge of system implementation scheduling is required to take advantage of cost reductions which accrue because of technology advancement and mass production techniques. In some cases considerations other than dollar cost may predominate because of factors such as security or spectrum conservation.

8.2.5 DATRAN GROUND SYSTEM MODEL. The ground system modelling program was used to establish bounds on cost of a Datran network. Network links were selected for minimum initial cost, although the program could base the network on combined initial and operation costs. Costs per mile for microwave were adjusted to 1970 values.

Route cost per mile	\$6720.00
Channel cost per mile	\$ 0.80
Route Maintenance (/mi. /yr.)	\$1200.00
Channel Maintenance (/mi. /yr.)	\$ 1.00

The Datran system has a 4000-channel trunk line of 4096-BPS digital data with very low error rate. The ground system model is a conservative network with all channels assigned to meet specified demands. Therefore a demand matrix was necessary to generate a network which approximates the Datran system. This was accomplished by setting the demand between cities as porportional to their population products. A cut made between

Chicago and Indianapolis was set to yield 4000 channels, i.e. The product of population of Chicago and cities west of Chicago times Indianapolis and cities east times a constant gives 4000. The constant is $2.4 \cdot 10^{-12}$.

Metropolitan areas corresponding to the Datran centers are shown in Table 8-6. Population values are 1960. Use of more recent data will result in greater demand in the western states with corresponding lowering in the east. The costs will not change significantly as long as demand is keyed to a fixed 4000-channel trunk value. Abbreviations in Table 10-4 are standard Ranally. Latitude and longitude are estimated for population center in the metropolitan area.

The demand matrix as generated by the program is shown in Table 8-7. The computer enters a minimum of 1 channel capacity required between all cities in the analysis. The largest computed value is 348 channels required between New York and Los Angeles.

Table 8-8 shows the computed great circle distance matrix between all nodes in the analysis. The longest distance is 2672 miles between Boston, Massachusetts and San Francisco, California.

The ordinary interconnecting tree is 6065 miles long. It follows the published route of the proposed Datran network closely except that the Richmond/Charlotte branch is deleted, and a shorter Cleveland to Columbus link is substituted to connect the east to west cities. Table 8-9 lists the tree links and lengths. Figure 8-15 shows a computer printout display of the ordinary interconnecting tree. While the resolution of the printer display is marginal, speed and economy in presentation of the graphic information is significant. Figure 8-15 illustrates use of 6 lines per inch printer format. The new 3.2 operating system for the CDC 6400 provides for printing 8 lines per inch and inhibit of the automatic page eject. This system will allow greater flexibility in the formatting of graphic printed outputs.

Table 8-6. User Designations and Locations

12/07/70 DATRAN - MICROWAVE SYSTEM - DEMAND = P1*P2*2.4E-12

USER DESIGNATIONS AND GEOGRAPHIC LOCATIONS

NUMBER	LONGITUDE	LATITUDE	POP/1000	ABBR.	NAME
1	77.00	38.80	2790	WASH	WASHINGTON, DISTRICT OF COLUMBIA
2	74.00	40.60	17135	N.Y.	NEW YORK, NEW YORK
3	118.40	34.20	8460	L.A.	LOS ANGELES, CALIFORNIA
4	87.80	41.90	7610	CHI	CHICAGO, ILLINOIS
5	76.60	39.30	1820	BAL	BALTIMORE, MARYLAND
6	71.10	42.40	3625	BOS	BOSTON, MASSACHUSETTS
7	90.20	38.90	2305	ST.L.	SAINT LOUIS, MISSOURI
8	80.00	40.40	1990	PGH	PITTSBURGH, PENNSYLVANIA
9	93.20	45.00	1675	MPLS-	MINNEAPOLIS, MINNESOTA
10	84.40	33.70	1380	ATL	ATLANTA, GEORGIA
11	81.70	41.40	2320	CLEV	CLEVELAND, OHIO
12	95.40	29.70	1710	HOU	HOUSTON, TEXAS
13	84.50	39.20	1350	CIN	CINCINNATI, OHIO
14	72.70	41.80	978	H-NB	HARTFORD, CONNECTICUT
15	86.10	39.80	930	IND	INDIANAPOLIS, INDIANA
16	83.00	39.90	870	COL	COLUMBUS, OHIO
17	88.00	43.00	1375	MILW	MILWAUKEE, WISCONSIN
18	94.70	39.10	1235	K.C.	KANSAS CITY, KANSAS
19	83.10	42.40	4455	DET	DETROIT, MICHIGAN
20	75.10	40.00	5115	PHIL-	PHILADELPHIA, PENNSYLVANIA
21	96.90	32.80	1435	DAL	DALLAS, TEXAS
22	122.50	38.70	4200	SF-C-	SAN FRANCISCO, CALIFORNIA
23	117.10	32.80	1135	SDGO	SAN DIEGO, CALIFORNIA
24	77.40	37.60	505	RICH	RICHMOND, VIRGINIA
25	80.80	35.40	355	CHRLT	CHARLOTTE, NORTH CAROLINA
26	86.80	33.50	640	BIR	BIRMINGHAM, ALABAMA
27	90.10	35.10	770	MEM	MEMPHIS, TENNASSEE
28	86.80	36.10	495	NASH	NASHVILLE, TENNASSEE
29	85.80	38.20	835	LOU	LOUISVILLE, KENTUCKY
30	89.40	43.10	242	MAD	MADISON, WISCONSIN
31	96.00	41.20	515	OMA-	OMAHA, NEBRASKA
32	93.60	41.60	288	DES	DES MOINES, IOWA
33	97.50	35.40	615	O.C.	OKLAHOMA CITY, OKLAHOMA
34	98.60	29.50	850	SANT	SAN ANTONIO, TEXAS
35	112.10	33.40	865	PHOE	PHOENIX, ARIZONA

Table 8-7. Demand Matrix

DEMAND (CHANNELS BETWEEN CITIES)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0																			
2	115	0																		
3	57	348	0																	
4	51	313	155	0																
5	13	75	37	34	0															
6	25	150	74	67	16	0														
7	16	95	47	43	11	21	0													
8	14	82	41	37	9	18	12	0												
9	12	69	35	31	8	15	10	8	0											
10	10	57	29	26	7	13	8	7	6	0										
11	16	96	48	43	11	21	13	12	10	8	0									
12	12	71	35	32	8	15	10	9	7	6	10	0								
13	10	56	28	25	6	12	8	7	6	5	8	6	0							
14	7	41	20	18	5	9	6	5	4	4	6	5	4	0						
15	7	39	19	17	5	9	6	5	4	4	6	4	4	3	0					
16	6	36	18	16	4	8	5	5	4	3	5	4	3	3	2	0				
17	10	57	28	26	7	12	8	7	6	5	8	6	5	4	4	3	0			
18	9	51	26	23	6	11	7	6	5	5	7	6	5	3	3	3	5	0		
19	30	184	91	82	20	39	25	22	18	15	25	19	15	11	10	10	15	14	0	
20	35	211	104	94	23	45	29	25	21	17	29	21	17	13	12	11	17	16	55	0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	10	60	30	27	7	13	8	7	6	5	8	6	5	4	4	3	5	5	16	18
22	29	173	86	77	19	37	24	21	17	14	24	18	14	10	10	9	14	13	45	52
23	8	47	24	21	5	10	7	6	5	4	7	5	4	3	3	3	4	4	13	14
24	4	21	11	10	3	5	3	3	3	2	3	3	2	2	2	2	2	2	6	7
25	3	15	8	7	2	4	2	2	2	2	2	2	2	1	1	1	2	2	4	5
26	5	27	13	12	3	6	4	4	3	3	4	3	3	2	2	2	3	2	7	8
27	6	32	16	15	4	7	5	4	4	3	5	4	3	2	2	2	3	3	9	10
28	4	21	11	10	3	5	3	3	2	2	3	3	2	2	2	2	2	2	6	7
29	6	35	17	16	4	8	5	4	4	3	5	4	3	2	2	2	3	3	9	11
30	2	10	5	5	2	3	2	2	1	1	2	1	1	1	1	1	1	1	3	3
31	4	22	11	10	3	5	3	3	3	2	3	3	2	2	2	2	2	2	6	7
32	2	12	6	6	2	3	2	2	2	1	2	2	1	1	1	1	1	1	4	4
33	5	26	13	12	3	6	4	3	3	3	4	3	2	2	2	2	3	2	7	8
34	6	35	18	16	4	8	5	5	4	3	5	4	3	2	2	2	3	3	10	11
35	6	36	18	16	4	8	5	5	4	3	5	4	3	3	2	2	3	3	10	11

Table 8-7. Demand Matrix (Contd)

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
21	0														
22	15	0													
23	4	12	0												
24	2	6	2	0											
25	2	4	1	1	0										
26	3	7	2	1	1	0									
27	3	8	3	1	1	2	0								
28	2	5	2	1	1	1	1	0							
29	3	9	3	2	1	2	2	1	0						
30	1	3	1	1	1	1	1	1	1	0					
31	2	6	2	1	1	1	1	1	2	1	0				
32	1	3	1	1	1	1	1	1	1	1	1	0			
33	3	7	2	1	1	1	2	1	2	1	1	1	0		
34	3	9	3	2	1	2	2	2	2	1	2	1	2	0	
35	3	9	3	2	1	2	2	2	2	1	2	1	2	2	0

Table 8-8. Distance Matrix

DISTANCE (STATUTE MILES BETWEEN CITIES)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0																			
2	202	0																		
3	2304	2453	0																	
4	608	722	1739	0																
5	41	165	2322	615	0															
6	397	195	2595	856	359	0														
7	710	868	1594	243	730	1029	0													
8	194	316	2138	419	196	482	553	0												
9	935	1018	1528	346	936	1116	449	741	0											
10	543	745	1942	597	581	940	483	523	911	0										
11	307	406	2050	317	305	550	481	113	630	553	0									
12	1222	1420	1382	944	1257	1609	702	1141	1065	703	1115	0								
13	404	565	1900	255	423	735	307	253	600	380	212	903	0							
14	307	107	2515	777	268	92	942	392	1051	849	466	1517	646	0						
15	492	641	1815	170	508	801	228	325	510	432	256	875	95	714	0					
16	330	477	1980	286	344	643	391	162	628	436	124	995	94	554	165	0				
17	644	740	1741	77	646	859	306	450	293	672	341	1007	320	785	242	336	0			
18	951	1102	1354	411	969	1253	242	786	415	684	704	651	547	1170	462	626	441	0		
19	406	487	1982	243	402	612	444	212	536	606	100	1113	233	535	238	173	252	649	0	
20	131	71	2398	676	93	266	809	260	983	674	359	1350	504	177	583	419	699	1045	448	0

Table 8-8. Distance Matrix (Contd)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	1188	1375	1242	803	1218	1554	565	1073	867	725	1026	232	822	1463	772	915	855	453	1004	1308
22	2428	2553	386	1831	2441	2672	1732	2248	1562	2139	2148	1663	2029	2601	1938	2099	1816	1491	2068	2507
23	2269	2425	122	1719	2289	2573	1560	2109	1529	1885	2026	1299	1866	2492	1785	1949	1726	1324	1962	2368
24	86	276	2291	627	125	471	700	239	965	477	349	1169	400	383	493	341	672	943	449	207
25	315	516	2124	587	355	711	572	349	931	236	418	937	332	622	421	334	652	806	500	445
26	658	859	1809	584	695	1052	419	607	865	139	614	570	415	960	437	490	660	586	648	788
27	767	956	1606	486	797	1139	263	662	704	339	630	485	419	1048	392	512	558	375	630	888
28	569	760	1784	405	600	945	269	474	701	215	458	667	249	853	259	335	482	480	479	691
29	478	652	1831	277	502	827	243	346	606	321	311	805	99	736	112	191	351	485	323	587
30	712	811	1673	116	715	929	293	519	230	704	411	984	371	856	285	398	71	391	324	770
31	1018	1148	1313	427	1030	1282	346	838	298	820	742	796	623	1204	529	688	429	161	670	1098
32	897	1022	1441	300	907	1154	259	714	236	742	616	829	507	1077	412	567	302	182	542	973
33	1153	1326	1188	690	1178	1494	469	1014	702	755	950	413	761	1406	694	852	731	299	912	1263
34	1389	1583	1206	1049	1421	1768	808	1292	1112	885	1254	193	1046	1676	1005	1139	1103	700	1241	1513
35	1984	2145	366	1448	2006	2299	1277	1829	1287	1592	1749	1016	1583	2215	1504	1668	1461	1045	1690	2086

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
21	0														
22	1488	0													
23	1173	508	0												
24	1149	2429	2251	0											
25	938	2293	2075	243	0										
26	587	2014	1749	600	367	0									
27	421	1800	1553	728	526	219	0								
28	619	1957	1736	530	340	180	198	0							
29	727	1975	1793	460	338	330	321	155	0						
30	821	1745	1660	737	703	679	555	504	388	0					
31	583	1410	1298	1023	916	734	530	609	581	363	0				
32	635	1534	1424	905	814	672	488	528	476	238	128	0			
33	183	1394	1135	1126	940	624	418	602	676	686	409	478	0		
34	249	1503	1117	1340	1114	748	630	823	948	1070	822	883	413	0	
35	881	687	293	1964	1784	1456	1261	1446	1507	1397	1035	1159	844	840	0

Table 8-9. Datran Tree Links

BAL	-	WASH	40.71	MILES
WASH	-	RICH	85.80	MILES
BAL	-	PHIL-	93.41	MILES
PHIL-	-	N.Y.	71.34	MILES
N.Y.	-	H-NB	107.08	MILES
H-NB	-	BOS	92.00	MILES
WASH	-	PGH	194.43	MILES
PGH	-	CLEV	112.62	MILES
CLEV	-	DET	99.89	MILES
CLEV	-	CCL	124.17	MILES
CCL	-	CIN	93.51	MILES
CIN	-	IND	94.94	MILES
CIN	-	LCU	98.53	MILES
LCU	-	NASH	155.36	MILES
IND	-	CHI	170.31	MILES
CHI	-	MILW	76.77	MILES
MILW	-	MAD	71.10	MILES
NASH	-	BIR	179.84	MILES
BIR	-	ATL	138.95	MILES
NASH	-	MEM	198.05	MILES
IND	-	ST.L.	227.93	MILES
MAD	-	MPLS-	230.08	MILES
MPLS-	-	DES	236.03	MILES
DES	-	OMA-	127.55	MILES
OMA-	-	K.C.	160.69	MILES
ATL	-	CHRLT	236.38	MILES
K.C.	-	O.C.	298.72	MILES
O.C.	-	DAL	183.09	MILES
DAL	-	HOU	232.03	MILES
HOU	-	SANT	192.94	MILES
SANT	-	PHCE	840.23	MILES
PHCE	-	SDGO	292.64	MILES
SDGO	-	L.A.	122.47	MILES
L.A.	-	SF-O-	385.79	MILES

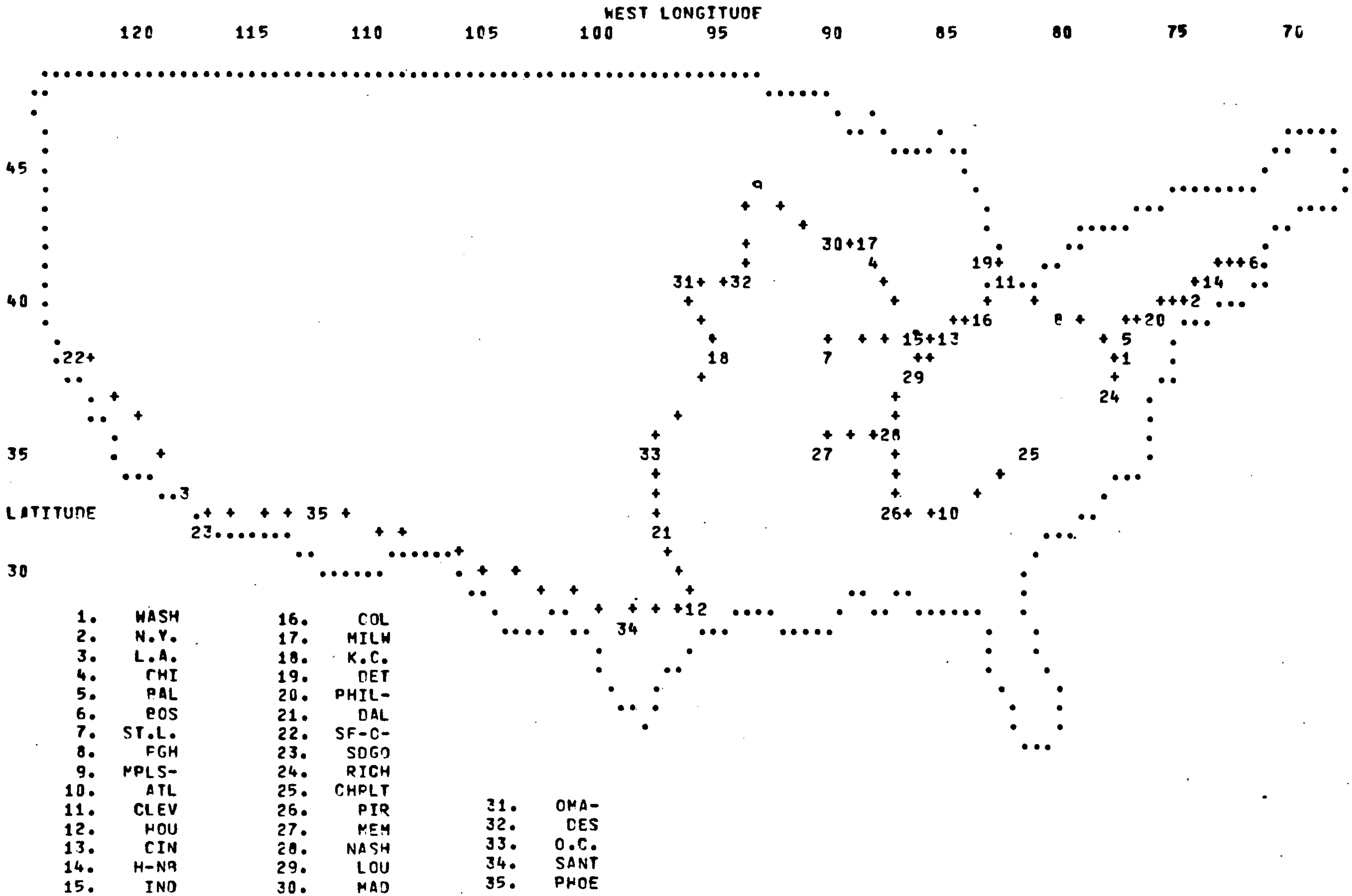


Figure 8-15. Ordinary Interconnecting Tree

Cost (lower bound) is estimated to be $47.38 million, resulting from 6065 route miles and 8.278 million channel miles.

The demand and distance matrix data is then processed to yield a network configuration. Table 8-10 shows the demand matrix after links have been deleted and demands grouped into the trunk lines.

Figure 8-16 shows the resulting network. There are now four cycles spanning from Washington to Omaha. These extra links have added 1080 miles to the network length (above the minimum tree). Channel miles increase to 12.906 million miles when constrained to follow the selected routes. Table 8-11 is a cost summary and comparison of the lower and upper bound cost estimates.

Table 8-10. Network Demand Matrix

DEMAND (CHANNELS BETWEEN CITIES)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0																			
2	0	0																		
3	0	0	0																	
4	0	0	0	0																
5	3804	0	0	0	0															
6	0	0	0	0	0	0														
7	0	0	0	0	0	0	0													
8	3461	0	0	0	0	0	0	0												
9	0	0	0	0	0	0	0	0	0											
10	0	0	0	0	0	0	0	0	0	0										
11	0	0	0	0	0	0	0	3536	0	0	0									
12	0	0	0	0	0	0	0	0	0	0	0	0								
13	0	0	0	0	0	0	0	0	0	0	0	0	0							
14	0	900	0	0	0	708	0	0	0	0	0	0	0	0						
15	0	0	0	2258	0	0	1594	0	0	0	0	0	3625	0	0					
16	0	0	0	0	0	0	0	0	0	0	3683	0	3688	0	0	0				
17	0	0	0	1629	0	0	0	0	0	0	0	0	0	0	0	0	0			
18	0	0	0	0	0	0	1982	0	0	0	0	0	0	0	0	0	0	0		
19	0	0	0	0	0	0	0	0	0	0	3831	0	0	0	0	0	0	0	0	
20	0	3236	0	0	3669	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

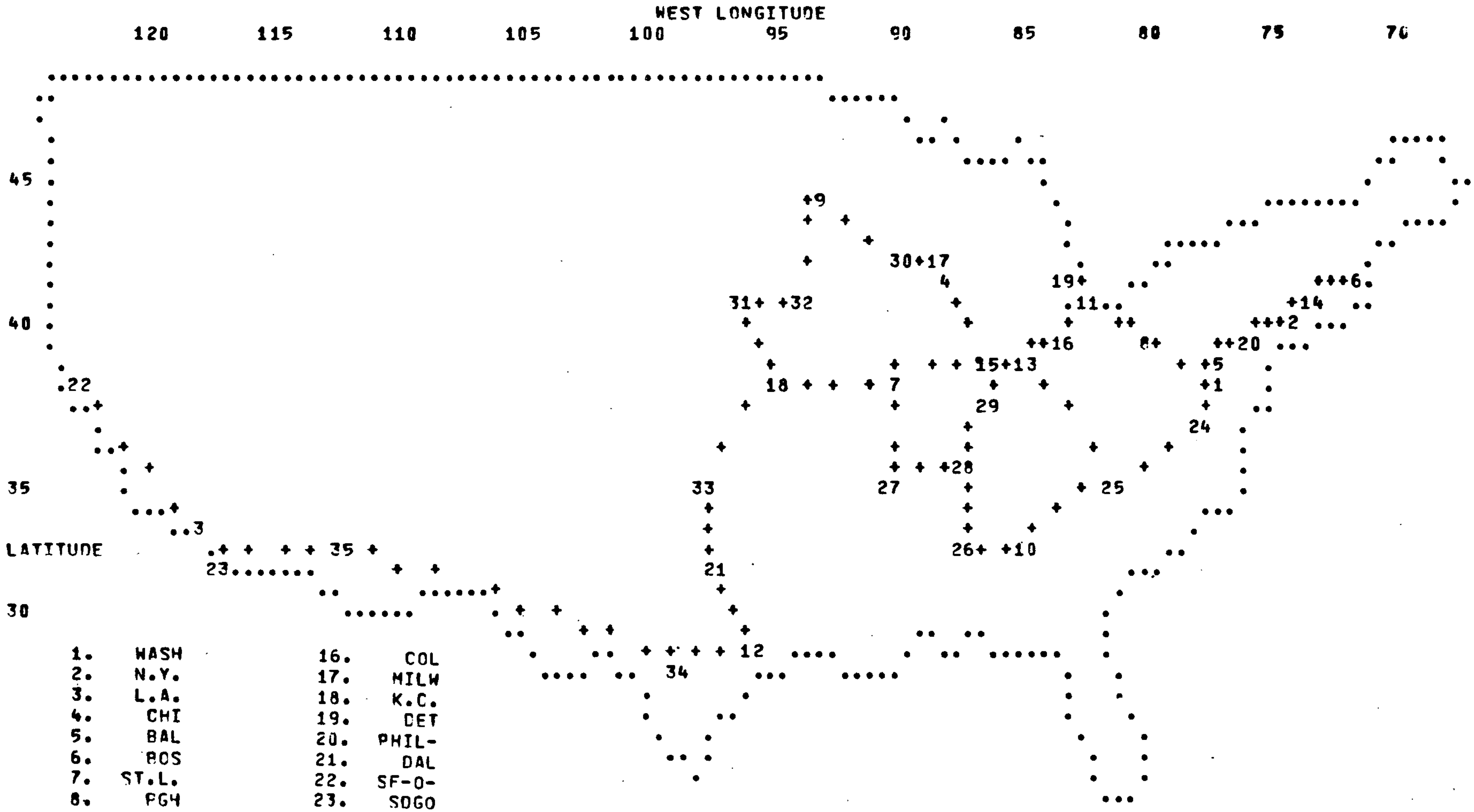
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	0	0	0	0	0	0	0	0	0	0	0	2793	0	0	0	0	0	0	0	0
22	0	0	809	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	2164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	654	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	550	0	0	33	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	598	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	722	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	698	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	1449	0	0	0	0	0	0	0	1479	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1392	0	0
32	0	0	0	0	0	0	0	0	1339	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3041	0	0
34	0	0	0	0	0	0	0	0	0	0	0	2574	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-10. Network Demand Matrix (Contd)

	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
21	0														
22	0	0													
23	0	0	0												
24	0	0	0	0											
25	0	0	0	562	0										
26	0	0	0	0	0	0									
27	0	0	0	0	0	0	0								
28	0	0	0	0	0	629	647	0							
29	0	0	0	0	0	0	0	367	0						
30	0	0	0	0	0	0	0	0	0	0					
31	0	0	0	0	0	0	0	0	0	0	0				
32	0	0	0	0	0	0	0	0	0	0	1337	0			
33	3091	0	0	0	0	0	0	0	0	0	0	0	0		
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
35	0	0	2330	0	0	0	0	0	0	0	0	0	0	2455	0

Table 8-11. Cost Summary

	LOWER BOUND	UPPER BOUND	PER CENT DIFFERENCE
GRAPH LENGTH (THOUSAND MILES)	6.07	7.15	17.8
CHANNEL LENGTH (THOUSAND MILES)	8278.39	12906.20	55.9
ACQUISITION COST ($MILLIONS)	47.38	58.34	23.1
MAINTENANCE COST ($MILLIONS/YEAR)	15.56	21.48	38.1



1. WASH
2. N.Y.
3. L.A.
4. CHI
5. BAL
6. BOS
7. ST.L.
8. PGH
9. MPLS-
10. ATL
11. CLEV
12. HOU
13. CIN
14. H-NB
15. IND
16. COL
17. MILW
18. K.C.
19. DET
20. PHIL-
21. DAL
22. SF-O-
23. SDGO
24. RICH
25. CHRLT
26. PIR
27. MEM
28. NASH
29. LOU
30. MAD
31. OMA-
32. DES
33. O.C.
34. SANT
35. PHOE

Figure 8-16. Datran Network

8.2.6 POPULATION DISTRIBUTION ANALYSIS. In structuring a ground system model, the users must be distributed geographically. With some exceptions (e.g., remote weather stations), the aggragate of users is population, and the distribution of users approximates the distribution of population.

The SRI and Lockheed reports have provided predictions of the number of users and demands but not provided the geographical distribution necessary for the model. A wealth of census data is available which provides population density to the level of country and to the level of communities of 2,500 persons or more. Generalizations are also available which can be used to predict the changes in this distribution for the time period of interest. Latitude and longitude addresses can be assigned to each "unit" of population, so all necessary raw data are available for construction of a population modeling system.

The objectives of this phase of the study were to:

1. Generate a population density function of latitude and longitude defined over the area of the continental United States.
2. For any defined closed boundary (e.g., time zone, antenna coverage) compute the area enclosed, the population of the area and population density, center of population and moment about center.

8.2.6.1 Population Density Function. Two methods of assigning population to area were investigated. The first uses a continuous function, a polynomial surface fit to the density surface. The second treats population as discrete points of specified magnitude distributed over the surface.

8.2.6.2 Polynomial Surface. A general purpose program is available which will generate coefficients (least squares best fit) to any number of points exceeding a minimum number for the specified degree. The program provides $(n+1)(n+2)/2$ terms for degree n of the form $a_{ij} X^i Y^j$, where $i + j \leq n$. A practical number of density values for input was estimated to be 100 to 200 with n = 6 to 13. This it was hoped would provide surface functions having up to about 40 maximi corresponding to major metropolitan areas and having the ability to conform to the large low density areas. For this attempt, the state populations and the estimated coordinates of each state's population center were used. Mathematically, the results were encouraging in that the computed surface fit the input data reasonable well -- but it was apparent that increasing the number of points and the degree of the polynomial would not improve the fit to the point where the results were really useful. For example, large areas in the best fit approximation showed negative population. It was found that some graphical means of visuallizing the result was necessary. Finally, points outside the boundaries were necessary to constrain the surface so that the fit remained useful to the continent edges.

The polynomial population density surface is particularly useful because population in an area defined by a closed boundary of line segments can be computed by a direct term-by-term integration of the polynomial around the boundary. The population varies from density as high as 75, 000 people per square mile in New York county to desert counties having less than 0. 5 people per square mile. An error of 1000 people per square mile may be acceptable in the metropolitan area, but not (for the purposes of the study) in the low density areas. For this reason, the surface fit was made to

$10 \log_{10}$ (population density), with 0 db defined as 1 person per square mile. The practical range of population then falls between 5 db for Wyoming and 41 db for the District of Columbia. The fit improved markedly, however, the integration now must be done numerically over the area.

The population density input data (now in db) was expanded to include a point for approximately 20,000 square miles of land area in each state. Density was taken for a typical county within the area. This approach was selected to save time (rather than adding counties within the area to get a more accurate average density) and to allow the addition of points later without recomputing the original values.

Figure 8-17 shows this model. The "X" indicates the point location, the state, and population density follows for the area. District of Columbia, Rhode Island, and Delaware are not included because of their small sizes.

Figure 8-18 shows a 10th-order surface fit to these db values. Viewer is at synchronous altitude and 75°W longitude. To aid in visualization, continent outline points were connected at a reference level of 0 db and at the computed population density height. True contours can be generated to fit the array of data corresponding to intersections of the latitude and longitude cuts, however, in this illustration contours are suggested (economically) by "X" and "+" printed whenever successive computed surface values span a preset contour value.

From this analysis it was found that the population surface is rather smooth, with emphasis placed as it was on the areas of lower population density. The peaks that are expected at major metropolitan areas are

Figure 8-17. Population Density Input Data

1960 Census Data
Viewer's Eye Position is 75° W.
Longitude at Synchronous Equatorial
Orbit

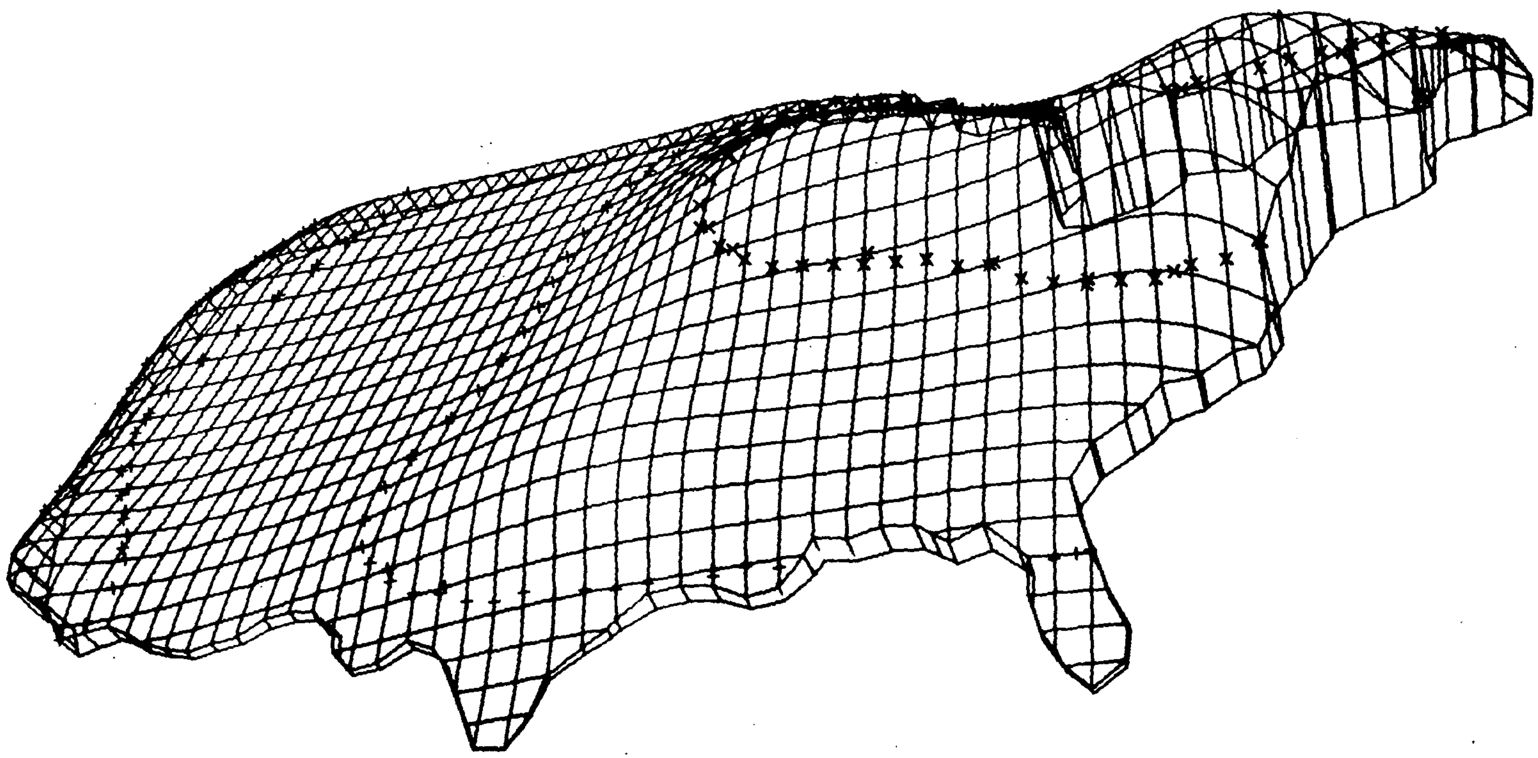


Figure 8-18. Population Density Model Showing Contours

smoothed into the surrounding area. The conclusion was reached that to arrive at a useful model, a combination of a surface representing essentially rural population density augmented by discrete points of metropolitan populations was required.

8.2.6.3 Population Point Analysis. The second approach to locating users is the assignment of all population within an area to a single central point. The population of a region is approximated as the total population represented by the points falling within the region. It is apparent that this approach becomes more accurate as the number of points increases. It is more accurate (unlike the first approach) in depicting metropolitan populations.

To maintain compatibility with the first approach, population was encoded by county, but in this case starting with most populous. The first 100 counties have populations in excess of 300,000 (1960) and a total of over 80 million people out of 179 million, or 44.5%. This percentage is probably increasing.

The population of a county is very nearly inversely proportional to its rank in the range of 100 to 1600.

County Rank	Population (1000)
100	314
200	157
400	75
800	38
1600	18

Therefore the additional population (after 100) incorporated in the model with the addition of counties to rank "R" can easily be estimated.

$$\text{Population} \cong (80 + 30\ln(R/100)) \times 10^6$$

Each doubling of the rank included adds 21 million. It would take 1600 points to get 90% of the population, and the full 3200 counties to get 100%. This would take considerable time to encode and probably would lead to excessive processing time if that many points will be used in each computer operation.

A compromise is proposed. The list is expanded from 100 to about 400 by grouping counties to achieve a population of approximately 300, 000 in each area. Figure 8-19 shows how the counties were combined for Alabama. Jefferson and Mobile had rank in the original 100. (Deleting Honolulu, rank 65, reduces original list to 99.) The remaining 65 counties of Alabama were combined into 8 areas. The number in each in parenthesis indicates the number of counties combined. The total population of the area follows. The "X" is the approximate location of the center of population, and the point at which the latitude and longitude is estimated. States, alphabetically through Georgia, have been subdivided in this manner, giving 53 new points. This activity was stopped at this point because it was becoming to large an investment in time for 1960 data, with 1970 data soon to be available. In particular, trend data for prediction of 1980 - 1990 population distribution will be much more accurate.

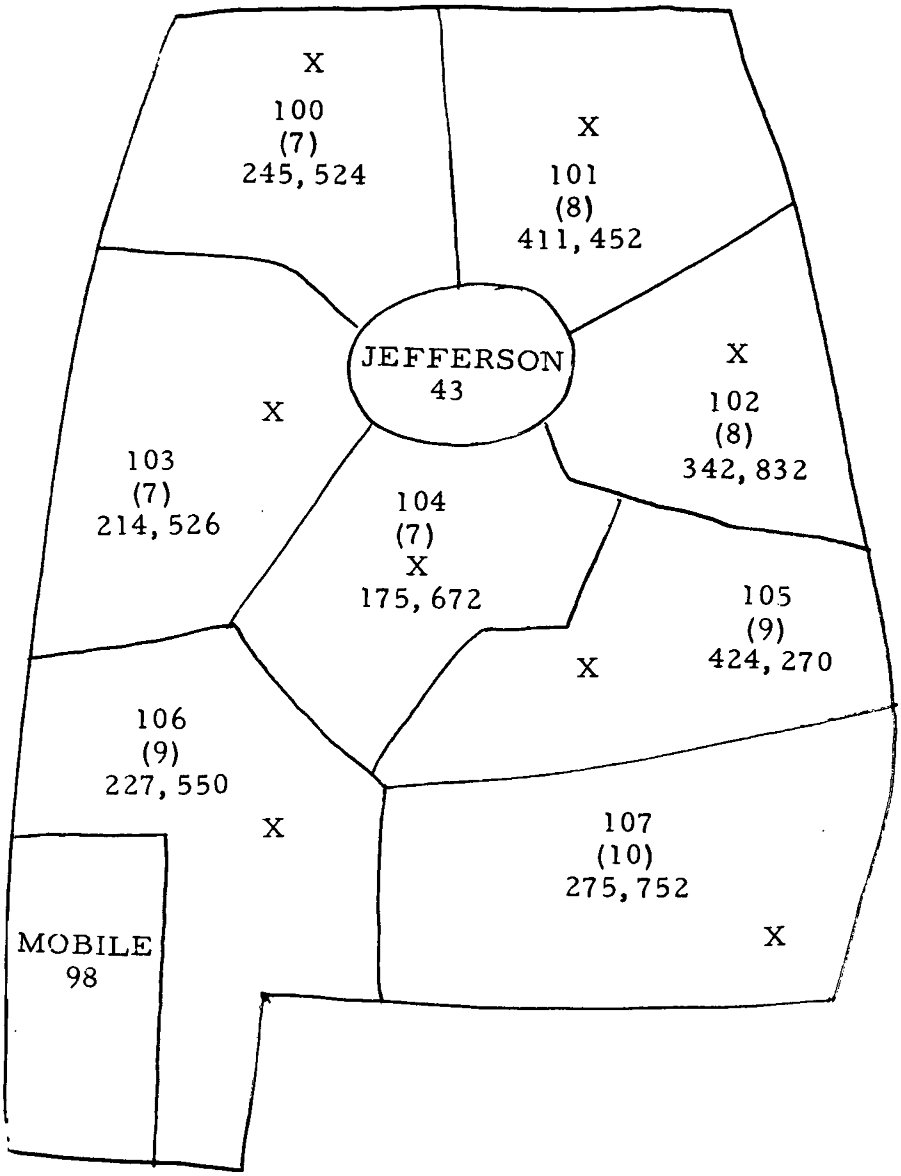


Figure 8-19. Alabama Population Model

8.2.6.4 Hybrid System

The hybrid approach appears to be suitable for accurate population prediction over the range of sparsely settled area to metropolitan area. It would use a population density function for prediction of rural population and augment this number with the population of metropolitan points included in the area.

The computer methods have been developed but the necessary census data has not been processed for input. The procedure required would be to generate a "rural" model. This would be accomplished by deleting counties from each state that have high population density compared to the state average. The remaining state area and population would be reduced to regions of varying population density. Counties deleted are not necessarily the most populous, San Bernardino, for example, ranks 63, with over 500,000 people, but has a density of only 25 people per sq. mi.

A surface function would be fit to the points representing the rural regions. Using this model, the rural population would then be computed for each deleted metropolitan county (computed density times area of the metropolitan county). The additional population needed to bring the county total to the census value would be the adjusted metropolitan population of that county. The 36 surface (degree 7) coefficients plus the 99 or so metropolitan data points would be sufficient to describe the population model.

9

TECHNOLOGY EVALUATION

9.1 INTRODUCTION

The purpose of this evaluation is to define critical technologies associated with each of the leading ITS Missions. A Matrix is generated that displays pertinent technology areas for each mission in two broad categories - satellite subsystems and ground systems. Those technology requirements shown as Critical on the matrix are tabulated according to present status, limitations and development required. This tabulation is augmented by a general discussion of some of the critical technologies tabulated. In presenting the technology evaluation, not only the impact of hardware availability but also the effect of component and subsystem costs are considered in evaluating the feasibility status of a mission. Reliability, especially of satellite subsystems are assumed a mandatory prerequisite of hardware availability with a 10 year satellite lifetime a firm requirement. Those cases where maximum allowable limits of a given technology are exceeded are identified. Alternate solutions, if possible, are presented. Some cases are identified where technologies only become critical as system requirements are expanded to meet future growth projections.

9.2 DEVELOPMENT OF TECHNOLOGY NEEDS FOR ITS MISSION CATEGORIES

The results of this analysis are displayed in matrix form in Table 9-1. Technology areas are separated into two broad categories - satellite subsystems and ground systems. When appropriate and available numerical quantities are inserted. In all other cases a square is checked when a given technology area is a critical or pacing item. The Missions listed on Table 9-1 are described elsewhere and therefore are not discussed in this section.

9.3 TECHNOLOGY REQUIREMENTS

The most critical and pacing technology requirements are tabulated in Table 9-2. Need date is based on the schedule proposed for the specified mission. Availability status if related to a proposed or planned development program is based on an early 1972 start date. Each of the technology areas are discussed in this section under the two categories of satellite subsystems and ground systems.

9.3.1 SATELLITE SUBSYSTEMS

9.3.1.1 High Power Transmitters. Related factors influencing the development of high power spaceborne transmitters are:

Table 9-1. Technology Needs versus ITS Mission Categories

TECHNOLOGY / MISSIONS	SATELLITES SUBSYSTEMS						GROUND SYSTEMS					
	Power (KW) Generation	Frequency (GHz)	Transmitters W.	Large Antennas	Multi-Beam Antennas	Thermal Dissipation	Multiple-Access Techniques	Low Cost Direct TVBS Receivers	Low Cost Facsimile Transceivers	2-Way TV	Store-and-Forward Techniques	Low Cost Up-Link Terminals
TELEVISION SERVICE												
a. TV Distribution	14	12	100			X						
b. CATV Interconnection	75	12	1000			X			X			
REMOTE AREA TELECOMMUNICATION												
a. Alaska	3-5	4&6	25	X			X	X	X		X	X
EDUCATIONAL SERVICES	50-100	12	150-500		4-8	X		X				X
DATA COLLECTION	1	.4-.42	10-20									X
CIVIC SAFETY	7	12	1300									
TRAVEL & RECREATION SERVICES	5	12	560			X						
MOBILE COMMUNICATION SERV.												
a. Aircraft	6	12	52								X	
b. Ships	3	0.8	100								X	X
BIOMEDICAL NETWORK SERVICES	100	12	1600			X	X	X		X	X	
BUSINESS MANAGEMENT SERVICES												
a. Stock Quotation	2	12	150						X			
b. Federal Reserve System	2.4	12	100								X	X
c. Credit Card Verification	5.4	12	560									
DOMESTIC WIDEBAND SERVICES												
a. Computer Access	2	12	75									X
MULTIPLE PURPOSE MISSION (combination of Law Enforcement, Credit Card Verification and Federal Reserve System)	6 to 10	12	500-1000			X			X		X	

Table 9-2. Technology Status Summary

REQUIRED TECHNOLOGY	NEED DATE	AVAILABILITY STATUS WITH EXISTING TECHNOLOGY	LIMITATIONS, REQUIRED DEVELOPMENT AND PROJECTED INCREMENTAL GROWTH
1.0 KW WIDEBAND 12 GHz TRANSMITTER	1985	100 W TWT SPACE QUALIFIED NOW	1980 - 5 KW
100 KW OF PRIME ELECTRICAL POWER	1980	A 10 KW SOLAR ARRAY IS AVAILABLE NOW	1980 - 30 KW SOLAR ARRAY 1985 - 300 KW RTG.
LARGE (20' X 100') SPACE ERECTABLE ANTENNA	1975	A 50' ANTENNA IS FEASIBLE USING EXISTING TECHNOLOGIES	A 100' ANTENNA CAN BE DEVELOPED BY 1980 IF FUNDED
MULTI-BEAM (4 to 8) SPACE ERECTABLE ANTENNA	1980	MULTI-BEAM ANTENNAS TECHNICALLY FEASIBLE; CONCEPTUALLY DESIGNS ONLY	1975 - 2 BEAM 1980 - 6 BEAMS
DISSIPATION IN SPACE OF 80 KW OF THERMAL ENERGY	1980	1.5 KW 1972	LIMITED BY SIZE & WT. OF SPACECRAFT. RADIATOR OF APPROX. 680 ft^2 REQUIRED TO RADIATE 80 KW ASSUMING TR OF 120°C PLUS HEAT PIPE WT. & VOL.
USE OF TIME DIVISION MULTIPLE-ACCESS (TDMA) TECHNIQUES	1975	EXPERIMENTAL TDMA SYSTEMS HAVE BEEN SUCCESSFULLY OPERATED IN SPACE	GREATEST NEED IS DEVELOPMENT OF LOW COST GROUND TERMINAL TDMA COMPONENTS
LOW COST 12 GHz CONVERTER TO AUGMENT CONVENTIONAL TV RCVR FOR DIRECT TVBS	1975	LARGE VOLUME COSTS FOR UHF AND S-BAND RECEIVERS USING 1972 TECHNOLOGIES ADEQUATE	DEVELOPMENT OF IMPROVED MASS PRODUCTION TECHNIQUES FOR 12 GHz RECEIVERS REQUIRED.
MULTI-CHANNEL REMOTELY TUNED 12 GHz RECEIVER	1975	TECHNICALLY FEASIBLE; CONCEPTUAL DESIGNS & COST ESTIMATES AVAIL-ABLE ONLY AT PRESENT.	IMPROVED PRODUCTION TECHNIQUES & LARGE QUANTITY DEMANDS FOR COMPONENTS REQUIRED TO DRIVE DOWN COSTS.
LOW COST FACSIMILE TRANSCEIVER	1975	LEASE COSTS OF FACSIMILE TRANSCIEVERS NOW ATTRAC-TIVE TO BUSINESS USER. LONG DISTANCE TELEPHONE RATES STILL PROHIBITIVE.	TECHNIQUES ARE BEING DEVELOPED TO REDUCE TRANSMISSION TIME. NATIONWIDE CATV NETWORKS VIA SATELLITE WOULD HASTEN DEVELOPMENT OF HOME FACSIMILE SYSTEMS PLUS WIDESPREAD USAGE
2-WAY TV LINKS VIA SYNCH SATELLITE RELAY	1980	OPERATIONAL ON LOS TERRESTRIAL MICROWAVE LINKS AT PRESENT.	SMALL USER UP-LINK PACING REQUIREMENT DUE TO HIGH ERP REQUIRED AT GROUND STATION. ALTERNATE SOLUTION MIGHT BE SLOW SCAN TV TO REDUCE BANDWIDTH.
LOW COST TELECOMMUNI-CATION GROUND TERM-INALS	1975	PRESENT STATE-OF-THE-ART IS ADEQUATE	MICROWAVE TRANSMITTING SYSTEMS AND TELE-PHONE TERMINAL EQUIPMENT AND SATELLITE CHANNEL COSTS ARE PROHIBITIVE FOR SMALL USER WITHOUT THE USE OF TECHNIQUES TO PROVIDE A HIGH UTILIZATION FACTOR.
USE OF STORE-AND FORWARD TECHNIQUE	1975	TECHNIQUE IS WELL AD-VANCED AND WIDELY USED IN BOTH MILITARY AND COMMERCIAL NETWORKS	ULTIMATE USE DEPENDENT UPON COST OF STORE-AND-FORWARD SERVICE RELATIVE TO COST SAVINGS DUE TO MORE EFFICIENT USAGE OF COMMUNICATIONS CHANNELS

1) High power tube development
2) RF voltage breakdown limitations in the space environment
3) Interconnection and switching of high power RF components

For the types of missions listed in Table 9-1, frequency modulation (FM) was the preferable type of modulation considered because the power amplifier may be operated near saturation allowing high efficiency. Also, from the standpoint of communications efficiency, a given quality of signal can be transmitted with less transmitter power by FM than AM modulation.

Analytical designs of spaceborne RF vacuum tube amplifiers have been developed under both NASA/LeRC. Contracts and a NASA/MSFC Contract with primary emphasis on achieving high overall efficiency. Based on immediate design and development efforts availability of 5 KW RF power is projected for 1975-1980 at 12 GHz using either Klystrons or TWTs. Table 9-3 lists applicable transmitter types for FM modulation above 2 GHz.

Table 9-3. RF Amplifier Study Summary

Frequency (GHz)		2	8	11
RF Power Output (KW)		5.0	5.0	5.0
Amplifier Type	Study Contractor			
EMFK	GE	X	X	X
ESFK	Litton	X	X	X
TWT	Hughes	X	X	X

EMFK - Electromagnetically Focussed Klystron
ESFK - Electrostatically Focussed Klystron
TWT - Traveling Wave Tube

Multistage collector depression (whereby electrons are decelerated before collection to minimize energy loss due to electron impact on collector) was incorporated in all the designs. A 20,000 hour minimum lifetime was a design requirement with a 50,000 hour lifetime prediction from the Hughes TWT study.

In a NASA review and study of RF breakdown problems, it was determined that failures were due to Corona and glow, arc-over and Multipacting. Among the causes of failure were:

a. outgassing
b. insulation breakdown
c. circuit configuration

d. Entrapped gas
e. Contamination
f. Pressure leaks
g. Environment plasma

Among significant parameters involved in breakdown are:

a. Electrode geometry
b. Pressure
c. Temperature
d. Electric field strength
e. Type of gas
f. Frequency
g. Radiation environment
h. Plasma in space
i. Type of dielectric
j. Type of conductor
k. Electrode history

The power handling capacity of transmission lines propagating pulsed signals is usually limited by breakdown due to ionization of the gas that fills the line. A minimum value of breakdown field occurs at a pressure (approximately 1 mm Hg) where the radio frequency is equal to the gas collision frequency. At lower pressure, the breakdown field strength increases rapidly. At pressures on the order of 10^{-6} mm Hg, breakdown is no longer due to ionization of the remaining gas molecules, but to other mechanisms. It seems likely that the most important process that occurs is field emission whereby electrons are pulled loose from metal surfaces by electric fields having strengths on the order of megavolts per centimeter. Such field strengths can arise from minute irregularities on the propagating surface even when the average field strength over the surface is much lower. Thus, it is very important in evacuated high-power filters and transmission lines that the inside surfaces be quite smooth.

Another phenomenon that occurs in a vacuum is called multipactor. This is a resonant secondary-emission phenomenon that occurs when an electron under the action of an electric field has a transit time between opposite electrodes equal to one-half the period of an RF cycle. Multipacting can occur in the space environment if the proper relationships between RF voltage, frequency, and electrode geometry exist.

All of the following conditions must exist to establish a multipactor discharge:

a. The mean free path of the electrons must permit an electron to be accelerated between the emitting surfaces with low probability of collision with ambient atoms or molecules.

b. The arrival energy of the incident electrons must produce a net secondary emission ratio greater than one.

c. The electron transit time must be in resonance with the applied frequency.

d. In order to maintain a multipactor discharge the applied voltage, ambient pressure, and emitting surface must not change. (The applied voltage may be altered because of detuning and variation in load impedance due to the detuning.)

Methods of eliminating the possibility of multipactor breakdown are:

a. Reduce the mean free-electron path length by means of pressurization or by utilizing foam or solid dielectrics.

b. Reduce secondary emission ratio of the electrode surfaces by using coatings or selecting low-emission-ratio materials.

c. "Detune" electrode geometry by proper choice of configuration and amplitude of RF signal. DC bias might also be used to alter resonance effects.

To provide a satellite system with a five year lifetime made up of elements of shorter lifetimes it is necessary to add redundant components with capability to switch them into the system. Applicable switches can either be mechanical or solid state. One example of a high RF power switching requirement is to switch the output of one of 2 or more transmitters to an antenna system. Three different techniques are applicable,

1) mechanical waveguide or coax switches
2) PIN diode solid state switch
3) Latching waveguide ferrite circulators

Mechanical devices operate over the widest bandwidth and are the most efficient. PIN diode switches require a continuous holding current and introduce more insertion loss than the mechanical device. Based on reliability and negligible operating power the latching waveguide circulator is the preferable switch contingent upon the relative tendancy for RF breakdown in the space environment.

9.3.1.2 Availability of 100 KW of Prime Electrical Power. The applicable regimes for typical space power systems is shown in Figure 9-1. From this figure it can be seen that for mission lifetimes in excess of one year, solar cell, isotope and reactor systems are applicable.

Nuclear reactor systems offer the greatest potential in terms of gross power capability. SNAP 10A, flown in April 1965, demonstrated a reactor/thermoelectric 500-watt system. SNAP 8, a reactor/Rankine system is under development at 30 KW. A growth potential for this system is projected to 300 KW. The main problems

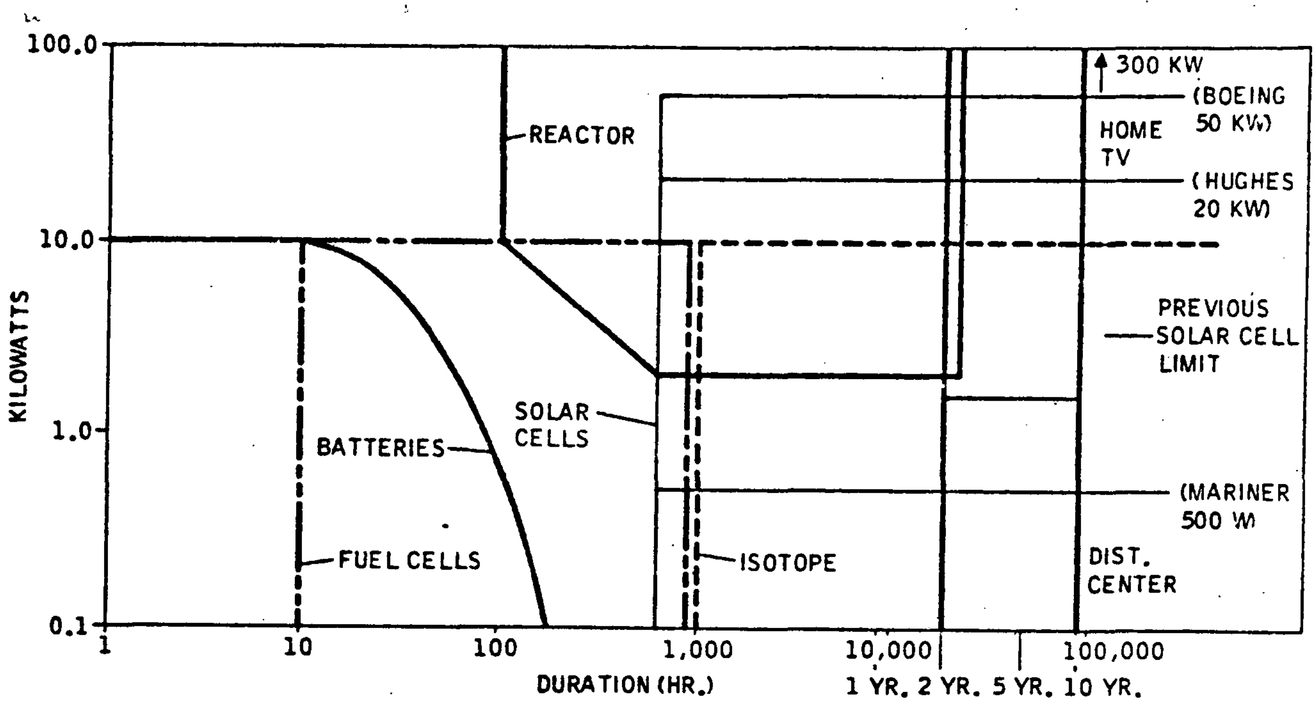


Figure 9-1. Power System Application

Table 9-4 Electrical Power Subsystem - Power Source

POWER SOURCE	MAIN ADVANTAGES	MAIN DISADVANTAGES
1. SOLAR CELL ARRAY	1. STATIC SYSTEM. 2. STRONG TECHNOLOGY BASE. 3. ADAPTABLE TO A WIDE VARIETY OF CONFIGURATIONS. 4. LONG LIFE	1. SENSITIVITY TO SPACE ENVIRONMENT 2. NONOPERATIVE IN ORBITAL DARK PERIODS. 3. ASSEMBLY FROM LARGE NUMBER OF SMALL COMPONENTS. 4. FLEXIBILITY, DEPLOYMENT & ORIENTATION
2. NUCLEAR REACTOR	1. SEMI-STATIC SYSTEM 2. SNAP-2, -10A, -8 & SPUR-50 DEVELOPMENT PROGRAMS IN PROGRESS. 3. COMPACT SYSTEM.	1. LIMITED LIFE. 2. HEAVY SHIELDING REQUIREMENTS. 3. LOW EFFICIENCY.
3. RADIOISOTOPE THERMOELECTRIC GENERATOR	1. LONG LIFE 2. SEMI-STATIC OR STATIC SYSTEM. 3. COMPACT SYSTEM	1. SAFETY-RADIATION HAZARDS. 2. TECHNOLOGY BASE INADEQUATE AT POWER RANGE OF INTEREST. 3. ISOTOPE AVAILABILITY -QUANTITY & COST.

associated with these systems are limited lifetime due to generation of helium in the fuel casings, heavy shielding requirements and development requirements in conversion equipment. Table 9-4 summarizes a comparison of three applicable power generation techniques.

9.3.1.3 Dissipation in Space of Thermal Energy from High Power RF Components. Dissipation of heat in satellite RF systems is concerned mainly with transmission line components and RF power amplifiers. The average power rating of microwave transmission lines is determined by the permissable temperature rise above ambient transmission-line wall temperature. When a specified power level is delivered to a transmission line with a specified termination VSWR, the transmission-line wall temperature rise and distribution can be determined.

In general, transmission line components such as circulators, filters, and hybrids do not operate satisfactorily at high temperatures. Thus, the problem of heat transport and radiation require careful consideration. The amount of heat generated is not negligible: For example, a circulator with matched terminations and 0.3 db loss will dissipate about 66 watts with a 1 kW incident signal. The maximum design objective of 1 db requires a thermal system capable of dissipating 205 watts. Heat-sinking the center conductor of coaxial cable represents a primary problem in a high power RF system design and requires a tradeoff investigation during the design phase.

Cooling of the RF power amplifier is difficult because of the high heat density typical of devices such as TWT's and klystrons. Heat pipes may be used to remove heat from a high density source and transfer this energy to a radiating surface.

In design of a radiation heat transfer system, the basic tradeoff encountered is that of determining the radiating surface temperature and surface area. Solid state devices such as transistors require low operating temperatures, on the order of 370°K, while amplifying devices such as gridded tubes and klystrons can operate at temperatures on the order of 470° to 500°K.

Heat pipes using water or organic fluids operate at low temperatures and require large radiating surfaces while liquid-metal heat pipes, operating at higher temperatures, require less radiator area. Low temperature operation is desirable from the standpoint of amplifying device reliability; however, the temperature must be selected by tradeoff between satellite size and weight.

Radiators provide the only practical means of dissipating excess heat in a spacecraft over a long time span. The maximum allowable size of the radiator determines the operating temperature of the high-power transmitting device.

The heat pipe is an active thermodynamic system involving state-change of such fluids as sodium, potassium, or cesium. The fluid medium is circulated by capillary wicking. No external pumps and values are required, so the life and reliability of the heat pipe is close to that of a passive radiator system. A significant problem with the heat pipe is that of incorporating it into the basic amplifier tube.

Use of the heat pipes to cool transmitters is being made by RCA, Varian Associates, and Litton. On the ATS-5 a heat pipe was used to cool the solar array. The Jet Propulsion Laboratory is also involved in heat-pipe work for spacecraft.

9.3.1.4 Antenna Technology. Spacecraft antennas can be divided into two categories: small antennas which can be launched in operating position; and large antennas which due to shroud limitations must be folded for launch and then deployed in space. An antenna diameter of approximately 10 feet divides the two classes. A variety of small antennas have been used in space and pose no major technological problems for the broadcast satellite.

Space erectable antennas to diameters of approximately 40 feet can be packaged in a petal or flexible rib configuration. Antennas of this type have been considered and a selection made for launch on the ATS-F technology satellite in the early 1970's. A prototype 10 feet diameter petal-type spacecraft antenna has been fabricated and tested. An antenna of this type was used in the Apollo mission program.

Extremely large antennas can be fabricated using the deep truss concept with hinged tubular struts that has been developed by General Dynamics Convair Aerospace for NASA/MSFC. Conceptual designs have been completed for diameters of 140 feet. Units have been fabricated and tested in sizes of 6, 10, and 15 feet. In a 15 foot erectable antenna built for NASA-Goddard under contract NAS 5-21133. The RF reflective surface is a lightweight flexible mesh which is supported and its shape defined by a subsystem of tension lines located immediately behind the mesh. Typical measure aperature efficiency at 8 GHz was 80% with simple waveguide feed. The deployable truss parabola affords excellent packaging characteristics, structural rigidity, resistance to thermal distortion, and high natural frequency that is necessary for compatibility with attitude control systems of satellites.

The high powers associated with the broadcast satellite make it desirable to keep the power radiated outside the area of interest to a minimum. This can be done by suppressing the side lobes adjacent to the main beam as low as possible. The results of a NASA/LeRC program to suppress the side lobes has shown that levels of -40 db below the main lobe power level out to angles of 15 degrees are possible.

Side lobe suppression by heavy taper and increasing antenna size results in decrease in antenna efficiency and some increase in half power beamwidth. This characteristic results when the first null is held constant. Side lobe levels are also affected by RMS surface error and aperature blockage, therefore stringent control on surface tolerance and minimization of feed and feed support blockage within the antenna aperature is required.

Pointing accuracy depends on the satellite structural flexibility. For small, rigid satellites the accuracy is limited by sensor performance. It is anticipated that in 1975 an accuracy better than 0.2 degrees can be attained for the large structure satellites.

The gain limits set for 1975 are as follows:

- At low frequencies a gain limit is set by the antenna size
- At higher frequencies the gain limit is set by beam pointing accuracies - .05 degrees for antennas less than 10 feet diameter and .2 degrees for a 30 foot diameter antenna.

Beam steering by scanning the primary illumination pattern in a parabolic antenna can be achieved with resulting loss in efficiency, and gain, and increase in side lobe levels.

Steerable - array antennas are far more complicated and heavier than conventional multiple aperture antenna. Since very large spacecraft (within limitations of current boosoers) are feasible, steerable-array configurations require reappraisal because weight of the antenna may be less decisive. Although the use of rapid inertialess beam pointing is not required when broadcasting from geo-stationary satellite, steerable array can be justified when multiple or shared aperture become more attractive than a single aperture. At lower frequencies apertures having high gain are so large that an electronically steerable-array becomes more applicable. In addition, distribution of transmitter power over many modules reduces high power concentration at a single point resulting in an increase in life and reliability of associated components. An array also provides redundancy in its basic design.

Multiple area earth coverage requires several beams from a single aperture. When the operating wavelength is relatively small (such as X-band) multiple area broadcast coverages is readily provided by a system of small, rigid antennas. At lower frequencies (UHF) large antennas are required and multiple area coverage is more difficult. Because of high power feeding problems and minimum obtainable angular separation of RF beams from stacked feeds, single beam apertures are still desirable. A major problem, however, in using large multiple apertures is the additional deployable structure required to mount the antennas.
In addition, solar cell power systems must not be shaded by the reflector system during operation. This again creates a requirement for additional deployable booms. These problems can be avoided by the configuration shown in Figure 9-2. This

concept utilizes the GD/C expandable truss to provide the multiple aperture substructure for reflective mesh/stand-off system, and also becomes a rigid structural support for a roll-out solar cell system. An off-set feed system is used with all radiating elements conveniently housed in a single module. Angular orientation of each aperture is adjusted prior to launch for desired earth area coverage.

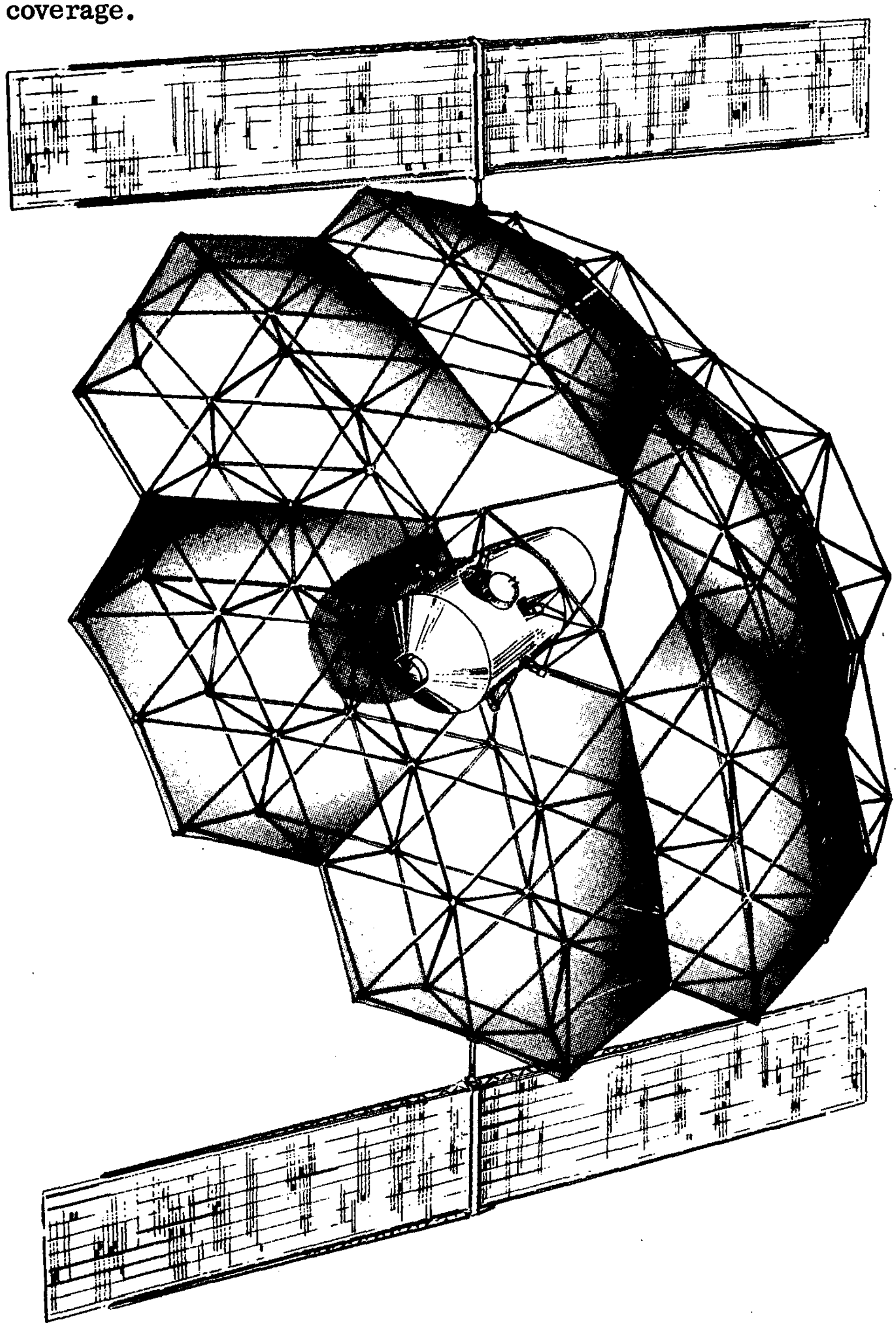


Figure 9-2. Integrated Six Beam Satellite System

9.3.2 GROUND SYSTEMS

9.3.2.1 Introduction. In the ground segment of a Communication Network in which a satellite relay links the ground stations the status of technology has its greatest impact in relation to bringing down costs of a particular service and to a particular user.

Direct users of the satellite service are those in urban areas which would be linked to the satellite through Gateway stations by means of switched telephone networks or microwave links depending on the type of service and users in remote areas that are linked directly to the satellite. This section is concerned mainly with the smaller terminal that is linked directly with the satellite and the interrelationship of technology and cost. The terminals are of two basic types, receive-only and send/receive. For the receive-only terminal the pacing technology requirement is the availability of low cost wide band receivers and converters at S-band and 12 GHz for receiving television signals. Another type of service to the receive-only station is that of being the recipient of timely disseminated information such as weather warnings, news, crime information, financial reports etc. Teletype and facsimile are the principal vehicles for receiving this type of transmission.

Send/Receive terminals are used in those cases where two-way communications with the user is required. Included in the types of service are voice, teletype and facsimile message/document interchange service and data collection where data flow is primarily from a small unattended terminal to a central information collection facility. The types of sources are human speakers, teletypewriters, facsimile scanners and telemetry transmitters. The two-way television channel is a special case that has an important application to the Medical Community to provide service to remote areas.

One of the major obstacles to providing two-way service to the small user is frequency allocation and the high cost of communication satellite channels. A promising solution to this problem lies in devising cooperative arrangements so that a number of low duty-factor users can share a common channel or frequency allocation band. For voice communications the solution lies in the use of multiple access techniques such as Time Division, Frequency Division and Spread Spectrum. To be viable a user must accept the possibility of a busy channel for a certain percentage of the time.

For the record message type of service (data, teletype and facsimile) a solution to provide high utilization of the allocated channels by a number of low duty-factor users is the use of the store-and-forward mode of operation. Store-and-forward would not establish direct circuits as in the voice communication service but instead messages would be stored at various points between the sender and recipient and could involve delays of seconds, minutes and hours depending on the grade of service desired. All message transmissions would be controlled by a computer located at a Gateway station that would send signals to the small user terminals via satellite to activate a transmitter for Message transmission. Data collection type of service would conserve spectrum and satellite channels by scheduling transmissions on a pre-arranged basis to allow time sharing of the allocated frequency. A further extension of the above techniques is the combining of a number of services into Multiple Purpose Mission. To be effective, close cooperation is required between the various services including the sharing of channels and facilities.

9.3.2.2 Use of Time Division Multiple Access (TDMA). Frequency Division Multiple Access (FDMA) because of compatibility was a logical extension of the standard FDM telephone transmission system. However, the extension of an FDM terrestrial telephone system to a multiple access satellite repeater carried with it the disadvantages of the FDM system and introduced additional problems when operated in a satellite repeater multiple access system. These disadvantages are intermodulation distorition, requirement for precise ground transmitter power control, inflexibility and inadaptability to demand access.

Associated with the trend of conversion of terrestrial telephone systems to digital PCM, there is considerable activity leading to the eventual operational use of digital TDMA systems associated with the synchronous satellite relay repeater. Some of the advantages of PCM systems are:

1) PCM is easily switched and routed,
2) PCM is less sensitive to interference,
3) There is no crosstalk or intermodulation distortion in the satellite repeater,
4) PCM is less sensitive to interference from other stations on the same frequency,
5) With an increasing amount of digital data traffic, a PCM system is more adaptable than an analog system to the transmission of digital data,
6) There is a favorable exchange of R.F. bandwidth and power in PCM systems when compared to analog FM systems,
7) Precise control of transmitted power is not required as with FDMA,
8) In a PCM system the pulse stream can be regenerated in the satellite repeater to improve the signal-to-noise ratio (uplink noise is not present on the downlink),
9) PCM lends itself to secure communications,
10) TDMA is adaptable to demand assigned multiple access.

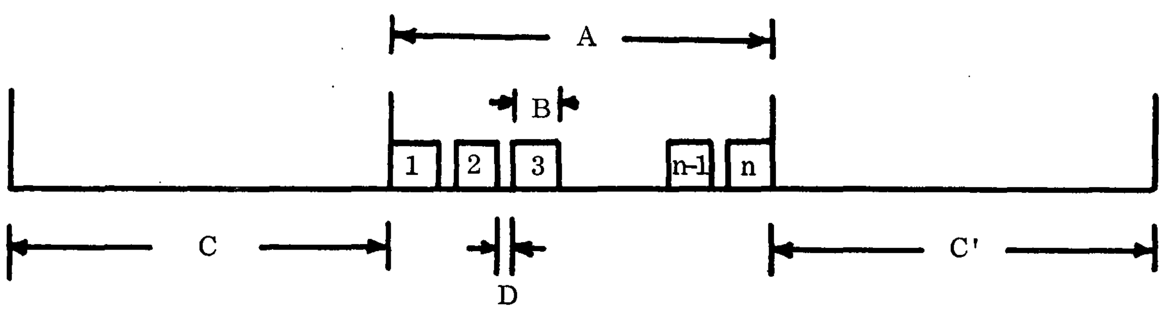
Figure 9-3 shows the basic format of a TDMA system. With each time slot, B, in the frame is a transmission burst from a ground station. Each participating ground station transmits one or more data bursts during a time frame.

Included in the data burst are binary words corresponding to digitized samples of analog voice signals or digital data words in the case of digital data sources. Also included within the burst are synchronization bits to assist a receiving station in acquiring and maintaining synchronization and a unique word to identify the originating station. In a fixed assigned multiple access system the format remains fixed with each time slot within the frame assigned to a specific station whereas in a demand assigned system, time slots are assigned to stations instantaneously on a demand basis. Also, the time width of data bursts within a frame may be variable. The bit rate within a frame would normally be constant. However, to accommodate small users of system capacity the bit rate within a given time slot can be lowered to reduce transmitter power and receiver sensitivity requirements.

These are some of the parameter limits in the TDMA format: For a fixed frame time the time-slot duration decreases as the number of time-slots per frame are increased. The minimum allowable time-slot duration is equal to twice the uncertainty in propagation time before acquisition between any ground station and the satellite so that an initiating synchronizing pulse, transmitted when access is initiated, does not overlap adjoining time-slots.

Guard time between time slots must not be less than the minimum time uncertainty associated with ranging after acquisition.

To assure proper interleaving of time slots of a station making access, a time reference must be established and maintained either at the satellite or at a ground station.



A: Recurring time-frame
B: Time-slot
C, C': Time-frames
D: Guard time

Figure 9-3. Format of a time-division multiple-access system.

Corrections for path delay and path delay variations must continuously be maintained to assure that time slots are synchronized to the frame reference. The station burst of each participating station has a format that contains preamble bits and information bits, according to Figure 9-4.

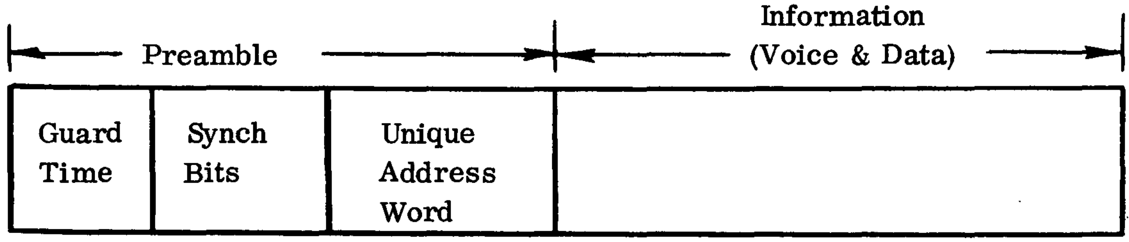


Figure 9-4. Preamble Format.

The preamble is made as short as possible to maximize efficiency to transmission or TDMA efficiency. The various parts of the preamble provide the following functions:

a. Guard time - this is non-transmission time inserted between data bursts to prevent accidental overlapping of bursts.
b. Synchronization bits are required to recover a coherent carrier and establish bit timing. This must be repeated for each burst because earth stations are not coherently related. During the first part of the preamble after the guard time only the carrier comes on to enable the receiver to achieve lock-on to the carrier and the system clock. The time required depends upon the characteristics of the receiver phase lock loops.
c. The purpose of the unique address word is to determine the time at which the burst begins by correlation detection of this unique word. This word also identifies which station originates the burst.

TDMA Experimental Results:

a. ComSat/Intelsat I Experiment - Field tests were made of a TDMA system that included three ground stations and the Intelsat I (Early Bird) satellite. The parameters of this system are:

No. of voice channels	24
System bit rate	6.176 M bits/sec
Frame period	125 microseconds
Burst period	Approx. 40 microseconds
Type of Modulation	Coherent 2-phase PSK

b. ATS Satellite Experiments - Applications Technology Satellites 1 and 3 served as repeaters for three earth stations participating in the experiments. The system was characterized by the following system parameters:

Clock frequency	13.644 MHz
Frame length	125 microseconds
Subframe length	40.98 microseconds
Preamble - data channel	7 bits
station code	7 bits
Type of detection	PSK 2-phase differential

c. A 50 M Bit/Sec Comsat TDMA Experiment - This experimental system was designed for tests that included ten earth station and the Intelsat III satellite repeater. The maximum capacity of the system is 782 voice channels.

System characteristics are as follows:

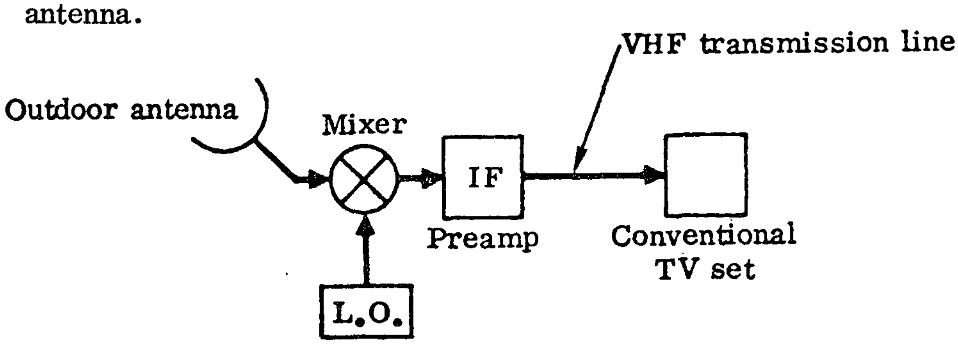
Maximum capacity	782 voice channels
Frame period	125 microseconds

The technology has been developed for the implementation of TDMA. The system is too expensive however, at present for the small user. The reduction in TDMA equipment costs would only partially alleviate the problem. Transmitter power and receiver sensitivity requirements are directly related to system clock frequency which in turn increases directly with system capacity. Therefore the small user is unduly penalized in a large capacity TDMA system.

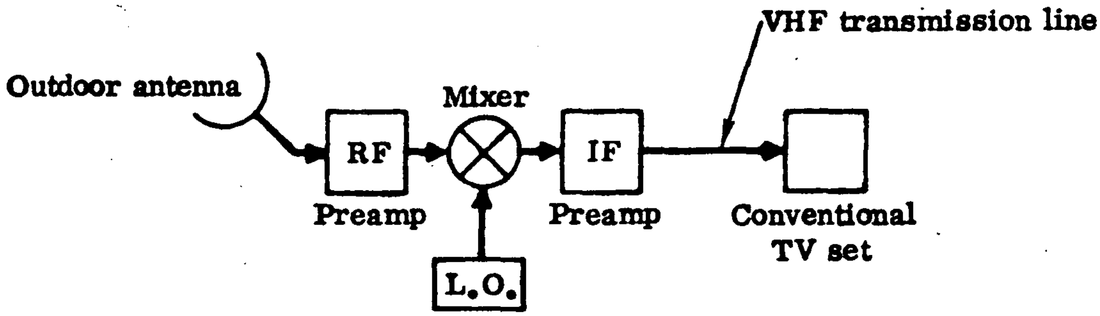
9.3.2.3 Ground Receiving Station Capability and Frequency of Transmission. In direct-to-user transmission the minimum effective radiated power (ERP) required from a synchronous satellite is constrained by cost considerations. ERP levels on the order of 70 to 90 dbw are required for transmission to unaugmented receivers with indoor antennas. Use of an outdoor antenna and incorporation of a modulation converter reduces the ERP requirement to a range of 30 to 70 dbw.

9.3.2.3.1 Receiver Configurations. Several of the basic receiver configurations that must be considered for use in conjunction with a satellite transmitter are as follows:

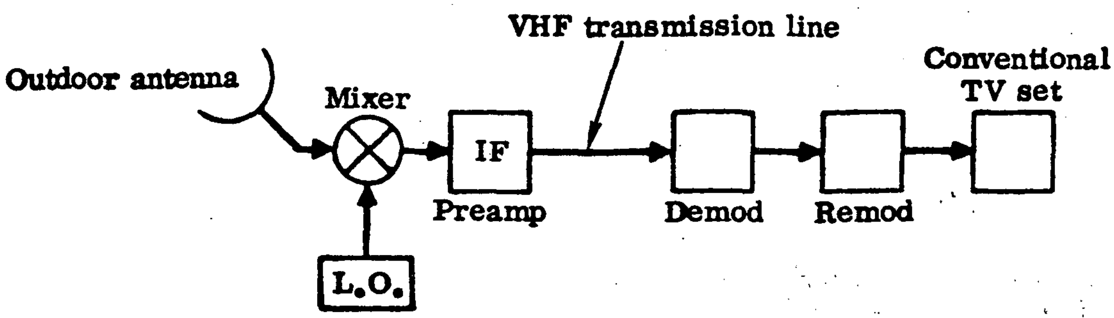
a. The frequency of transmission is above the UHF band, requiring the addition of a frequency converter (balanced or single-ended mixer) on or near the antenna.



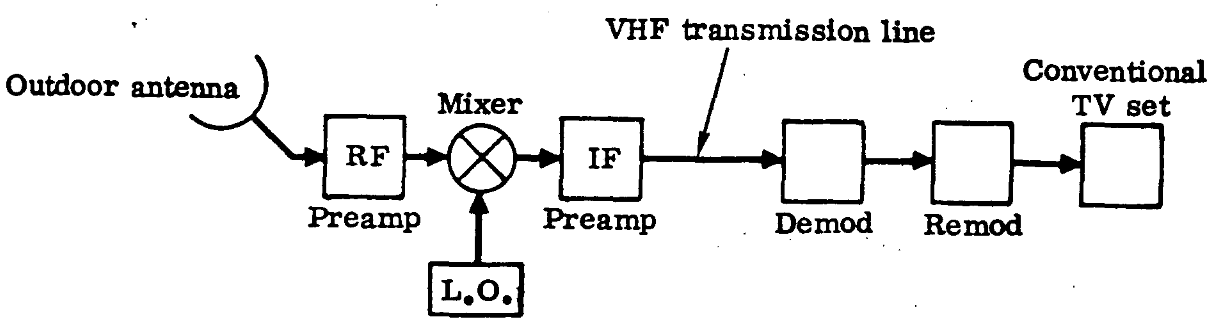
b. This configuration is similar except that a preamplifier is mounted near or on the antenna to reduce effective system noise temperature.



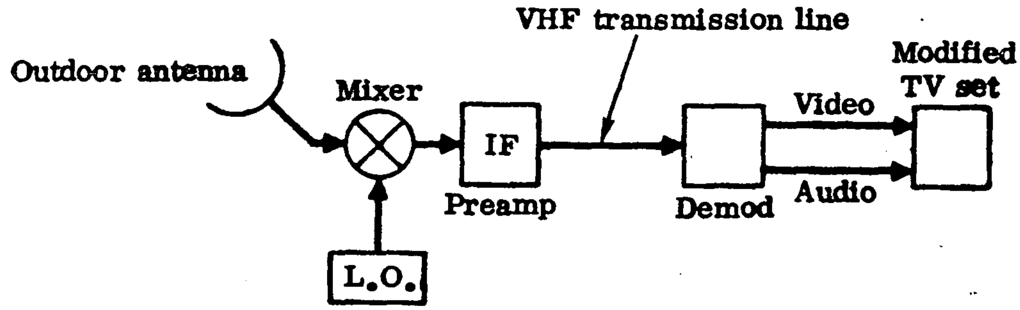
c. The satellite signal is frequency modulated; thus, the use of a modulation converter is required to transform the signal into standard AM-VSB format.



d. The configuration is the same as c except that a preamp is mounted near the antenna to reduce the overall system noise temperature.

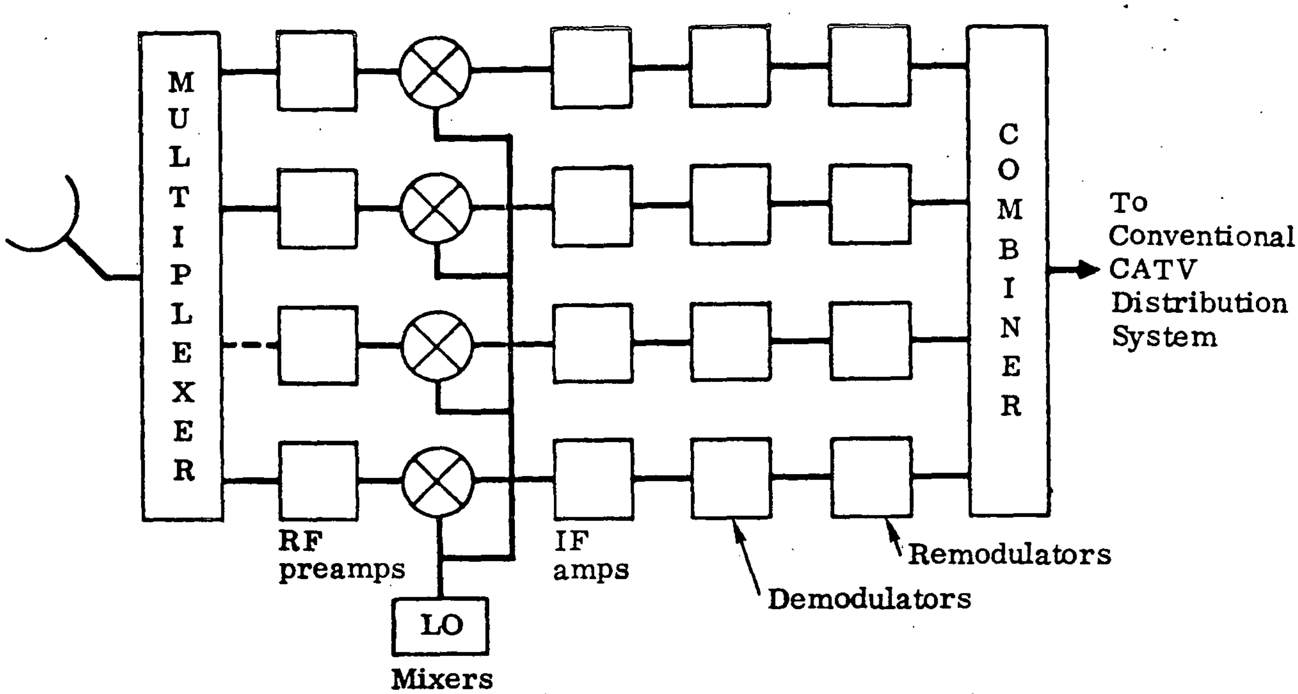


e. This configuration is the same as d except that no remodulator is used to convert the signal to standard format. Instead, the receiver is wired to allow direct injection of video and audio into the set.



f. This configuration is the same as e except that a preamp is added as in configuration c in order to reduce overall effective system noise temperature.

g. The receiver configurations described above would be utilized in connection with a direct broadcast satellite. To provide a broadcast service involving the distribution of programs through rebroadcast or cable networks a more complex receiving system would be required. A simplified block diagram of a redistribution type of receiving system is shown. Consideration of many variations of receiving systems in such an application is beyond the scope of this report, although future consideration of such systems appears to be mandatory, particularly in view of interference and sharing constraints.



9.3.2.3.2 Receiver Cost. In order to "size" a spacecraft transmitter a wide range of receiver quality and cost data is required. Technical and cost data found in GE and CCIR reports has been utilized as a base to develop the range of ground receiver parametric data required.

Noise characteristics of typical receivers which may be available in 1975 are shown in Figure 9-5. A block diagram of an FM receiver which illustrate the type of receiver that would be obtained for the indicated costs is shown in Figure 9-6. Production cost estimates versus time for annual production volumes of one thousand to one million units are shown in Figures 9-7 and 9-8 for S band and 12 GHz FM receivers.

It may be anticipated that a multiple-channel capability will be required for most satellite broadcast applications. In view of this requirement, multiple-channel receiver cost estimates are shown in Figures 9-9 and 9-10. A general block diagram of the multiple-channel receiving system is shown in Figure 9-11.

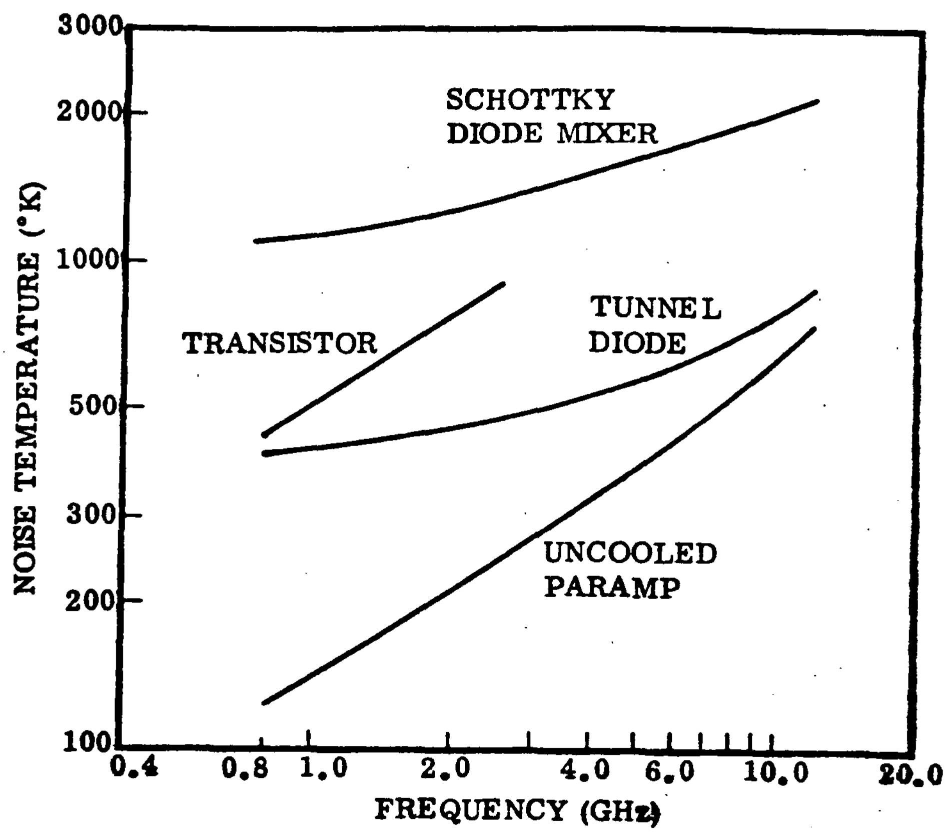


Figure 9-5. Noise Characteristics of Typical Receivers - 1975 (from CCIR Study Group IV Report)

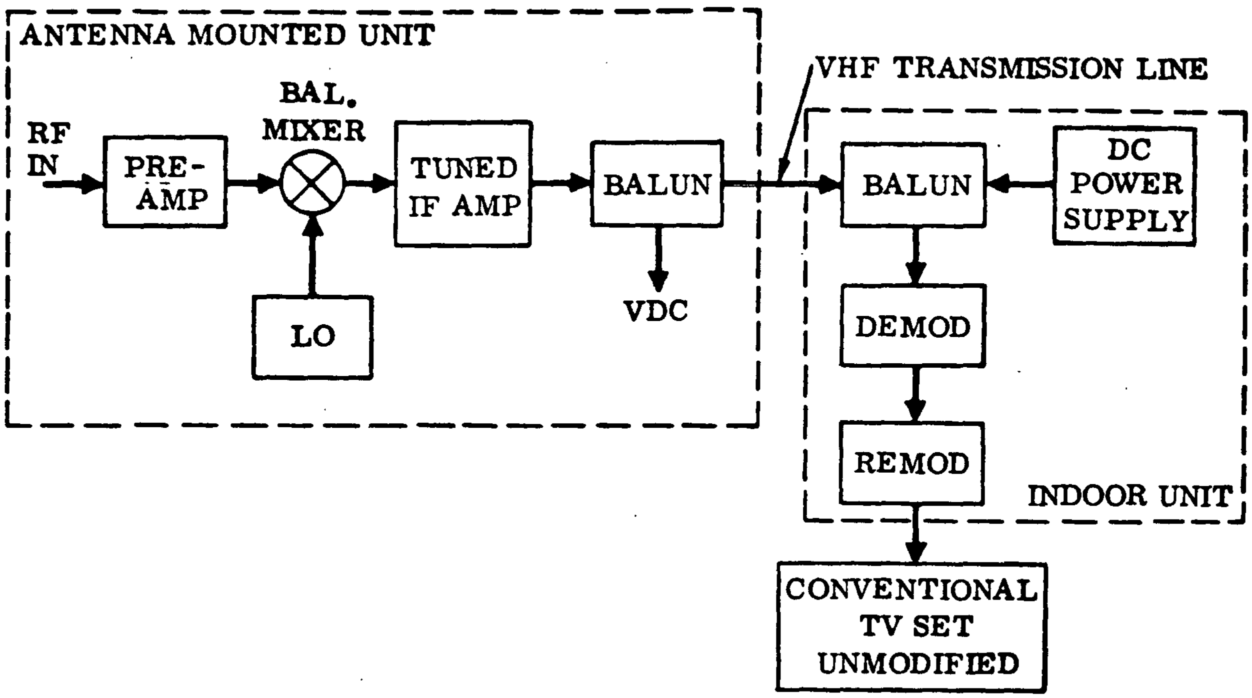


Figure 9-6. FM Receiver Block Diagram

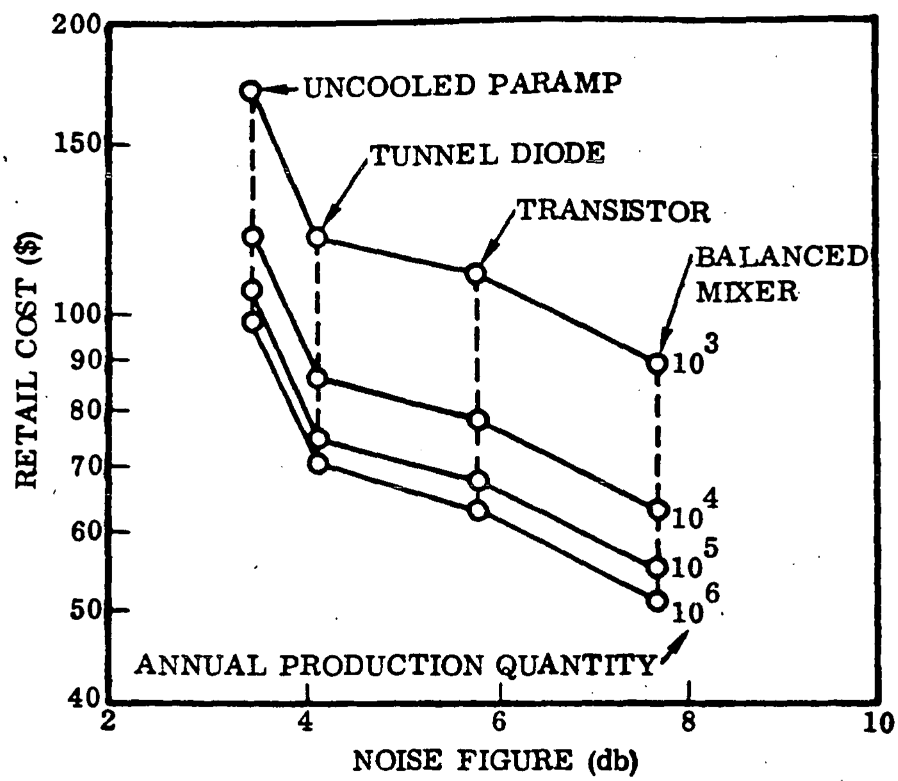


Figure 9-7. Satellite 2.25 GHz FM Signal Processor Retail Cost vs. Noise Figure - 1969

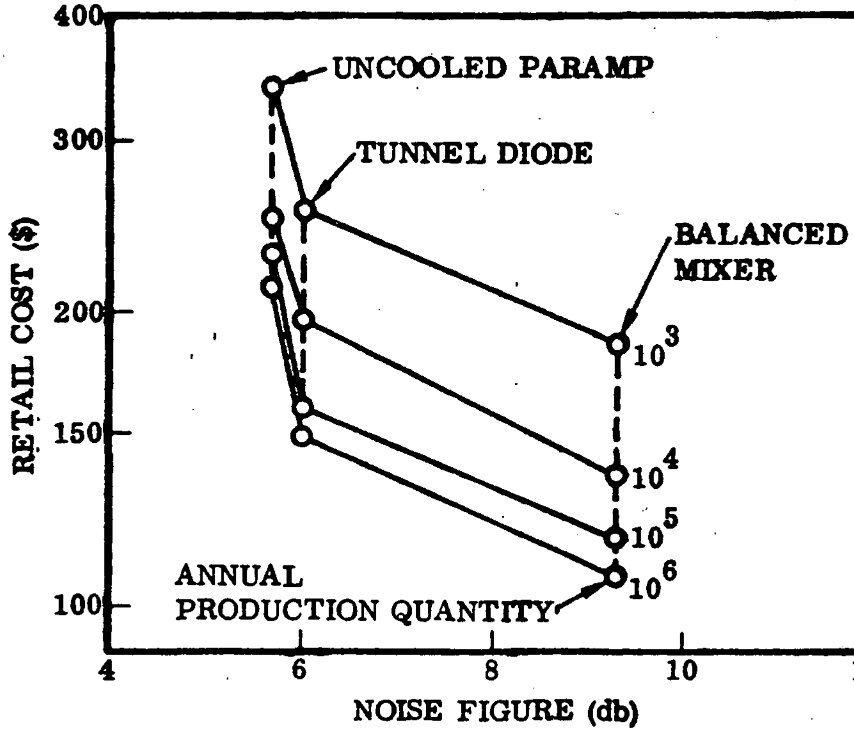


Figure 9-8. Satellite 12.0 GHz FM Signal Processor Retail Cost vs. Noise Figure — 1969

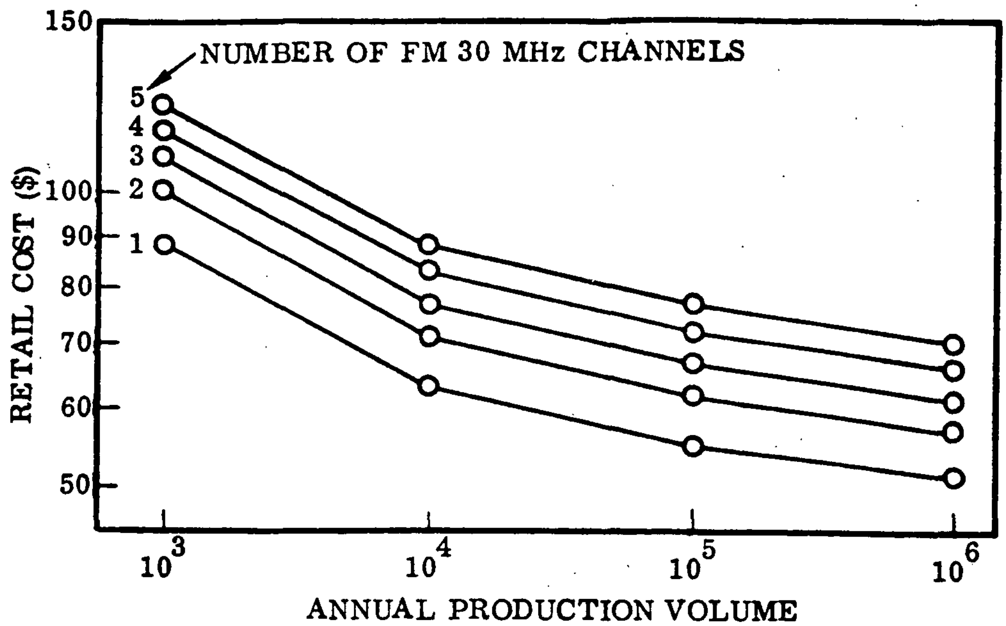


Figure 9-9. Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 2.25 GHz FM)

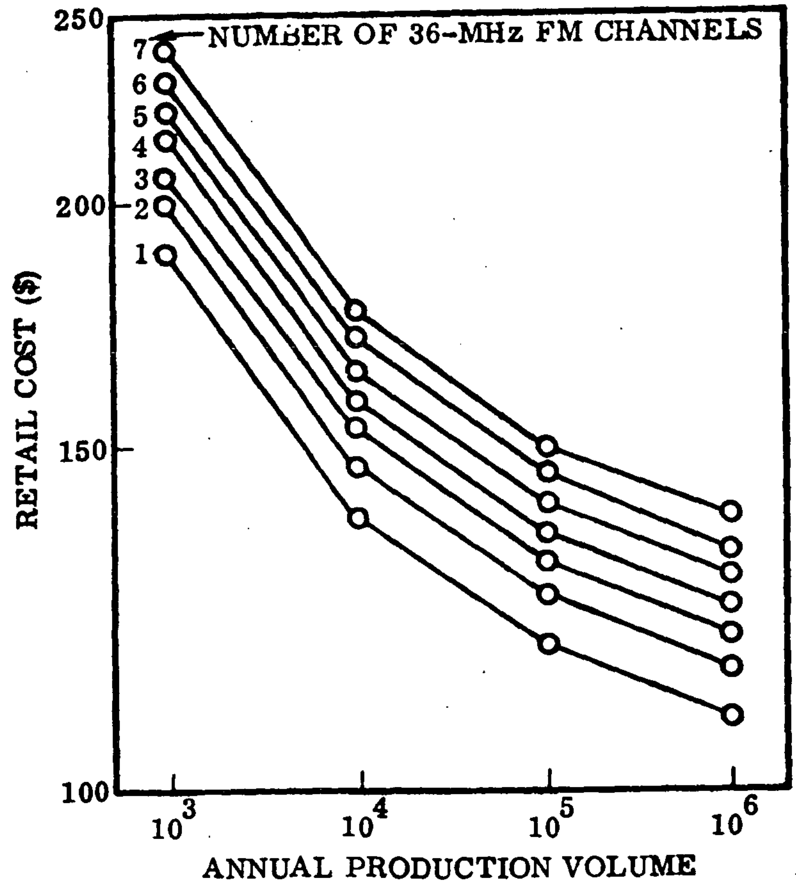


Figure 9-10. Multiple-Channel Satellite Signal Processor Retail Cost — 1969 (Balanced Mixer for 12.0 GHz FM)

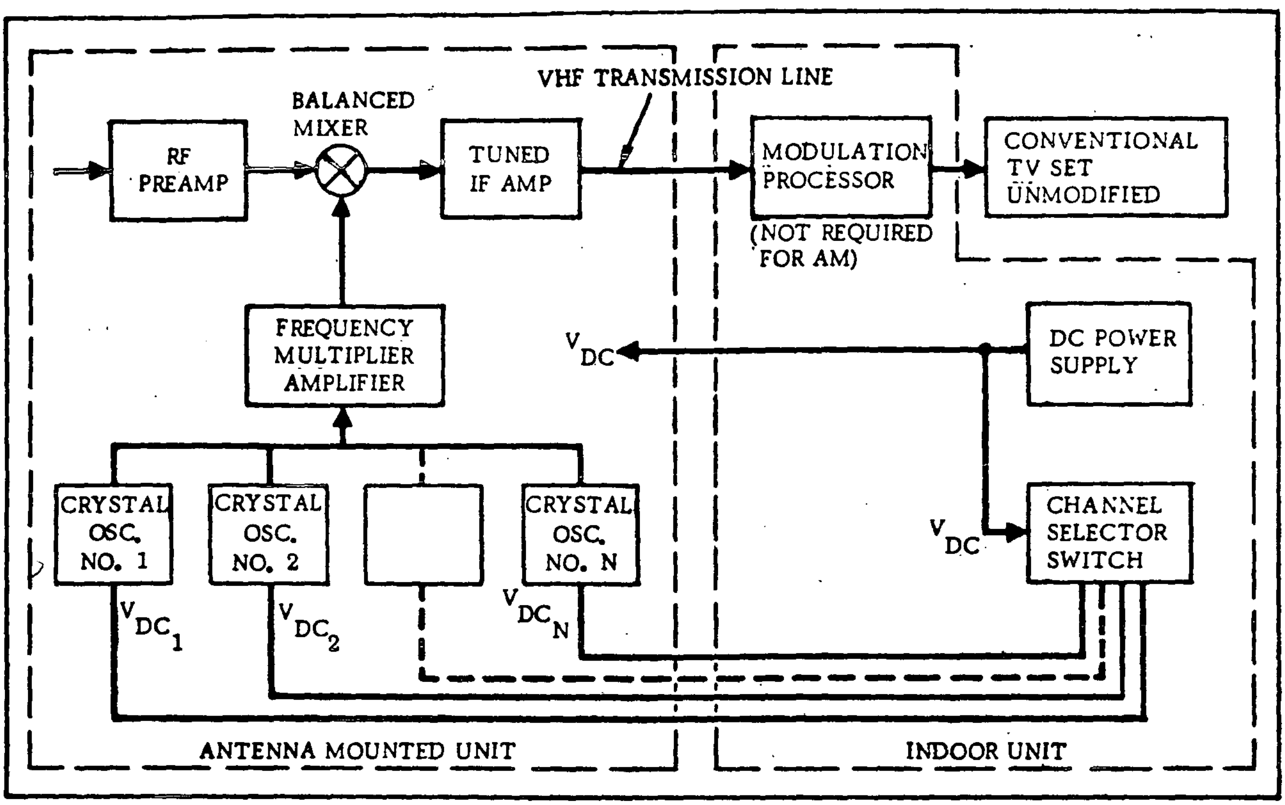


Figure 9-11. Multiple-Channel Receiving System

9.3.2.4 Facsimile Transceiver Technology. Most facsimile transceivers have been designed to be compatible with transmission on the commonly available common carrier channels; namely voice, group, supergroup and wideband. Nominal copy sizes are 8 1/2" X 11" for documents, messages, drawings and pictures, and 22" X 15.4" for newspaper transmission.

Scanning is usually either electromechanical using a rotating drum and a high intensity light attached to a lead screw moving along the drum or electronic using a CRT to produce a flying spot scan of the copy moving linearly past the beam. The resolution of the transmitted copy is determined by the scanning lines per inch. The Channel response characteristics are determined by document size, scanning density and time required to transmit a copy. Most facsimile transceivers are analog systems using either double sideband amplitude modulation (DSB-AM) or vestigial sideband AM (VSB-AM). With the increased availability of digital communications links, there will be a greater demand for digital facsimile systems. In a digital system the scanning is performed in the same manner as analog facsimile but the output is sampled and a comparator converts the samples to a two-level signal corresponding to black or white elements. The resulting bit rate is twice the channel frequency response.

Most recently developed low cost facsimile transceivers are designed for transmitting 8 1/2 X 11" documents over a voice grade lines using analog modulation (DSB-AM) with a 6 minute transmission time and a resolution of about 100 lines per inch. Charges are the same as a regular phone call so that business firms can send 10 documents 8 1/2" X 11" each from New York to Chicago for less than $3 per page including equipment lease costs. To make facsimile systems even more attractive for office use telephone costs are being reduced by developing techniques to speed up the transmission time. One experimental system cuts the transmission time of a standard one page letter to less than a minute from the three to six minutes needed on facsimile machines currently in use. Lease costs for facsimile transceivers are generally in the 100 - 200 dollar per month range with $65/month being the cheapest lease rate.

Predictions for facsimile use in the home are based on requirements for service by multi-channel CATV systems and a breakthrough in cost of facsimile systems. The receive-only mode will precede the home use of receive/transmit facsimile systems. Some authorities visualize facsimile transmission as a TV frame coded for identification with the option to store and display or make a hard copy.

9.3.2.5 Two Way TV Links via Satellite Relay. An important application of two way TV links is for remote diagnosis and treatment of patients located in remote areas. An experimental system referred to as Telediagnosis is now operating via microwave link between Massachusetts General Hospital and Logan Airport in Boston. The techniques are thus developed and verified to be useful. For remote areas reached only via satellite relay, a pacing problem area is the requirement for a high power television transmitter at the remote site to transmit a high quality television signal to the satellite in synchronous orbit. Even if a centrally located satellite uplink facility serves a number of users in a remote area, costs may be prohibitive using presently available equipment and techniques. Therefore, the satellite ground facility is envisioned as a terminus for a number of remote diagnosis facilities connected to it by microwave links. To provide greater utilization and cost sharing of the 2-way TV links, consideration should also be given to using these links for two-way conferences and wide-band data transmission.

9.3.2.6 Use of Store-and Forward Techniques. There are two types of switching commonly employed in a data communications network, circuit switching and message switching. Circuit switching is used to establish a circuit between two terminals connected to the network. Message switching is a type of switching used to store a particular message and then, at a later time, to forward it to one or more recipients. Store-and Forward is an implementation of the latter type of switching.

Store-and Forward switching in simple form consists of the component blocks shown in Figure 9-12.

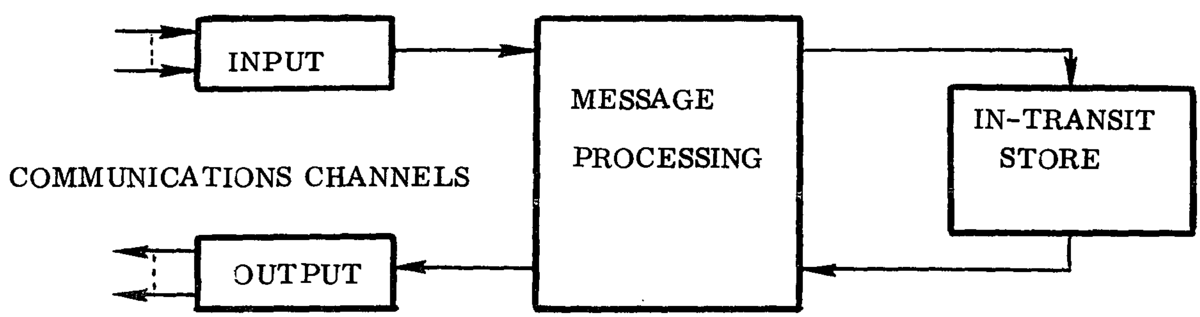


Figure 9-12. Store-and Forward Switch Functional Diagram

The Input/Output Channels are time-shared to the greatest possible extent. Each message is received in its entirety before it is relayed to the next destination. Incorporated in the Store-and-Forward switch is a computer that provides extensive random access message storage and the necessary logic and memory to recall and transmit the stored messages to the output channels in the required order, code and format. The in-transit store is used for temporary storage of a single message. As soon as the message has been completely transmitted and acknowledged, the space is made available for a new message. One of the largest users of Store-and Forward switching is the Defense Communications Agency AUTODIN Network.

Store-and-Forward is most advantageous when traffic volume is large and a great many terminals are connected by costly long-haul transmission channels. Store-and Forward switching provides the capability of concentrating traffic on the available channels with maximum efficiency. Networks utilizing computer-controlled message switching operate at about an 85% loading factor compared to about a 20% loading factor and a requirement for 4 or 5 more trunks for a network without message switching.

The largest cost item in a store-and-forward switch is the computer and associated software cost. However, computer costs have decreased drastically during the past decade and predictions forecast a continued decline during the 70s. For instance, in teleprocessing systems computer costs have been dropping at a rate of about 25% yearly. Thus, taking into consideration the improved efficiency afforded by store-and-forward techniques to utilize expensive satellite channels coupled with a downward trend in computer costs, use of computer-controlled message switching should become increasingly attractive to alleviate telecommunications costs.

ITS TECHNOLOGY SECTION

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10

CONCLUSIONS

The two primary objectives, originally assigned to the Information Transfer Satellite Concept Study were:

1. The development of tools and techniques for ITS planning,
2. Selection of viable applications for Information Transfer Satellites.

These objectives, of necessity, include the development of a data bank of user's needs and requirements, communications techniques, implementation approaches and related hardware characteristics.

10.1 PLANNING TOOLS

The development of two computer programs was initiated during the study. They are described in detail in Chapter 8 of this volume.

1. Satellite Telecommunications Analysis and Modeling Program (STAMP). This program was the major processing tool for the analysis and synthesis of single and multipurpose missions. Section 8.1 gives a brief overview of the program approach and techniques. Greater detail is contained in Volume IV, Computer Program Manual. This program is complete and deliverable under this contract.
2. Ground System Mode. This program is discussed in detail in Section 8.2 of this volume. The basic approach has been estab lished and verified, however, the program lacks detailed station, terminal and equipment models and needs further analysis for developing suitable weighter's factors for various segments of the system. It is not complete and is not deliverable under this contract.

10.2 MISSION SELECTION

10.2.1 <u>GENERAL CONSIDERATIONS</u>. Table 10-1 lists the mission groups finalized under this study. The groups are broad enough in context and scope to include most applications that come to mind. An assessment is made of the probability of implementation of a satellite system for these missions. Six missions are considered to be "likely" for the

Table 10-1. ITS Mission Groups

MISSION GROUP	PROBABILITY OF IMPLEMENTATION		
	LIKELY	POSSIBLE	UNLIKELY
1. TELEVISION SERVICES	X		
2. REMOTE AREA TELE-COMMUNICATIONS SERVICES	X		
3. EDUCATIONAL AND INSTRUCTIONAL SERVICES			X
4. DATA COLLECTION AND DISTRIBUTION SERVICES	X		
5. CIVIC SAFETY SERVICES		X	
6. TRAVEL AND RECREATIONAL SERVICES		X	
7. MOBILE COMMUNICATIONS SERVICES	X		
8. MEDICAL COMMUNICATIONS SERVICES	X		
9. BUSINESS MANAGEMENT SERVICES		X	
10. DOMESTIC WIDEBAND SERVICES	X		

reason that there is an extensive community of interest supporting each of them and they have potentially large benefits to offer the general public. One of the missions is considered unlikely to result in a satellite system — Educational and Instructional Services. This is a "labor intensive" application that is straining under a heavy burden of rising costs. Total system costs for the supplementary satellite system are also very high — due primarily to the large number of participating schools. It would depend for its success on the very group it would impact the most adversely — the teachers. Some new policy or approach, national in scope, is required to promote this mission.

The remaining three systems have long term potential dependent, primarily, on the development of a supporting community of interest.

10.2.2 SYSTEMS CONSIDERATIONS. In analyzing the many systems that were synthesized the following general observations were made:

1. Economies of Shared Systems. For most cases, benefits were obtained when several users shared the satellite and launch vehicle and/or the ground facilities. This feature is to be expected since the percentage of cost increase is usually much less than the percentage of increase in service. On the other hand, some users were penalized economically when sharing was exercised. These cases occurred when the single user achieved a minimum cost at or near a payload constraint. The addition of other users required a reduction in that user's share of the satellite if the same launch vehicle was used. If a larger launch vehicle was used, the increase in cost for the space segment again penalized the major user.

2. Economies of Scale. Similarily, additional capability may be added at small cost increments for a particular user until a constraint is encountered. Above this point, the size of the cost increments increased drastically.

3. Dominant Ground Systems. Several cases were observed that exhibited small changes in cost during the cost minimization process. Examination of the cost elements revealed that the major portion of the implementation cost was composed of constant cost items which were magnified by the large number of ground facilities. These items typically included operations and

personnel costs and, for television redistribution systems, video tape recorders.

4. Constrained Systems. Cases that were synthesized with constraints imposed either by regulatory or arbitrary means, such as the constraint of an Intelsat IV satellite antenna for the Alaska cases, were always more expensive than if those constraints were not imposed. Those systems that were constrained by payload characteristics exhibited either economic advantage or disadvantage when the constraint was relieved by the use of a larger launch vehicle. The direction of the impact was dependent upon the cost increment for the larger launch vehicle.

5. Questionable Viability. Some systems exhibited, at best, questionable benefits when a geostationary satellite was used to fulfill their requirements. Small, mobile data collection platforms (DCPs), such as would be used for migratory animal studies, did not effectively utilize the characteristics of the satellite. External tracking techniques were required which heavily penalized the size of the DCP.

6. Medium Size Antenna Requirements. Most systems that were examined did not require antenna sizes larger than approximately 20 feet due to allocation constraints of K-Band operation. Those systems that could operate in the lower frequency bands, e.g., data collection from DCPs, required fairly wide beamwidths.

7. Cost Effectiveness of Medium Size Launch Vehicles. In very few cases the Saturn V was cost effective. Most systems that did require launch vehicles larger than the Titan IIID/Centaur, had minimum cost solutions in the region of 12,000 to 18,000 pounds.

8. Distribution of System Costs. As the number of ground stations are increased, tradeoffs are made within STAMP to provide an economical balanced system. The ratio of each of the system costs to the total system is not static as shown in Figure 10-1. For a small number of stations, such as the Federal

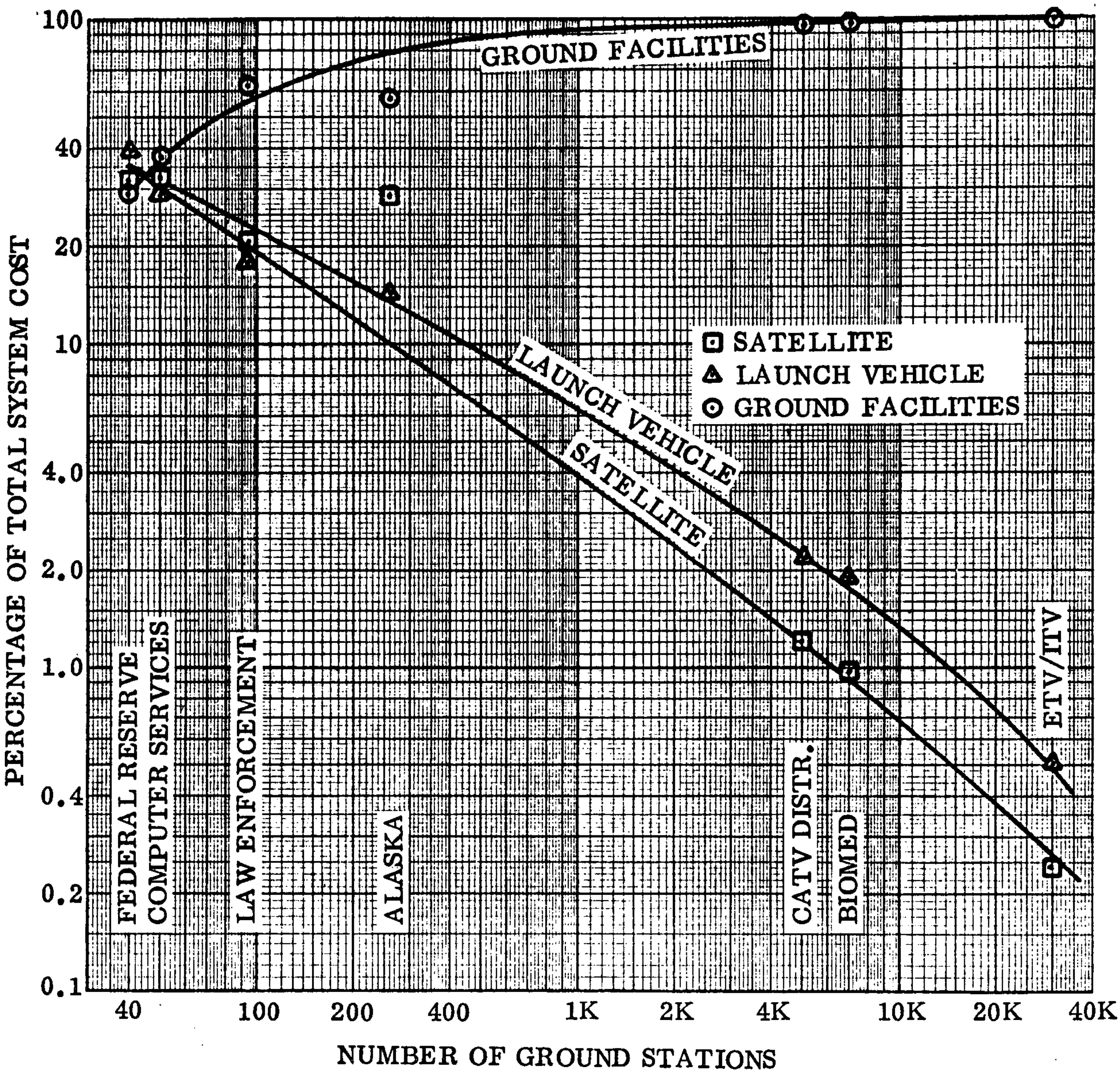

Figure 10-1. Distribution of System Costs For Seven Representative Missions.

Reserve System, the ground station, satellite and launch vehicle comprise approximately equal portions of the total system costs. As the number of ground stations increase, however, the percentage of the total cost is increasingly dominated by these stations. This is due to the multiplication of cost elements in the ground facilities by the number of stations.