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TECHNOLOGY REQUIREMENTS FOR POST-1985 COMMUNICATIONS SATELLITES

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TECHNOLOGY REQUIREMENTS FOR COMMUNICATION SATELLITES IN THE 1980s

By

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FOREWORD

This report was prepared by Lockheed Missiles & Space Company, Inc., Sunnyvale, California, under Contract NAS2-7073, for NASA, Ames Research Center, Advanced Concepts and Mission Division, Space Utilization and Technology Branch.

The study on which this report is based was conducted under the direction of J. M. Deerwester and E. M. Van Vleck of the NASA, Ames Research Center.

ABSTRACT

This report defines the key technology requirements for meeting the forecasted demands for communication satellite services in the 1985 to 1995 time frame. Evaluation is made of needs for services and technical and functional requirements for providing services. The future growth capabilities of the terrestrial telephone network, cable television, and satellite networks are forecasted. The impact of spacecraft technology and booster performance and costs upon communication satellite costs are analyzed. Systems analysis techniques are used to determine functional requirements and the sensitivities of technology improvements for reducing the costs of meeting requirements. Recommended development plans and funding levels are presented, as well as the possible cost saving for communications satellites in the post 1985 era.

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Section 1
SUMMARY AND CONCLUSIONS

Introduction

Communications satellite technology has made dynamic progress since the launch of the first commercial satellite, Intelsat I, in 1963. The satellite weighed only 38 kg and provided 240 voice circuits. Present Intelsat IVs weigh 730 kg and provide 6000 voice circuits. The objective of this study is to determine the key technologies and development plans required to sustain the growing demands for satellite communications into the 1985 to 1995 time frame. If such plans are not made and improved technologies for reducing costs not developed, then new and important services of benefit to society which can best be provided by satellite communications will be inhibited due to lack of capacity or high communications costs. The study is focused on the technologies required to fill the future needs of our society.

Needs Model

The needs model for 1985 to 1995 era services is critical because it provides the basis for determining technology requirements. A suitable model was developed by refining and updating the model of the "Information Transfer Requirements Study," CR-73421, performed by Lockheed Missiles & Space Company in 1971. The model is based on 322 separate needs which are grouped into 32 generic categories such as education, computer communications, earth resources data collection, etc. Each need is based on established user needs such as information retrieval, education, entertainment, obtaining assistance, computation services, remote process control, etc. The basis for the needs and for formulation of the 32 elements of the needs model are defined. Each element of the needs model is defined for three time frames. Present needs and services are defined to provide an established base line of viable services. The progressive expansion of needs are forecasted for the 1975 to 1985 time frame and the 1985 to 1995 time frame. Each element represents a need for service which could be independently fulfilled in total or partially by means of a dedicated satellite, terrestrial, or hybrid network.

Study Methodology

The methodology used to determine key technologies from the needs model is to formulate conceptual networks for filling the needs in 1985 and perform a sensitivity analysis of the effect of improvement of each critical technology parameter on system cost. The methodology essentially simulates the future as it might unfold in an evolutionary manner. Trend forecasts are made to determine what the expected maximum demands for services will be. Technology growth is forecasted without the benefit of special stimulation resulting from the study recommendations. Forecasted technology capabilities are used to formulate the conceptual systems for filling the future demands for services.

The methodology is straightforward, and it provides reasonable results and insight into the basis of technology requirements relevant to user needs for services. Accurately forecasting the future is not a certainty, however, and therefore there is a question of viability and accuracy of results. The approach taken to ensure determination of useful and viable technologies is to consider conservatively worst case conditions. For the results to be viable, the worst case conditions are the maximum expected demand and the minimum expected technology growth. These biases result in greater needs for technology development than might actually occur; but the results are relatively safe. An opposite bias would result in minimum demands and possibly unattainable levels of technology which would tend to indicate that there would be no need for technology stimulation or special development. The likely result being that the needed technologies might not be developed because they were forcasted to be developed, or appeared to be not needed for filling demands for services. Latent demands would be unfilled due to a lack of technology providing sufficiently cost effective services. This is exactly the situation which the study is intended to prevent from occurring. Therefore, the proper biases are used and the study results are quite viable if it is realized that maximum possible demands for service are used in order to provide a safety margin of required technology. A slight over-development of technology will stimulate demand by providing the capability for improved services at lower costs. Therefore, the biases used will tend to bring about the forecasted growth of demand.

Functional and Technical Requirements

Functional and technical requirements are determined for each of the needs of the 1985 to 1995 time frame in Section 5. Requirements are based on the numbers of users for each service, required coverage, type of service, number and type of channels required. All services can be provided by means of three types of communication channels: voice/data (slow speed), video, and digital data channels. Functional requirements reveal the need for improved technical capabilities such as antenna beam contouring and improved control of side lobes for better use of the available frequencies. Paragraph numbers of the functional requirements for each of the 32 services correspond to the sequential reference numbers of the needs model for ease of cross reference between needs and service requirements.

Categorization of Requirements

The 32 different needs are grouped into seven categories of service on the basis of similarity of functional and technical requirements. Some needs such as "Area Support Networks" for developing nations are subdivided and listed with more than one functional category. Needs are listed in numerical sequence for each category of service.

I. Television Service

- 1 Public Schools
- 2 Higher Education
- 4 Teleconferencing
- 5 Biomedical
- 7 Public Broadcast
- 16 State Government
- 23 United Nations
- 32 Area Support
- 30 Religious
- 31 Home TV

II. Digital and Voice Service

- 3 Libraries
- 8 Public Telephone
- 9 Business
- 10 Value Transfer
- 11 Securities and Commodities
- 12 Reservation and Ticket Services
- 13 General Computer Services
- 15 General Services Network
- 16 State Administrative Network
- 17 National Law Enforcement
- 18 Emergency and Disaster
- 24 Electronic Mail
- 26 Electronic Publishing
- 29 Language Translation
- 32 Area Support Network (Telephone)

III. High Speed Data Relay

14 High Speed Computer Network

IV. Mobile Services

21 Marine
22 Aircraft
25 Ground Vehicle

V. NASA Tracking and Data Relay Network

19 NASA Space Operations Network

VI. Earth Resources Data Collection

20 Earth Resources Data Relay

VII. RF Environment Monitoring

28 RF Environment Monitoring

Forecast Trend of Technology Growth

Despite recent funding curtailment for research and development, it is concluded that funding levels will grow in the future and that technology will grow faster in the future than it has in the past. Analysis of the trend of communication satellite technology development indicate that:

1. The cost per two-way voice channel in 1972 dollars can be reduced approximately 10 percent per year due to improvements in earth stations, Ref Fig. 7-10.
2. The cost per two-way voice channel in 1972 dollars can be reduced an additional 15 percent per year due to improved spacecraft and booster system technology.
3. A potential 50 percent improvement in satellite system cost effectiveness can be realized over a ten year period due to the Space Shuttle/Tug system providing increased capability at a lower transportation cost.

Analysis shows that booster systems, earth stations, and spacecraft technology are of relatively equal importance for providing service and improving cost effectiveness. Booster costs and capabilities significantly affect spacecraft configuration and cost. Space Shuttle/Tug is expected to result in a 20 to 30 percent reduction in total spacecraft cost and possibly a 50 percent increase in spacecraft total weight. The result is about a 40 percent reduction in the cost per kilogram of spacecraft. Development of Space Shuttle reduces the technology requirements for providing special services, and has a greater impact due to the reduced costs and constraints than on-orbit refurbishment. On-orbit refurbishment is not considered in determining spacecraft cost effectiveness for the 1985 to 1995 time frame.

The available and developing technologies are adequate for filling forecasted 1985 to 1995 demands for services. Forecasts of technology growth are based on the application of demonstrated laboratory technology and theoretically attainable capabilities. The present rate of technology development indicates that the required capabilities will be available before 1985. Many of the capabilities will be developed for space applications other than communication satellites.

Forecast of Terrestrial Communications Growth

The growth of satellite systems is dependent on how well satellites perform both in competition with and in conjunction with terrestrial networks. Forecasted growth of terrestrial systems includes demands which could be filled by satellite if they are sufficiently cost effective. The forecasted growth of the telephone system is for a 3,500,000 increase in required equivalent voice circuits from 1972 to 1985.

Telephone system tolls are expected to decline but at a much slower rate than the declining cost of satellite communications. The study of terrestrial communications growth substantiates the demands and functional requirements of the needs model. Terrestrial systems will continue to grow, provide improved services at reduced rates, and carry most of the nation's communications. There is, however, a need for satellite systems to augment the established terrestrial networks, provide improved services to remote areas, improve system flexibility, and stimulate the development of new and improved services by providing effective competition.

Cost Effectiveness of Domestic Satellite Systems

Determining the cost effectiveness of domestic satellite systems in competition with the established terrestrial telephone network tests the viability of satellite systems. Five different types of satellites based on available technology but with different numbers of transponders were tested. A 48 transponder satellite is the most cost effective and can compete with the present long distance tariff rates at distances of 200 miles or greater, if short term (15 minute) periodic outages are allowed. Such outages are believed to be acceptable for high quality services provided at lower costs than the present services.

The analysis verifies the validity of domestic communication satellites and many services of the needs model. The optimum conceptual satellite for competing with the terrestrial networks was used as a baseline from which to formulate conceptual spacecraft for the future.

Available Frequency Spectrum

A critical factor in evaluating key technologies for the future is the availability of sufficient frequency bandwidth at desirable frequencies. Future demands cannot be filled without adequate bandwidth. The allocated frequencies are adequate for filling future demands – if properly utilized. A series of link calculations were performed to indicate the earth station and spacecraft communication equipment requirements for best meeting the functional requirements for each type of service. All of the forecasted functional requirements and levels of demand can be met with the available technologies and frequencies. Trade-off analyses based on the link calculations indicate that services for mobile users having to use L band (1550 MHz) and higher frequencies will be improved or costs drastically lowered by use of steered or switched narrow beam directional antennas on the user vehicles. Results of the link calculations and trade-off studies were used for formulating conceptual spacecraft. The studies show that most domestic needs, including semi-direct TV distribution, can be filled by means of Delta launched spacecraft. Technology improvements which can provide 300 degree Kelvin wide bandwidth receivers costing several thousand to several hundred dollars reduce the need for the high radiated power levels which were believed to be required in the past. Recent improvements in data compression essentially halve the radiated power and bandwidth required per video channel.

Cost Model for Conceptual Systems

Costs of over eleven spacecraft were analyzed and the following cost model developed for costing conceptual spacecraft.

$$\text{Sat Cost} \approx (\text{No Transponders}) \times \$0.5 + \$2 + (\text{Sat Wt kg}) \times \$0.004$$

Sat cost is the recurring satellite cost in millions. Non-recurring costs for commercial spacecraft are twice the recurring cost for the 1980 to 1985 time frame. Cost per transponder and related equipment is estimated to cost \$0.3 million in 1972 dollars in 1985 rather than \$0.5 million as for the 1972 era spacecraft. Transponder costs were appropriately reduced for low frequency, narrow bandwidth solid-state transponders. Results of the cost model for 1985 conceptual spacecraft agree with estimated costs of present spacecraft designs such as Intelsat V revised to incorporate forecasted technology improvements for a second generation, VA, spacecraft. NASA spacecraft costs were increased by 50% to allow for special test, reporting and reliability requirements, use of more advanced technology, and experimental equipment development.

Although the cost model may seem overly simple, it is adequate for the purpose used and provides a simple rule for costing future conceptual spacecraft. Very detailed cost models are available but the slightly increased accuracy is inconsistent with the uncertainties of the forecasted 1985 needs and technology capabilities. There is no means of knowing the exact configuration of a 1985 spacecraft down to the exact number of transponders, exact capacity of the power system, and spacecraft weight. It is possible to determine conceptual systems which will be adequate if used, and it is feasible to estimate costs sufficiently accurately for the study purposes with a simple model. The model does not apply for special "low cost" technology spacecraft developed for Space Shuttle.

Conceptual Satellite Systems

Conceptual satellite systems were formulated for each of the seven types of services. Spacecraft presently being developed were adapted to the 1975 to 1980 time frame requirements to provide baseline systems. The system concepts and costs are defined. Spacecraft for each of the seven types of system weigh approximately 450 kilogram, are Delta launched, and use common components.

The 1980 to 1985 spacecraft for filling the needs of the 1985 to 1995 time frame are formulated by improvement of the baseline spacecraft by means of the minimum expected technology growth. The Delta launch capability is maintained to provide continuity with presently designed spacecraft. The service costs due to the conceptual systems are consistent with the historical and forecasted future trends of spacecraft system cost reductions. Cost savings due to technology improvements of the conceptual spacecraft are converted to savings for Space Shuttle/Tug launched spacecraft on the basis of reduced transportation costs.

Sensitivity Analysis Methodology

The sensitivity analysis determined the potential cost savings due to improvement of spacecraft and earth station technology parameters of each of eight types of systems. Savings are primarily due to discrete 20 percent reductions of cost and weight of each subsystem. Such reductions are feasible. This mode of sensitivity analysis is used because the developing technologies can fill the future needs for communications satellites. Cost and weight reductions improve spacecraft cost effectiveness.

Weight savings are converted to cost savings based on a cost of $22,000 per kilogram placed in orbit by means of the Delta booster. Cost savings for a shuttle launched spacecraft are based on a $6500 per kilogram transportation cost.

If the conceptual spacecraft design were converted to a Space Shuttle launched design, a 20 to 30 percent savings of basic spacecraft costs should result due to relaxed constraints and reduced cost for weight saving. Spacecraft weight would probably increase approximately 50 percent to allow reduced development and manufacturing costs. The net result would be that each subsystem would become 50 percent heavier, and 20 to 30 percent less expensive. Use of Shuttle and modified spacecraft without on-orbit refurbishment should result in average savings of about $9 million per spacecraft. Such savings do not include reduced discounting of investment for spacecraft and launch costs. The attainable savings due to reducing the total spacecraft weight and cost 20 percent due to technology improvement are about $5 million per Delta launched spacecraft. Space Shuttle therefore has a greater impact on costs than the conservatively estimated attainable technology improvements for reducing cost and weight.

The key technologies and priorities are similar for the Delta and Shuttle launched spacecraft. The sensitivity analysis results for the Delta launched spacecraft are easily converted for Shuttle launched spacecraft. Use of Space Shuttle reduces the need for technology improvements of basic spacecraft subsystems such as structures, power, and attitude control.

Special technology parameters were used for the antenna, transponders and earth stations due to the results of the functional requirements and RF link analyses. The importance of these parameters increases for Shuttle launched spacecraft. Antennas were evaluated for cost savings due to improved beam-shaping, reduced side lobes, and switched or steered multiple beams. Transponders were evaluated for increased DC to RF power conversion efficiency as well as weight and cost savings. Earth terminals were evaluated for switched or steered multiple beam antenna improvements and improved data compression technology.

Study Results

The sensitivity analysis shows that antenna technology improvements for spacecraft and earth stations can generally provide greater savings than any other technology. Earth resources data collection systems and RF monitoring and test systems benefit the least from improved antenna technology. Mobile vehicle terminals need improved antennas for more efficient operation and reuse of the spectrum at L-Band frequencies. Transponder technology is the second most important technology, except for aeronautical and slow-speed earth resources in situ data collection satellites with solid state transponders. The forecasted development of 4/6 GHz solid-state transponders focuses the need for technology improvement on development of solid-state 12/14 GHz and 20 GHz transponders.

Options for Stimulation of Technology Growth

Options for development of antenna, solid-state transponders and other important technologies are defined in Section 11. The options presented were derived by spacecraft engineering specialists working on advanced concepts for the 1975-1980 era and who forecasted the technology growth and reviewed the 1985 to 1995 functional requirements.

Recommendations

Section 12 presents the recommendations for technology improvements and planning outlines for technology development. It is recommended that antenna technology and solid-state transponder technology be stimulated over the next seven to ten years. A funding of $30 million is recommended for spacecraft antenna technology improvements plus $10 million for a flight test article.

Fifteen million dollars is recommended for development of improved aircraft antennas over the next seven years for satellite communications.

A funding level of $1 to $2 million per year plus $10 million for development of transponders for flight tests is recommended when the technology is ready.

Funding of up to $1 million a year is recommended for development of improved video channel compression techniques and hardware. Up to $10 million should be funded if necessary to develop low cost earth terminal compression hardware when the technology is ready.

Recommended Funding for Sustaining Development

It is recommended that a total funding of at least $10 million per year be used to develop improved technologies and sustain expertise in the following technical areas:

- Ion propulsion
- Power subsystems and components
- Attitude stabilization and control
- Thermal control
- Integrated microelectronics
- Laser communications
- On-orbit chemical thruster propulsion
- Tracking, telemetry and control components
- Automatic control and test components and systems

Flight Testing

Flight testing and demonstration of new technology capabilities is highly desirable. The ATS-F and Canadian Technology Satellite will demonstrate the available and near term technology capabilities. Communication technology experiments are planned for some operational spacecraft and should nurture technology growth until the Space Shuttle system becomes operational in the 1980s.

Use of ion engines for operational spacecraft will reduce the propellant weight required for North-South stationkeeping and provide increased on-orbit weight capability for experiments. Reduced transportation costs due to Space Shuttle will reduce the costs for experimental spacecraft and for carrying experiments on operational spacecraft. An experimental test-bed type spacecraft should be developed for use with Space Shuttle to test technologies, techniques, and devices which are radically new, novel, or hold promise of providing a breakthrough in communications.

Value of the Development Plan

The total recommended development plan will cost approximately $170 million over the next seven to ten years. NASA is presently funding $2.6 million per year for communications satellite technology improvement. This is in addition to development and application funds for the ATS-F spacecraft development. The value of the recommended development plan is $587 million savings if 42 spacecraft are developed, launched on Space Shuttle, and operated over a seven year period between 1985 to 1995. The minimum expected payoff on the total recommended development plan is about 3.5 to 1.

Effect of Space Shuttle/Tug

The effect of Space Shuttle on the mix of 42 conceptual spacecraft for the eight types of networks considered in the final sensitivity analysis is to reduce the total discounted recurring and nonrecurring, from $1975 million to $1325 in 1972 dollars; savings are $650 million. Space Shuttle has a greater potential impact on future communications satellites than the recommended development program and attainable technology improvements. Use of the Space Shuttle reduces the need for technology improvements for reducing spacecraft weight. The value of the recommended development plan increases from $584 million to $645 million is Space Shuttle is not used.

Section 2
INTRODUCTION

The first commercial communication satellite was launched in 1963; it weighed 38 kg and could provide 240 circuits. Present Intelsat IVs weigh 730 kg and provide 6,000 voice circuits across the major oceans, forming a truly global communications network interconnecting most nations of the world. Transoceanic communications services have been improved and rates have been reduced due to improvements of communications satellites over the past decade. Ocean cable improvements have been stimulated by improved services such as transoceanic television transmission and reduced costs provided by satellites. International and domestic long distance common carrier satellites need no special stimulation of technology to insure their future development. There are, however, many other types of services of possible equal benefit to the nation and our worldwide neighbors that could benefit from satellite communication. Typical of such services are distributions of educational TV programs and biomedical support services by satellite; these are now receiving significant attention. The rapid growth of international and domestic common carrier satellite networks and the impact of new technology on the available allocated frequency spectrum affects the likelihood (and future costs) of providing special services. There is, therefore, a need to evaluate the growth and development of communication satellites over the next twenty years.

Technology development over the past ten years has been focused primarily on improving the performance and cost effectiveness of common carrier satellite networks. Such terrestrial and satellite networks are extremely important because they form the backbone of our available long distance electronic communication system. The establishment and rapid growth of such networks should not however overwhelm the philanthropic needs or limit the development of technologies required for providing more specialized services.

If specialized communications services are to develop and flourish, attention must be given to their unique technical requirements and the means for best providing services in the future. How such services are provided in the future and to what extent, is highly dependent on the cost of providing services of proper quality and convenience. The essence of this study, therefore, is to derive the technical and functional requirements for services from a suitable "needs model" (a representative set of future user needs for services), and identify technology advancements that will most benefit each identifiable group of users in obtaining the needed services.

A suitable needs model was developed by updating and refining the needs model defined in the "Information Transfer Requirements Study," NASA CR-73421, performed by Lockheed Missiles & Space Co., in March 1971, under NASA Contract. Additional data were obtained from "A Study of Trends in the Demand for Information," CR-73426, performed by the Stanford Research Institute under NASA Contract. A special study report "World Communications" by Arthur D. Little, defines markets, technologies, and forecasts future trends of the common carrier terrestrial and satellite networks. Considerable work was performed in refining the needs model and forecasting the demands and technology growth impacting future dedicated networks for providing special services. Defining the future demands for services and technology capabilities of the 1980s is one of the most critical elements in determining key technologies for providing special services between 1985 to 1995. The needs model is based on 322 separate needs for long distance communications. The 322 needs were formed into 32 different types of generic services. These were formed into seven functional categories of basic services. Conceptual communications networks were formed for each major category of service and the cost savings due to technology improvements were determined for each category of service. Cost savings are based on significant improvements of important technologies beyond the level of forecasted technology capabilities for the 1980s. Future technology capabilities are forecasted on the basis of historic trends and attainable levels of technical improvement over the present technical capabilities.

Conceptual 1980 to 1985 era spacecraft and networks were formulated for each major category of service. Conceptual systems were based upon improvements over the 1975 to 1980 era systems which are now being planned and developed. Extensive use was made during the study of the technologies developed and documented for the Intelsat V satellite study program directed by Mr. J. J. Knopow, Manager of Lockheed's International Communications Satellite Programs. Additional baseline data were obtained from the original filings before the FCC for domestic satellite networks and technical descriptions of ATS-F.

Optimized conceptual domestic satellite designs developed for the 1975 to 1980 era are consistent with filings presented to the FCC for domestic satellite network franchises; NASA reports on the ATS-F satellite; reports on Aeronautical and Tracking and Data Relay Satellites; and results of extensive domestic satellite optimization studies performed under the technical direction of Mr. D. A. Krejci and Mr. W. A. Koenig, of the Lockheed's Domestic Communications Satellite Programs. Definition of Space Shuttle/Tug systems and operating requirements for the 1985 era were obtained from the "Payload Effects Follow-on Study," NASW-2312, performed for NASA under the direction of Dr. R. M. Gray, Manager of Lockheed's payload integration group.

The study methodology used is similar to the methodologies defined for communication system planning by Arthur D. Hall of Bell Telephone Laboratories in "A Methodology for Systems Engineering," D. Van Norstrand Company, 1965. Analysis of competing conceptual systems is a basic tool of systems and cost analysis which is widely used to determine the best concepts and technologies for meeting needs.

Section 3

OBJECTIVES AND GUIDELINES

The objectives and guidelines for the study effort are to:

1. Develop a needs model for the 1985 – 1995 era of all viable needs for long distance communications.
2. Identify the key space technologies for fulfilling the needs of the 1985 – 1995 era, and relate technology requirements to specific needs for services.
3. Prioritize key technologies in terms of needs for service. This was determined by quantifying cost savings due to specific technology improvements for one dedicated network for each category of service.
4. Outline technology development plans for providing the improved technologies at the time of need to satisfy requirements for new or improved service.
5. Develop a clear viable methodology which can be readily utilized to expand or refocus the study results.
6. Emphasize important new technology developments that will particularly foster unique new uses of Infosats, rather than technologies developed specifically for common carrier satellite networks.
7. Develop tradeoff studies to determine the optimum means of fulfilling communications needs, whether by terrestrial or satellite communications. Only needs for long distance communications which can conceivably be best met by satellites are considered for determining future demands and technology requirements.

Section 4

MODEL OF FUTURE USER NEEDS 1972 – 1995

The needs model is one of the most important elements of the study because it affects the study results in two areas:

1. It determines the satellite networks that are synthesized and analyzed for fulfilling future needs.
2. The key technologies are dependent upon the functional requirements for providing the services defined in the needs model.

Both the user needs and the networks for fulfilling needs affect the final study results.

4.1 BACKGROUND CONSIDERATIONS

Network costs are highly sensitive to network concepts and configurations that result in high switching, operation, and management costs. Key technologies for networks with high switching costs are technologies that reduce switching costs. This study is directed toward long-distance satellite communications rather than switching. The relative costs for switching versus providing communication channels determine the optimum network configuration. If long-distance communication links are expensive or the number of available channels is limited, then switching is needed in order to share the available channels among many users and reduce overall systems cost. Serving many different types of users by means of a universal network tends to increase the network complexity and switching costs. Complexity increases maintenance, operations, management, and switching costs. Such costs presently dominate the total costs for long-distance telephone communications. This tendency towards a single universal switched network is counteracted by determining the needs for each of the possible and viable information transfer networks needed. The particular functional requirements of each network were determined on the basis of basic user needs. This approach generated conceptual networks that were as closely related to the basic needs of users as was practically possible and requiring a minimum of switching and hierarchial network management.

A brief review of telephone statistical data show the impact that the switching and operating costs can have upon a system and why it is important to avoid super telephone network concepts and to work with basic needs. Of the $53.7 billion total plant investment of all U. S. telephone companies at the end of 1969, $34.5 billion was required for buildings, office equipment, station apparatus, station connections, and large branch exchanges (Ref 10, pp. 18, 22, and 25). Central office equipment alone accounts for nearly one-third of the total telephone plant investment. Less than one-third of the total plant investment is for communications lines such as pole lines, cable, and radio links. Only 5 percent of the total number of telephone employees maintain all of the outside cables and lines. Some 210,487 operators and support personnel, 79,348 central office craftsmen, and 87,095 installation and exchange repair craftsmen are required to maintain and operate the central plant and switching operations. These statistics indicate that if all of the long-distance interstate lines, cables, and microwave channels were provided and operated free of charge, the nation's total telephone operating costs could be reduced by only 15 percent.

Telephone companies offer rate reductions for users with sufficient needs to warrant the leasing of lines. Leased-line systems form essentially dedicated networks which, as integral parts of the telephone system, are especially allocated for the convenience of prime customers. According to AT&T (FCC Docket No. 18128), 59 percent of the total mileage of equivalent voice grade circuits is leased by private users such as airlines, railroads, general businesses, and the Federal Government. In 1969, 43 million equivalent voice circuits were leased by business and government users at a cost of $210 million (Ref 7). The needs model lists significant needs by user group or by functions or services that could support a dedicated communications networks by the 1985-1995 era. Satellite technology advancements are needed for providing new and improved services at lower costs. Improved satellite systems are providing the competitive impetus compelling terrestrial systems to provide better services for more effectively meeting user needs for long-distance communications.

Terrestrial networks are needed to support satellite systems and provide the best balance of terrestrial and satellite capabilities for minimizing costs and conserving satellite channels. The conceptual networks formulated from the needs model are not intended to dictate the use of completely separate satellites, ground stations, and auxiliary terrestrial networks for each category of service. Dedicated networks should share satellites and ground facilities where practical and utilize dedicated channels to ensure user convenience and control of communications services and priorities.

4.2 NEEDS MODEL

The needs model consists of the three sets of matrixes of Tables 4-1 through 4-3, which list basic services required for different categories of users in three different time frames, 1972 – 75, 1975 – 85, and 1985 – 95 respectively. This study is directed toward those needs to be fulfilled during the 1985 – 95 time frame. These needs will be met by satellite systems developed and launched in the 1980 to 1985 time period. The satellite system capabilities and costs will be determined by the technology available. The needs for the 1972 – 1975 time frame listed in Table 4-1 are existing needs that are now being met. As these needs are satisfied, they will stimulate needs for newer and better services and the development of technologies required for providing better services.

Table 4-2 lists the forecasted needs for the 1975 – 1985 era that can be fulfilled with limited improvements of present-day technology. Many of the 1985 to 1995 needs could conceivably be fulfilled by exploitation of available technology. Such fulfillment would not be competitive with the forecast development of terrestrial communications presented in par. 8.1.2.

The numbers and types of communications channels required for each category of user needs are defined in Section 5, Functional and Technical Requirements. The 32 dedicated service networks listed fulfill 134 needs defined by the Information Transfer Systems Requirements Study, NASA CR-73421 (Ref 4).

Each category of user need for services listed in the needs model is sufficiently important and unique to justify a dedicated network. These dedicated networks for services such as education, air traffic control, etc., are the basic means for differentiating different types of services for different types of user needs. Each network can be synthesized to best meet each user's needs in the most convenient and economical manner on the basis of available and estimated future technology development. Conceptual satellite networks are analyzed in Sections 9 and 10 to determine the most important areas of technology for improving effectiveness and reducing costs. The number and extent of dedicated satellite networks eventually implemented will be dependent upon the network costs and the benefits provided by networks fulfilling the following types of basic users' needs:

1. Person-to-person communications over extended distances at a savings in time and effort to fulfill needs for:
   - Obtaining a sense of social well being, entertainment, and enjoyment
   - Obtaining information, direction, and instructions
   - Giving instructions, assurance, and assistance
   - Summoning aid and assistance
   - Influencing or motivating action

2. Broadcast communications over extended distances to effect savings in time, costs, and effort to reach large audiences with concise communications for purposes of:
   - Educational instruction and information
   - Entertainment
   - Influencing or motivating change or action

3. Man-to-machine communications to:
   - Store information and data for future use
   - Retrieve and display information
   - Process or modify information and data
   - Direct and control machines that produce or process products
   - Amplify human knowledge, memory, and cognitive abilities by means of machine capabilities

4. Machine-to-machine communications which are a form of man-to-machine interface and communication and are used as follows:
   - Man-operated, programmed, and controlled machines automatically and continuously operate and control other machines at remote locations.

- Machines serve as buffers to simplify accessing and using large complex machines
- Machine systems monitor, warn, and safeguard man in systems providing services such as aircraft collision avoidance, plant operation monitoring, and control of manufacturing processes

Each of the information transfer services listed in the needs model fulfills one or more of these basic needs. The needs for person-to-person and mass (group) communications are the basis for our ability to communicate with one another. Only the means of providing better services for fulfilling these needs are changing with time through technology developments and innovations. Man-to-machine communications, for example, originated with the development of graphics, which provided a means of storing ideas, memories, and knowledge for use at a later time. Present alphanumeric display terminals provide better means and service capabilities for fulfilling the basic needs for graphics. Everything presently written or printed could be entered into computer accessible memories for automated retrieval, image enhancement, electronic transmittal, and display.

Machine-to-machine communications are strongly emphasized in the needs model because of the rapid development of new technologies to form new systems that are the precursors of electronic mail, electronic publishing, electronic libraries, and file systems. Part of the services presently provided by means of written paper systems will eventually be provided by electronic "machine" systems, with the following benefits:

1. Improved ease of access and retrieval of information
2. Essentially instant and universal access to dedicated library and information systems
3. Reduced effort and costs for generating and publishing information in the form of electronic books and technical papers stored in computers versus generating, publishing, and storing paper copies
4. Reduced response time for publishing and distributing a completed manuscript
5. Reduced volume of stored materials in libraries and files located throughout the nation for physical access by users
6. Conservation of raw materials and resources

Machine-to-machine communications are as important a step forward in the development of communications services as the developments of printing and electronic communications. The needs model lists only a limited set of baseline service functions and is far short of expected breadth of machine-to-machine services that will be developed in the 1985 era. Although some services may presently appear visionary, they must be considered in order to ensure evaluation of the full range of possible technology requirements that will affect the future development of information transfer satellites.

Table 4-1

MODEL OF FUTURE USER NEEDS, 1972-1975

Dedicated Networks	User Category	Services
1. Elementary and secondary schools – state, time zone, and national coverage	Public and private school districts, handicapped at home	1. Development of instructional television, adoption of video tape recorders for making programs, use as a teacher training aid, program distribution
		2. Computer-aided instruction provided by remote computer to limited number of schools; CAI experiments performed via satellite
		3. Remote job entry computer services and time-share computer services provided by land line and some radio channels
		4. Experimental service to homes, most home service audio
		5. Experimental direct broadcast TV by ATS
2. Higher education network – time zone and national coverage	Colleges, universities, vocational schools, universities without walls, continuing education at home	1. Limited use of commercial and public broadcast services for universities without walls and home-education programs
		2. Closed circuit instructional TV, relay of video, film, and taped programs
		3. Computer-aided instruction
		4. Computer use for administrative and scientific data processing, problem solving by time-share, and remote job entry

Table 4-1 (Cont)

Dedicated Networks	User Category	Services
3. Library network – state, time zone, and national coverage	College, university, Government, research institutes, business, and public libraries	1. Interlibrary loan communications, TWX, data terminal 2. Automated bibliography search from remote data base 3. Automated index card preparation and distribution 4. Limited facsimile and microfiche transmission
4. Teleconferencing – time zone and national coverage	Professional meetings, symposiums, schools, professional and civic groups	Teleconferencing of meetings by professional and academic groups; televised symposiums
5. Biomedical network – regional and national coverage	Doctors, dentists, paramedics, nurses, students, patients	1. Instructional TV 2. Two-way voice, TV for remote diagnosis, consultation, instruction 3. Transmission of analog and digital data for remote processing and analysis 4. Alphanumeric, analog, and digital record transmittal
6. Commercial broadcast –	General public at home	National distribution of commercial audio and video programs
7. Public broadcast service – time zone and national coverage	General public at home, limited use by schools	1. National distribution of public service audio and video programs 2. Experimental direct broadcast to schools through ATS satellite

Table 4-1 (Cont)

	Dedicated Networks	User Category	Services
8.	Public telephone – national and international	Public, business, government	1. Point-to-point switched communications – voice, analog, digital, video 2. Provide leased circuits for implementation of dedicated networks for voice, analog, video, and slow-speed and high-speed digital data 3. Telephone services to ships, aircraft, trucks, automobiles
9.	Business networks – national and international	Manufacturing and service businesses	1. Dedicated business voice, teletype, slow-scan communications 2. Management information systems – digital 3. Remote job entry and computer interconnection 4. Remote statusing, process control
10.	Value transfer – national	Credit card service, banking	Automated credit service, credit checks, billing, loan approval
11.	Securities and Commodities exchange – national	Investors, traders, brokers	Automated recording, transmittal, and display of transaction data and values, bid and ask values for over-the-counter stocks
12.	Reservations and tickets – national	Airlines, hotels, theaters	Automated reservation service with leased lines – examples, Saber, Reservations World
13.	General computer networks – national	Businesses, schools, institutions, local government	1. National and regional time-share computer networks 2. Remote job-entry systems, with available programs for special purposes

Table 4-1 (Cont)

	Dedicated Networks	User Category	Services
14.	High-speed special computer network – national	NASA, universities	Use of wide bandwidth communications to provide input data for super-computers
15.	General Services Administration net – national	U.S. Government agencies	Leased communications channels for long-distance, dedicated GSA networks to carry voice, analog data, digital data, and video, e.g., NCIC net, VA network
16.	State networks – statewide and regional coverage	Administrative agencies of state and local governments	1. State law enforcement network – voice, data 2. Welfare aid and administration communications – voice, data 3. General administrative voice communications, teletype, and computer input/output data
17.	National law enforcement networks – regional and national	State, local and national law enforcement agencies	National crime information center data retrieval
18.	Emergency and disaster network – regional and national	Civil defense and disaster relief organizations	Emergency communications during national emergency or local disasters
19.	NASA space operations network – global	NASA	Tracking, telemetry, and control data relayed from ground tracking and control stations to central command and control centers
20.	Earth resources and ocean buoy data relay network – global and national	Government agencies, scientists, schools, businesses	1. Transmittal of data from monitoring stations to central data collection stations 2. Relay data from ships, ocean buoys, etc.

Table 4-1 (Cont)

	Dedicated Networks	User Category	Services
21.	Marine communications network – global and regional	Ships	1. Marine telephone communications 2. Navigation satellite services
22.	Aircraft network – global, national and regional	Aircraft	1. Air traffic control communications, aircraft telephones 2. Collision avoidance, navigation aids experiments, limited use of navigation satellites
23.	United Nations communications – global	United Nations agencies, consuls, envoys, etc.	1. Communications between UN delegates and their governments 2. Hot lines between nations
24.	Electronic mail – national and regional	Business and commerce, government, general population	Experimentation and development of means of long-distance mail transmission by automated electronic communications
25.	Ground vehicle, communications – state, local, regional	Police, fire fighters, Forestry Service, trucks, buses, trains, automobiles	1. Mobile telephone and citizens' band communications 2. Vehicle position location and monitoring 3. Telemetering of emergency patient data from ambulances
26.	Electronic newspaper – regional, national	General public at home	Transmission of news data to homes for reading from display consoles or paper-copy printout
27.	Electronic publishing – national	Publishers	1. Electronic transmittal of manuscripts and automated type setting at remote locations convenient to major markets 2. Electronic distribution of information to multiple receivers by teletype

Table 4-1 (Cont)

	Dedicated Networks	User Category	Services
28.	RF environment monitoring – global, national	Federal Communications Commision, researchers	1. Monitoring and analysis of RF environment 2. Policing of frequency uses for conformity to regulations and licensing provisions 3. Noise measurement
29.	Language translation – global	Universities, businesses, United Nations	1. Experiments for development of direct verbal and audio communication with computers 2. Development of alphanumeric language translation of manuscripts
30.	Religious programs and education – national, regional	Churches, church schools	1. Dedicated microwave and cable video education programs 2. Dedicated audio broadcast 3. Limited TV program broadcasts
31.	Home communications – national, regional	Households, using available communications	1. Home protection services 2. One-way video, video feedback experiments, tape recorders 3. Electronic newspapers, special services
32.	Area Support Network – global	Remote areas, Alaska, India, etc.	1. ATS experiments for Alaska, India, South American nations; education, medical, cultural programs 2. Amateur radio services 3. Citizens' band radio services

Table 4-2

MODEL OF FUTURE USER NEEDS, 1975-1985

Dedicated Network	User Category	Services
1. Elementary and secondary schools – national, regional, state	Elementary and secondary school districts, private schools, handicapped at home	1. Instructional television, video tape and audio distribution
		2. Computer-assisted instruction and program distribution
		3. Computer services: remote batch processing, information retrieval
		4. Interactive, time-shared, multiple-access computer services
2. Higher education net – national, regional	Colleges and universities, vocational schools, universities without walls, continuing education at home	1. Instructional, video tape and audio distribution
		2. Computer assisted instruction and program distribution
		3. Computer services – remote batch processing, information retrieval
		4. Interactive, time-shared, multiple-access computer services
3. Library network – national, regional, state	Colleges and universities, government, research, business, public libraries	1. Subject and abstract searches by computer, automated browsing
		2. Automated abstracting and indexing services
		3. Automated document retrieval and reproduction from remote data banks
		4. Electronic document distribution

Table 4-2 (Cont)

Dedicated Network	User Category	Services
4. Teleconferencing – national, regional	Professional meetings, symposiums – academic, professional societies, civic groups	1. Teleconferencing of technical, administrative, political, cultural meetings 2. Distribution of papers, presentation of graphics during discussion 3. Use of multiple video channels to allow interactive personal discussions to be conducted live by television
5. Biomedical network – national, regional	Doctors, dentists, paramedics, nurses, health-care students • Medical schools • Hospitals and clinics • Administrative and doctor's offices	1. Instructional TV for undergraduate, and continuing education 2. Telemedicine, remote diagnosis and consultation (encoded) 3. Teleconferencing for medical, health-care specialists (encoded) 4. Retrieval and updating of medical records and histories (encoded) 5. Remote analysis of medical biological data by computer and specialists 6. Administrative records processing and retrieval 7. Dedicated library service 8. Automated retrieval of products and procedure information
6. Commercial broadcast – national	General public at home	1. Distribution of programs to commercial radio and TV stations for broadcast 2. Distribution of programs to cable TV networks 3. Direct broadcast of radio and TV by satellite to isolated communities

Table 4-2 (Cont)

Dedicated Networks	User Category	Services
7. Public broadcast service – national, regional	General public at home	1. Distribution of educational and public-service programs to public-service radio and TV stations and cable networks 2. Direct broadcast of radio and TV programs by satellite to community cable systems
8. Public telephone – global, national	Public, business, and government	1. Point-to-point switched communication of telephone (voice), picture phone, video, analog and digital data 2. Provide leased circuits for implementation of dedicated networks carrying voice, analog, video, slow-speed and high-speed digital data 3. Telephone service to aircraft, ships, automobiles, trucks
9. Business networks – global, national	Manufacturing and service businesses	1. Digital computerized management information systems, business control net 2. Process and operations control by remote computer (digital limited analog) 3. Automated inventory control and statusing of operations and services 4. International-management-information-systems development

Table 4-2 (Cont)

	Dedicated Networks	User Category	Services
10.	Value transfer net – national, regional	Banking, credit, financial transactions for public and business	1. Computerized credit check and automated financial transactions for purchases by credit or identification card – international in scope 2. Automated bank transactions, loans, monetary transfer 3. Automated analysis of nation's economy and output
11.	Securities and Commodities Exchange – national	Investors, traders brokers	1. Computerized securities quotation and market data 2. Computerized handling of transactions, securities transfer, and accounting
12.	Reservations and tickets – global, national	Airlines, hotels, theatres, etc.	Computerized handling of reservations and confirmation of space – international in scope, automated billing and value transfer integrated with reservation services
13.	General computer networks – global, national	Businesses, schools, institutions	1. Nationwide time-share networks 2. Nationwide remote job entry network for special programs 3. Limited use of global computer facility networks
14.	High-speed, special computer network – national	NASA, universities research institutes	Super computer network to perform such special tasks as image enhancement, analysis on a nearly real-time basis of weather conditions, weather and ecology systems simulation

Table 4-2 (Cont)

	Dedicated Networks	User Category	Services
15.	General Services Administration net – national	U.S. Government agencies	1. Veterans Administration data network 2. Internal Revenue and other agency nets provided by GSA 3. Computerized services and data retrieval
16.	State administrative networks – state	Administrative units of large states such as Alaska, Texas, California, Nevada, etc.	1. State law enforcement network 2. Welfare aid and administration 3. Highway and works, water, and health department nets 4. General administrative communications, computer input/output data
17.	National law enforcement net – national and regional	State, local and national law enforcement agencies	1. Computerized crime information network – (encoded) 2. Video communications between law enforcement agencies (encoded)
18.	Emergency and disaster communications net – national and regional	Civil defense and disaster relief organizations	1. Emergency communications networks – mobile user communications 2. Disaster warning to all villages, all households
19.	NASA space operations network – global	NASA	1. Tracking data and spacecraft position determination, relay of command and control signals for orbital space operations 2. Relay of tracking, telemetry, and command signals for space probes

Table 4-2 (Cont)

	Dedicated Network	User Category	Services
20.	Earth resources and ocean buoy data relay net – global	NASA, Government agencies, schools, researchers, industry	Relay of data from earth-monitoring stations, balloons, animals, ocean buoys to central data collection stations
21.	Marine communications network – global, regional	Ships – cargo, passenger, fishing, pleasure	1. Marine communications, television, computer data, voice 2. Ship position and status monitoring 3. Emergency communications for rescue and aid 4. Weather and fishing reports, warnings 5. Status and location of goods enroute
22.	Aircraft network – global, national, regional	Aircraft	1. Aircraft traffic-control communications, passenger telephones 2. Aircraft position and status monitoring 3. Emergency communications, location and rescue aid
23.	United Nations network – global	United Nations consuls and agencies	1. Diplomatic messages between UN and member nations 2. Emergency hotlines 3. Technical aid and support to developing nations 4. Automated language translation experiments
24.	Electronic mail – national, regional	Government agencies, business and commerce	Automated scanning and electronic transmission of long-distance mail to remote post office for automated reproduction and sealing

Table 4-2 (Cont)

	Dedicated Network	User Category	Services
25.	Ground vehicle communications network – regional	Police, fire control, Forestry Service, trucks, buses, trains	1. Emergency request for aid and rescue 2. Communications – voice and digital for law enforcement, fire fighting, government agencies, logistics monitoring 3. Traffic monitoring and control, telephone communications
26.	Electronic newspaper – national, regional	General public at home	Newspaper sections of interest produced at home on request – disply by video tube, paper readout, or plastic readout mats
27.	Electronic publishing – national	Publishing firms, Government agencies, business firms	Electronic transmittal of text and graphics to regional offices for automated printing for regional distribution
28.	RF environment monitoring – global, national	Federal Communications Commission, researchers, communications users	Monitoring and evaluation of RF environment, channel discipline, and protection of assigned frequencies
29.	Language translation – global	UN officials, tourists, travelers, business and professional	Computerized language translation and communications service – conversion of alphanumeric text of standard words, terms, and phrases from one language to several other languages
30.	Religious programs and education – national, regional	Private schools religious and ethnic groups, churches, church schools, home	Private audio and video network for religious education, training, and services

Table 4-2 (Cont)

	Dedicated Network	User Category	Services
31.	Home communications – national, regional	Households, using available services	1. Home protection 2. Library services 3. Education services 4. Home management and planning computer 5. Shopping 6. Political activities 7. Business operations at home
32.	Area support network – global	Third World, developing areas	Provide extensive narrowband communications and limited video to low-cost, self-contained ground stations located in remote areas – simplicity and reliability of user equipment are key requirements.

Table 4-3

MODEL OF FUTURE USER NEEDS, 1985-1995

	Dedicated Network	User Category	Services
1.	Elementary and secondary schools – national, regional, state	Elementary and secondary school districts, private schools, handicapped at home, home study programs	1. All services from 1975-1985 era improved in quantity and quality 2. Expanded services to homes and remote areas – comparable to the best-quality experimental programs of the 1970s 3. Extensive voice, digital, and video services for Third World and highly industrialized nations – global education communication services
2.	Higher education network – national, regional	Colleges, universities, vocational schools, universities without walls, home study programs	1. Improved quantity and quality of 1975-1985 era services 2. Extensive video, audio, and computer-aided instructional programs for home and office study by professionals in remote and rural areas
3.	Library network – national, regional	Libraries, colleges and universities, businesses, government, research institutes, home study and reference, travel library	1. Subject and abstract searches, automated abstracting and indexing services 2. Electronic browsing 3. Automated location and retrieval of books, papers, reports 4. Remote reproduction of library reference data 5. Inter-library communications 6. Communications with library from home, office, aircraft, trains, ship, etc.

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
4.	Teleconferencing and electronic travel network – global, national, regional	Electronic meetings and travel for professional, civic, political, business, fraternal, ethnic groups	1. Electronic meeting and travel viewing in which several persons or scenes can be seen in 3-D color simultaneously by large audiences; each viewing terminal has facilities for selection and enlargement of a scene of special interest
			2. Computer support and printout of notes and papers, answering of queries
5.	Biomedical network – national, regional	Medical, dental health care specialists	1. Improved quantity and quality of 1975-1985 era services
			2. Emergency telemetering of biomedical data from aircraft, ships, trains, ambulances
			3. Continuing home education for health-care specialists in remote rural areas
			4. Extension of 1975-1985 era domestic services to Third World
6.	Commercial broadcast – time zone and national coverage	General public, commercial advertising	1. All audio and video services delivered by cable to homes in urban areas, voting feedback, electronic ordering
			2. Semi-direct broadcast by satellite to small, remote rural communities for community cable TV

Table 4-3 (Cont)

	Dedicated Network	User Category		Services
7.	Public broadcast – regional and national coverage	General public at home	1.	Semi-direct broadcast to urban and suburban areas with community antennas and apartment and home antennas where cable systems do not carry public broadcast channels
			2.	Direct-to-home broadcast by satellite to remote rural areas
			3.	Broadcast by satellite to aircraft, ships, trains, buses of music, news, entertainment – audio and video
			4.	Audio broadcast service to automobiles and trucks
8.	Public telephone – global and national coverage	Point-to-point public, business, government	1.	Point-to-point switched distribution of telephone picture-phone, video, slow-speed and high-speed data; extensive use of picture-phone and slow-scan video for personal communications
			2.	Increased use of leased circuits for forming dedicated net for government and business services – for voice, teleconferencing by video, and slow scan; development of extensive terrestrial data networks by AT&T, GTE, MCI, Datran, etc.
			3.	Extensive voice and data service to moving vehicles, aircraft, ships, boats, buses, trains, trucks, automobiles
			4.	Development of direct satellite telephone communications for remote wilderness areas and emergency telephones with self-contained power supplies for communications

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
9.	Business networks – national, and international	Manufacturing, service business, plants, warehouses, stores, restaurants, offices	1. Extensive reduction of business clerical and management paperwork through use of computers, extensive use of local data files, use of communications and display consoles to greatly reduce the need for paper reference materials and local paper files 2. Essentially real-time management-information recording, monitoring and reporting of critical variances 3. Extensive international management information and control networks operated by large international corporations 4. Extension and refinement of business control and management information systems of the 1975-1985 era; development of totally integrated computer-monitored-and-controlled operations from raw material through final delivery 5. Product performance, maintenance, and reliability monitoring
10.	Value transfer network – national, and international	Banking and credit transactions for public, business, banking	1. Development of a cashless and checkless society; monetary transactions predominantly made by computer systems, with projections of future assets or indebtedness due to fixed expenses and general living expenses 2. Extension and refinement of services developed in the 1975 to 1985 era, automated value transfer providing real-time inputs for management information and control

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
11.	Securities and Commodities Exchange – national, and international	Investors, traders, brokers, businesses, purchasers of raw materials	1. Extension and refinement of services developed in the 1975-1985 era 2. Transactions automated and handled as part of the automated value-transfer system 3. International service capabilities with Government-controlled limitations on trading and market manipulation 4. Electronic communication of prospectuses, stockholder reports, and, investment reference data to brokers' offices and investors' homes
12.	Reservations and tickets – national, and international	Airlines, hotels, resorts, theaters, restaurants, etc.	1. Automated search for and confirmation of reservations, electronic ticketing by means of credit card; payment by means of value transfer systems 2. Full reservation availability review from home consoles
13.	General computer utilities – national, international	Home, schools, small businesses	1. Extensive regional and national time-share computer networks with standard programs available for home management, investment, insurance analysis, scientific problem solving, business management, operational control, etc. 2. Interactive systems with small local computers interacting with large central computers and data storage units on a time-shared basis as needed for problem solving and information retrieval 3. International remote-job-entry systems for aiding the Third World nations

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
14.	High-speed, special computer net – national, international	NASA, Government agencies, universities, research institutes, large corporations	Time-shared and remote job entry of problems for very high-speed super-computers, expansion and refinement of 1975-1985 era capabilities
15.	General Services Administration network – national	Federal Government agencies	1. Management information and control network interconnecting computers and consoles to provide the same degree of information availability and operations control as developed for item 9 (business networks) for all governmental agencies to reduce paper storage and work requirements 2. Assurance of privacy and data control by each using agency 3. Dedicated telephone and alphanumeric communications
16.	State administrative networks – state and regional	State governmental agencies	Same type and degree of services as provided for federal agencies provided at the state level and under control of each state
17.	National law enforcement networks – regional, national	National, state, and local law enforcement agencies	1. Computer crime information network – encoded data 2. Transmittal of fingerprints, photographs 3. Closed-circuit voice and video network, alphanumeric messages

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
18.	Emergency and disaster network – regional	Civil defense and disaster relief agencies, general population	1. Emergency communications for police, fire, medical units – nationwide network interconnecting to local units 2. Emergency warning to all households by cable
19.	NASA space operations network – global	NASA, scientific community, weather and earth scientists, etc.	1. Relay of tracking, telemetry, and command data between earth operations centers, and orbital and space exploration spacecraft 2. Data buffering, error checking, and correction by data relay satellite 3. Deep-space experiment data gathering, monitoring, and control
20.	Earth resources and ocean data – global, national	NASA, scientific community, U.S. Government agencies, foreign government agencies, state agencies, industry	Relay of data by satellite from remote earth-monitoring stations, ocean buoys, ships, aircraft, balloons, migratory animals

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
21.	Marine communications network	Ships – cargo, passenger fishing, pleasure	1. Marine communications for transoceanic ships; television programs, computer support, navigation and position, collision warning, and traffic control 2. Ship position, performance, maintenance, monitoring, business operations and control communications 3. Weather forecasts, emergency and rescue communications 4. Fishing reports and conditions 5. Telephone service – worldwide ship-to-shore, ship-to-ship
22.	Aircraft network – global, national, regional	Aircraft	1. Continuous monitoring of aircraft position and performance 2. Computer-assisted air traffic control and collision avoidance 3. Emergency location, communication, and rescue aid
23.	United Nations network – global	United Nations member nations, consuls, agencies	Expansion and refinement of services developed during 1975 to 1985 era. Telecommunications (hotlines) and video teleconference meetings between diplomats and heads of states throughout the world

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
24.	Electronic Mail – national	Government agencies, businesses, general population	1. Direct alphanumeric "mail" distribution between home consoles 2. Electronic distribution of business mail directly between consoles without the use of paper records 3. Pre-recorded audio and video mail distributed directly between multiple-user console
25.	Ground vehicle communications network – state, local, regional	Police, fire units, Forest Service, buses, trucks, trains, automobiles	1. Low-cost, light-weight systems for emergency communications 2. Extensive digital and voice communications and position fixing for law enforcement, fire fighting, forest, fish and service agencies, Government agency and business service vehicles, trains, buses, trucks, etc. 3. Relaying of ground-traffic monitoring and control signals 4. Statusing location of goods in transit

Table 4-3 (Cont)

	Dedicated Network	User Category		Services
26.	Electronic newspaper – regional, national	General public at home or traveling	1.	Personalized newspaper transmittal to home on request, readout on consoles, flexible plastic readout devices, or paper printout
			2.	Newspapers transmitted to aircraft, buses, trains, ships
			3.	Computerized electronic classified advertisements displayed upon request – queried or answered by use of an alphanumeric console; video display to show goods, services, etc.
27.	Electronic publishing – national, global	Publishing firms, Government agencies, business firms, libraries	1.	Electronic transmittal of text and graphics directly to users for automatic recording, updating of library or file subject index, inclusion of abstract, subject search, key word inputs; automated signaling of status of new publications and data
			2.	Publications transmitted to aircraft, ships, buses, trains, resorts, automated vehicles
			3.	Electronic publishing by use of electronic storage and memories without the use of paper
28.	RF environment – global, national	Federal Communications Commission, researchers, communications users	1.	Monitor and measure RF environment, communications channel discipline, protect RF channels from infringement
			2.	Conduct RF communications experiments

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
29.	Language translation and communication augmentation – global	Tourists, international businessmen, professional people	1. Use of man-computer/man-communications links for automated language translation and aid for improving personal communications by detecting ambiguities and communications mismatches 2. Use of computers to enhance communications by means of charts and diagrams as presently used to aid the communication of ideas and concepts during formal presentations 3. Computer generated graphic displays and format modification to improve effectiveness of communications
30.	Religious programs and education – national, regional	Churches, church schools, ethnic groups, home use	Numerous private networks for carrying audio and video programs to religious and limited audiences with special interests

Table 4-3 (Cont)

	Dedicated Network	User Category	Services
31.	Home communications – national, regional	Household use of available services	1. Home protection, health status monitoring – particularly for the elderly, handicapped, or those recuperating at home 2. Home library, education, news, information, and entertainment services 3. Electronic newspaper, publishing, and mail services 4. Electronic travel, teleconferencing, and meetings at home 5. Electronic shopping and purchasing from home 6. Participation in political activities 7. Conduct of business operations and service from the home or from a business office close to home
32.	Area support – global	Isolated, remote Third World areas, Alaska, etc.	1. Provide extensive audio, narrowband and wideband data, and video communications between 500-2000 ground stations throughout an area. Low-cost stations to receive wideband signals, transmit narrowband signals 2. Provide the same level of services as were available throughout the U.S. during the 1975-1985 era.

Section 5

FUNCTIONAL AND TECHNICAL REQUIREMENTS

5.1 INTRODUCTION AND SUMMARY

The important functional and technical requirements for communications in the 1985-1995 era are defined for each service of the needs model. Several services are especially important because of the large number of potential users, the potential economic and social benefits, and the special functional and technological requirements. Such services are education support communications, teleconferencing, telephone services, computer and data communications, aircraft and maritime communications, earth resources data collection, and communications for space operations and exploration. The importance of each service of the needs model has been tested and determined during previous studies (Refs. 4 and 9). Important services are defined in considerably greater detail than other services with similar requirements but generally lesser benefits or less accepted and generally less understood benefits. Global communications and communication services for developing nations, for example, may very likely be the most important undertaking of satellite communications or space technology. The integrated long-term benefits may greatly exceed the benefit of providing U.S. domestic educational television by satellite, for example. But in the interest of briefness and to avoid repetitious statement of established functional requirements, many service requirements are therefore defined in only a brief, cursory manner.

For example, video program distribution and computer support services for the nation's elementary and secondary schools (see par. 5.2.1) are of special importance because of the potential long-term social and economic impact of a network serving some 22,000 school districts in 50 states with approximately 50 million attending students. Similarly, the biomedical and teleconferencing networks could improve health services for the nation by improving the quality of medical and professional training. The cost effectiveness of such networks is dependent upon communications technology.

The public telephone service (par. 5.2.8) is of special importance because the domestic satellite systems being franchised and implemented in the 1972-1977 era as commercial common carrier systems will grow and provide better services for users of the nation's telephone system. Hopefully, the satellite communication companies will develop and market some of the services, such as teleconferencing and library network communications defined in the needs model.

The public telephone system is considered to include the following services, which are also listed as possible smaller dedicated satellite service networks:

- Commercial broadcast distribution
- Business communications
- Value transfer
- Securities and commodities exchanges
- Reservations and tickets
- General computer network
- General Services Administration network
- Electronic mail
- Electronic newspaper
- Electronic publishing

Audio and digital communications for aircraft (par. 5.2.22) and terrestrial vehicles (par. 5.2.25) are also of special importance because of the millions of potential users and the specifical technology required. Vehicle communications present special problems, because communications must be made through a vehicle antenna that is moving and randomly oriented. Vehicle antenna beam pointing presents complex problems, and there is limited space and power available in small aircraft and automobiles. Small, simple omnidirectional antenna require greater radiated power to and from the satellite than if aimed narrowbeams are used in the earth vehicle. Hence, the need for special antenna technology for small moving vehicles. The technology required is similar to the technology requirements for small, low-earth-orbit satellites using a tracking and data relay satellite. Antennas for moving terrestrial vehicles should cost less than $100 each in large quantities. Spacecraft antennas can cost thousands of dollars each for small quantities due to reliability, environment and weight constraints.

Tables 5-1 and 5-2 present tabulations of the functional requirements in matrix form for each of the 32 services of the needs model in the 1985–1995 era as described below in pars. 5.2.1 through 5.2.27. The notations of matrix columns in Table 5-1 are as used in NASA CR-114314, Final Report Information Transfer Satellite Concept Study, Volume IV, Computer Manual (Ref. 4, pp 4 through 38, and 309). Six areas of satellite beam coverage are listed: Hawaii, Alaska, Pacific Zone, Mountain Zone, Central Zone, and Eastern Zone. These columns also indicate requirements for such global areas as Pacific Ocean, Alaska, South America, Cental America, and Atlantic Ocean areas. The number of user facilities is listed for each service and area of coverage. Type I facilities are primary earth stations; Type II are smaller secondary facilities servicing the remote user, such as a rural school district, a mobile user, or a small orbiting spacecraft. Each service is not limited to six satellite beams or areas, as indicated in Table 5-1. The numbers of satellite beams used are as required to best meet the service functional and technical requirements. All user facilities may be considered to be covered by one large 3-1/2 x 7 degree satellite beam, as shown in Fig. 5-1, or by many small beams, as shown in Fig. 5-4. The matrices show the general locations, numbers and communications service requirements for each of the 32 types of users and service listed.

Figures 5-1 through 5-6 show coverage as viewed from the satellite. Coverage capabilities are shown for various size beams. Figure 5-1 shows 48-state coverage by means of one 3-1/2 x 7 degree beam. There are many possible sizes and shaped beams for optimizing coverage and ground station received power levels. The coverage patterns shown are sufficiently close to the ideal cases to reveal the important technical requirements associated with the functional requirements of a particular service. Figure 5-2 shows the time zone coverage as it would appear if four beams, each 2-1/2 x 2-1/2 degrees wide were used. The coverage would be more effective if the beam patterns were elliptical or shaped.

Figure 5-3 shows coverage patterns for 10 beams, 1-1/2 x 1-1/2 degree width. The coverage patterns show that the State of Texas, for example, could be well served by means of one 1-1/2 x 1-1/2 degree beam. Figure 5-4 shows a typical coverage pattern for 13 beams 1-1/2 x 1-1/2 degree wide for the 50 states. This figure presents the earth as viewed from the satellite.

Table 5-1

FUNCTIONAL REQUIREMENTS 1985 – 1995

Number of Facilities Per Area

	Coverage	Hawaii and Pacific Ocean I	Hawaii and Pacific Ocean II	Hawaii and Pacific Ocean III	Alaska I	Alaska II	Alaska III	Pacific Zone I	Pacific Zone II	Pacific Zone III	Mountain Zone I	Mountain Zone II	Mountain Zone III	Central Zone I	Central Zone II	Central Zone III	E. Zone and Atlantic I	E. Zone and Atlantic II	E. Zone and Atlantic III
1. Elementary and secondary schools	National, state	1	20	–	1	500	–	5	700	1400	6	1500	–	16	4000	8000	23	1500	4000
2. Higher education network	National, reg	4	–	–	4	10	–	275	–	–	100	100	–	1030	–	–	1000	–	–
3. Library network	National, reg	4	–	–	4	–	–	7	200	–	3	90	–	30	300	–	21	300	–
4. Teleconferencing	National, reg	4	–	–	4	–	–	275	–	–	100	–	–	1030	–	–	1000	–	–
5. Biomedical	National, reg	4	–	–	1	500	–	7	100	–	5	200	–	30	200	–	21	50	–
6. Commercial broadcast	National, reg	–	1	4	–	4	100	6	4	30	5	3	50	8	12	50	6	6	40
7. Public broadcast service	National, reg	–	1	5	1	2	500	1	2	100	1	8	3000	1	5	400	1	5	400
8. Public telephone	National, global	1	4	–	1	100	–	5	–	–	8	–	–	9	–	–	12	–	–
9. Business networks	National, global	1	–	–	5	–	–	10	–	–	10	–	–	25	–	–	30	–	–
10. Value transfer	National, global	1	–	–	5	–	–	10	–	–	10	–	–	25	–	–	30	–	–
11. Securities and com exchange	National, global	1	–	–	5	–	–	10	–	–	10	–	–	25	–	–	30	–	–
12. Reservations and tickets	National, global	1	–	–	3	–	–	5	–	–	8	–	–	9	–	–	12	–	–
13. General computer network	National, global	1	10	–	1	5	–	1	9	–	1	10	–	4	21	–	5	25	–
14. High-speed computer network	National, global	–	1	–	–	1	–	2	2	–	–	2	–	3	4	–	3	8	–
15. General Services Network, U.S. Gvt	National	1	–	–	5	–	–	10	–	–	10	–	–	25	–	–	30	–	–
16. State Government networks	Reg and state	1	20	–	5	500	–	13	1000	–	20	1000	–	26	1000	–	35	1000	–
17. National law enforcement net	National	1	20	–	5	500	–	13	2000	–	20	2000	–	26	2000	–	35	2000	–
18. Emergency and disaster network	National	1	20	–	5	500	–	13	2000	–	20	2000	–	26	2000	–	35	2000	–
19. NASA Space Operations	Global	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	3	–	–
20. Earth resources and ocean buoy data relay	Global	–	10K	–	–	10K	–	–	10K	–	–	10K	–	–	10K	–	1	10K	–
21. Marine comm network		2	5K	–	4	5K	–	5	20K	–	–	–	–	–	–	–	5	20K	–
22. Aircraft comm network	National, global	2	1K	–	4	1K	–	6	10K	–	7	10K	–	20	10K	–	22	10K	–
23. United Nations network	Global	–	–	–	–	–	–	–	50	–	–	20	–	–	20	–	1	–	–
24. Electronic mail	National	1	–	–	5	–	–	10	–	–	10	–	–	25	–	–	30	–	–
25. Ground vehicle communications	National	4	10K	–	5	100K	–	20	1M	–	20	1M	–	20	1M	–	20	1M	–
26. Electronic newspaper	National	1	–	5	1	–	500	2	–	100	4	–	3000	2	–	400	2	–	400
27. Electronic publishing	National	1	–	5	1	–	500	2	–	100	4	–	3000	2	–	400	2	–	400
28. RF environment monitoring	National, global	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	1	–	–
29. Language translation	Global	5	100	–	5	100	–	5	100	–	5	100	–	5	100	–	5	100	–
30. Religious programs	National, reg	–	1	5	5	10	500	5	5	100	5	10	3000	5	10	400	5	10	400
31. Home comm	Regional	1	10	–	5	1K	–	5	100K	–	5	200K	–	5	100K	–	5	100K	–
32. Area support network	Regional, global	5	1K	5K	5	1K	5K	10	1K	5K	10	1K	5K	10	5K	10K	10	5K	10K

Facility Communication Requirements – Type I

	Video NC Trans	Video NC RCV	Video S/N	Audio NC TR	Audio NC RCV	Audio S/N	Digital NC TR	Digital NC RCV	Digital Bit Rate	Digital S/N Ratio
1. Elementary and secondary schools	4	4	50	10	1200	50 15K	60	2	300K	60 dB
2. Higher education network	3	20	50	30	30	50 15K	3	3	300K	60 dB
3. Library network	–	–	–	10	10	50	2	2	300K	50 dB
4. Teleconferencing	2	175	50	–	–	–	–	–	–	–
5. Biomedical	5	15	50	–	–	50	10	15	10K	50K
6. Commercial broadcast	10	40	60	30	30	50	–	–	–	–
7. Public broadcast service	5	10	60	70	20	50	1	1	10K	50 dB
8. Public telephone	20	20	60	10K	10K	50	40	40	6 MBS	50 dB
9. Business networks	20	20	60	5K	5K	50	5K	5K	50K	50 dB
10. Value transfer	–	–	–	–	–	–	500	500	50K	50 dB
11. Securities and com exchange	–	–	–	–	–	–	100	100	50K	50 dB
12. Reservations and tickets	–	–	–	–	–	–	200	200	50K	50 dB
13. General computer network	–	–	–	–	–	–	2K 100	2K 100	50K 10 MBS	60 dB 60 dB
14. High-speed computer network	–	–	–	–	–	–	1 20	1 20	1 GBS 100 MBS	60 dB
15. General Services Network, U.S. Gvt	4	4	50	500	500	50	500	500	60K	50 dB
16. State Government networks	5	5	50	200	200	50	200	200	20K	50 dB
17. National law enforcement net	4	4	50	10	10	50	10	10	60K	50 dB
18. Emergency and disaster network	–	–	–	10	10	50	10	10	60K	50 dB
19. NASA Space Operations	10	10	60	20	20	50	– 5	4 30	100 MBps 10 KBS	60 dB 50 dB
20. Earth resources and ocean buoy data relay	–	–	–	–	–	–	15	15	0, 2K	50
21. Marine comm network	4	4	50	100	100	40	100	100	2 KBS	40 dB
22. Aircraft comm network	–	–	–	900	900	40	100	100	20 KBS	40 dB
23. United Nations network	10	10	50	100	100	50	10	10	1 MBS	50 dB
24. Electronic mail	–	–	–	–	–	–	1K	1K	50K	50 dB
25. Ground vehicle communications	–	–	–	1K	1K	30	–	–	2K	40 dB
26. Electronic newspaper	–	–	–	–	–	–	1	1	1 MBS	40 dB
27. Electronic publishing	–	–	–	–	–	–	1	1	100K 1 MBS	50 dB
28. RF environment monitoring	–	–	–	–	–	–	–	–	–	–
29. Language translation	–	–	–	100	100	50	100	100	50 KBS	50 dB
30. Religious programs	1	1	50	–	–	–	–	–	–	–
31. Home comm	100	100	50	1K	1K	40			60 KBS	40 dB
32. Area support network	5	5	50	500	500	40	500	500	50 KBS	40 dB

Facility Communication Requirements – Type II

	Video NC TR	Video NC RCV	Video S/N	Audio NC TR	Audio NC RCV	Audio S/N	Digital NC TR	Digital NC RCV	Digital Bit Rate	Digital S/N
1. Elementary and secondary schools	–	4	50	2	–	50	–	1	300K	60 dB
2. Higher education network	–	10	50	2	30	60	–	1	300K	60 dB
3. Library network	–	–	–	1	1	40	–	–	–	–
4. Teleconferencing	–	–	–	–	–	–	–	–	–	–
5. Biomedical	1	5	50	–	–	–	1	1	10K	50
6. Commercial broadcast	2	40	60	2	30	50	–	–	–	–
7. Public broadcast service	1	10	60	2	20	50	1	1	10K	50
8. Public telephone	2	20	50	100	100	50	100	100	50K	50
9. Business networks	–	–	–	–	–	–	–	–	–	–
10. Value transfer	–	–	–	–	–	–	–	–	–	–
11. Securities and com exchange	–	–	–	–	–	–	–	–	–	–
12. Reservations and tickets	–	–	–	–	–	–	–	–	–	–
13. General computer network	–	–	–	–	–	–	100	100	60K	50 dB
14. High-speed computer network	–	–	–	–	–	–	10	10	100 MBS	60 dB
15. General Services Network, U.S. Gvt	–	–	–	–	–	–	–	–	–	–
16. State Government networks	1	4	50	10	20	50	5	5	60K	50 dB
17. National law enforcement net	1	1	50	5	5	50	2	2	10K	50 dB
18. Emergency and disaster network	–	–	–	1	1	40	1	1	2K	50 dB
19. NASA Space Operations	3	3	50	10	10	50	1	1	10 MBps 10 KBS	50 50
20. Earth resources and ocean buoy data relay	–	–	–	–	–	–	1	1	200	30
21. Marine comm network	1	4	50	2	2	40	1	1	2K	40
22. Aircraft comm network	–	–	–	1	1	40	1	1	10K	60 dB
23. United Nations network	1	4	50	1	4	50	1	1	60K	50 dB
24. Electronic mail	–	–	–	–	–	–	–	–	–	–
25. Ground vehicle communications	–	–	–	1	1	40	1	1	2K	40 dB
26. Electronic newspaper	–	–	–	–	–	–	1	1	2K	40 dB
27. Electronic publishing	–	–	–	–	–	–	1	1	2K	40 dB
28. RF environment monitoring										
29. Language translation										
30. Religious programs										
31. Home comm	1	1	50	1	1	50	1	1	60K	50
32. Area support network										

Facility Communication Requirements – Type III - Receive Only

	Video NC RCV	Video S/N	Audio NC RCV	Audio S/N	Digital NC RCV	Digital Bit Rate	Digital S/N	NOTES
1. Elementary and secondary schools	4	50	4	50	1	300K	60 dB	C/N threshold at 14 dB; facilities based on number of school districts
2. Higher education network	–	–	–	–	–	–	–	Distribution to homes by cable and public broadcast
3. Library network	–	–	–	–	–	–	–	Based on number of colleges; class I station only; data buffered and switched to proper beam for nationwide communication – in satellite
4. Teleconferencing	–	–	–	–	–	–	–	
5. Biomedical	–	–	–	–	–	–	–	
6. Commercial broadcast	40	60	30	50	–	–	–	*National coverage on one 3-1/2 x 7 deg beam
7. Public broadcast service	10	50	20	50	–	10K	50	Digital channel used for news printout, also for high quality audio
8. Public telephone	–	–	–	–	–	–	–	No Type III facilities
9. Business networks	–	–	–	–	–	–	–	No Type II facilities; all major cities equal
10. Value transfer	–	–	–	–	–	–	–	No Type II facilities
11. Securities and com exchange	–	–	–	–	–	–	–	No Type II facilities
12. Reservations and tickets	–	–	–	–	–	–	–	No Type II facilities
13. General computer network	–	–	–	–	–	–	–	
14. High-speed computer network	–	–	–	–	–	–	–	
15. General Services Network, U.S. Gvt	–	–	–	–	–	–	–	
16. State Government networks	–	–	–	–	–	–	–	100 Type I in 50 states, 55,000 Type II
17. National law enforcement net	–	–	–	–	–	–	–	
18. Emergency and disaster network	–	–	–	–	–	–	–	
19. NASA Space Operations	–	–	–	–	–	–	–	Type I stations are on earth, Type II in orbit
20. Earth resources and ocean buoy data relay	–	–	–	–	–	–	–	Type II stations are data collecting and transmitting platforms interrogated by satellite command
21. Marine comm network	–	–	–	–	–	–	–	Global communications requirement – 2,000 voice/data channels/satellite
22. Aircraft comm network	–	–	–	–	–	–	–	
23. United Nations network	–	–	–	–	–	–	–	
24. Electronic mail	–	–	–	–	–	–	–	All Type I facilities
25. Ground vehicle communications	–	–	–	–	–	–	–	
26. Electronic newspaper	–	–	–	–	–	–	–	
27. Electronic publishing	–	–	–	–	–	–	–	
28. RF environment monitoring								
29. Language translation								
30. Religious programs								
31. Home comm	–	–	–	–	–	–	–	Direct to home by satellite
32. Area support network								

*Includes South America for nondomestic service needs

FOLDOUT FRAME

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1

B

FOLDOUT FRAME

2

Table 5-2

SUMMARY OF NETWORK CHANNELS REQUIRED PER SERVICE FUNCTION

Service Network	Network Coverage	Channels Required For Total Coverage		
		Voice Slow-Speed Data	Video	No. Channels/ Data Rate
1. Elementary school	National, regional, state	2600	20	2600 / 300 KBps
2. Higher education	National, regional	160	60	1500 / 300 KBps
3. Library	National, regional	516	–	120 / 300 KBps
4. Telecon-ferencing	National, regional	–	260	–
5. Biomedical	National, regional	1500 / 50 KBps	325	–
6. Commercial broadcast	National		60	–
7. Public broadcast	National, regional	30	10	–
8. Telephone	National	280 K / 50 KBps	400	1000 / 6 MBps
9. Business	National	140 K / 50 KBps	140	Uses video / Ch/~20 MBps
10. Value transfer	National	30 K / 50 KBps	–	Uses grouped slow-speed channels
11. Securities and com exch	National	8 K / 50 KBps	–	Uses grouped slow-speed channels
12. Reservations and tickets	National	15 K / 50 KBps	–	Uses grouped slow-speed channels
13. General computer	National, international	20 K / 50 KBps	–	130 / 10 MBps
14. High-speed computer	National	–	–	5/1 GBps 100/100 MBps
15. General services	National	100 K / 50 KBps	40	Uses groups of slow-speed ch

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Table 5-2 (Cont)

Service Network	Network Coverage	Channels Required For Total Coverage		
		Voice Slow-Speed Data	Video	No. Channels / Data Rate
16. State Government	State	2000 / 2 KBps	200	3000 / 50 KBps
17. National law enforcement	State, national	1000 / 2 KBps	100	1000 / 60 KBps
18. Emergency and disaster	National	100 / 200 Bps	–	–
19. NASA space operations	Global	100	20	4 / 200 MBps
20. Earth and ocean data relay	Global	–	–	15 / 200 Bps
21. Marine communications	Global	2000 / 2.4 KBps	4	–
22. Aircraft communications	Global, national	1000 / 2.4 KBps	–	–
23. United Nations	Global,	100	20	1 MBps
24. Electronic mail	National	–	–	20 / 4 MBps
25. Ground vehicle communications	Regional	800 K	–	–
26. Electronic newpaper	National, regional	–	–	10 / 2 KBps
27. Electronic publishing	National	–	–	1000 / 2 KBps
28. RF environment monitoring	Global	–	–	1 / 1 GBps
29. Language translation	Global	1000	–	1000 / 50 KBps

Table 5-2 (Cont)

Service Network	Network Coverage	Channels Required For Total Coverage		
		Voice Slow-Speed Data	Video	No. Channels Data Rate
30. Religious programs	National	–	20	–
31. Home communications	Regional	–	1000	–
32. Area support network	Regional	10,000 / 50 K	100	10 / 1 MBps

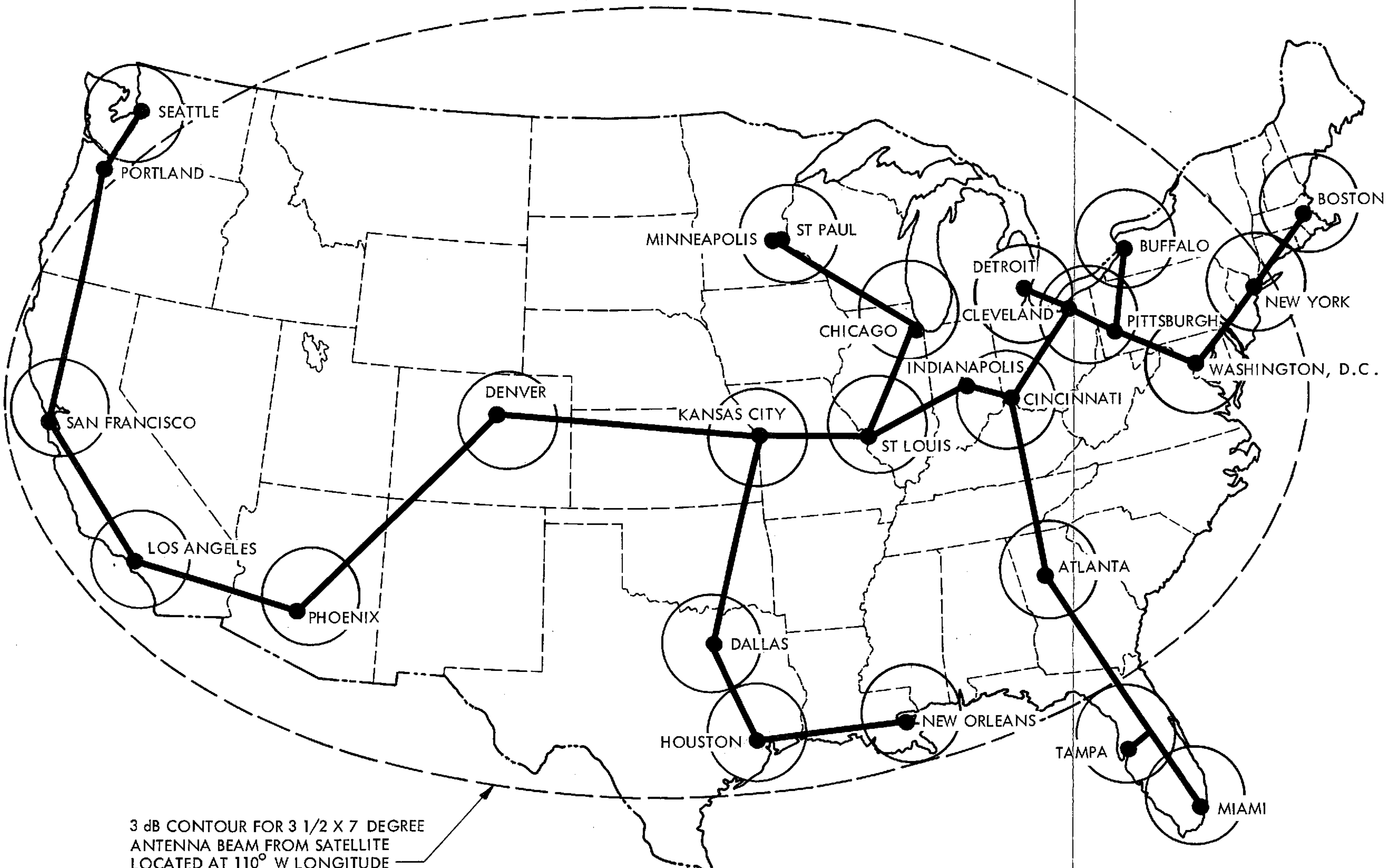

Fig. 5-1 Twenty-Two Major Urban Areas Connected by 6,850 Mile Network

A

B

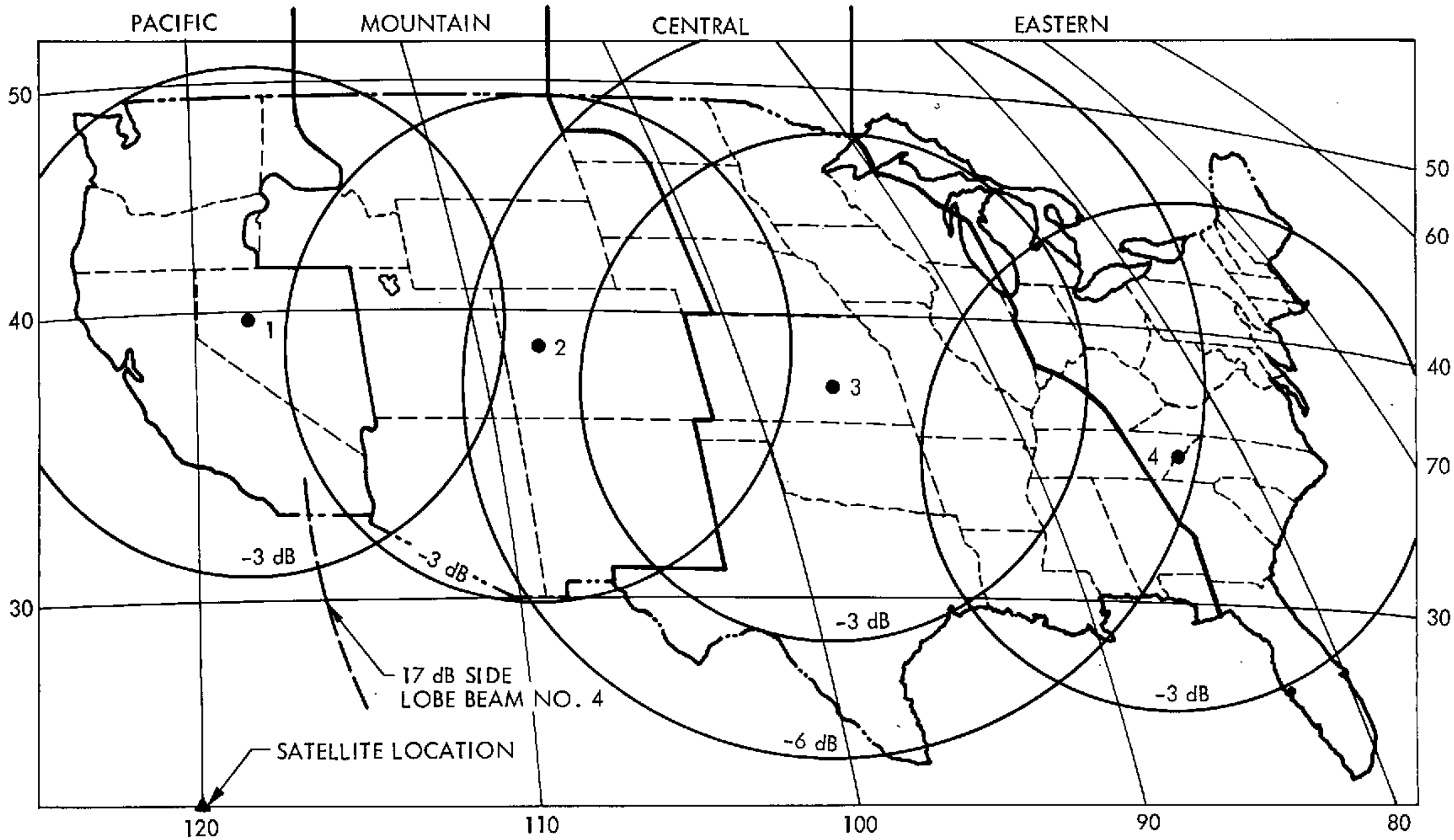

Fig. 5-2 Time Zone Coverage – Four Beams, Each 2.5 x 2.5 Degrees

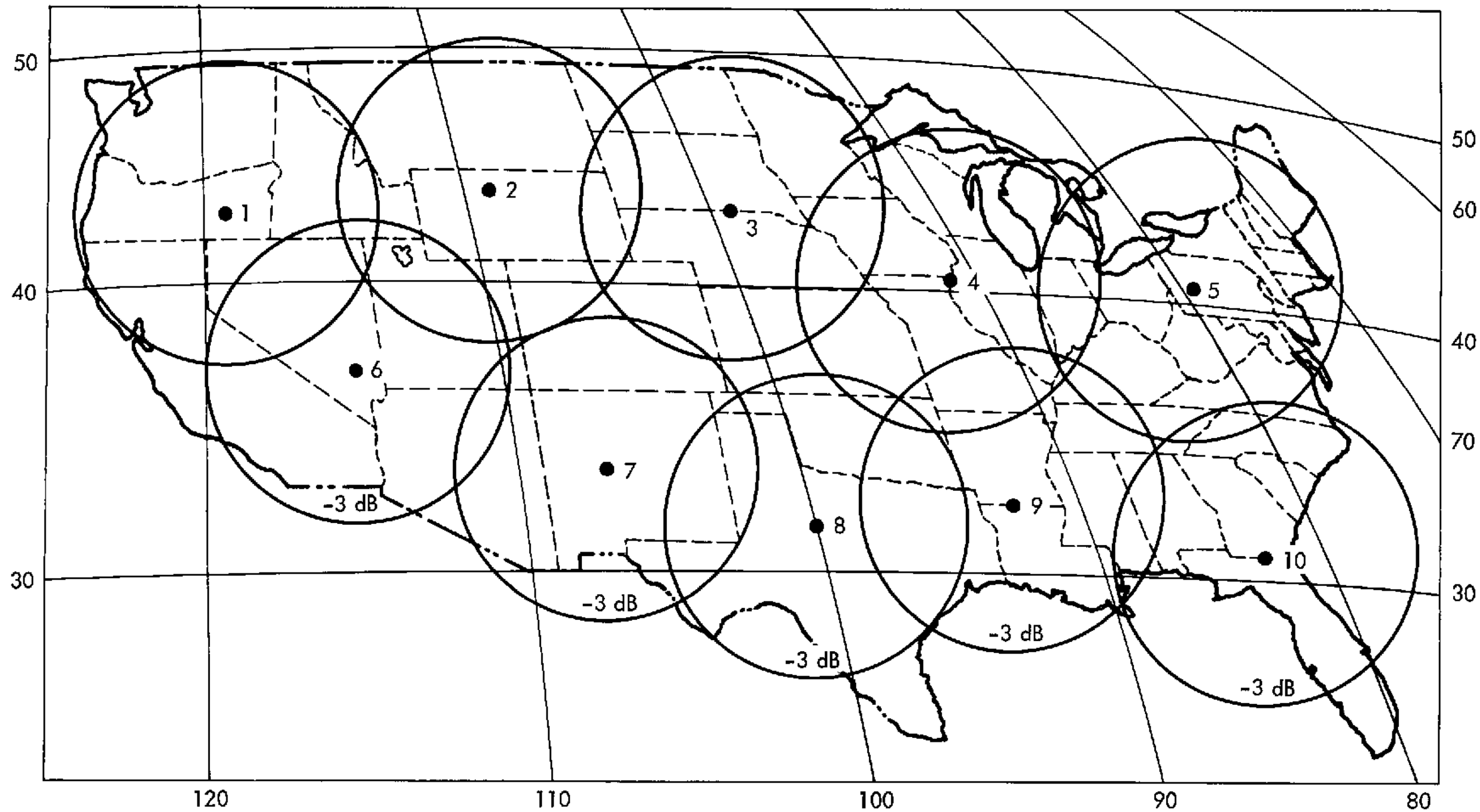

Fig. 5-3 Coverage With 10 Beams, Each 1.5 x 1.5 Degrees

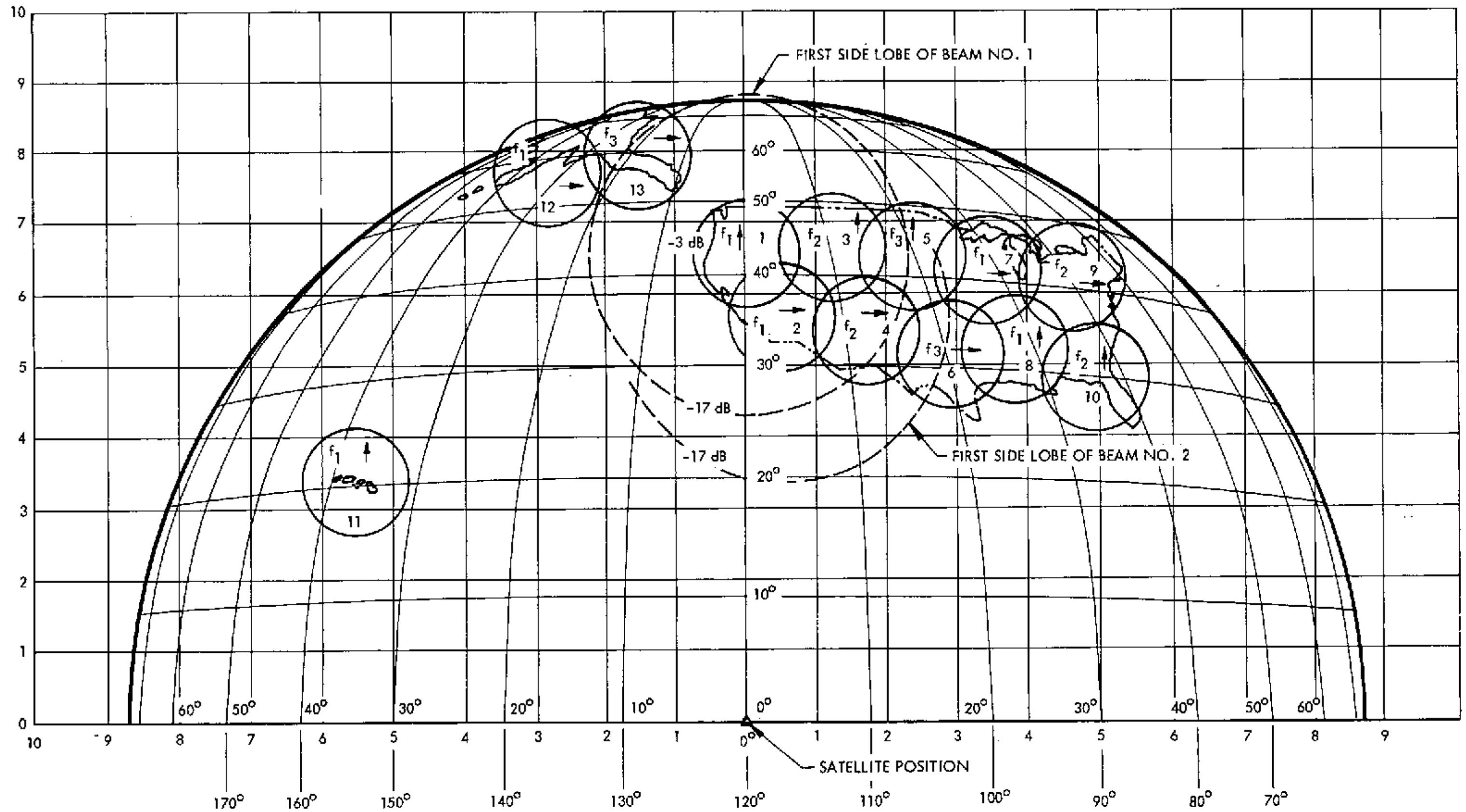

Fig. 5-4 Coverage With 13 Beams, Each 1.5 x 1.5 Degrees

Figure 5-5 shows the type of coverage attainable with 1 x 1 degree beams providing about 45 dB of satellite antenna gain. This coverage pattern can fulfill the functional requirements for statewide communications services and communications with ground vehicles.

Figure 5-6 shows the type of coverage attainable with 1/2 x 1/2 degree beams suitable for meeting functional requirements of services such as local ground vehicle communications, narrowbeam communications trunk links between major metropolitan areas, etc. Requirements for the various coverage concepts are described within the functional requirements of pars. 5.2.1 through 5.2.31, following.

(The last number of each paragraph corresponds to the reference number of the corresponding service of the needs model defined in par. 4.3.)

5.2 REQUIREMENTS, 1985 – 1995 SERVICES

5.2.1 Elementary and Secondary School

Table 5-3, Educational Communications Service Applications, lists the types of communications and computer services that are in the early stages of development and acceptance (Ref. 1, Fig. 2). These services will be used in most schools in the post-1985 era. Table 5-4, Estimates of Technology Utilization in Education, 1975 – 1985, With Estimates of Potential Satellite Utilization, (Ref. 1, pp 43b), indicates the expected increased use of communications for education and library networks from 1975 through 1985.

There are four prime needs for dedicated networks for carrying education communications as follows:

1. Elementary and secondary school networks serving public and private elementary and secondary schools, community learning centers, and adult summer-school education programs, and carrying programs to the handicapped confined to home.
2. Higher education network to provide services for formal education beyond the high school (secondary) level. The network would service colleges, universities, vocational schools, and community learning centers. Programs would be provided for graduate, undergraduate continuing education, and the university without walls.

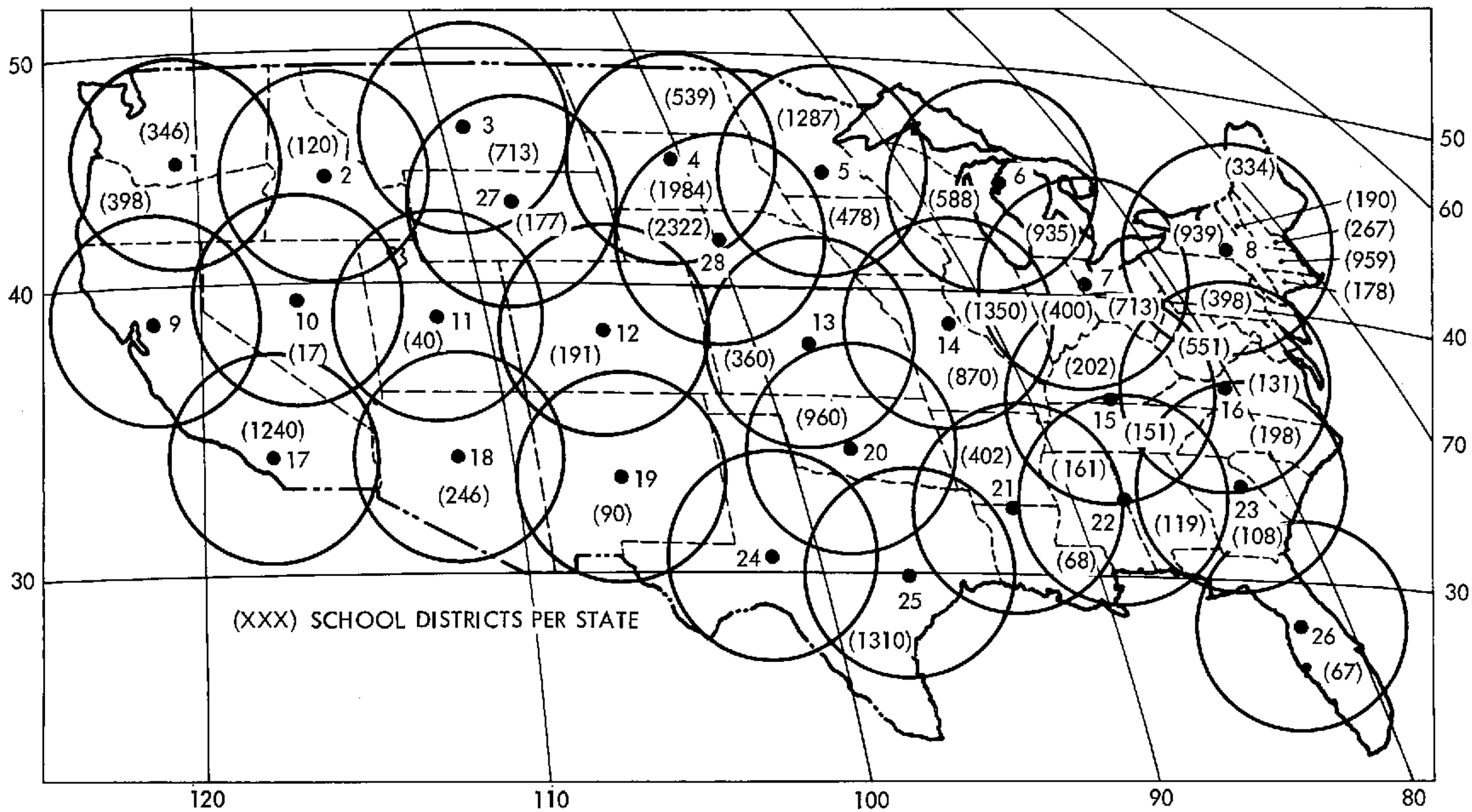

Fig. 5-5 Coverage by States – 27 Beams, Each 1 x 1 Degree

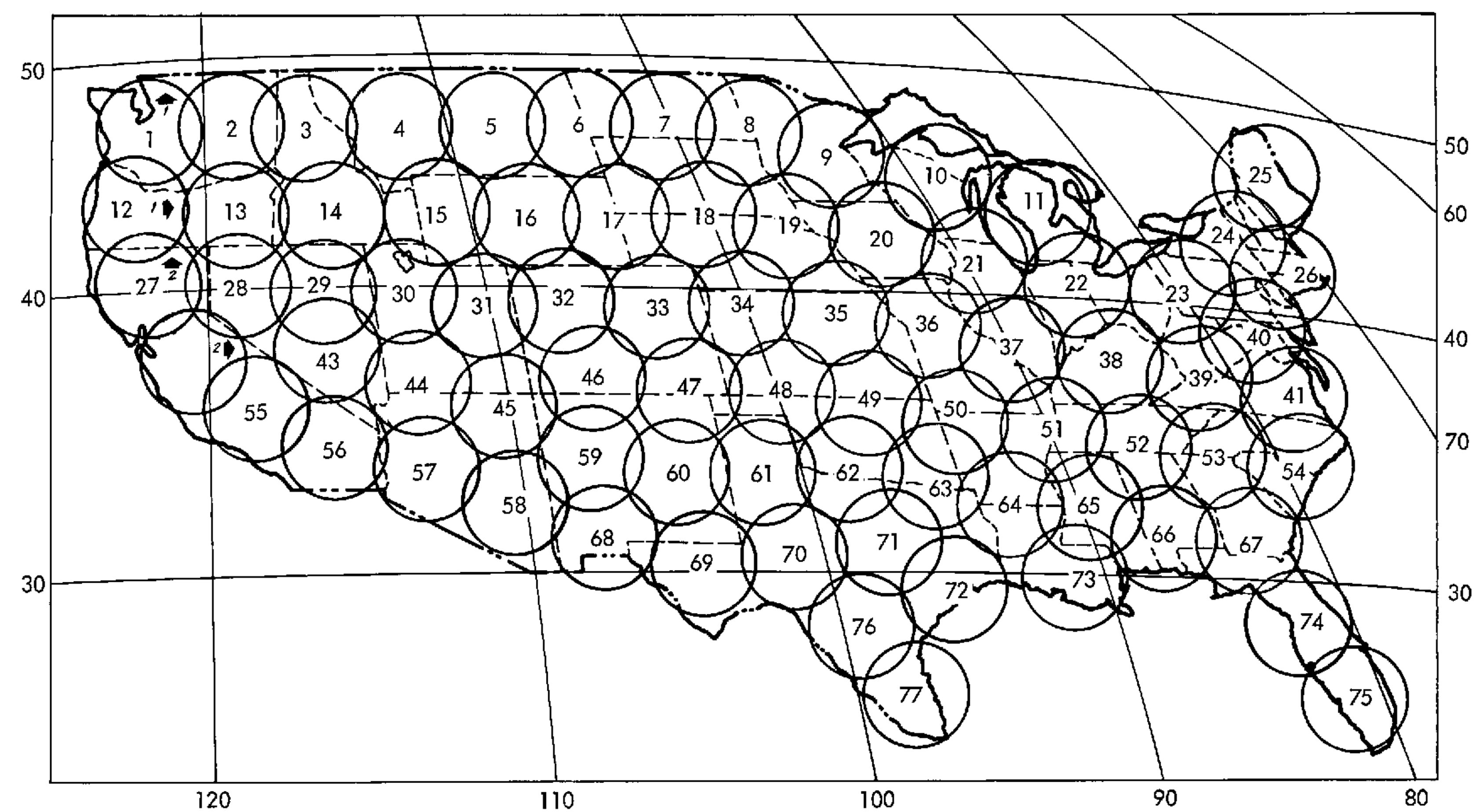

Fig. 5-6 Coverage by 77 Beams, Each 0.5 by 0.5 Degree

Table 5-3

EDUCATIONAL COMMUNICATIONS SERVICE APPLICATIONS

User Location	Public Television	Instructional Television	Computer-Assisted Instruction	Remote Batch Processing	Interactive Multi-Access Computing	Inter-Library Comm	Interactive Information Retrieval	Teleconferencing
Elementary schools		I, C	I, C	A	A, I		C	
Secondary schools		I, C	I, C	A, I	A, I		C, I	
Institutions of higher education		I, C	I	A, I, R	A, I, R	R	C, I, R	A, I, R
Vocational education		I	I					
Community learning centers	G	C, I	C, I		C, I		C, I	C, I
Homes	G	C	C				C, G	C, G

A = Administrative uses
C = Continuing education and/or formal out-of-school education
G = General information and/or educational cultural entertainment
I = In-school instruction
R = Research applications

Table 5-4

ESTIMATES OF TECHNOLOGY UTILIZATION IN EDUCATION, 1975-1985, WITH ESTIMATES OF POTENTIAL SATELLITE UTILIZATION

	Service	Percentage Utilization 1975 Elementary Education	1975 Secondary Education	1975 Higher Education	1985 Elementary Education	1985 Secondary Education	1985 Higher Education	Primary Roles For Satellites	Percent of Potential User Institutional Population Likely To Make Use of Satellite-Based Services: Elementary Education	Secondary Education	Higher Education
	Instructional television (ITV) #	3 – 6	4 – 8	5 – 10	4 – 20	4 – 25	5 – 20	Direct delivery to schools; to broadcast stations, and ITFS and cable headends for further redistribution	40 – 90	40 – 90	20 – 50
	Computer-aided instruction (CAI) #	0.1 – 2	0.3 – 2	1 – 3	1 – 10	5 – 20	5 – 20	Delivery of CAI to small, remote institutions, particularly those 70-80 miles or more away from a major metropolitan area.	15 – 30	15 – 30	5 – 10
Computing Resources	Multi-access interactive computing	4 – 10	5 – 12	15 – 30	8 – 20	15 – 50	50 – 80	Delivery of interactive computing to remote institutions for the purposes of problem solving, EIS, etc.	15 – 30	15 – 30	10 – 20
Computing Resources	Batch processing (including remote-batch)*	7 – 35	30 – 50	65 – 75	15 – 70	50 – 80	80 – 100	Delivery of raw computing power to small, isolated, and remote institutions for instruction, administrative data processing, etc.	20 – 30	20 – 30	2 – 5
Computing Resources	Computer interconnection	0+	0+	0.8 – 2	0+	5 – 10	10 – 20	Delivery of raw computing power to small, and remote institutions for instruction, administrative data processing, etc.	40-80 of regional computing networks 60-80 of campus computing facilities (higher education)		
Information Resource Sharing	Interlibrary com --TWX, facsimile*	0	0+	10 – 20	0.5 – 1	2 – 5	20 – 40	For bibliographic search, inter-library loans, etc.	5 – 10	25 – 40	40 – 70
Information Resource Sharing	Automated remote information retrieval	0	0+	0.8 – 2	0	0+ – .5	2 – 5	For remote information retrieval, automated bibliographic search from specialized centers	0	1 – 10	40 – 70
Information Resource Sharing	Teleconferencing* (long distance)	0+	0+	4 – 5	0.5 – 2	0.5 – 2	6 – 10	For access to specialists in distant areas	3 – 10	3 – 10	10 – 30

\# Percentage expressed in terms of time spent by student in classroom

* Percentage of total educational institutions having this capability

\+ Interconnection among centralized computing networks may develop during 1975+

A

B

2

3. ETV net (Educational Television) controlled by the Public Broadcast Service provides general education and information to the home. ETV is presently used by some schools to take advantage of special programs. Use of ETV by schools will decline as more television courses designed specifically for school use are provided over public school networks.

4. Library networks to aid in providing better library services to the nation's students. The network would interconnect college and university libraries to permit automated reference or subject searches and transmittal of material as permitted by copyright laws or agreements. A natural outgrowth of improved and growing library networks is the concept of electronic publishing. Manuscripts may be entered into electronic, microfilm, or tape memories and transmitted to all libraries for recording of abstract, subject reference, and automated data search reference input. The work might never appear in published form except when printed out on command at a library to fulfill a need for hardcopy or reference data. Many reports are presently published mainly in microfilm form. Microfilm copies are distributed to libraries for optical reader viewing. Paper copies are made as required.

Table 5-5, Estimated Number of Channels Required for Education for Each of Five Time Zones, gives the number of video, voice feedback, and data channels needed for three time-frames as determined from the Washington University and the Barnett and Denzan study (Ref. 1, p 69) for national and regional educational television and computer system support.

Type I stations listed in Table 5-1, Functional Requirements, 1985-1995, are the central stations for broadcasting audio and video programs and providing computer support to remote rural school districts having Type II stations. The Type II stations receive audio and video programs and provide two-way data communications for on-line computer-aided instructional programs. Student-operated user terminals request inputs for the next possible data frames by means of a voice/data channel capable of carrying 9600 Bps. Two such voice/data channels are provided for each Type II station under the designation of audio channels. The Type I station responds with the required data on the 300,000 Bps data channel shared by several Type II stations. It is estimated that there will be approximately 13 million elementary and secondary school students living in rural areas by 1985. A 20 percent utilization rate for computer-aided instruction requires provisions for servicing 2.4 million users by means of large remote computer facilities (Ref. 1, Figs. 2 and 31 and Table 13). The total of 2310 data channels operating at 300 KBps could provide approximately 700 megabits per second or 500 words per minute for 2.4 million students.

Table 5-5

ESTIMATED NUMBER OF CHANNELS NEEDED FOR EDUCATION FOR EACH OF FIVE TIME ZONES

Dedicated Networks	1970-1975 Video	1970-1975 Voice, Data Feed-Back	1970-1975 15 kHz Voice, 50 KBps Data, Slow Scan	1975-1985 Video	1975-1985 Voice Feed-Back	1975-1985 15 KHz, Voice, 50 KBps Data Slow Scan	1985-1990 Video	1985-1990 Voice, Data Feed-Back	1985-1990 15 KHz, Voice 50 KBps Data, Slow Scan
1. Elementary and secondary school net	1	400	400	3	400	400	4	500	500
2. Higher education net	1	3	10	5	15	50	10	30	300
3. Public ETV net	1	3	3	1	3	3	2	3	6
4. Library net (excluding video tape)	-	1	1	-	2	2	-	5	5
Total per time zone	3	407	414	9	420	455	16	538	811

The public school system consists of some 70,000 elementary and 27,000 secondary schools with a combined enrollment of 45 million studients (Ref 2, pp 102, 103, and 106). One-third of the student population resides in approximately 14,000 places of 2,500 population or less (Ref 2, p 22). It is estimated that approximately 5,000 earth stations could serve such rural areas. Four thousand ground terminals could cover the contiguous 48 states with a terminal approximately every 30 miles across the length and breadth of the 48 states. There are approximately 4,000 places of between 2,500 to 10,000 population that could use satellite terminals. Places with populations greater than 10,000 are estimated to have sufficient resources to obtain local computer capability to support computer-aided instruction, computer management, technical and administrative computing, and video tape libraries by 1985. There are approximately 2,000 schools or school districts in need of central computer support for computer-aided instruction and other computer support functions.

The network structure utilized affects costs, user acceptance, and total benefits of distributing educational TV, instructional TV, and computer programs to schools, community learning centers, and homes. Costs will be sufficiently high to restrict acceptance if programs are distributed to regional or metropolitan centers by satellite and then distributed locally by the present telephone system at present rates. One of the major obstacles in the present development of regional and national education service networks is the high cost of long-distance communications by telephone networks. There are inherent inadequacies in the telephone plant originally designed only for voice communications. Economic necessity generally requires each improvement to be compatible with the existing telephone system. The cost of a short-distance (200 miles) telephone channel appears to have been constant over the past decades, as shown in Fig. 7-1, while the cost of computers has been dropping at about 25 percent every year. If this trend continues, the communication costs will eventually become the dominant cost component of most teleprocessing network systems.

A recent Stanford Research Institute study concludes that telephone system communication costs are expected to show only a small decrease in the 1970s. This may appear to be surprising in view of the advances in terrestrial microwave, coaxial line, and millimeter waveguides that have taken place and have been entered into service during the 1970s. The fact is that development in long-haul systems has reduced the long-haul portion of telephone channel costs, and further reductions are expected of its contribution to the overall cost. The problem, however, is that the local telephone plants with their associated switching equipment and labor costs account for over 80 percent of the communication costs of long-distance calls. This condition therefore necessitates exploration of communication systems and techniques that allow bypassing the local subscriber plant and associated switching equipment in order to reduce total educational communications service costs. For consistent communication between fixed points, a network using several thousand low-cost terminals situated in the vicinity of the institutional or community head-ends offers interesting prospects for meeting the service needs at an acceptable cost for communications.

Most of the multipurpose satellite systems proposed in the domestic filings to the FCC do not allow maximum cost reduction, because they are used in the 4 to 6 GHz frequency bands that inhibit low-cost small terminal use. The wave length and required low effective radiated power levels dictate use of earth terminals with high sensitivity (G/T).* Satellites proposed in the domestic filings are appropriate for an environment of a relatively small number of high-capacity earth stations rather than several thousand small remote earth stations. The final choice among the options of building an educational satellite system depends on (1) the extent to which educational services can be pooled, (2) the size and distribution of the user population, and (3) the use of available local terrestrial communication facilities such as cable TV or microwave networks for the distribution of service to individual schools and homes.

It is impractical to attempt to directly interconnect each of some 88,000 elementary and secondary schools by satellite communications. Such a system would require extensive earth-station investment, or development of very low-cost earth stations capable of transmitting and receiving video. Approximately 8,000 video channels would be required in order for each school district to provide some of its own special programs to each school in its district. The practical approach to education program distribution proposed by the Washington University study progress report on Application of Satellites to Education Development, Nov 1971, is to interconnect the schools of each school district by terrestrial microwave or cable system (Ref 1, pp 67 and 72).

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*G/T = Antenna gain/receiver noise temperature

This proposed system requires 1,000 to 20,000 earth stations to reach the nation's 50 million students. The number of earth stations is dependent upon the organization and structure of terrestrial communications networks developed. Figure 5-7, Distribution of Educational TV Stations and Networks, shows the present locations of existing stations and statewide networks that could benefit from a national and regional satellite distribution service.

It is presently possible to develop earth-receiving center stations costing about $5,000 for receiving on the order of 10 video channels and transmitting 1 voice data channel of 25 GHz bandwidth. The technology goal is to reduce total systems cost and meet the user needs as to:

1. Number and quality of video and voice/data channels required
2. Number of earth stations to be serviced at various locations

Future developments of terrestrial communications technology such as the development of light pipes for distributing thousands of video channels locally at lower costs per channel will aid the use of satellites for distribution of programs to urban and suburban school districts for distribution to school classrooms.

In a study performed by Barnett and Denzau of future development of instructional television and costs of alternative earth distribution systems (Ref 3), the alternatives are developed as the following four stages of possible system development.

Stage I

Approximately 1972-1976

Purpose:	Experimentation and learning by classroom teachers
Equipment:	One mobile TV set and one mobile video tape recorder/player (VTR) per five rooms; tape library; other items

Fig. 5-7 Distribution of Educational Television Stations and Networks

Stage II

Approximately 1975 onward. Depends on successful Stage I.

In substantial degree, fullscale use of television instruction in individual schools, averaging 20 percent of classroom time. Continued development of program material and incorporation in formal classroom and individualized instruction.

Equipment: A TV receiver and VTR in each room, a large school tape library, and other items

Stage III

Approximately 1976 onward. This stage might occur without Stage II, but its entrance depends on a successful Stage I. Fullscale use of television instruction, up to 20 percent of class time as in Stage II. Programs provided by the city school district from a centralized head-end facility to all schools.

Additional equipment requirements and alternatives:

1. A four-channel broadcast system with centralized school district origination of programs, plus, at each school, an active head-end facility to record programs and provide delayed play as needed by schedule.

2. Four instructional channels on a city CATV system, with centralized school district origination of programs and active school head-ends, as immediately above.

3. A 40-channel school cable system connecting all schools and school district headquarters. The district head-end provides all programs. There will not be active school head-ends, since the numerous program repetitions accommodate diverse school schedules without recording and delayed play.

Stage IV

Approximately 1977 onward. Builds upon previous stages. A substantial degree of satellite relay of instructional broadcasts to the head-ends of city school districts or of schools. These programs supplant some or all of the cities' program origination activity of the Stage III or the school origination of Stage II.

Additional equipment:

A multichannel satellite system that relays to city head-ends. From there, the signal travels to schools and homes on a city cable network and to rooms on each school's cable network. This system substitutes for the broadcast systems of Stage III. An alternative is a multichannel satellite that relays direct to school head-ends. The signals are carried to rooms on each school's cable network.

The summary and conclusions of the Barnet-Denzau study are as follows:

1. Television instruction could be an innovation of great importance. It holds large promise in lectures, display, and demonstration; in computer assisted instruction; in home as well as school education; and in education of both adults and children. The prospects include increased individualized instruction; repetitions for slow learners, acceleration for fast learners; and offerings from the best of teachers to all students. Cost savings are also possible.

2. ITV (instructional television) in schools is now in an undeveloped state for two reasons. Technology, both hardware and software, is still immature and has been expensive. And teachers have yet to learn how to use the innovation. The first important stage in the development of ITV is for teachers to experiment with and use TV programs and to learn how to incorporate them into classrooms.

3. A breakthrough is now at hand that will both greatly reduce cost and assist teachers in learning how to use instructional TV. This breakthrough involves the perfection of inexpensive video tape recorders/players (VTR) and inexpensive tapes and cameras that allow teachers to make, view, and review

tapes and experiment with ITV over the next several years. The proposed equipment consists of 10 mobile VTRs and TV sets, a tape library, and several TV cameras per school of 50 rooms, and proportionate equipment for schools of other sizes. This would cost only about $5 per student per year, less than 1 percent of the usual school budget. It would seem a small price to pay for introducing ITV in the educational establishment and obtaining benefits over the next 5 years.

4. The subsequent use of TV in schools is considered a major instrument in instruction. We conceive of ITV employed in up to 20 percent of classtime in some school districts beginning in about 1974, and conceive that the innovation spreads rapidly to other districts. If an active head-end at each school transmits the ITV programs by cable to the classroom, the cost would be about $33 per student per year. If the city school districts transmit the programs to the classrooms, the cost would only be about half as much; this reduction is due to economics of scale in the head-end facilities and labor.

5. It appears that the most promising system for school ITV in the latter stage of implementation is a dedicated school-district cable system. This is a 40-channel cable to each school and thence to each classroom. On its multiple channels, the school district head-end transmits a schedule with numerous repetitions of each program to accommodate diverse individual classes, and also transmits programs in response to special request from teachers. In addition, this system includes a limited number of VTRs, TV booths, cameras, etc., in each school for individual teacher and student use. This aggregate of 40-channel cable services and other facilities costs perhaps $15 per student per year, about 2 percent of the average school budget. In turn, it provides TV instruction for an average of about 20 percent of class time. The innovation offers considerable opportunity for improving the quality and content of the school's instructional offerings, or for reducing cost, or both.

6. The FCC-sponsored, four-channel ITFS service or four leased channels on a commercial CATV system appears less desirable. Relative to the 40-channel cable service above, they provide less flexibility; would be slightly more costly for approximately equal service to classrooms; and, in the case of ITFS,

would be less favorable in signal quality and less attractive for potential expansion of ITV to home instruction of the handicapped.

7. Satellites distributing national programs have been proposed as a major system in ITV. One concept is to provide service from a national head-end facility by satellite to ground stations at individual schools. Another concept conceives of service to a city school-district cable system from a national head-end facility and satellites to individual city reception equipment.

8. Satellites have also been proposed for areas with small and dispersed populations, such as Alaska. With the advent of inexpensive VTRs and tapes, this attractive innovation is becoming available for such areas. The nature of the costs of a school or classroom VTR system is that they are approximately proportionate to population numbers. Thus, small populations can be served at small costs. In Alaska, for example, the individual classroom or individual school VTR system could provide ITV to its 78,000 school students for a total of about $3 million per year ($39 per student per year), including TV sets. This is one alternative to a specialized, multiple-channel Alaska satellite that would broadcast to school head-end receivers, with distribution on a school cable system to individual classroom TV sets. The $3 million is thus a rough estimate of the cost of the Alaska ITV equipment component of a satellite system.

Figure 5-5, Coverage By States – 27 Beams, Each 1 x 1 Degree, shows the total number of school districts for each time zone of the contiguous states. The Central Time Zone contains over half of the nation's school districts and is covered by 12 of the beams. Circles represent the 3dB or 1/2 power contour of each beam's coverage of geographic areas. Each beam shown is for a satellite located at 120 deg west longitude. The technical requirements provide for at least one Type I station for each state and for each beam to cover a significant part of each state. Technical requirements are based on state operation and control of statewide communications links provided by satellite. The 1-degree beamwidth allows assignment of one dedicated beam to each large Western state such as Montana, Colorado, and Utah. The 1-degree and 1-1/2-degree beamwidth coverage concepts shown are not suggested design parameters, but conceptual parameters developed to expose the technical requirements and problems that will be encountered in providing services such as statewide satellite communications systems or regional biomedical networks to meet the possible future user needs in the 1985 to 1995 timeframe.

There are wide diversities in communications requirements for each beam. Beam No. 5 covering Nevada would service 17 school districts, while Beam 28 covering the New England area would service some 2,700 school districts. The type of satellite system ultimately used and the type of beam coverage used will depend on user preference and political and social factors. The link calculations and sensitivity analysis of Section 10 are based on the different beamwidths that might be needed to provide the required coverage to effect different types of systems with different optimum technical requirements.

Figure 5-4, Coverage with 13-Beams, Each 1.5 x 1.5 Degrees, shows the earth as viewed from the satellite and the general areas of coverage of different regions of the U.S. by each beam. Reducing the number of beams reduces the number of times each frequency can be reused. Various frequencies are designated as f1, f2, and f3. Polarizations are designated by vertical and horizontal arrows. Frequency f1 is used six times by means of selective beam pointing, change of polarization, and use of frequencies f2 and f3 for adjacent beams. The complete technology does not presently exist for developing a single antenna or lens capable of providing the desired capabilities and beam patterns shown in Figs. 5-2 and 5-4. Antenna side lobes present a critical problem. In Fig. 5-4, the dashed line annotated as -17 dB, the first side lobe of Beam No. 2, is shown to pass through Beams 5, 6, 7, and 13, and therefore would degrade the carrier-to-noise ratio within the beams if the same frequencies and polarization were received as for Beam 2. The first side lobe of Beam No. 7 could also degrade the carrier-to-noise ratio within Beam No. 2 to a maximum of 14 dB. Technology is needed for providing antennas with reduced side lobes, for providing close spacing of beams from a common antenna, and for providing isolation between beams of the same frequency but different polarization. The importance of this technology is dependent on the number of channels required and the frequencies available for providing needed channels.

5.2.2 Higher Education

The functional and technical requirements for elementary and secondary schools surpass the general requirements for the higher education network, because there are far more elementary and secondary schools than colleges and universities. There are approximately 3,000 colleges and universities generally located in urban areas, and they have considerably greater financial resources than many rural elementary and secondary schools. The technology developed to meet the future needs for the elementary and secondary school networks will generally fulfill the basic education communications requirements for the higher education network. Colleges and universities have a greater need for video channels because of their greater number of course offerings and because their offerings of unique, timely, and changing programs are not highly adaptable to being recorded for reuse in subsequent courses. Institutions of higher education, including vocational schools, will have access to the following networks:

1. Higher education network
2. Library network
3. General computer network
4. Limited access by universities to special, high-speed computer networks

The higher education network is based on servicing colleges and universities in each time zone with 10 regional video channels plus 10 national video channels. Each university is capable of transmitting three video channels. All universities and colleges have Type I stations. Only Alaska and the Mountain Time Zone have remote Type II stations that receive audio, video, and data, and they only transmit voice/data channels for voice feedback and computer-aided instruction digital feedback. The higher education networks would use time zone and national coverage beams because of the wide geographic range of interest of universities. The university population is composed of professionally and intellectually oriented groups distributed throughout the nation and the world and having a need for intergroup communication. Communications between professionally oriented groups such as doctors, lawyers, scientists, etc., are needed on a state, national, and international scale to promote professional development, offer greater intellectual stimulation, and provide more-thorough dissemination of new knowledge and procedures.

5.2.3 Library

The library network is based on 68 major, Type I library earth stations serving 890 secondary earth stations. Each major library center would have 10 voice/data channels capable of carrying 9600 bits per second per channel, plus two 300 KBPS data channels. Each secondary station would have one channel. The distribution of channels in each time zone is shown in the Table 5.

Table 5-6

LIBRARY SERVICE REQUIREMENTS

	Hawaii	Alaska	Pacific	Mountain	Central	Eastern
Type I station	4	4	7	3	30	21
Type II station	-	-	200	90	300	300
Regional channel (9.6 KBPS)	20	20	100	100	100	100
National channel (300 KBPS)	20	20	20	20	20	20
National channel (9.6 KBPS)	6	6	6	6	6	6

There are fewer library earth stations than colleges or cities because several college and city libraries of various types within an area can be interconnected by means of leased telephone lines. The development of improved alphanumeric electro-optical scanners will allow transmittal of a 300-word page of text in approximately 1 second at a 9600 BPS rate over a voice telephone line. Numerous regional library networks using leased telephone circuits are presently in existence throughout the nation (Ref 8, pp 235 and 242). Electronic transmittal of microfiche, browsing, and mass distribution of text would be by means of the 300 KBPS national channels between earth stations.

The estimated average leased-line length for local libraries feeding into the earth station adjacent to a major local library is 30 miles and would cost in the order of $100 per month for a voice-grade circuit. There is also the possibility of using direct dialing by a minicomputer, with error checking logic that could automatically dial the "local" number for the local earth station; the cost would probably be less than for a leased line if a low volume of service, as for a neighborhood city library, is required.

Since each region has twenty 300 KBPS national data channels, several separate channels can be dedicated for separate library networks for such disciplines as law, medicine, science, literature, products and specifications, etc. Each Type I earth station has 10 receive and 10 transmit channels, so each station can serve 10 to 30 secondary stations within a region and also relay requests to other Type I stations through the 20 national data channels. The six slow-speed (9.6 KBPS) national channels are available for network coordination and operation.

The 120 data channels provide the capability of transmitting an average of 200 words of text per 10-hour day for each of 14 million college-level and vocational-school students. Communications requirements for transmittal, between institutions, of alphanumeric data and graphics are significantly less stringent than distribution of video programs between secondary school districts or colleges. Key factors presently restricting the development and growth of library communications networks are:

1. Performance and speed of facsimile devices (most devices will not accommodate books, and transmission is slow and expensive)
2. Limitations of electro-optical scanners for transmitting text in alphanumeric form in an efficient manner for remote printout
3. Limitations of efficient graphics transmittal in accordance with Item 1 above
4. Limited storage of text and references in automated retrieval and reading devices
5. High cost of long-distance communications because of the limitations of present input-output devices.

The concept of providing library services to homes by 1980 and to moving vehicles such as aircraft, ships, and trains by 1990 greatly increases the scope of functional and technical requirements. These requirements are defined under para 5.2.22 for aircraft, para 5.2.25 for ground vehicles, and para 5.2.32 for home communications.

5.2.4 Teleconferencing

The need for face to face communications and growing participation in conferences will be satisfied in the future by increased use of video and less use of travel for attending meetings. An important driving force for this type service is to conserve time and money due to travel.

Functional Description of Service Concept:

Coverage: All of U.S.

Origin and Terminal Distribution: Pt to Multipoint – one way – video
Pt to Pt – return – video/voice

Type of Service: Information dissemination and broadcast of meeting and remote meeting participation

Service Usage: Week days and early evening.

Basis of Need:

600,000 academic, scientific, and technical organizations
500,000 health and medical organizations
Labor, political, and fraternal groups

Indications of Need:

U.S. trunk airlines revenues
Use of interstate long distance telecommunication lines for televised conferences
Number of scientific, professional, political, and fraternal meetings per year

Description of Service:

Users will participate in remote meetings and conferences by means of two-way video communications. Groups will assemble at local centers with viewing consoles and camera equipment for a national or regional electronic meeting. Several sets of two-way communications channels will be required for large meetings with panel discussion groups or several separate working groups transacting business at the same time.

Service Requirements:

The number of channels is based on service for 20 million people regularly participating in meetings and conferences (Ref. 3, p II-41). The average meeting has an estimated 100 to one million spectators, and there may be on the order of 10,000 national and regional groups, each conferring for approximately 20 hrs per year and requiring 4 channels; thus, an estimated 80,000 channel hours are required. On the basis of 3,000 hours a year (10 hours a day, 6 days a week). Fifty conferences might be in progress on the average at a particular time. To allow a margin for peak use, planning is for 60 conferences, with each conference having access to an average of four video channels. Therefore, the estimated need by 1985 is for some 260 one-way video channels. This would provide one channel for about every 10 colleges throughout the nation or 2 to 3 channels for each of the 96 major cities listed in par. 5.2.8. The 260 teleconferencing channels can therefore be distributed over the nation in proportion to the number of colleges or general population in each area, plus extra channels for colleges in such remote locations as Alaska, where teleconferencing may be needed to a greater extent to replace travel than in such areas as New York, Chicago, Miami Beach, or Los Angeles, which are traditional centers for meetings.

A conceptual allocation of video channels for national and regional time zone coverage is presented in Table 5-7.

Table 5-7

TELECONFERENCING REQUIREMENTS

Time Zone	No. Colleges	Time Zone Coverage Channels	National Coverage Channels	
			Trans	Receive
Hawaii	4	5	5	100
Alaska	4	5	5	100
Pacific	275	30	20	100
Mountain	100	20	20	100
Central	1000	100	25	100
Eastern	1030	100	25	100
Total	2313	260	100	

5.2.5 Biomedical

A detailed study of the biomedical network functional requirements indicates that approximately 200 video channels could be used in the 1975 to 1985 era, and approximately 300 video channels and 1,420 data channels could be utilized in the 1985 to 1995 era. An estimated 6,000 voice/data 4 kHz channels could be utilized for document and data handling in the 1975 – 1985 era because of the expected heavy reliance on facsimile transmission during the early phases of biomedical information transfer. The trend toward automated data retrieval would reduce the number of 4 kHz voice/data channels required from 6,000 to 1,400. The expected area distribution of biomedical network ground stations and channels is shown in Table 5-8.

Table 5-8

BIOMEDICAL REQUIREMENTS

			Time Zone			
	Hawaii	Alaska	Pacific	Mountain	Central	Eastern
Type I stations	4	1	7	5	30	21
Type II stations	–	500	100	200	200	50
Video channels	7	50	50	100	100	25
Data channels	20	100	200	400	500	200
Population (in millions)	8.0	0.3	25.0	8.0	46.0	122.0
Video channel/ million population	7.0	150.0	2.0	12.0	2.0	0.2

The state of Alaska is allocated 50 video channels, even though the total population is less than 300,000,in order to service the remote villages. Approximately 450 of the 500 earth stations would serve communities of less than 1,000 population. The number of video and data channels per million population is higher for Alaska than for other areas, and the number of earth stations per channel is also greater because of the demographic characteristics. The Eastern Time Zone has fewer earth stations and video channels per million population because of the heavy population concentrations in major metropolitan areas. Areas such as New York and Boston have medical schools and medical centers that can serve the large surrounding population by means of terrestrial networks.

Five of the video channels assigned to each area are for continuing education. Only data and video channels are included in the network simulation. The data channels could be used as alternate audio channels for network management and coordination. Separate voice channels are not included in the network, because they would increase system complexity and costs if included as separate entities.

5.2.6 Commercial Broadcast

The requirements for commercial broadcast are based on requirements data provided spacecraft contractors by the networks and adjusted for forecasting 1985 to 1995 era requirements. The 151 ground stations specified for 1975 were increased to 155, and the number of channels increased from 29 to 60 for the contiguous 48 states. Ten of the 60 channels are for the public service broadcast network. The most significant change is the addition of stations for Hawaii and Alaska. Provision is made for four transmit and receive stations plus 100 receive-only stations in Alaska. Audio channels are provided for network management and switching control. (Ref. 41, p 17)

5.2.7 Public Broadcast

The public broadcast conceptual system has 10 video channels and serves 4,000 earth stations in the 48 states plus 500 earth stations in Alaska. The conceptual network is the same as presented in the "Information Transfer Concept Study" (Ref. 4, Vol. II, pp 7-12 thru 7-15). The public broadcast service has fewer channels than projected for the three major networks ABC, CBS, and NBC combined. More earth stations are provided for public broadcast, particularly in Alaska, to provide noncommercial programs to isolated areas. Provision for 3,000 receive-only earth stations for the mountain states (Ref. 4, p 7-15), are provided, plus 1,000 additional stations to be located throughout the nation.

The possibility of developing such a system is heavily dependent on the costs of receive-only ground stations for users in isolated areas. The important technologies required are for low-cost user antennas and a low-cost antenna preamplifier with a noise level on the order of $300^{\circ}K$. Ideally, the cost for the antenna and preamplifier should not exceed the cost of a quality color television set, or $500. The use of small widebeam user antennas in conjunction with a high satellite radiated power level will cause interference from adjacent satellites and limit frequency reuse. The user antenna should have a 2-degree or narrower beamwidth and the satellite radiated power should not exceed 50 watts per video channel in order to reduce interference and facilitate frequency reuse.

The technology required for public broadcast services by satellite is also required for public school TV distribution by satellite.

5.2.8 Public Telephone

Figure 8-1 (refer to par. 8.2, Growth Trend of Long Distance Communications) shows that the long-distance telephone system is expected to increase from 500,000 interstate equivalent voice circuits in 1972 to over 3 million equivalent voice circuits by 1985. Much of the increase in channel capacity will be obtained through the installation of new cable systems. Satellite systems could provide from 10 to 50 percent of the 3 million channels required by 1985. The satellite capacity required is on the order of 300,000 to 1,500,000 combination voice and 50 KBps data channels. The present state-of-the-art can provide 40,000 voice channels by means of an 800 Kg Atlas/Centaur-launched satellite utilizing multiple spot beams. The total voice and data traffic capacity of satellite systems may, however, be determined largely by regulatory and economic factors rather than by purely technical capabilities. There will be a need for some 400 video channels for purposes such as TV distribution and teleconferencing. Approximately 1,000 channels carrying 6 megabit data rates of picture phone communications will be required.

The telephone system requires a higher degree of reliability and flexibility than most other service functions. Satellite systems offer a means of providing system flexibility and reliability by being capable of picking up traffic between overloaded nodal points of the system, or providing alternate routing in case of a trunk-line outage. In order to provide maximum flexibility and compatibility with the existing terrestrial network, the satellite systems will be compatible with the major terrestrial system. An estimated 100 small earth stations will be required to service small Alaskan cities and villages capable of sustaining local terrestrial telephone networks by 1985. Additional earth stations are required for Hawaii and Puerto Rico. Major satellite earth stations must be capable of handling about 30,000 equivalent voice circuits or approximately 10^9 BPS as digitized voice circuits, wideband computer data, picture phone, and digitized video channels. Figure 5-1 shows the location of the nation's 22 major urban areas containing over 60 percent of the population and the equivalent minimum length terrestrial trunk network for interconnecting these major areas by means of an auxiliary or competing terrestrial trunk communications network.

The 22 major metropolitan areas would generate most of the telephone system business, teleconferencing, computer, and audio traffic. The addition of local secondary feeder networks from the major metropolitan areas to interconnect some 60 smaller areas throughout the nation – such as San Antonio, Texas, Salt Lake City, Utah; Las Vegas, Nevada; Birmingham, Alabama, etc. – will provide service for 95 percent of the nation's population. The cities to be serviced by networks in order of importance for formulating a network to serve general areas are listed in sequence by time zones for 96 areas of the nation:

Eastern Zone

1. New York
2. Washington
3. Boston
4. Atlanta
5. Detroit
6. Miami
7. Louisville
8. Cincinnati
9. Pittsburgh
10. Cleveland
11. Buffalo
12. Indianapolis
13. Utica
14. Scranton
15. Columbus
16. Toledo
17. Fort Wayne
18. Lansing
19. Charleston
20. Richmond
21. Knoxville
22. Roanoke

Eastern Zone (Cont)

23. Greensboro
24. Charlotte
25. Raleigh
26. Columbia
27. Macon
28. Savannah
29. Jackson
30. Tampa
31. Tallahassee
32. Norfolk
33. Marquette
34. Augusta
35. Montpelier

Central Zone

1. Chicago
2. St. Louis
3. Memphis
4. New Orleans
5. Minneapolis
6. Kansas City
7. Dallas – Fort Worth
8. Houston
9. San Antonio
10. Nashville
11. Birmingham
12. Amarillo
13. Corpus Christi
14. Shreveport
15. Little Rock
16. Oklahoma City
17. Tulsa
18. Springfield
19. Wichita
20. Lincoln
21. Peoria
22. Des Moines
23. Madison – Milwaukee
24. Duluth
25. Jackson
26. Lubbock
27. Mobile

Mountain Zone

1. Denver
2. Salt Lake City
3. Phoenix
4. Tucson
5. Albuquerque
6. Boise
7. Casper
8. Rapid City
9. Butte
10. Glendive
11. Kalispell
12. Bismark
13. Scottsbluff
14. Grand Junction

Pacific Zone

1. Los Angeles
2. San Francisco
3. Portland
4. Seattle
5. Spokane
6. San Diego
7. Fresno
8. Las Vegas
9. Reno
10. Bakersfield
11. Eureka
12. San Bernardino
13. Klamath Falls
14. Eugene
15. Baker
16. Walla Walla
17. Lewiston
18. Aberdeen
19. Medford
20. Tonopah

5.2.9 Business Network

The functional requirements for long-distance business networks are the same as for the public telephone system. The nation's long-distance telephone system has been developed primarily to serve business needs, which constitute the bulk of the long-distance traffic. The development of an all-digital long-distance communications link will make the system highly compatible with business voice and machine communications needs. Business communications were carried almost exclusively by the telephone system in the past and are therefore considered as a functional part of the telephone system. Business is not completely satisfied with the available telephone service and tariffs, and growing numbers of private networks are being developed by such businesses as railroads, pipelines, and trucking.

Several independent communications corporations have been formed to offer services in competition with AT&T. These companies will provide nationwide satellite network services with 20,000 to 100,000 equivalent voice circuit capacities per network by 1985. To be competitive with the AT&T system, each simplex circuit should be capable of carrying one voice channel or about a 50,000 BPS data rate. Most satellite systems will probably be compatible with the terrestrial telephone system in order to provide the maximum convenience and flexibility to customers using both systems. Twenty to 80 earth stations will be required for systems serving the major metropolitan areas and regional offices of major businesses. Major earth stations will need to be capable of handling on the order of 10,000 to 20,000 voice/data circuits during peak demand periods.

The franchised terrestrial communications companies such as AT&T and GTE are required by law to provide service interconnections between independent satellite company ground stations and their customers. Leased terrestrial links between ground stations and local customer facilities are a critical concern of the independent satellite communications companies. One area of critical technical need is for improved terrestrial laser and microwave links capable of facilitating the acquisition of dedicated feeder communications channels between earth stations and local customer facilities. Such technologies would help to free the independent satellite companies from dependence upon AT&T and GTE.

Technologies which reduce the costs and increase the capabilities of small- and medium-sized earth stations will also help the satellite companies develop more competitive networks that are less dependent on established terrestrial companies. Important technologies for reducing earth-station costs are technologies that allow earth stations to be essentially automatic, with emergency remote control capabilities, and requiring only part-time or periodic inspection and maintenance. Such technologies would reduce the high operating costs associated with having large numbers of earth stations operating in many remote medium-sized towns of some 10,000 population. Ideally, any area within 100 miles of a system maintenance center, having potentially 1000 or more long-distance calls per day or receiving cable TV for over 1,000 people, should be capable of supporting an automated earth station operated by a commercial satellite company.

Business networks will carry video/data channels for management video conferences to reduce travel and will be used as high-speed data links. Technologies are needed that reduce the costs of two-way video teleconferencing. Important technologies for meeting the needs of business management are all-digital compressed video channels carried on a time-division multiplexed network. The system requires relatively low-cost automated switching, which promotes fast multiple access by customers with groups using communications between different facilities. The system should also be usable as essentially a direct-dial demand access system that could be scheduled or reserved in advance for important meetings.

5.2.10 Value Transfer

Value transfer communications will be handled over dedicated networks formed by credit-card companies and banks leasing long-distance lines from terrestrial and satellite communication companies. Value transfer functional requirements are compatible with the requirement for long-distance business communications (par. 5.2.9); but will use essentially voice/data channels for local communication of multiplexed, higher speed trunk circuits.

Forecasted System Development

Projected retail sales will reach $575 billion annually and banks will be processing 45 billion checks annually by 1980 – unless extensive use is made of computerized value transfer systems. Computer data systems are being extended to the point of retail sales to ensure correct recording of transactions, determine taxes, compute discounts, status delivery and make automatic credit extensions.

A reduction of 10 billion checks per year will save 470 million annually in the cost of processing checks if electronic fund transfer can be substituted for the use of checks. Improvements are being made to reduce the annual loss running to 2.5 billion annually due to worthless checks. The trend is toward elimination of checks by means of automated fund transfer from the account of the consumer to the account of the merchant, from buyer to seller, from employer to employee. Instead of writing a check or paying cash for a purchase, a consumer will be able to control transfer funds automatically, without paper, to make payment to the account of the merchant or seller.

In the future, except for the smallest of transactions, money will no longer be a physical thing. It will be a set of numbers in a computer memory. Transactions will be made over data links.

We are in fact starting to use "electronic money" today to a considerable extent, with checks and credit card receipts serving as the authorization for fund transfers performed by computer systems.

Potential System

There are various means of providing increased security, positive identity and convenience for a person making a purchase with a plastic credit card. A person might make a purchase from his home for goods which he might view on a video phone or television commercial. The credit card could be inserted into the telephone card reader slot and the purchaser billed by the card and telephone numbers which would be correlated by computer.

Purchases at stores can be made by inserting the credit or identification card into the reader slot providing a voice identity or perhaps placing a thumb or finger on a scanning window. The identification data are compared with stored identification data in the central computer for the given credit service.

The amount and terms would be entered into the sales control console. An indicating light on the console indicates whether or not the customer's account is adequate to cover the purchase. If the transaction is completed, the buyer's account is debited, the seller's account credited, and a receipt generated if required. The terms and cost of purchase might be spread over a time period. The system can provide an instantaneous status of an account with a minimum of paper work and expense.

Data links connect the retail terminals to the various central bank and credit card centers as required for continuous on-line, time shared, real time operation of the complete system. Each identity card carries a code designating the central bank or system containing the account. Long distance data links will provide a nationwide service for purchases and payment of expenses during business trips, vacation and general travel.

Information Requirements

	Existing	Projected	Future
Type Data	Digital voice	Digital voice	Digital voice
Quality	Commercial telephone	Commercial telephone	Commercial telephone
Input/Output	Touch-tone Card Dialer Telephone/ Computer terminal and Telephone	Sales console/ Computer	Retail console/ Computer or Home console/ Computer

5.2.11 Securities and Commodities Exchanges

Securities and commodities brokers presently use computers and electronic display systems designed to provide market information. Long-distance communication lines are presently leased from the telephone companies to form dedicated information networks. Such networks will continue to use leased lines for real-time data transfer. Individual investors and brokers will use local cable or telephone circuits for obtaining information and placing orders through local interconnections with leased long-distance networks provided by major brokerage houses and securities exchanges.

System Concept for 1975 to 1985

There will not be an increased need for improved technology to handle quotation, transaction or control of stock market data. There will be a more extensive implementation of the presently available network concept. Quotations, transactions, and control accounting are being expanded to include all exchanges, all brokers, regardless of size. Stock certificates will not be distributed but rather stored in an accounting computer for reference and retrieval. The net will include the information generators (exchanges), regional centers where all data will be stored and will service a region including approximately 200 brokers. Terminal equipment will be video tube type , but will include voice communication as well as digital data.

System Concept for 1985 to 1995

The big improvement in transfer of stock market information in the 1985 era will be providing complete service to the home. Quotations, transactions, and accounting control will be accomplished directly between buyer and regional broker.

Background Considerations

The breadth of Wall Street's involvement with the new technology extends far beyond paperwork tasks. Innovation is well underway in the public board rooms of brokerage offices where advanced-design display and stock-quote devices are being installed. The individual trader is being offered new machines and services that help him follow the market in the privacy of home or office. The greatest impact is the in-road that the computer is making into investment analysis and decision making.

As an example, the high speed data systems of the American and New York Stock Exchanges report a transaction over automated reading and transmission devices. The data is transmitted to central processing computers, which automatically check for errors. The transaction is transmitted simultaneously to thousands of "tape" displays throughout the nation.

Each transaction is stored on magnetic tape, and periodically the computers process the raw data to produce the stock indexes, lists of the most active stocks, etc. The computers monitor trading for security price changes that exceed pre-programmed limits. Should suspicious movements in a security occur, the volume, price, and time of trade to the nearest minute can be obtained from the computer for every transaction.

The raw data is processed and used by the exchanges, government agencies, and private firms. The data is stored for near-real-time readout over stock – quote machines in brokerage offices throughout the nation.

Data will be distributed throughout the U.S. All market places such as New York Stock Exchange, American Stock Exchange, Midwest, and Pacific Stock Exchanges will provide all data inputs. These inputs will be augmented by foreign exchanges such as the Canadian, France, etc., and receive data from 4 major stock exchanges and 12 commodity exchanges.

5.2.12 Reservations and Tickets

Computerized ticket and reservation systems are presently in operation to record sales and confirm reservations from central computer memories. Most reservations systems use leased communications and are included as part of the total requirements for Business Networks (par. 5.2.9).

5.2.13 General Computer

The changes required to the telephone system to make it better fulfill the future needs of digital and general computer networks are discussed in par. 8.1. AT&T is developing digital data services and all-digital long-distance communications designed to meet the nation's growing digital and general computer network requirements. The functional system capabilities being offered represent the results of detailed market and technical studies performed for the purposes of selecting the best systems capabilities for maintaining AT&T's strong competitive position in data communications. The recent growth of independent companies is largely due to the following shortcomings of AT&T's Bell System network during the 1960s:

1. Customer modems were required which could convert digital data to analog signals for transmission and reconvert analog signals back into digital data at the receiving terminal.
2. Customer modems had to be acoustically coupled to a telephone handset or be approved by AT&T for hardwire interconnection to the Bell System.
3. Data rates were generally limited to 2,400 to 4,800 BPS per audio channel because of channel limitations.
4. The use of modems with acoustical couplers for small remote computer terminals created inconveniences for timeshare computer service customers.
5. High bit error rates and the interchanging of leased lines resulting from Bell System operating procedures created problems for leased-line users.
6. The high cost of long-distance lines (in proportion to the bit rate throughput resulting from tariffs and restrictions imposed by AT&T) created the need for alternative long-distance communications. This high cost was exploited by small common carrier companies. Many large corporations such as railroads built private, dedicated networks.

AT&T is acting to overcome some of these limitations and the potential loss of customers by converting a large portion of the Bell System to all-digital networks designed to meet the present and foreseeable future requirements for computer networking. The functional capabilities of the Bell System become the general computer network standards of the nation, because most computer communications interface equipment is designed to be compatible with the available telephone service. AT&T by virtue of its size and omnipresence sets the standards for digital communication systems if the service provided is adequate and economically attractive. The 64-kilobits-per-second digital voice/data service being developed by AT&T will provide on the order of a hundred fold improvements in capability over the leased voice/analog system of the 1960s.

Communications carriers such as DATRAN and MCI (Ref 91, 92) effectively compete with the Bell System by offering specialized services such as 150 and 14,000 Bps digital channels at rates lower than obtainable from the Bell System. In response to this challenge, AT&T is developing a data system providing similar services and a switched 50,000 BPS capability over digital voice circuits that allow direct dialing by computers for machine-to-machine communications. Development of the T-1 cable provides a 1.2 megabit per second capability per wire pair. The new T-2 cable developed for Picturephone, which is also a computer accessing terminal, will carry 6.3 million bits per second and will probably eventually allow direct dialing over 6 MBps networks. Bit error rate will be improved from 10^{-5} to 10^{-7}. These improved capabilities will be adequate for most general computer networks over the next decade and should allow on the order of a 10 to 1 reduction in computer network communications costs (see Figs. 7-3 and 7-4). Computer communications controllers will continue to utilize buffer memories and error detecting or correcting codes to ensure end-to-end bit error rates on the order of 10^{-12}. The acceptable communications link bit error rate is usually dependent on total communications costs that are based upon end-to-end bit speed after error correction. A 50 KBps data rate will meet most computer data terminal user needs over the next decade. A 50 KBps channel will be multiplexed down to 100 BPS for serving remote CRT/keyboard terminals. By the 1990s there will be numerous computer networks transmitting data in short synchronized bursts at rates of 1 to 10 MBps. Time-division multiplexing will be extensively used to simplify network switching, conserve communications channel capacity, and make the network transmission mode compatible with the characteristic machine-to-machine operating modes; data will be requested by means of short, high-speed data bursts, and replies will be received as quickly as possible in the form of a data burst. A required data response may consist of from 100 to 10,000 bits for example, and occur as one burst or a series of bursts during each cycle of an automated computer routine or time division multiple sequence.

The important satellite communications technologies are those that will facilitate time-division multiplexed system operation and also facilitate cost effectiveness and system capacity per unit of allocated bandwidth. Data compression and error correction are considered here to be responsibilities of the users and the using computer system. The important technologies for computer service therefore deal with improving the signal-to-noise ratio to maintain bit error tolerances, providing modulation techniques that resist noise, and having a high bit capacity per hertz of bandwidth. Since most general computer network users, and particularly those using high bit rates, are located in the vicinity of less than 100 urban areas, the system lends itself to the use of multi-narrowbeam communications links. Such narrowbeam links from satellite to city area facilitate high signal-to-noise ratios with a minimum of satellite power and extensive frequency reuse.

An additional means of conserving satellite power and frequency spectrum is by time-division multiplexing or switching of antenna beams (data streams) by satellites and earth stations. A major earth station, for example, can transmit a continuous data stream to the satellite, multiplexing a portion of the stream in time sequence to each of several cities by antenna beam switching. Ideally, the full capacity of the satellite transponder would be fully used almost continuously.

An additional possibility for digit networks is high-speed synchronized earth station up and downlink beam switching between multiple satellites. Such a system when properly implemented could provide advantages of system flexibility and redundancy and would simplify satellite switching requirements.

If sufficient cost reduction and technology advances are made in rapid switching or steering of narrowbeam earth station and satellite antennas, it will become feasible to time share several satellites in slightly inclined synchronous orbit to provide communications during sun occultation periods by the earth or when the satellite and sun come in conjunction. Accurate beam steering or multibeam switching can be used to reduce the need for highly accurate stationkeeping and precise attitude control of the satellite orientation.

As the required network capacity increases, and the resulting bit stream rates of the major communications links increase, the technical requirements of the general computer network become increasingly compatible with the requirements for high-speed computer networks. The important difference is the extent of time-division multiplexing at each ground terminal and the numbers and bit rates of the using machines.

5.2.14 High-Speed Computer

Data rates generally between 100 MBps to 1 gigabit per second will be transmitted over high-speed data networks. High-speed data terminals require special terminal connections and communications channels for handling the high data rates. Time-division multiplexing of real-time operations is possible only if the link data rate is higher than the computer operating bit rate or transmission rate. Frequency-division multiplexing or slow-speed channel switching requires accessing and holding a channel at the exclusion of all other traffic. Some present systems use a narrowband channel for an extended time and use tape or memory to store data and free the computer for other tasks during transfer of data. Such methods of operation limit the effective utilization of the large computer. Satellites designed for extensive high-speed computer networks should provide time-division or high-speed switching between spot beams, illuminating different terminals so that a super-computer can serve on a convenient and economically attractive time-share basis.

Eventually, 1-gigabit-and-higher data rate networks will be developed for very high-speed data systems. The feasibility of 1-gigabit communications links has been demonstrated. Such links will utilize the higher frequencies, such as the allocated 29.4 to 31.0 GHz earth-to-space and 19.7 to 21.2 GHz space-to-earth frequencies. Use of the 92 to 95 GHz earth-to-space and 102 to 105 GHz space-to-earth frequencies for very high-speed data links will require development of efficient narrowbeam antennas plus sufficiently light and efficient transponders operating at these frequencies to make satellite use practical in spite of the high atmospheric attenuation.

5.2.15 General Services Administration

The dedicated (leased) General Services Administration network is similar to many large corporate-based networks, but larger and more extensive. For this study, the

GSA networking that might be relayed by satellite would provide on the order of 40 nationwide video channels for teleconferencing between major administrative offices. Additional services include on the order of 100,000 equivalent two-way voice channels for carrying voice, or 50 kilobits per second of data interchangeably. Groups of voice/data channels or video channels could be used as required for high-speed digital data transfer. This estimate is perhaps conservative in that it is based on the Federal Government service remaining at approximately 5 percent of the national workforce and requiring essentially a proportionate portion of the forecast future long-distance communications circuits, all of which would be provided by satellite. Analysis of future trends, and particularly the trend toward a service economy, indicates the future need for greater control, regulation, and coordination by use of long-distance communications channels.

The GSA network will benefit from technologies that provide better quality and more cost-effective communications for general telephone, business, and computer networks.

5.2.16 State Government, 5.2.17 State Law Enforcement, and 5.2.18 Emergency and Disaster

These three network functions are combined as a functional system, because the services considered are generally provided by state and local government agencies. Different service agencies can each benefit by sharing the earth stations but by having separate or dedicated frequencies and channels. Several states, notably Nebraska and Georgia, are developing integrated statewide-dedicated communications networks for providing such improved services as state administrative telephone and data communications, distribution of public school educational TV programs, law enforcement voice and computer data, emergency and disaster communications (Ref. 1, Fig. 6 and Ref. 13, pp 114, 267, 274). The state of California has a 90,000 channel-mile dedicated communications network.

Each statewide communications network would utilize a separate antenna beam or share a beam between several small adjacent states, as shown in Fig. 5-5. The 48 states could be covered by means of 27 one-degree beams or approximately 50 beams of 3/4 degree. The average state would have 2 major earth stations, 100 small fixed earth stations, and 1,000 mobile stations.

Each of the 100 small fixed stations per state would be capable of receiving four video channels plus 20 voice/data channels and transmitting up to 10 voice/data channels. Forty voice/data channels are allocated for 1,000 state service vehicles. The total state network system for the 50 states would include 100 major or Type I earth stations, 5,000 small fixed earth stations, and 50,000 mobile stations. The communications satellite would be required to relay 200 television channels and 5,000 two-way voice/data channels of audio bandwidth and on the order of 10 kHz RF bandwidth.

Reuse of frequencies (because of pointing angles of narrowbeams and difference of polarization for video signals to fixed earth stations) reduces the RF spectrum required. The average state requires approximately 300 MHz for the downlinks and 300 MHz for the uplinks. Use would be made of the 2.5 GHz frequency for educational television and 20 GHz frequencies for mobile communications. The use of lower frequencies such as VHF at 100 MHz would greatly reduce the technical and RF power requirements, but such frequencies are not expected to be available with sufficient bandwidth to fulfill all needs.

Earth vehicles would use local terrestrial communications when practical and switch to the satellite relay channels when beyond the range of a terrestrial radio staion. Interstate communications would be through the Federal Government's General Service Administration Network. Therefore, there would be no communications or message switching between beams. The state communications satellite system, with limited channel switching between beams, provides a system for meeting the basic requirements for underveloped areas as defined by Item 32 of the needs model. The narrow beams allow controlled illumination within an area with a minimum of overspilling into adjacent areas with different needs and different political orientations. Narrow beams reduce interference and provide higher effective radiated power levels within an illuminated area so that relatively inexpensive earth stations can be utilized for direct broadcast reception. Lightweight two-way portable battery-powered earth stations can be utilized where there are limited vehicle-mounted units. The technology for low-cost, lightweight earth stations with a steered or switched antenna beam capable of autotracking is applicable to the following:

State government fixed and mobile earth stations
State and national law enforcement agencies
Emergency and disaster networks
NASA Space Operations Network space vehicle data relay for small satellites
Earth resources data relay stations
Marine communications
Aircraft communications
Ground vehicle communications
Area support network

5.2.19 NASA Space Operations

NASA Space Operations will probably utilize the Tracking and Data Relay Satellite (TDRS) in the 1985 – 1995 time frame. The TDRS will track launch and orbital vehicles and relay command and telemetry data between the space vehicles and their mission control center. On the order of 100 active space vehicles will eventually be in orbit at one time.

Tracking and communications will be maintained by means of three to four TDRSs. Wideband communications links capable of transmitting on the order of 10^9 BPS will be needed between adjacent TDRSs to form a continuous global space command and monitoring capability.

Communications with a spacecraft will be passed from one TDRS to another to maintain continuity of command and telemetry as low-orbit space vehicles circle the earth. Numerous "small" spacecraft will probably have data rates on the order of 1 KBPS to 20 KBPS for housekeeping and experiments. Use of a TDRS to provide nearly continuous coverage is expected to reduce the use of onboard data recorders and allow a reduction of the housekeeping and experiment data rates. The growth of technology and use of microminiaturization tend to generate more data per pound of satellite weight. The use of the Space Shuttle will reduce the cost per pound of satellites placed in orbit and will encourage the trend toward larger scientific satellites. The expected effects of these factors is for the "small" scientific satellites of the 1960s to grow to weigh on the order of 500 kilograms in the 1960s and have housekeeping data rates on the order of 10 KBPS, which is comparable to the present Nimbus spacecraft requirements. The readout sensor and experiment data from small and medium-size satellites is expected to range between 100 BPS to 30 MBps (Ref. 38, pp 5-6, 5-8, and 5-10), (Ref. 35, pp 3-3, 3-4, and 3-5).

Space Shuttle, manned space stations, and large automated spacecraft such as observatories and RF monitoring systems will require data rates on the order of 1 to 200 MBps (Ref. 35, p 3-6, Ref. 38, p 3-4). Earth resources satellites may possibly transmit gigabit data streams to TDRS by laser for relay to earth over RF links or laser links to earth stations located in arid regions.

These functional requirements indicate that the following key communications technologies are required for NASA space operation in the 1985 era:

- Spacecraft-to-spacecraft communications
- Improved spacecraft autotracking antennas for small spacecraft in low earth orbit with limited power and data rates
- Improved spacecraft autotracking antennas for megabit and gigabit data rates
- Onboard data handling and storage for high-speed data streams

The need for improved beam pointing or autotracking can be met by means of phased arrays, switched beam antennas, switched lens beams or gimballed dish antennas, or possibly slaved mirrors for laser systems. The need for beam pointing and for 10 to 60 dB of RF antenna gain is partially to reduce the transmitter power requirements and perhaps more important, to provide discrimination against interfering background signals from the earth and other spacecraft. The important technologies listed are predicated on the basis of expected technology advances that will provide lighter weight, lower noise factor, and more reliable transmitters and receivers by 1985. Present levels of spacecraft technologies, such as power systems and attitude control, plus the cost savings and orbit weight capability of the Shuttle system indicate that the space operations communications needs will remain sensitive to further antenna improvements.

Technology is moving toward gigabit data rates carried on narrow, high-frequency beams above 10 GHz, where there is sufficient available bandwidth to support the data rate. These higher data rates present requirements for spacecraft equipment capable of recording, storing, and switching blocks of generated or received and to-be-transmitted data. Therefore, a need exists for developing spacecraft-qualified memory or storage devices capable of reliably handling gigabit data rates. Ancillary equipment will be required for gigabit data coding, decoding, error correction, data compression, and switching. The effectiveness of such equipment is dependent on antenna systems, transmitters, and receivers capable of delivering the data stream to the processing equipment with a sufficiently low bit error rate to permit the total communications system to operate efficiently and with a minimum outage. The need for on-board memory and processing diminishes with improved capability of continuous real-time relaying of data from the spacecraft to earth stations.

5.2.20 Earth Resources and Ocean Buoy Data

This category of communication service covers only the relaying of data from earth, airborne, and ocean-data-collection platforms. Data from Earth Resources Satellites in low earth orbit will be relayed by means of TDRS to earth stations and are not a part of this service. The estimated number of data collection platforms to be serviced by 1990 and the message size in bits are presented in Table 5-9. Each station will have an address and be interrogated by a command address. The normal reporting interval is 6 hours.

Table 5-9

EARTH RESOURCES SENSING PLATFORMS

	Number	Message Size	Position Fix Reqd	Bits Per Day
Balloons	10,000	100	Yes	4×10^6
Land stations weather	10,000	1,500	No	60×10^6
Shipboard stations	2,000	300	Yes	2.4×10^6
Ocean science ships	50	10,000	Yes	2×10^6
Buoys	1,000	3,000	Yes	12×10^6
Aircraft	1,000	1,000	Yes	4×10^6
Hydrologic	10,000	1,000	No	40×10^6
Seismic	1,000	500	No	2×10^6
Agricultural	10,000	100	No	4×10^6
Forestry	10,000	100	No	4×10^6

The total daily bit load by 1990 is estimated as 1.2×10^8. Seven data channels capable of 200 BPS could carry the basic bit load. An estimated 12 channels would be adequate and allow separate channels for each type of platform.

Location of moving stations should have a resolution of less than 1 nm. The use of multiple data relay satellites can provide location information without the need for transmission of ranging tones or the need for accurate clocks at each platform.

Measurement of the time delays associated with receiving a common data message at each of three satellites provides a position fix if altitude is known. Pressure altitude would be measured and transmitted for aircraft and balloon stations.

Important communications technologies are lightweight, rugged, inexpensive data platforms capable of providing at least 3 dB of antenna gain. A global earth resources monitoring system will be aided by development of technology for data relay between synchronous orbit relay satellites.

5.2.21 Marine Communications

The Marine Communications Network will provide worldwide ship-to-shore voice and digital communications. There are presently some 50,000 merchant ships, 13,000 fishing ships, and 50,000 utility and pleasure boats that could use improved long-range communications for navigation, emergencies, personal telephone calls, and administrative and maintenance information. It is estimated that by 1985 there will be on the order of 100,000 ships at sea, carrying several million people as crew and passengers. It is estimated that at least one voice/data channel will be required for every 30 ships. Three marine navigation/communications satellites could cover all the oceans. Each satellite would provide 2,000 two-way voice/data channels for coverage of ocean areas within 70 degrees of the equator.

Emergency communications are an important factor for maritime communications systems. In 1965 712 ships, each over 5,000 tons, were in distress. By 1985 an estimated 300 ships of over 100 tons each will be lost every year. An improved emergency communications is needed for summoning aid, determining position, and obtaining survival information. High-gain spot beams would be provided on each satellite for emergency search and communications. The steered high-gain satellite antennas will provide emergency two-way voice communications through battery-powered hand-held radio.

The satellite communication system will require approximately 100 MHz of bandwidth in the 1535 to 1542 MHz and 43 to 48 GHz maritime frequency bands. Each channel would utilize 10 kHz of bandwidth to provide a combination voice or digital channel.

Communications within harbors and on final approach to harbors would be provided by local shore-based radio. Satellite communications would be used for communicating over distances greater than 50-100 nm and for precise navigation at sea.

Ships presently use gimballed, parabolic dish antennas to communicate by the INTELSAT IV satellite at 4-6 GHz. Such antenna systems make marine television for passengers and crew a logical future development of the present developing marine satellite communications systems.

5.2.22 Aircraft Communications

The aircraft communications net would provide air traffic control communications from aircraft to air traffic control centers. The system would also provide ARINC communications between air traffic control centers and from aircraft to administrative and maintenance facilities. Domestic private aircraft for business and recreation are potentially the greatest users of enroute air traffic control communications. An estimated 300,000 US aircraft will be operating by 1990 (Ref. 5, profile for "Transfer of Enroute Air Traffic Control and Communications Information." An estimated 15 percent of all available aircraft in operation during a peak period would create a need to serve 45,000 domestic private and commercial aircraft. Only about 300 aircraft operated over the Atlantic and Pacific Oceans during peak traffic times in 1970. The number is not expected to change significantly by 1985, because of the use of larger and faster aircraft. The major use of future aeronautical communications satellites could therefore be for domestic, enroute flight operations. The system should provide both digital and voice communications to provide more efficient communications and control for a large number of aircraft.

Local voice communications links from the aircraft to control tower and local air traffic control centers will continue to fulfill most of the communications requirements for information and direction of small civil aircraft. Uniform communications coverage for enroute flight operations could be provided throughout the US and the rest of the world by use of communications satellites. Future aeronautics communications satellites will provide voice channels for passenger and crew radio-telephone service.

Computer controlled two-way digital communications links are expected to provide most aircraft performance monitoring and inflight direction. Aircraft identification, position, altitude, and heading will be routinely transmitted from aircraft to air traffic control center computer systems about every minute. The computer will assist air traffic controllers by providing estimates of projected traffic conflicts plus suggesting alternate solutions. Information will be transmitted in digital form for alphanumeric cockpit display or printout of a permanent record copy for large commercial aircraft. Complete aircraft in-flight performance monitoring will be provided for large commercial and military aircraft by digital telemetry relay from satellites. Airline operations and maintenance centers will use computers to analyze flight data in real time and provide running status reports on each aircraft.

A typical aeronautical satellite system for the 1985-1995 era could provide on the order of 1,000 two-way voice/data channels for such operational areas as North Atlantic Ocean, Europe, North Africa, South Africa, the Eastern Mediterranean, or various regions of the United States. A two-way digital traffic monitoring and ranging channel would serve numerous aircraft by interrogating each aircraft by identification code and receiving a status word showing altitude, heading, and speed. A single 20 KBPS channel could monitor approximately 1,000 aircraft each minute. The digital rate could be reduced to lower the required power levels. Voice channels, for obtaining verbal instructions, and flight plans presently constitute most of the air traffic communications and channel utilization. Digital communications will reduce the need for verbal air traffic control communications.

A relay system with high-gain, steered-beam satellite antennas and omnidirectional aircraft antennas is in the final report, "Navigation/Traffic Control Satellite Mission Study," December 1968, by RCA under NASA Contract NAS 12-596. The system defined meets the 1968 minimum requirements for transoceanic air traffic control and navigation by providing six voice channels and two 100 BPS data channels. Two satellites are required to provide navigation position information. Satellite-to-aircraft antenna gains on the order of 30 dB are needed to reduce the transmission power levels and interference. Use of a steered or switched beam antenna mounted on each aircraft appears to be the most practical approach for meeting long-term future requirements. Aircraft antennas should provide beams that can receive signals from multiple navigation and communication satellites for aircraft position fixing. Satellites would provide selective coverage of such operational areas as the North Atlantic air routes by means of shaped beams.

The Federal Aviation Administration and the European Space Research Organization (as reported in the October 11, 1971 issue of Aviation Week, p 53) requires 20 two-way channels for each of the Atlantic and Pacific Ocean areas, and a 10 MHz bandwidth high-speed data and surveillance channels for experimental purposes in the 1970s. It is believed that these initial requirements and the demonstrated effectiveness of aeronautical satellite communications will stimulate the need for the full level of requirements defined for the 1985-1995 era.

5.2.23 United Nations

United Nations networks will serve two prime functions. The first is to facilitate communications and coordinations between member governments of the world. Present day satellite hot lines will hopefully grow to international video teleconferencing networks, allowing group meeting and conference between heads of states throughout the world. The second function is to provide technical support and aid to developing nations. This function will utilize the area support networks defined in par. 5.2.23.

The prime United Nations network should be global in nature and provide the highest quality, two-way video channels between member nations and the UN Headquarters. An estimated minimum of 20 video channels could be used for teleconferencing by heads of state, UN service committees, and delegation members conferring with their government officials at home. An estimated 100 voice/data channels and 10 1-megabit, high-speed channels could be used for providing data and computer support to developing nations.

The technical requirements for this service are compatible with the requirements for teleconferencing networks, telephone networks, and the area support network. Satellite-to-satellite communications are an important technology for this service for two reasons: first, to allow the most efficient communications possible for a totally global communications network; second, to facilitate communications between the UN satellite and the area support satellites of developing member nations.

5.2.24 Electronic Mail

The US Postal Service handled 51 billion airmail and first class letters in 1971 (Ref. 45, p 491). The volume is doubling every 20 years. The forecast 1990 volume is 100 billion. Twenty thousand one-way circuits could carry 10 billion units of long-distance mail on the basis of 1,000 words per average letter or unit and 250,000 bit per second capacity per circuit. It is estimated that twenty 40-MHz bandwidth transponders would be required in orbit to provide a smooth flow of electronic mail services and to handle peak loads.

Major city earth-terminals such as New York or Chicago would require an estimated 1,000 circuit (50 MBps) capacity for simultaneous transmit and receive. Electronic mail is expected to develop into direct point-to-point electronic message transmission by 1990. The present handling of letters is expected to become as obsolete as the hand-delivered telegraph message of the early 1900s.

5.2.25 Ground Vehicle Communications

Extensive communications by satellite between ground vehicles such as automobiles, trucks, buses, and trains present the most difficult technical problems of the needs model. The need is to provide satellite telephone and data communications to moving vehicles outside of central cities with established radio-telephone services. When a vehicle would lose terrestrial radio-telephone service, it would switch to satellite telephone service. The nation could be serviced by 77 antenna beams of 0.5 by 0.5 degree, each covering an area approximately 200 miles in diameter as shown in Fig. 5-6. An alternative is to use 27 1-degree beams, as shown in Fig. 5-5. Vehicles would use assigned frequencies for each area of operation within a given satellite antenna beam. Most vehicles such as police cars, buses, trucks, and trains would always operate within one or a maximum of several specific areas. All communications with vehicles via satellite would be through a fixed central earth station that would relay the communication to a final destination or second vehicle. The functional operation of the system is analogous to the present radio-telephone system using multiple cells formed by the location of fixed-relay radio stations, with each cell covering a fixed area. Separate channels, frequencies, and earth stations could be required for separate functional users such as police, emergency communications, civil radio telephone, etc. The system would be capable of providing approximately 1,000 two-way voice channels in a one-beam coverage area, depending on modulation techniques. The system would provide some 50,000 channels and will require about 1 GHz of bandwidth. The forecasted market potential is 3 million vehicle telephones and a required 100,000 channels if service costs can be reduced to approximately $40 a month, as presented in par. 7.6 (Ref. 46, p 42). The practicality of the system depends on the development of vehicle antennas capable of finding and locking onto a satellite reference signal with a 10 to 30 dB vehicle antenna beam.

5.2.26 Electronic Newspaper

The electronic newspaper network would distribute major news items and advertisements from the major city of a region to smaller cities where local news and advertisements would be added. The local cities would redistribute the local electronic newspaper by cable, automated telephone, or local radio broadcast at 1 MBps, or by video channel. Direct broadcast by satellite to terminals such as homes, aircraft, automobiles, or trains would be by means of a slow-speed channel operating on the order of 2 KBPS. The electronic newspaper would be stored in memory at the receiver for selection and display upon user command. Updating would be performed for direct satellite subscribers.

Distribution of newspapers and periodicals by electronic communications for regional publishing is presently practiced and requires no new technology. Distribution will be aided by further development of technologies that provide better, more cost-effective satellite telephone and business network systems, as presented in par. 5.2.8 and 5.2.9.

Direct distribution of news in alphanumeric form with pictures will be aided by development of rugged low-cost user terminals for the home and for use by travelers. Ultimately, the user readout devices may be developed in the form of portable headsets resembling large opaque glasses with earphones.

5.2.27 Electronic Publishing

Electronic publishing would be similar to the electronic newspaper but with distinct operational differences. The total number of end users ultimately reached would be the same as for the electronic newspaper. Publications would be relayed to regional and local library memory banks for direct use and local distribution. Books and programs would be transmitted to users at home, at work, in school, or traveling. Traveling users would use a library channel to request transmittal of indexes or volumes, which would be transmitted in short sequences (bursts) of approximately 100 words (200 bits) per second until the complete volume was transmitted and stored. A key requirement for this system is the user terminal and memory device, which should be relatively inexpensive, lightweight, portable, and flexible enough to serve as a terminal for the electronic newspaper, emergency aid or rescue, voice communications terminal, and minicomputer.

5.2.28 RF Environment Monitoring and Testing

RF environment monitoring will be performed by a satellite in synchronous orbit with receivers capable of monitoring the full range of frequencies that could interfere with communications satellite operation. Receiver output will be compressed and transmitted to earth terminals. The RF environment monitoring satellite would also be used for experimental testing and development of advanced communications concepts and components such as modulation techniques, antennas, and laser systems. The future usefulness of communications satellites is dependent on the RF environment in which they operate, and on development of advanced communications technology capable of meeting the future needs.

The following candidate experiments that might be performed from synchronous orbit or low earth orbit are excerpted from Report No. ATR-72(7312)-1, Vol. II, NASA Payload Data Book, prepared by the Advanced Vehicle Systems Directorate, Systems Planning

Division, The Aerospace Corporation, El Segundo, Calif. These experiments are listed as candidate experiments for a Sortie-Communications/Navigation Laboratory Spacecraft, for NASA 10A, Code NC2-53 and NC2-54.

Experiment Class	Purpose
Terrestrial sources of noise and interference	Map terrestrial noise and interference sources in operational and projected frequency bands of interest.
Susceptibility of terrestrial systems to satellite radiations	Evaluate magnitude of interference experienced by terrestrial communication systems from transmissions by orbiting spacecraft.
RF propagation	Investigate RF propagation effects, including multipath, scintillation, and Faraday rotation.
Plasma propagation	Investigate feasibility of transmitting signals from a reentering vehicle via a relay satellite, instead of direct to the ground.
Communication relay tests	Evaluate equipment, procedures, and techniques related to communications via a data relay satellite (TDRS).
On-board data processing	Demonstrate techniques to reduce interference, alleviate multipath, provide direct user control, and improve flexibility.
Laser communications	Refine and extend laser technology space in applications at various optical frequencies.
Fixed multibeam antenna	Demonstrate and evaluate, in a space environment, the relative performance of competing multiple-beam concepts, investigating frequency reuse, polarization isolation, and beam and side-lobe control.
Narrowbeam tracking	Measure and optimize performance of ultranarrow beam antennas for space-to-space communication applications.

Experimental Class	Purpose
Range and range rate navigation and surveillance	Demonstrate and evaluate range and range rate measuring techniques for future terrestrial navigation, surveillance, and search/rescue systems.
Interferometric navigation	Demonstrate the line-of-sight measurement accuracy of a long-baseline, spacecraft receiving interferometer as a candidate for future navigation or surveillance systems.
Landmark tracking	Determine the feasibility and accuracy of autonomous navigation, using unknown earth landmarks.
Horizon altitude and radiation	Measure the spectral radiance profile of the earth, and especially the horizons, for application to earth-pointing systems.
Optical propagation	Extend the knowledge of optical wavelength propagation phenomena in the atmosphere and free space.
On-board data processing	Demonstrate techniques to reduce interference, alleviate multipath, provide direct user control, and improve flexibility.
Large deployable reflectors	Evaluate the deployment mechanism/ sequence and performance of large deployable reflectors in space
Laser ranging	Evaluate utility and accuracy of an on-board laser ranging system for application with cooperative and uncooperative targets.

5.2.29 Language Translation

In the language translation network, two people speaking different languages could communicate by telephone through an interpreter. Eventually, computer interpretation may provide audio and alphanumeric interpretation services. Communications links will be required between users and large special-purpose interpretation computers or language interpretation centers.

5.2.30 Religious Programs

The requirements and functions of the religious programs network services will be similar to those of the elementary school network for distributing video programs but would be smaller for each denomination. It is possible that the combined demand by all religious groups for religious program distribution and video and computer program support for private schools could equal or surpass the functional requirements for the public elementary school network (par. 5.2.1).

5.2.31 Home Communications

Ideally, home communications providing all the services desired in the home, could be facilitated by means of communications. Typical services are:

- Home entertainment by:
  - Video
  - Radio
  - Electronic newspaper
  - Electronic publishing
- Home protection and assistance
- Electronic voting and polling
- Teleconferencing and electronic travel
- Electronic shopping and business transactions

All these services are forecast to become common in the future. The degree to which these services will be provided by satellite communications is dependent on two factors:

1. Availability of adequate communications capacity
2. Cost and means for providing broadband satellite communications direct to the home or office

Analysis of developing terrestrial and satellite systems and technologies indicates that the services listed will be provided by hybrid satellites – terrestrial systems using cables or light pipes for local distribution, and satellites to reach remote and mobile users. The most isolated 1 percent of the nation's population (500,000 families) could conceivably use on the order of 1,000 channels of two-way video capacity if they were available and economically feasible. The service would provide the isolated users living in remote areas with access to the information, cultural, and entertainment resources of major metropolitan areas.

5.2.32 Area Support

The functional and technical requirements for area support networks for the developing nations are similar to the requirements for state government networks described in par. 5.3.16 and the elementary school network described in par. 5.3.1. A developing nation could use an estimated 100 video channels for the more-important video services, such as teleconferencing, biomedical education, and entertainment. An estimated 10,000 voice/data channels could be used for basic telephone communications services and several 1-megabit computer channels used for technology support. The area support networks should enable key people to access any cooperating support agency in any more-technically developed country.

Section 6

CATEGORIZATION OF NEEDS AND FUNCTIONAL REQUIREMENTS

The needs model defines many services which have a high degree of similarity as shown by the functional and technical requirements defined in Section 5.0. It is convenient to group similar services into functional categories in order that all of the service requirements can be studied by analyzing some seven categories of services rather than 32 generic services or some 300 separate demands. Study results can be affected by the types and degree of categorization (generalization) utilized. The basis and rationale for categorizing the needs are defined as well as the categories of functional services used throughout the remainder of this report. Categorization serves the very important function of summarizing and focusing attention on the important functional and technical requirements that are common for many needs. The relative importance of a technology is dependent on the total cost savings that can be attained by using the technology for many and varied services. Key functional and technical requirements that are common to several important growing services motivate development of the needed technology improvements. Determination of such common requirements is of benefit for forecasting technology growth.

6.1 BASIS AND RATIONALE FOR CATEGORIZATION

The 32 different needs and related functional requirements can logically be grouped into 6 to 10 different functional categories on the following basis:

1. Many of the needs have similar functional requirements that can be met by similar or identical satellites; this is evident from the present satellite systems and networks fulfilling broad mixes of needs for different types of services.
2. The ability of a satellite network to efficiently handle many different types of needs is in part due to the similarity of functional and technical requirements for fulfilling many different types of needs for services.

Most of the 32 categorized needs for services require only two or three different types of communications – voice, video, or digital data for information transfer. The present trend toward digital pulse code modulation for voice, video, and data communications is resulting in all-digital, long-distance communications networks. Consequently, the key message format difference between future system voice, video, and data transmission channels will be the required bit rate per channel.

3. The important differences between individual user networks are the required total bit rates (bits per channel x number of channels), allocated frequency, coverage, and numbers and sizes of ground terminals for an optimum system design. The total bit rate affects the required bandwidth, satellite power, satellite weight, and number of satellites. The bit rate is dependent on the demand for services and on the basic service needs that define the communications load per user.

4. The study results are not highly sensitive to forecasted total communications demand for a particular category of need, provided there is adequate bandwidth and adequate orbit slots available to fulfill the maximum expected demand. The sensitivity analyses show that all forecasted demands can be met. Variations in total demand will affect the total number of satellites and the number of separate networks required. Each satellite can be designed to provide a reasonably near-optimum cost effectiveness and service capacity per orbit slot on the basis of required coverage, allocated frequency, and other functional requirements.

The 32 different needs for services can logically be grouped by unique functional requirements into categories of needs on the basis of the following four factors:

1. Exceptional difference of message format requirements, such as very high continuous (200 MBps) data or very low intermittent (100 bit) rates.
2. Different numbers, types, and locations of user terminals requiring different types and areas of coverage; for example, 22 metropolitan terminals requiring spot beams versus 30,000 ship terminals requiring area coverage.
3. Different terminal characteristics, such as receive only, or receive video and transmit back voice or data; for example, broadcast versus two-way communications.
4. Basic network structure difference, such as point-to-point, point-to-multipoint, multipoint-to-multipoint, multipoint-to-point.

Each unique category formed on the basis of these differences can be expected to require a different type of network, a different satellite configuration, and different technologies to provide the most nearly ideal service capability and cost effectiveness.

6.2 CATEGORIZATION OF NEEDS

Each of the 32 different services of the needs model was considered as a dedicated network designed to meet the needs of each group of users. Adequate numbers of dedicated channels were assigned to each service to fulfill the forecasted 1985-1990 demands. It was assumed that each user group would have full use of the assigned channels. Separate sets of ground stations were considered for each need, although commonality of operational requirements and ground station locations of various networks favors the combining of related networks into common satellite systems. Formulation of such networks shows that one satellite or a family of similar satellites could accommodate several dedicated networks. The manifestation of such similarities became the essence of the categorization process. Standardized communications satellites, such as the present Anik, GTE, and Western Union satellites, for example, have similar transponders and antennas but service separate and different dedicated networks. Such satellites will provide communications between separate sets of earth stations and handle different and varying message mixes.

The 32 services of the needs model logically define from 6 to 10 different functional categories, depending on the degree of differences selected. Categories can be easily expanded or compressed during the detailed analysis. The seven categories are listed below, with the elements of the needs model listed by item number of the needs model. Some elements of the needs model are listed for more than one category, because some elements, such as Area Support, have significant needs with multiple functional requirements that could be better served by separate networks.

I. Television service networks in which long-term dedicated or leased television channels constitute the major bandwidth requirement for the system and only fixed ground stations are used. Most communications are point-to-multipoint. Most users have small, relatively low-cost terminals with a receive-only or a limited-voice, data, or single-channel video transmit capability. The following users are serviced by this type of satellite system:

1. Elementary and secondary schools
2. Higher education and vocational schools
4. Teleconferencing users
5. Biomedical, the health care community
6. Commercial broadcast distribution
7. Public service broadcast distribution
16. State government networks (video)
23. United Nations
30. Religious programs
31. Home (video)
32. Area support networks (video)

II. Digital and voice service networks are characterized by the use of large numbers of channels of varying bandwidth; most channels are narrowband combination voice and digital data channels. Equal communication capabilities are generally provided in both directions between user terminals. Most communications are point-to-point on a one-time basis, or a limited-time lease arrangement with no long-term commitment to one system by users. Only fixed-user ground stations are considered in this grouping. Mobile-user stations are considered as a separate category. Users serviced by this type of satellite network are:

3. Libraries
8. Public telephone
9. Business
10. Value transfer
11. Securities and commodity exchange systems
12. Reservation and ticket services
13. General computer services
15. General Services network
16. State administrative networks
17. National law enforcement network

18. Emergency and disaster network
24. Electronic mail
26. Electronic newspaper
27. Electronic publishing
29. Language translation
32. Area support network (telephone)

High-speed computer networks operating at data rates between 6 to 100 MBPS are grouped with digital telephone system services that also carry video and picturephone data. A 50-MBPS data rate requires about a 40-MHz bandwidth channel, which can also be used to carry one or two television channels or about 1,000 64-KBPS digital voice channels. The required carrier-to-noise ratio is about the same for the digital link as for TASO Grade 1 television. High-speed data and digital video channels can be interchanged in telephone systems of the future to alternately sup- support computer services or video program distribution and teleconferencing.

III. Very high speed data relay service is characterized by the need to transmit data at rates on the order of gigabits per second for such special computer applications as input data for super-computers and the trunking of digital service networks. The use of time-division multiplexing and all-digital communications cause the high-capacity trunk-digital and voice service networks to become very similar to the very high-speed data relay networks. The service is listed in the needs model as No. 14 high-speed computer network.

IV. Mobile services are characterized by satellite communication to mobile user vehicles. Although various types of vehicles are served, the technical communications problems are similar. Communications are predominately narrow bandwidth voice or data channels. An economically feasible satellite communication service for thousands of terrestrial vehicles is the determining need for advance technology for this category of services and is therefore considered separately in parts of the sensitivity analysis. The service needs are:

21. Marine communications and navigation
22. Aircraft communications and navigation
25. Ground vehicle communications

V. The NASA tracking and data relay network service is characterized by communications and tracking service for earth-orbiting spacecraft. The economic feasibility and operational advantages of a tracking and data relay satellite are documented (Ref 31, p 3-31). The service is defined in the needs model as:

19. NASA Space Operations Network – global

VI. Earth resources data collection services are characterized by the relaying of low-data-rate information on the order of 100 bits per second from widely scattered environmental sensors. Many of the sensors are in remote locations such as mountain-top weather stations, stream gages, etc. Many of the sensors are mobile units carried on ocean buoys, ships, aircraft, balloons, and animals. The unique functional requirements are as follows:

- Simple, rugged, lightweight, long-lived, and low-cost data transmitters
- Low bit rate and short message length
- A multiplicity of data transmitting stations – on the order of 1 million stations distributed globally by 1990
- Determination of location of moving stations
- Interrogation of stations in a random or planned manner several times per day

The service is listed in the needs model as:

20. Earth resources and ocean buoy data collection

VII. RF environment monitoring and testing services include satellite monitoring of the spectrum allocated for space communications in order to determine compliance of spectrum users to regulations and agreements. There is also a need to test the radiation environment of space, new hardware, and technology, which affects the planned, future operating capabilities of communications satellites. The service is listed in the needs model as:

28. RF environment monitoring and testing

Section 7
TREND OF SATELLITE TECHNOLOGY GROWTH

Determining the trend of space communications technology growth is necessary to determine the degree to which the expected future technology capabilities will be able to fulfill the future demands for services defined by the needs model of Section 4.0 and the functional and technical requirements defined in Section 5.0.

The state-of-the-art capabilities of spacecraft technology are analyzed and the trends and technical capabilities for the 1985 era are forecasted without special stimulation of technologies as the result of the conclusions of this study. The forecasted technology capabilities provide a baseline against which the technology needs for the 1985-1995 era are measured to determine the key technologies requiring stimulation.

7.1 METHODOLOGY FOR FORECASTING TECHNOLOGY GROWTH

7.1.1 Basic Considerations and Rationale for Forecasting

The development trends of technology are dependent on the levels of funding available over a period of years and on the efforts to develop improved products and services requiring an advanced technology. Analysis of economic indicators and the long-term trends of expenditures for research and development in electronics, computer systems, space applications, and communications indicate that the rate of technology development will continue to accelerate during the next 20 years. New developments that create social changes will meet some resistance; but new technologies for providing improved services that benefit society as a whole will be developed and implemented if the cost is acceptable. Despite the reductions of funding for some areas of research in 1970 and 1971, and the attacks on technology resulting from an emphasis on social and environmental problems, the overall funding and general pace of research will continue to increase. Increased funding for research and development will be provided to protect both domestic and export markets. Europe and Russia are challenging American domination of the world commercial aircraft market and are active in communications and satellite development. Japan is a major producer of communications satellite ground stations and is challenging American dominance of semiconductor and integrated circuit markets. There is growing international competition in aerospace, electronics, and communications. Important advancements in communications technology will continue to be made in the United States, Russia, Europe, and Japan during the next 20 years. The available scientific knowledge and rate of technology development are such that it is only a question of when the needed feasible technology improvements will be made. Figure 7-1 indicates the general trend of long-distance common carrier communications technology growth.

Figure 7-2 shows the total annual expenses, excluding taxes and profits for publishing and communication (Ref 2, p 318). These expenses amount to approximately 2-1/2 percent of the Gross National Product (GNP). The forecasted $30 billion annual expense for communications provides a strong economic incentive for technology developments that will improve productivity and service quality. About 1 percent of the GNP is due to the telephone industry, and 1-1/2 percent is generated by the combined telephone, broadcast, and the electronic communications industries. Figure 7-3 shows that the trend of total national expenditures for research and development is approximately 2-1/2 percent of the GNP. About 20 percent of the nation's total R&D effort is being expended to develop improved electrical and electronic systems. This is in general agreement with one-third to one-half of the GNP being due to information services such as handling, filing, and storing information; generating information, and communicating information (Ref 11, p 298).

The forecasted rate of technology advancement differs from the slope of the R&D funding-trend curves for the following reasons:

1. The future rate of development would be about the same as in the past decade, if there were no real increase in funding levels. If the long-term level of funding were increased sufficiently to offset the effects of inflation, then, on the basis of funding levels, the rate of new development could be expected to continue at a constant rate. R&D funding is expected to increase at a rate of 6 percent per year corrected for inflation.
2. The forecast long-term trend of a generally evenly growing level of R&D funding is expected to be more productive than the fluctuating funding levels of the past.
3. The national growth of education continues to produce a pool of competent scientists, engineers, and technicians. Achievement tests show recent graduates to be better educated than their predecessors, (Ref 19, p 1219).

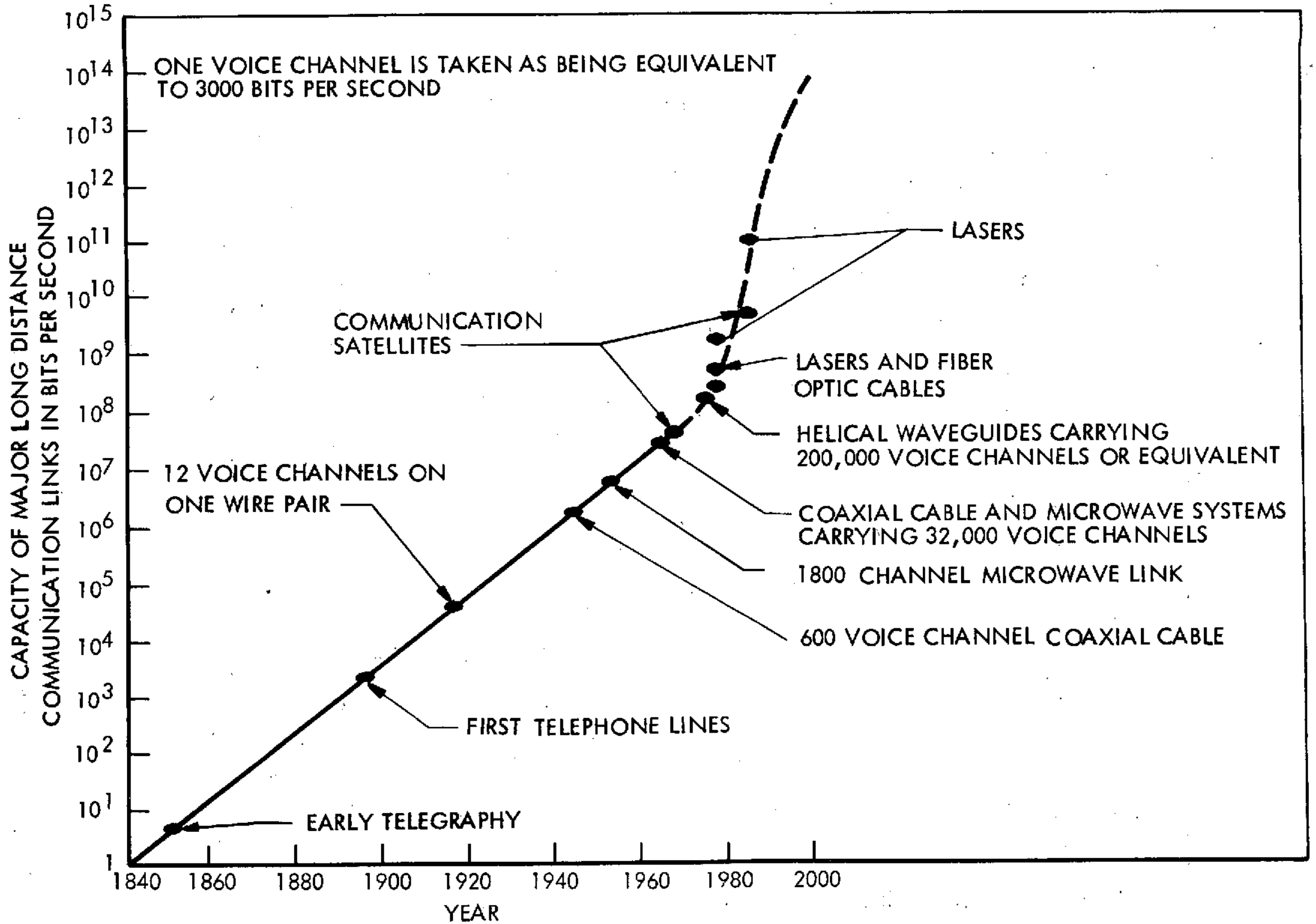


Fig. 7-1 Growth of Long-Distance Communication System Capacity

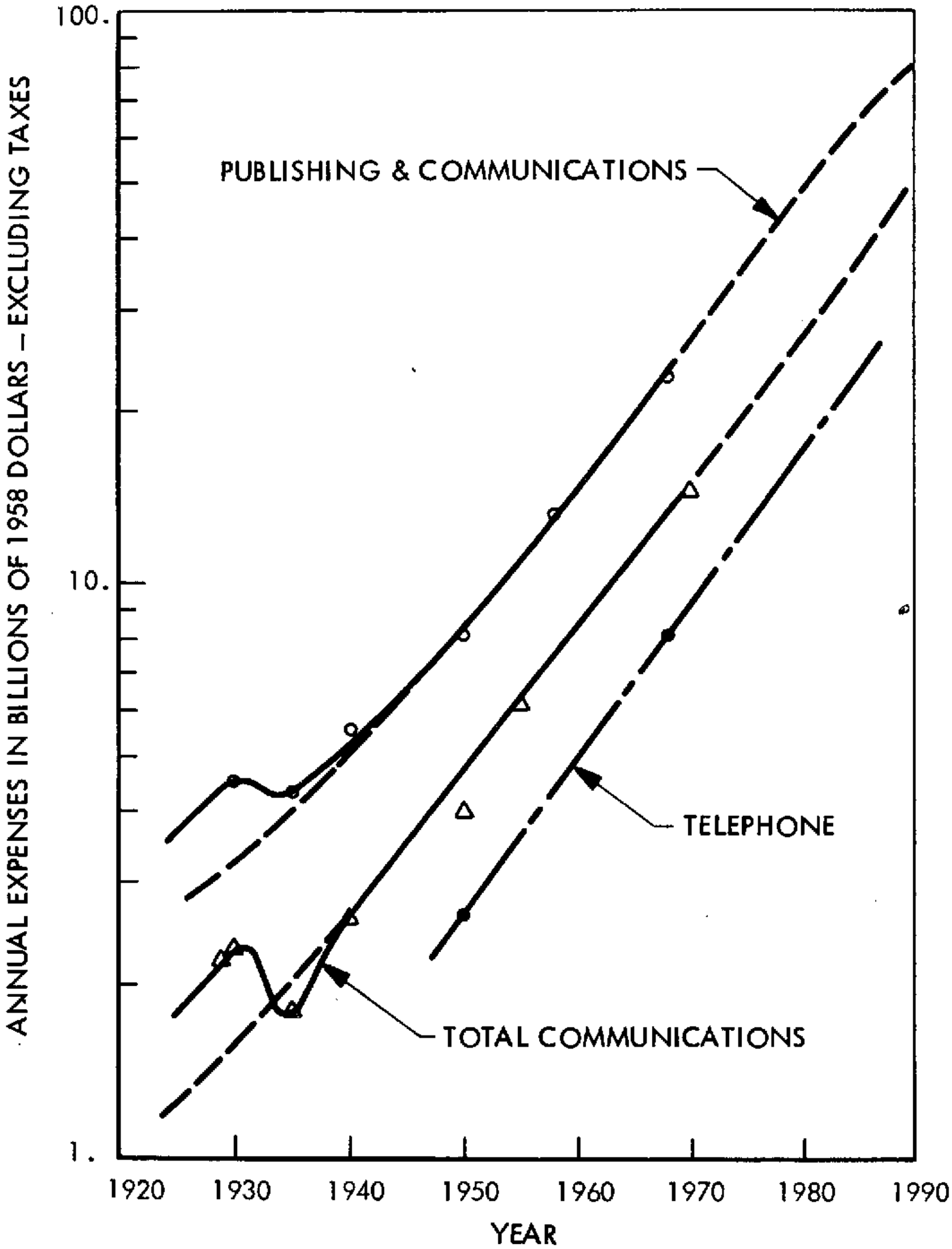


Fig. 7-2 Total National Expenses for Communications and Publishing

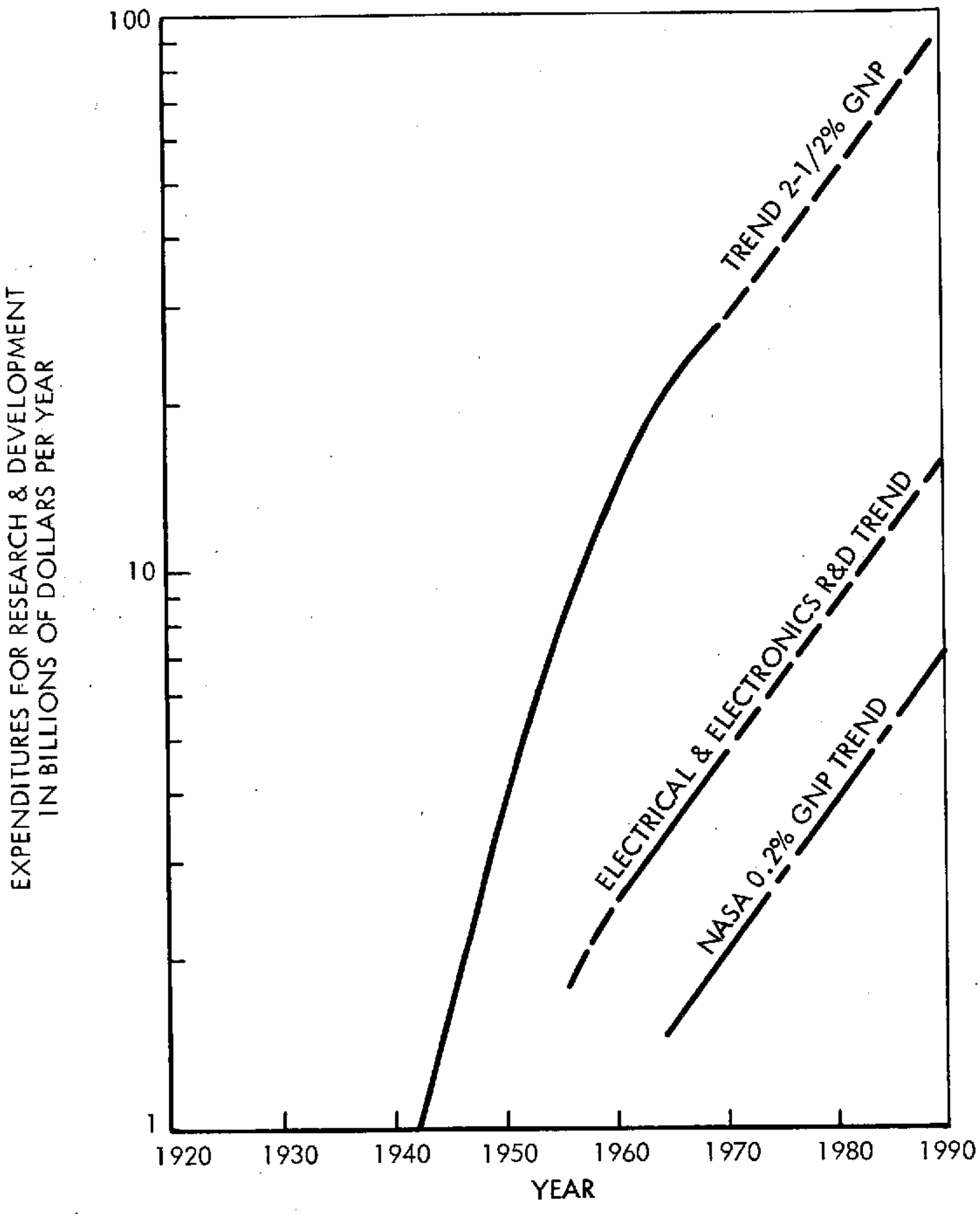


Fig. 7-3 Expenditures for R&D

A growing number of scientists and engineers is available with graduate degrees, and a progressive improvement in course content has resulted from new knowledge and from techniques created by new discoveries. Improved facilities and tools for experimentation and laboratory work are available to students at all levels of education.

4. Society is becoming more conditioned to change and improvements, and it expects technology to provide new services and an improved standard of living. A typical human reaction is "If they can go to the moon, why can't they solve my problem?"

5. Customer expectations of improved services and a competitive market force industry to continually develop improved products to stimulate or protect their sales. Recent improvements in solar cells, spacecraft regenerative metal-hydrogen batteries, and traveling wave tubes, for example, have been brought about in part by the effort to stay ahead of the competition.

6. The productivity of research and development is being improved by the use of such new and improved tools and methods as better, more-powerful computers and programs, better electronic instruments, improved materials, and improved information accessibility and transfer.

7. The time span between laboratory demonstration of concept feasibility to market application is shortening because of competitive pressures. Twenty-three years passed from Marconi's first radio transmission to the operation of the first commercial broadcast radio station. Today products move from the laboratory demonstration phase to the market phase in 3 to 5 years.

8. Research and development has become a competitive industry in itself, with some companies and organizations committed solely to invention and development of new products and technologies.

9. The development of new products and technologies in Europe, Japan, and Russia stimulated R&D in the United States. New products developed in foreign countries and marketed in the United States are creating increased pressures for more productive domestic R&D efforts. Increased global trade, global communications, and global competition are being financed by governments.

These nine factors have been considered in forecasting the trends of satellite and terrestrial telephone system technology growth.

7.1.2 Methodology Used for Forecasting

The forecasted trends have been developed by use of the established forecasting procedures and methodologies defined in Long Range Forecasting and Planning, A Symposium Held at the U.S. Air Force Academy, 16-17 August 1966 (338.544 Q32), which deals with the problems of forecasting trends of technology development and future technology requirements needed to counter military threats and meet national goals. Contributors are from NASA, industry, the academic community, and the Army, Navy, and Air Force. The subject matter deals with the space program, social and economic problems, and military needs for technology advancements. A more recent description of the specific methodologies is presented in "Technology Forecasting," in the IEEE Spectrum, October 1972, page 32.

In brief, the forecasting of future technology and of cost trends for planning new technology requirements was accomplished by the following seven-step process:

1. Engineering assessments were made of present, known technology capabilities. Assessments were made of possible improvements to existing hardware to better meet future requirements. For example, by knowing the capabilities of Intelsat IV and hardware improvements developed since the initiation of the Intelsat IV design, it is possible to determine the attainable performance capabilities of Intelsat V to provide increased capacity and serve a growing number of ground stations at a lower cost per channel year.

   The engineering assessments of expected developments were then carried further into the future by evaluating laboratory development efforts that show promise of resulting in further improvements of hardware and system capabilities. For example, increases in the efficiency of spacecraft solar cells from 11 to 15 percent, or possibly 18 percent, are expected before 1980. This forecast is based on the recent development of experimental cells of 15 to 18 percent efficiency. Factors affecting future use of these improved solar cells are design refinements, production procedures, and tooling development to provide the required volume of reliable cells at acceptable costs. How soon these problems will be solved by cell manufacturers depends largely on the importance of increasing cell efficiency as determined by market pressures for improvements, and on available funding. Increased cell efficiency is of considerable importance to users of spinning synchronous satellites in order to increase satellite power within the constraints of the booster shroud diameter, which restricts the satellite drum diameter and the area available.

   This type of background understanding has been applied in evaluating key technical parameters such as battery capacity in watt-hours per pound and traveling wave tube efficiency. Preliminary trend curves were constructed of key technology parameters to show expected capability from 1972 through 1985 on the basis of engineering assessments of present and developing technology, promising laboratory experimental results, and the driving motivation for hardware with specific performance capabilities to meet mission requirements. Such assessments were made by experienced specialists, each working only in his particular area of technical expertise related to the development of advanced communications satellites.

2. The second step was to collect and analyze historic data. Historical trends were developed for key technologies. Trend curves showing the rate of technology development were projected into the future on the basis of achievable

capabilities within the bounds and constraints of the scientifically possible and the limits of expected future funding for development.

3. The forecasts of future capabilities derived from the engineering assessments were correlated with the historic trends and projections.

4. The fourth step was to analyze the basic need for a technology improvement. An evaluation was made of the relationships between technology and the benefits, goals, and objectives to be fulfilled by the technology. The important question being Why is the technology important and what are the possible alternate technologies for meeting needs? These analyses provided an understanding of the technology growth phenomena and helped to reveal why the growth was as it was and what its expected limits should be. In some cases, correlation charts were prepared of forcing functions versus technology growth to provide insight into the relationships between selected forcing functions and technology growth.

5. The trends versus benefits relationships were considered. New technologies that show promise of great financial reward and benefit are expected to have much higher rates of technology improvement than mature technologies that are deemed to be essentially adequate. This fact should be reflected by the trend curves. Solid-state electronic technology, for example, will have a greater rate of technology advancement than satellite structures technology. Improvements in communications electronics directly impact the performance, effectiveness, and cost of communications, while structural improvements, for example, have a secondary impact because of weight or cost savings that affect only a minor portion of the total communications system.

6. The previous steps in trend forecasting were reiterated and refined, and final curves were generated that combined historic and future trends of technology development.

7. The results of technology forecasts were reviewed with experts working in the field of interest and were compared with related forecasts obtained from technical papers. The forecasts were refined on the basis of additional data obtained, and any reasons or basis of differences between the forecasts of future technology growth were determined.

The effects of a 1980 Space Shuttle/Tug transportation system capable of putting 2,300 to 6,000 kg of useful payload into synchronous orbit at a cost of on the order of $12 to $16 million per mission were evaluated. The transportation system cost estimate is based on a cost of $10 to $12 million for the Shuttle and $1 to $4 million for each Tug flight, depending on the type of Tug system used and whether or not it is recoverable. An important factor impacting future technology requirements is transportation cost for putting a pound of payload into synchronous orbit. Present costs are on the order of $22,000 per kg for Delta, Atlas/Centaur, and direct injection by Titan IIIC. Expected future costs are on the order of $2,600 to $6,500 per kilogram for Shuttle/Tug.

The effect of a conservative $6,000 per kilogram transportation cost will be to reduce requirements for satellite technology developments directed primarily towards satellite weight reduction. High transportation costs and the limited weight capability of boosters has resulted in considerable technology development in the past toward reducing satellite weight. Table 7-1 lists booster system performance parameters and cost per pound placed in synchronous orbit.

Table 7-1

TRANSPORTATION PARAMETERS FOR SYNCHRONOUS ORBIT SATELLITES

Year	Booster	Cost M $	Synchronous Orbit Weight Capacity lb	kg	Cost K $/lb	K $/kg
1963	Delta	4.6	85	38	54.0	118.0
1967	Delta	4.6	192	87	24.0	53.0
1969	Delta	4.6	334	154	18.0	39.8
1973	Delta	8.0	770	350	10.0	22.0
1971	Atlas/Centaur	16.0	1584	715	10.0	22.0
1974	Atlas/Centaur	17.0	1760	800	9.8	21.6
1971	Titan IIIC	24.0	3000	1360	8.0	17.6
1975*	Titan IIIC	29.0	3400	1550	8.5	18.7
1975*	Titan IIIC/K	30.0	4800	2180	6.2	13.7
1978*	Titan IIID	37.0	7000	3180	5.4	11.9
1985*	Shuttle/Tug	16.0	8000	3640	2.0	4.4

*Estimated in 1973 dollars

7.2 TREND OF COMMUNICATIONS SATELLITE TECHNOLOGY GROWTH

The forecasted growth of performance capabilities of the total spacecraft is evaluated in this paragraph of section 7.0, and the forecasted growth of subsystem capabilities and supporting technologies in paragraph 7.3. Forecasts of satellite technology growth are related to Intelsat and Domestic Satellite (DOMSAT) systems, because these are the only systems for which accurate, consistent data are available for the historic, present, and planned future systems. The Intelsat satellites provide the best set of consistent data for satellite technology forecasting.

Conceptual satellite systems formulated for the missions contained in each of the seven categories of need defined in Section 6 are presented in Section 10, Sensitivity Analysis. The 1985 era conceptual systems have been formulated from the forecasted technology growth and costs defined in this section.

7.2.1 Trend of Intelsat Technology Growth

The trend analysis makes use of historic trend data and information on planned future developments of Intelsat communications satellites, which are available in technical literature prepared by the staff of the COMSAT Corporation (Ref 42, p 36). Figure 7-4 shows historic and forecasted costs for the various Intelsat configurations and the expected effect of future options upon costs. Cost per two-way voice channel per year is based on the design operating life of the satellite when all transponders are fully utilized and in a traffic service mode. Network service requirements limit the number of voice channels that can be carried per transponder because of the present need to relay several carriers rather than a single carrier per transponder in order to serve all ground stations. The average two-way channel capacity per satellite is dependent on the network configuration, ground station antenna size, receiver noise temperature, and message format and modulation technique. The costs per channel-year include satellite development costs prorated for the number of satellites, satellite recurring costs, and booster costs. Table 7-2 presents data on satellite cost, weight, life, booster system, and number of channels which provide the basic data for Figs. 7-4 through 7-7 on satellite development trends. The Intelsat satellites serve a growing network providing point-to-point communication of voice, data, and video between over 40 ground stations in the Atlantic basin alone. Standard Intelsat ground stations have a ratio of antenna gain to effective noise temperature of 40.7 dB/^{o}K. Consequently, Fig. 7-4 indicates results of technology developed and applied to best satisfy the needs of the Intelsat network. User data transfer, for example, is usually carried on voice circuits. Therefore, the SPADE multiple access system with PCM channels was

Table 7-2

COMMUNICATIONS SATELLITE CHARACTERISTICS AND COST

Satellite	Weight (KG)	Design Life/ Power (KW)	No. Two-Way Voice Channels	No. Trans-ponders and BW (MHz)	No. Satellites	Program Cost for Satellites (M$)	Booster	Total Cost Per Sat. Inc. Booster (M$)	Total Sat. Cost Per Kg/ Cost Per Transpt Year (K$)	Cost Per Two-Way Voice Channel Year (K$)
Intelsat I	38	1.5/0.03	240	2/26	2	10	Delta	10	260/3300	28.0
Intelsat II	87	2.0/0.1	240	1/126	5	18	Delta	8	92/4000	16.0
Intelsat III	154	5.0/0.13	1,200	2/225	8	56	Delta	13	87/1300	2.2
Intelsat IV	715	7.0/0.6	4,500	12/36	8	112	A/C	31	44/370	1.0
Intelsat IVA	800	7.0/0.7	6,000	24/36	3	73	A/C	41	51/240	1.0
Intelsat V*	800	7.0/1.1	13,000	15/180	6	110	A/C	35	44/330	0.38
Intelsat VA*	840	7.0/2.0	25,000	20/200	6	114	A/C	36	42/260	0.20
Intelsat VI*	1,820	7.0/3.0	30,000	30/150	6	130	S/Tug	33	18/160	0.16
Westar	270	7.0/0.3	2,500	10/36	3	21	Delta	15	55/210	0.85
Anik	270	7.7/0.3	2,500	10/36	3	33	Delta	19	70/270	1.1
RCA*	450	7.0/0.8	9,000	24/36	3	60	Delta	30	67/180	0.40
GTE**	270	7.0/0.3	5,000	10/36	3	24	Delta	16	60/230	0.46
1985 DOMSAT*	740	7.0/5.0	35,000	48/60	6	116	S/Tug	24	33/71	0.09
1985 DOMSAT*	495	7.0/5.0	35,000	48/60	6	145	Delta	34	70/101	0.13

*Possible configuration for future satellite application.
**Serving five-ground-station network with 92-ft antennas.

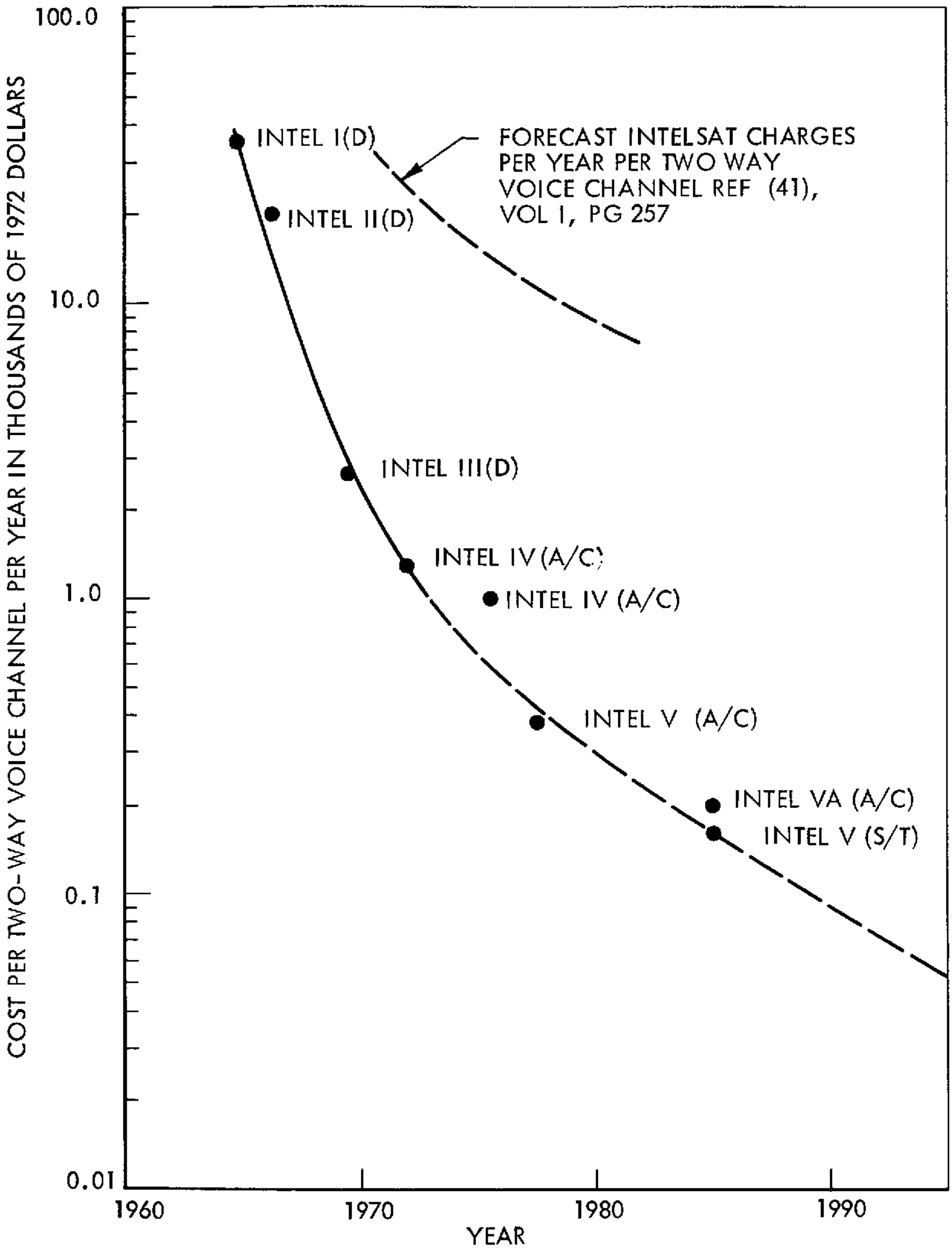


Fig. 7-4 Trend of Intelsat Costs Per Two-Way Voice Channel, Per Year for Satellites and Boosters

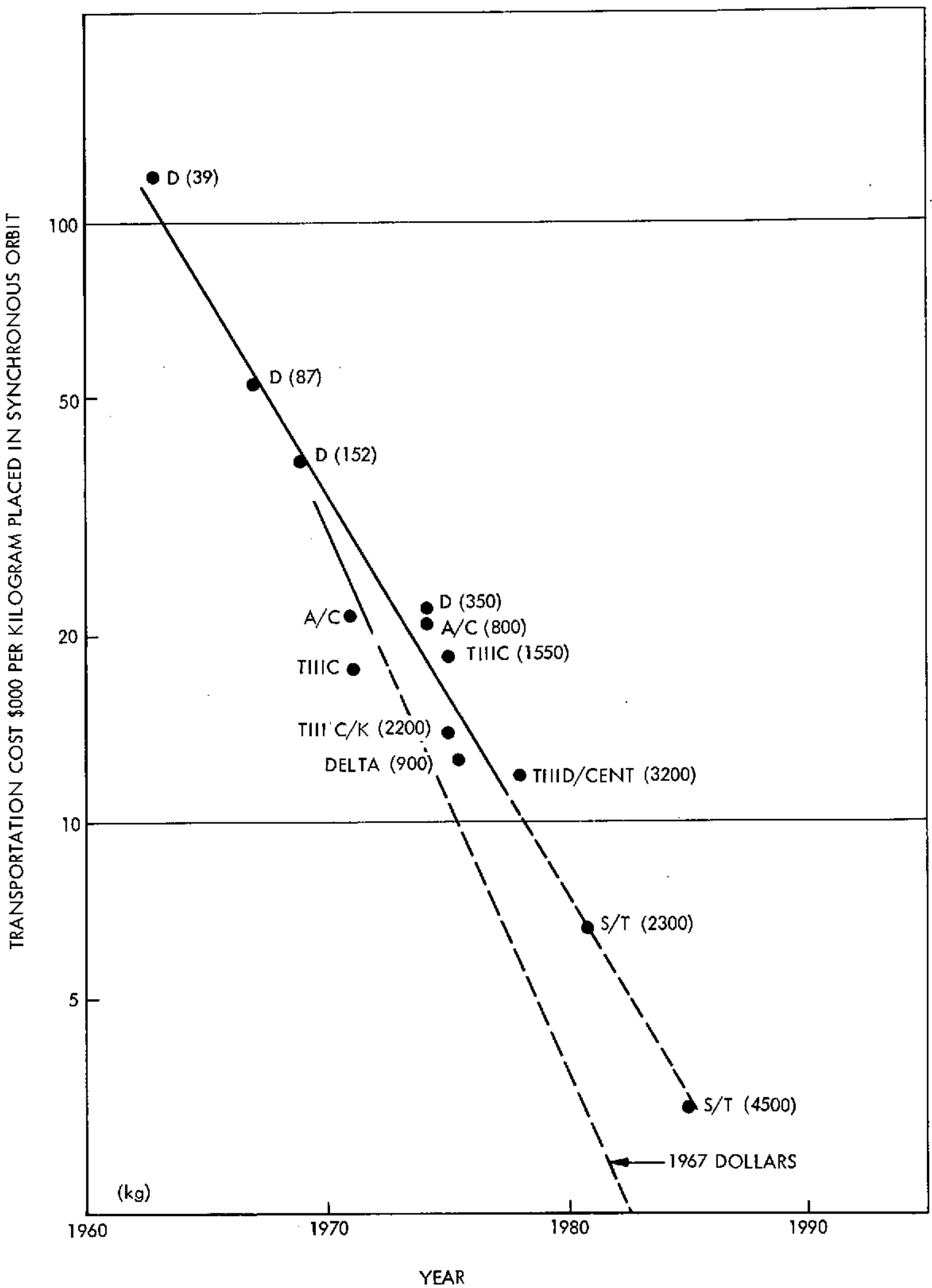


Fig. 7-5 Trend of Transportation Costs per Kilogram Placed in Synchronous Orbit

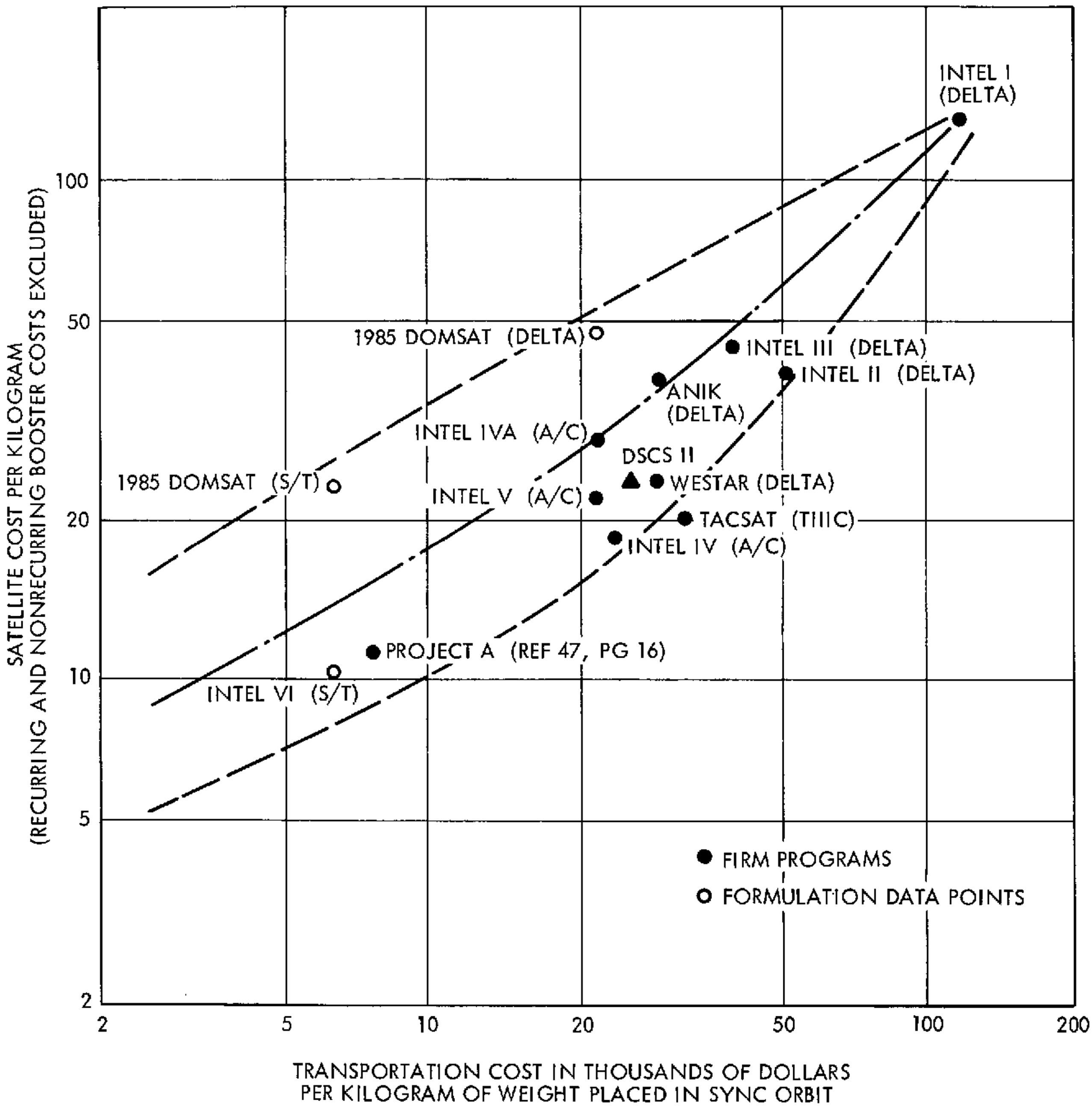


Fig. 7-6 Correlation Between Transportation Costs and Satellite Costs

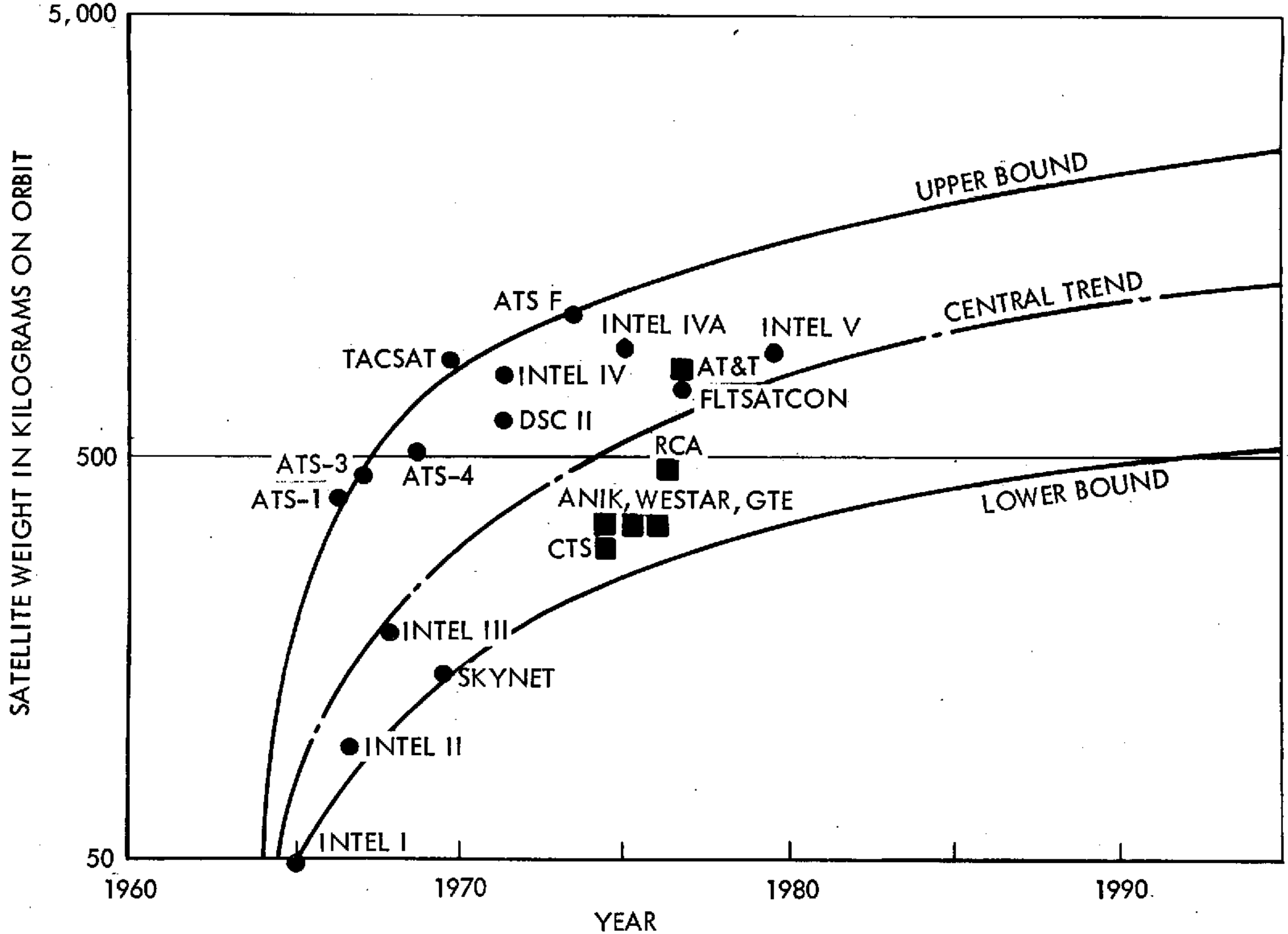


Fig. 7-7 Growth Trend of Communication Satellite Useful Weight on Orbit

developed to provide a 64 KBPS capacity per digitized voice circuit. The forecast Intelsat user charges per two-way voice channel presented in Fig. 7-4 are independent of ground terminal costs. These charges lag the cost per two-way channel year capacity, because the charges must cover unused periods for demand access channels plus provisions for administrative overhead, technology development, profits, and taxes.
profits, and taxes.

The Intelsat V data point is based on the results of a funded study performed by Lockheed under the direction of COMSAT for the International Telecommunications Satellite Consortium, (Ref 43). Intelsats I through III were launched on Delta boosters and IV, IVA, V, and VA on Atlas/Centaur boosters. Intelsats I through IVA are spinning satellites. Intelsats V, VA, and VI are three-axis-stabilized with unfurlable solar arrays and multiple spot beams.

The Intelsat V satellite has the following technical features:

- Three-axis-stabilization – two-axis gimballed momentum wheel
- Extendable flexible solar arrays with single-axis sun tracking
- Hydrazine plus ion thrusters for N-S stationkeeping
- Ni-Cd batteries for full eclipse power
- Ten preassigned 4/6 GHz plus five 11/14 GHz transponders
- Eight spot beams by means of one multiple feed reflector antenna

Equivalent two-way voice channel capacity per satellite listed in Table 7-2 is based on the usable channel capacity for the most probable network traffic configuration and use of a combination of frequency-division multiple access (FDMA) and time-division multiple access (TDMA) in 1975-era satellites.

The 1985-era Intelsat VA is similar to Intelsat V but with the following improvements which are due to expected future technology development:

- Weight increase of 40 kg resulting from booster improvement
- Reduced use of hydrazine propellant and total dependence on ion thrusters for N-S stationkeeping
- Use of Ni-H_2 batteries with 20 to 35 watt hr/kg capacity

- Extensive use of time-division multiple access (TDMA)
- Use of 10 spot beams provided by lens antenna with up to 4 transponders per spot beam

Intelsat VI will use the same technology base as Intelsat VA but will use the Shuttle/Tug transportation system for orbit injection. The forecast cost reduction of Intelsat VI over VA per channel is based on the expected benefits of the Shuttle system, as defined in para 7.2.2, following. Communications satellite design and cost effectiveness are highly sensitive to booster system capability. Therefore, the impacts of boosters and the Shuttle/Tug transportation system on communications satellites is examined briefly. Future communications satellite technology requirements are affected by such philosophies as use of on-orbit repair, refurbishment, or fuel resupply. Therefore, the needs for and economics of on-orbit refurbishment of synchronous communications satellites are briefly evaluated in para 7.2.5

7.2.2 Trend of Booster and Transportation Costs

The general conclusion resulting from analysis of effects of booster systems is that the lower the total transportation cost per pound for synchronous orbit injection, the less need there is for advances in basic spacecraft technology capabilities for meeting future needs. Advancements in the communications technologies are needed regardless of the booster system developed; this need is due to crowding of the available radio frequency spectrum, potential interference problems, and the demands for newer and better communications services, as summarized in para 5.3. Table 7-1, Transportation Parameters for Synchronous Orbit Satellites, shows that transportation costs have been steadily declining as a result of numerous improvements in booster performance. In 1963 the Delta booster put 38 kg into synchronous orbit at a cost of $4.6 million, for a cost of $260,000 per kg in orbit. One present Delta configuration can put 350-kg into orbit at a cost of about $8 million, or $22,000 per kg. The present trend of booster technology development indicates that transportation costs will decline during the next 10 years at about the same rate as during the past 10 years, as indicated in Fig. 7-5, which was plotted from the data of Table 7-1. The long-term trend of transportation cost reduction in 1973 dollars is expected to continue into the 1990s before leveling off.

The development of the Titan IIID/Centaur and the proposed improvements uprating of the Delta, Atlas, and Titan boosters substantiate the forecast trend of improvements in booster cost effectiveness. The forecast cost reduction and increased cost effectiveness of Intelsat VI over Intelsat VA, as shown in Table 7-2 and Fig. 7-4, is the result of use of the Shuttle rather than the Atlas/Centaur. The expected booster cost for Intelsat VA is $18 million to inject some 820 kg into orbit. The Shuttle/Tug is expected to inject some 4,000 kg, consisting of two to four satellites, for on the order of $16 million, or double the satellite weight for half the cost per satellite. The $16 million estimate is based on the following:

$12 million per Shuttle mission
$3 million for an expendable Tug
$1 million for multiple payload integration and launch support
$16 million total

These costs are expected to decrease with time, as shown by Fig. 7-5. The values given are conservative estimates and are based on available information on planning for the Shuttle and Tug programs. Although the estimates are conservative for the 1982 era, if costs or performance vary by 50 percent, the basic trends or conclusions of this analysis will not be significantly altered. Generalization and suboptimization have been used to determine general trends independently of detailed booster and transportation system capabilities and costs, which cannot be accurately forecast at this time.

The ideal Shuttle/Tug costs and capabilities to be used for this analysis are such that optimists and strongest proponents of the Shuttle/Tug program may consider the values pessimistic or conservative, while pessimists and opponents may regard the values as possibly attainable but optimistic. The downward trend of space transportation costs forecasted in Fig. 7-5 indicate that a $1,000 to $8,000 cost per kilogram for injection of 1,000 to 4,000 kg satellites will be realized by some means during the 1980–1990 era.

Developing capabilities and changing policies by the USSR, China, Japan, and Europe will eventually result in a more competitive offering of booster capabilities in the 500 to 4,000 kg range. Such competition will impact the use and costs of transportation systems. Costs for competitive booster service may be determined as a matter of national policy affecting the utilization and amortization of a national resource in the best interest of the nation's image. National image and prestige have been the bases for some of the most expensive expenditures by governments. The forecasted values presented therefore serve as reasonable estimates of future cost trends in a competitive world market. Such cost estimates are needed for cost-effectiveness and sensitivity analyses of various satellite technologies. Technology parameters are evaluated in Section 10 for the 1975 and 1985 era satellites based on present booster costs. The results are adjusted for 1985 era satellites on the basis of the forecasted 1985 era transportation costs.

7.2.3 Correlation Between Transportation and Satellite Costs

Figure 7-6 shows the relationship between satellite cost per pound on orbit and transportation costs per pound placed in orbit. The general relationship is based on a mix of Intelsat, COMSAT, and Military Satellite Systems. Satellite cost per kg includes prorated development costs plus recurring costs. Satellite costs become less sensitive to transportation costs as the transportation costs approach zero. Electronic ground station equipment with essentially zero transportation cost, for example, can cost on the order of $100 per kilogram because of its inherent complexity. Present day booster costs of approximately $22,000 per kilogram are a major contributing factor to present satellite costs. The formulated Intelsat VI and DOMSAT Shuttle/Tug-launched satellites are based on the conservative cost and capability values defined in para 7.2.2, above, and presented in Figs. 7-4 and 7-5. No satellite cost savings were allowed as a result of on-orbit repair or refurbishment. Cost reduction per kilogram was based on:

- Greater use of available standardized or flight-proven components wherever practical
- Reduced development and production costs resulting from reduced constraints imposed by booster system volume and weight capacity
- Reduced development and production costs resulting from reduced need for weight savings to limit transportation costs

The cost per kilogram for the Shuttle/Tug-launched DOMSAT communications satellites is in general agreement with the Payload Effects Follow-On Study final report, "Impact of Low Cost Refurbishable and Standard Spacecraft Upon Future NASA Space Programs." NASA Contract NAS W-2312, dated 15 May 1972, pages 2-2 and 6-13. The data were developed independently from the effort performed on the Payload Effects Follow-On Study but utilized the same 1975 baseline satellite concepts and technology base as a starting point for analysis.

Satellite cost is sensitive to several interrelated factors other than transportation costs, and therefore several different correlations are possible. Satellite costs per pound also correlate well with gross satellite weight for the following reasons:

1. There is generally a close correlation between booster capability, which determines gross satellite weight, and transportation cost per kilogram.
2. There are economics of scale affecting satellite costs. Communications satellite costs for program management and systems test are fairly fixed and do not increase in direct proportion to satellite weight. This factor favors the cost-versus-weight ratios of large satellites using large boosters.
3. Satellite cost parameters tend to decrease with time as experience and competition increase. The first communications satellites, although small, required extensive original development. Each generation of satellites benefits from the available technology, experience, and results of previous satellites. This trend of spacecraft development and maturity has been occurring simultaneously with the similar trend in booster development shown in Fig. 7-5 and has resulted in increased weight capability at a decreased cost in constant value dollars.

Figure 7-6 showing that spacecraft costs are related to booster costs confirms the results of NASA Report TMX-62,223, "Space Program Payload Costs and Their Possible Reduction," pages 2 and 3, dated January 1973. The forecasted trend of reduced satellite costs per pound is consistent with the applicable recommendations and conclusions of this report. The baseline Intelsat satellites were developed under commercial procurement contracts that specify cost limitations and performance. Scientific requirements and costs for development of new subsystem technologies are minimized.

7.2.4 Impact of Transportation Costs and Capabilities on Satellite Size and Technology

The continued use of numerous small and medium-sized satellites weighing 250 to 850 kg is expected to continue due to present booster costs, and continued technology growth, which facilitates increased communications capacity per kilogram of satellite (see Fig. 7-11). Present booster cost and capacity constraints impact the study results and conclusions, because the satellites developed in the late 1970s affect the uses, operating philosophies, and technologies utilized for satellite systems in the 1980s. Figure 7-7 shows the trends of weights of communications satellites launched since 1962. Intelsats I, II, III, ANIK, and WESTAR are relatively small Delta-launched satellites. Such satellites are attractive due to the minimum risk and cost required during the startup phases of network operation. Future Delta-launched satellites are expected to grow to $\sim$ 600 kg by the late 1970s. Although it is possible to place some 2,300 kg into synchronous orbit by means of a Titan IIIC with an optimum apogee stage, most plans are limited to the use of Atlas/Centaur or Delta. The $30 million Titan IIIC cost tends to price this booster outside of the commercial market. COMSAT's present plan to launch Intelsat Vs on Atlas/Centaurs in the late 1970s and early 1980s indicates the trend toward satellites weighing between 260 to 850 kg in the early 1980s. Available satellite and earth-station technologies can provide the required communications capacity with a 800 kg orbit weight capability. Therefore, the need for satellites weighing over 2,000 kg is eliminated unless the present cost per kilogram placed in orbit is significantly reduced,

The present costs of approximately $10 million for a Delta launch, $20 million for an Atlas/Centaur, and $30 million for a Titan IVC are incentives driving weight-saving technology growth. Such cost differentials represent important risk factors for commercial communications companies such as COMSAT, AT&T, GTE, CML, and RCA. Clearly the booster (transportation system) capability and cost have a prime impact on the trend of future satellite technology development, and this impact needs careful consideration when determining key technologies most worthy of further development to enhance total systems cost effectiveness.

If the transportation cost per kilogram of spacecraft injected into orbit is $22,000 for the Delta booster and possibly $6,500 for the Shuttle/Tug system, then a 3:1 increase in satellite weight (caused by design for module replacement when the Shuttle/Tug system is used) would consume the savings resulting from lower transportation cost (Ref 89, p 46). If the Shuttle/Tug development objective of about $3,330/kg transportation cost is realized, then about a $5 million savings per satellite, with a 3:1 weight growth, could be realized because of reduced transportation costs. A greater transportation cost savings can be realized by switching a 500 kg satellite from a $10-million-per-launch Delta to a possible $3-million-per-launch Shuttle/Tug that boosts several satellites into orbit and allows a sharing of launch costs. Much of course depends on the Tug concept developed and the final philosophy for supporting communications satellite usage.

Relaxation of tight satellite weight and volume constraints can lower satellite cost per kilogram and per unit of service. Many costs, however, are fairly fixed. Traveling wave tube costs, for example, are dependent on costs for administration, design, manufacturer's adjustment, and extensive testing for performance to specification requirements; and it is doubtful that a traveling wave tube amplifier costing $25,000 and weighing 1.5 kg could be reduced 40 percent in cost if it were allowed to weigh 4 kg. The same is true for many other components, such as solar cells, batteries, and solid-state electronic assemblies. If the Delta or Atlas/Centaur boosters are used, each kilogram of spacecraft weight is worth approximately $25,000 in booster costs. Therefore, $25,000 can be justified in added recurring and nonrecurring costs per kilogram of launch spacecraft weight saved. Use of the Shuttle/Tug system instead of the Delta or Atlas/Centaur implies that an added kilogram of spacecraft weight must save, total recurring and nonrecurring costs, between $3,300 to $6,500 for each spacecraft assembled and injected into orbit.

It is estimated that a reduction of booster costs from $22,000 to $6,500 per kilogram plus reduction of volume, weight, and ascent load restraints could result in a 30 percent reduction of combined recurring and nonrecurring costs. The expected savings are due to reduction of analytical costs, use of less expensive fabrication methods where practical, greater use of available flight-proven components, and limited redeveloping or redesign for minor weight and volume savings. The resulting spacecraft would be on the order of 50 percent heavier, would be slightly larger, and would have greater inherent redundancy. Such a spacecraft would not require extensive on-orbit testing except by means of the earth station command and telemetry system, and there would be no provision for modular replacement or repair after the initial launch. If a vehicle failed, it would be replaced by a second vehicle for recurring costs on the order of $10 million for the spacecraft plus on the order of $5 million for transportation.

An analysis of module replacement concepts resulting from use of the Space Shuttle system is beyond the scope of this study. System requirements for cost-effective on-orbit refurbishment are analyzed in par. 7.2.5 sufficiently to determine the probable impact on spacecraft technology requirements.

7.2.5 Cost-Effectiveness Requirements for On-Orbit Refurbishment

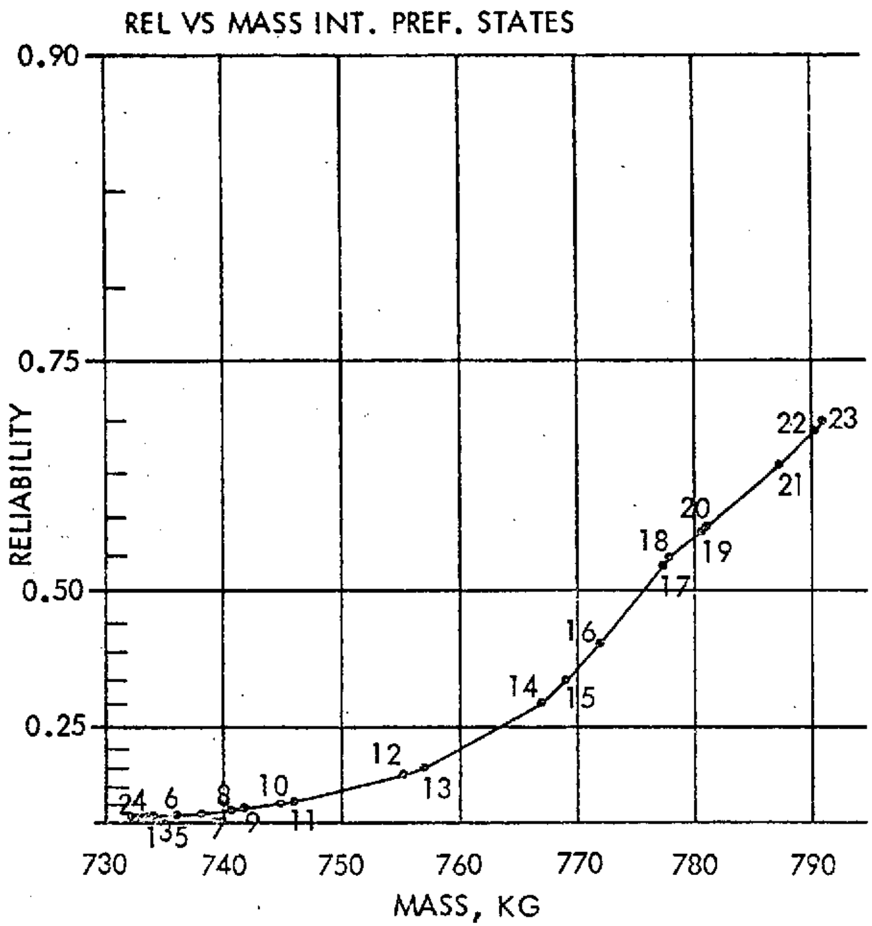
Communications satellites are highly sensitive to booster performance because of the high energy of 39,680 ft/sec required for synchronous injection. Many of the advantages of Space Shuttle systems that can be readily applied to low-earth-orbit spacecraft can not be easily applied to commercial communications satellites. The formulated DOMSAT conceptual satellites are not repairable systems for the following reasons. The estimated satellite recurring cost is on the order of $15 million with a 700 kg orbit weight. Recovery from orbit would cost on the order of $7 to $14 million. There would be additional costs for spacecraft repair and testing plus $5 million for reinjection of the satellite. Therefore, it does not appear economically feasible to recover low-cost synchronous spacecraft from orbit, repair, and reinject a partially expended and possibly near obsolete spacecraft.

On-orbit repair and refurbishment of communications satellites is highly sensitive to the final Shuttle/Tug, teleoperator, and communications satellite capabilities, costs, and operating philosophies. If the rate of technology development and growth of demand for information transfer are such that operational satellites become obsolete within approximately 5 years, then the satellite life and attainable reliability may be such as to make refurbishment unattractive. The Intelsat V study configuration provides a 7-year operating life and a 0.7 probability of success. Increased weight capability plus reduced transportation costs due to use of Space Shuttle will likely result in greater utilization of redundancy and switching to further improve satellite reliability.

Figure 7-8 shows the incremental increases in expected reliability over a 7-year life versus weight increase for selected redundancies as noted for a 800-kg, 7-year life, 14-transponder domestic satellite configuration (Ref 44). Figure 7-9 shows the variation of expected reliability versus time. The values are based on allowing failure of 4 of the 14 transponders for successful operation.

To be cost effective, the total cost for making a satellite refurbishable or repairable on-orbit, plus the cost for transportation of the refurbishment module, the cost of the module, and the cost of the teleoperator should be less than the product of probability of failure on-orbit times the recurring cost of the baseline satellite on-orbit. If technology growth coupled with lower transportation costs foster a doubling of expected satellite reliability by 1985, the refurbishment system costs must be lowered proportionately to remain cost effective. As technology continues to provide lighter-weight, more-reliable standardized components of lower cost in constant dollars, the use of multiple, light-weight, low-cost, non-refurbishable satellites may prove to be economically attractive.

Figure 7-9 shows that the calculated probability of a conceptual Intelsat V configuration performing properly for 5 years is 0.8. Therefore, a refurbishment system should cost less than 0.2 (20 percent) of the satellite and transportation charges. A 10 to 20 percent variation in the spacecraft and transportation costs presented in Figure 10-13 would result in about a 5 to 10 percent variation in total system cost over the seven-year operating period. Estimated cost variation due to use of on-orbit refurbishment for commercial spacecraft in synchronous orbit is on the order of half of the expected savings attainable due to use of Space Shuttle/Tug to replace Delta or Atlas/Centaur boosters. The potential effect of on-orbit refurbishment may be very significant in



INT. PREF. STATES

STATE	SUBSYSTEM MODULE
1	TDA + TRANSISTOR AMPLIFIER
2	CMD LOGIC DECODER
3	CMD POWER SUPPLY
4	LOCAL OSCILLATOR
5	LOCAL OSCILLATOR
6	DC-DC CONVERTER
7	DC-DC CONVERTER
8	MIXER + BB 4 GHz TRANSISTOR AMPLIFIER
9	RECEIVER LOCAL OSCILLATOR
10	ATTITUDE CONTROL ELECTRONICS
11	MIXER + BB 4 GHz TRANSISTOR AMPLIFIER
12	SPOT BEAM TRANSISTOR AMP + TWTA
13	WHEEL ACTUATORS
14	SPOT BEAM TWTA
15	TRANSMITTER LOCAL OSCILLATOR
16	TRANSISTOR AMP + MIXER UP CONVERTER
17	POWER CONDITIONER + CONTROL
18	CMD POWER SUPPLY
19	HORIZON SENSOR + ELECTRONICS
20	CMD LOGIC DECODER
21	TLM REDUNDANT ELEMENTS
22	ATTITUDE CONTROL ELECTRONICS
23	TDA + TRANSISTOR AMPLIFIER

Fig. 7-8 Reliability Versus Mass Plot

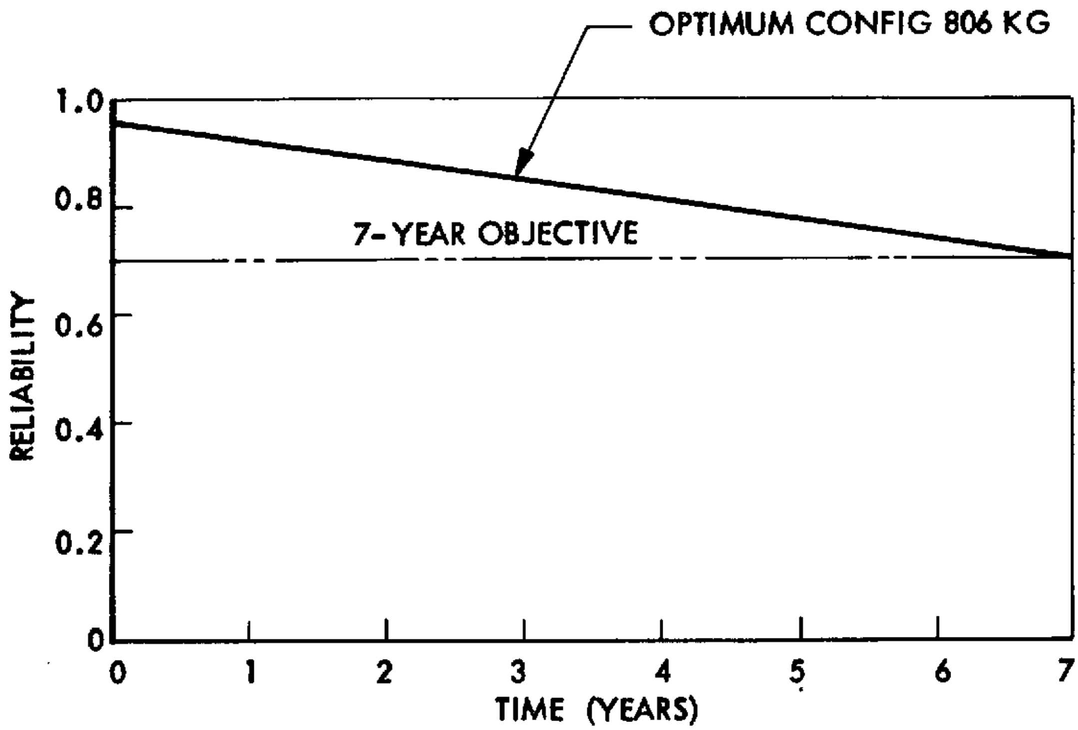


Fig. 7-9 Reliability Versus Time Plots

total dollar savings. It appears, however, that the effects of on-orbit refurbishment on synchronous commercial communications satellite cost effectiveness will be sufficiently less than other factors. The potential capabilities and cost effectiveness of on-orbit refurbishment systems and refurbishable spacecraft design concepts are not expected to change the study results. On-orbit refurbishment is therefore not considered as a specific element affecting the forecasted trends of technology development or the characteristics of conceptual spacecraft presented in this study.

The concepts of developing standard hardware items and repeatedly utilizing standard flight-proven hardware to the maximum extent possible to reduce the risks and costs of spacecraft development is an important factor which affects total system costs and cost trends. The expected reduction of costs due to technology improvement and standardization are reflected in the spacecraft cost model defined in par. 10.4.1 of the sensitivity analysis section.

7.2.6 Trend of Satellite Technology Growth

Figure 7-10 shows that the effective (constant year dollar) trend in cost per two-way voice channel (including satellite development, recurring costs, and booster costs) has the potential of declining at a rate of about 40 percent per year. This cost improvement trend is due to a combination of three factors.

1. More cost-effective booster, as shown in Fig. 7-5
2. Improved ground stations; communications processing, compression and handling
3. Improved communications satellite technology

The general trend curve is fairly representative of both Intelsat and Domestic satellites. Special applications satellites such as Aerosats and Maritime satellites should follow a similar, parallel, trend curve; because, available technology and hardware are used for terminals, communications satellites, and booster systems.

Figure 7-11 shows the decreasing trend of satellite weight in orbit required per two-way voice channel. The solid curve shows the trend of improvement from satellite technologies. The dashed curve shows the differential of expected improvement from better ground stations, communications processing, compression, and handling. These trends are fairly independent of the effects of booster systems because they show the ability of technology development to provide increasing capability per kilogram of satellite. Also the curves are fairly independent of distortions caused by monetary inflation.

The dashed line curve of Fig. 7-11 is based on forecasted ground-station developments that will increase satellite capacity by means of Time Division Multiple Access systems, data compression, and speech interpolation. The technologies required for accomplishing the degree of improvement forecast have all been demonstrated either by COMSAT Corporation with Intelsat IV, by NASA with ATS, or experimentally by laboratory demonstrations. COMSAT's Digital Television Communications System, for example, is capable of doubling the capacity of present satellite television services by use of existing commercial satellites and earth stations. The system converts the video and audio signals into digital form and uses a form of differential-pulse-code modulation to reduce or compress the digital signal. Forward-acting error coding

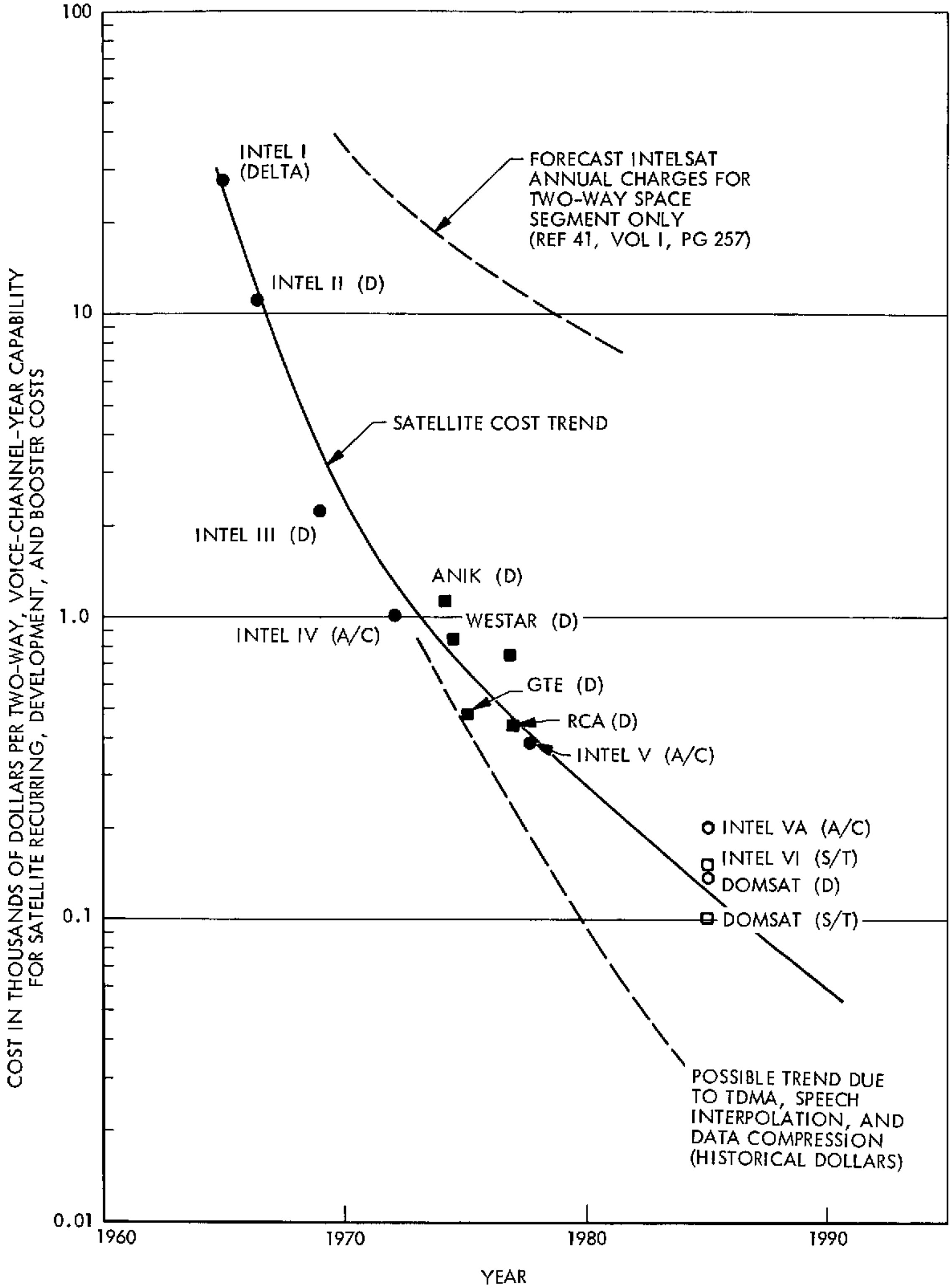


Fig. 7-10 Satellite Cost Trend Per Two-Way Voice-Channel-Year

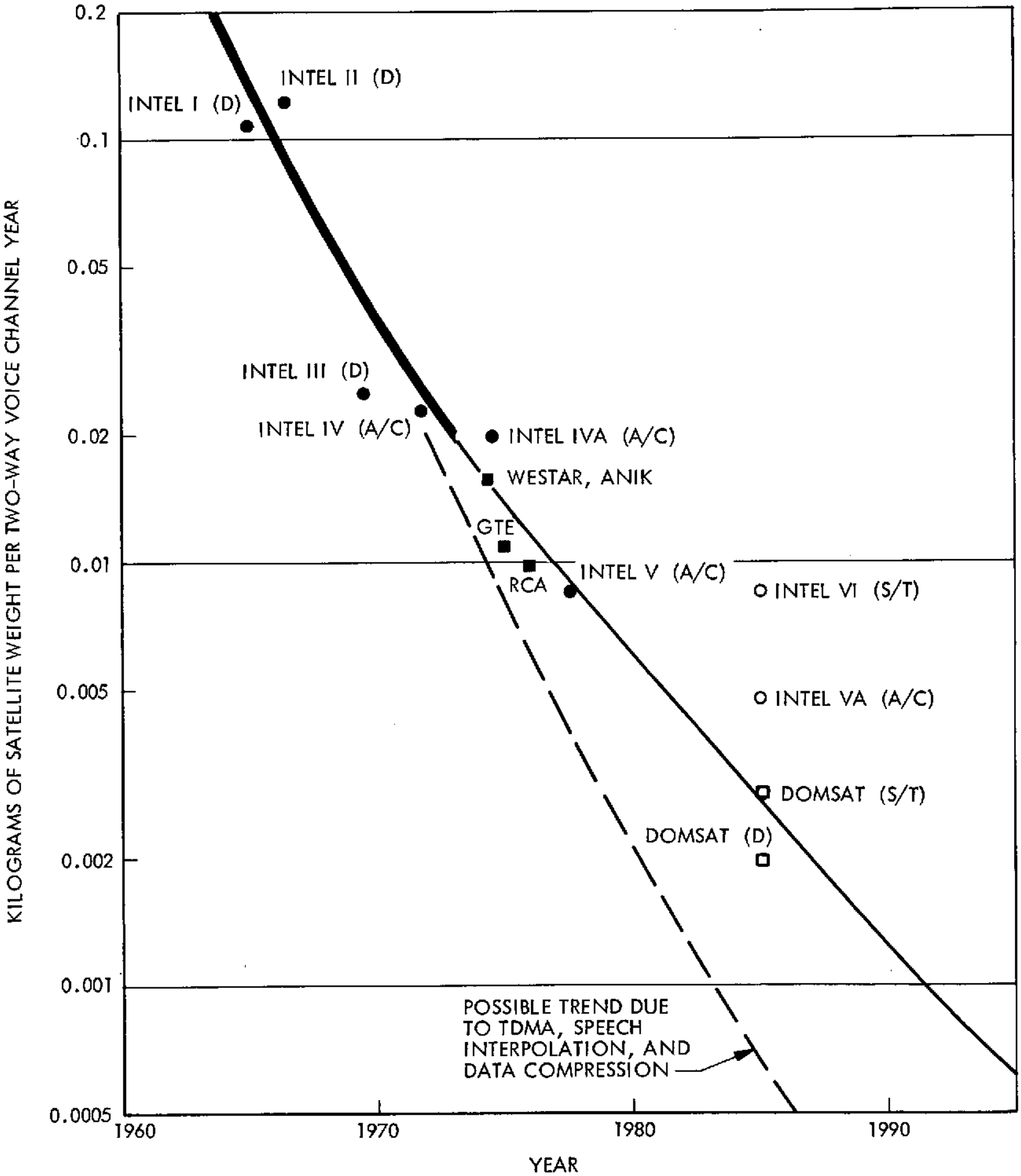


Fig. 7-11 Trends of Communication Satellite Technology Development as Indicated by Satellite Weight Per Two-Way Voice-Channel-Year Capability

is employed to save power by providing the desired bit error rate at a reduced carrier-to-noise ratio. The system allows trading of capacity for power and provides the ability to deliver full broadcast quality TV into small earth stations with 15-ft-diameter antennas by means of Intelsat IV. COMSAT's SPADE system for essentially doubling the channel capacity of transponders carrying demand access channels is described in the January 1971 IEEE Spectrum, page 59. Extensive work is proceeding on video-channel signal compression. The July 1972 Proceedings of the IEEE, Vol 60, No. 7, "Special Issue on Digital Picture Processing," reviews the past and present state of the art.

Experimental work has shown that further compression of the video data transmitted can be accomplished by means of Hadamard codes or transformations. The development of relatively low-cost digital integrated circuitry is providing a means for developing cost-effective coding systems capable of achieving on the order of a 5 to 1 digital video signal compression. It is forecasted that most satellite systems will use digital channel formats by 1985, for the reasons presented in par. 5.3, Summary of Technical Requirements.

The trend curves of Figs. 7-10 and 7-11 indicate that the effects of expected technology development will be as follows from 1975 to 1985:

1. A potential 10 percent per year reduction in cost per two-way channel-year obtained by considerable investment in improved earth stations. This level of improvement is indicated by the difference in slope of the solid line of Fig. 7-10 and the lower dashed line showing the potentially lower costs per two-way voice-channel-year attainable with earth station improvements such as addition of TDMA, time assigned speech interpolation and data compression. The earth station technology improvements considered increase the capacity of the spacecraft and the communications network without requiring larger or additional earth station antennas.

2. A potential 15 percent per year reduction in costs per two-way channel-year obtained by improved spacecraft technology and improved booster systems. This potential improvement is a minimum expected capability based on Intelsat V and 1985 DOMSAT concepts and uses only the technology improvements now nearing the flight demonstration stage. Such improvements are ion propulsion, improved batteries, lightweight extendable solar arrays, and multiple spot-beam antennas (Intelsat only). The effects of these minimum expected improvements are shown by the solid trend curve of Fig. 7-10. The slope of the curve between the years 1975 to 1990 indicates a 15 percent annual cost reduction. It is important

to consider when examining Fig. 7-10 that the circles represent Intelsat spacecraft and the squares domestic spacecraft for different types of networks. The GTE spacecraft appears technically superior to other spacecraft because the GTE system operates with only five earth stations with 30 meter antennas. The implications of these differences are defined in more detail in Section 9. The reason for the apparent high performance capability of the GTE system is that it is a satellite trunking system with few earth stations and therefore its performance approaches the theoretical limits of the transponder capacity. The RCA and Intelsat V spacecraft serve networks with many earth stations and therefore must handle many more interconnecting links between earth stations. The satellites must either operate with multiple carriers per transponder (which reduce total transponder capacity) or use Time-division multiplexing (TDMA) in order to provide all required earth station interconnections. The maximum number of interconnections being the square of the number of earth stations served. Intelsats are further handicapped by providing 18 degree wide global coverage beams. The domestic spacecraft generally require 4 x 10 degree antenna beam widths which conserve radiated power. Although Fig. 7-10 presents a diverse set of spacecraft, the general trend is sufficiently consistent to strongly indicate that at least a 15 percent per year reduction in spacecraft and booster costs per equivalent two-way-voice-channel-year can be realized through 1990. Part of this cost reduction is due to reduced booster costs. The effect of booster performance is indicated by the differences of cost for 1985 DOMSATs utilizing a Delta booster and utilizing Space Shuttle.

3. A potential 50-percent improvement in satellite cost effectiveness over a 10-year period should result from development of the Shuttle/Tug system providing increased capability at a lower transportation cost per kilogram in orbit. The percentage improvement is indicated by the difference of the solid trend line of Fig. 7-10 which would result if start of Shuttle/Tug were considered for 1985 spacecraft boosters rather than Atlas/Centaur and Delta.

An important factor to be considered is the trend of technology development and attainable real (constant dollar) cost reductions for communications services using Delta boosters in comparison with DOMSATs utilizing Shuttle/Tug, (S/T). Figure 7-11 indicates spacecraft technology growth as measured by kilograms of weight required per two-way-voice-channel-year. The trend is affected by increased booster capability, but spacecraft technology growth is the dominant trend indicated. The attainable cost reductions have an important impact on the results of Section 9 which examine the viability of domestic satellite systems coexisting with terrestrial systems.

Cost reductions based upon minimum technology growth, which can be readily attained, show that many of the future demands of the needs model for improved communications can be provided by communication satellite systems which will be cost effective and viable with other modes of communication. These interpretations of the trends presented are consistent with the detailed results of the sensitivity analysis presented in Section 10 and the recommendations presented in Section 12.

The cost factors and values given do not apply directly to all types of communications satellites, because the trends are based primarily on Intelsat and presently proposed DOMSAT systems and do not include Aerosats and other types of related applications. A direct broadcast satellite, for example, or a domestic satellite allowed to radiate a relatively high EIRP at high frequencies to many small user terminals would have a high cost per channel-year when plotted on Fig. 7-10. Such a satellite system would look very favorable, however, when costs per channel-year divided by numbers of terminals served were compared with Intelsats or domestic trunk telephone satellites.

The trend curves, when properly interpreted, provide only general guidelines of technology development in the three major areas of communications satellite systems:

1. Boosters or transportation systems
2. Ground stations and communications technology
3. Satellite technology

This analysis shows that these three areas are interrelated and of relatively equal importance for the development of more-cost-effective communications satellite systems. The trend forecasts indicate that it is reasonable to expect a 100-fold reduction in constant dollar costs of long-distance satellite communications between earth stations over the next 25 years. This expectation is dependent on a balanced development effort for the three primary areas of communications satellite system technology.

7.3 TRENDS OF SPACECRAFT SUBSYSTEM TECHNOLOGY GROWTH

Substantial improvements in satellite subsystem technology will be made over the next decade, primarily because of the efforts to improve the cost effectiveness of Intelsats, DOMSATs (common carrier) TV distribution satellites, Aerosats, Maritimesats, and NASA and DoD spacecraft. Development work is expected to continue to be funded by NASA, DoD, satellite communications companies, spacecraft contractors, and equipment vendors. Important physical constraints affecting future development are the limited available RF spectrum, atmospheric and space attenuation, background noise and interference, and booster performance and costs.

The forecasts of technology growth are based on needs for technology, functional requirements, and constraints. The maximum number of 36 MHz transponder channels per satellite, for example, is affected by the capacity and reuse of the 4 and 6 GHz frequencies and power levels required for utilization of the allocated 11/14 and 20/30 GHz frequencies. The receiver noise temperatures of small rural earth stations, for example, have a strong impact on required spacecraft-radiated power levels. Recent improvements in pumped parametric amplifiers and solid-state devices can easily result in reducing noise temperature to 300°K. Such advancements in technology reduce the required satellite transmitter power and, consequently, the primary power needed for providing services such as TV program distribution to small rural communities and school districts, if interference between satellite networks is properly controlled. Interference control is dependent on limiting radiated power, proper antenna-beam characteristics, and use of FM or digital modulation.

The size of antenna required for low-cost earth stations is dependent on isolation from such interfering noise sources as adjacent satellites operating at the same frequency and local terrestrial electromagnetic interference. Small earth-station antennas with relatively wide antenna beamwidths limit the number of usable satellite orbit slots available for a given frequency. Frequency reuse is affected by the higher satellite-radiated power levels normally required to work with small antennas, interfering with other users. Communications link calculations presented in Section 10, Sensitivity Analysis, provide a more detailed definition of relationships between basic constraints and communications technology parameters. The functional requirements for a communications network determine the communications subsystem requirements which, in turn, determine the spacecraft technical requirements for structures, power, attitude control, and other subsystems.

The power outputs required for each spacecraft RF channel range from about 1 to 200 watts. Most channels will require between 5 to 20 watts. These power levels are well within today's capabilities for long-life, space-qualified traveling wave tubes (TWTs). The total prime power required for the total number of channels required for a particular service need and an amplifier efficiency of present TWTs may approach 20 kW. Total system or network power will generally be supplied by several satellites; two or more satellites will serve each large dedicated network. Transmitter efficiency and antenna gain are key factors considered in the growth of technology. Present-day amplifiers frequently use redundant TWTs to ensure reliable system operation, but with consequent weight and volume penalties. Amplifier reliability or life is therefore also an important factor in the growth of amplifier technology. Reliability consistent with the goal of a system life of 7 to 10 years is required.

Detailed system design may determine that rather wide bandwidths may be required for some applications. For example, it is not unreasonable to expect a required input bandwidth of about 1 GHz at a nominal center frequency of 20 GHz for high data rate links.

The antenna beamwidth required is a determining factor for satellite attitude stability. Attitude pointing errors cause a shift of the antenna beam with respect to a given point on the earth surface and thus a reduction in the signal energy received by an earth station. Attitude stability accuracies of 0.05 to 0.1 degree will limit the degradation in carrier-to-noise ratio at an earth station to an acceptable value for most systems. The magnitude of stability control required is near the present state of the art. The principal need is for improved attitude sensing systems. A recent preliminary study has shown that radiowave attitude sensing systems show promise of eventually being able to provide improvements over present infrared sensors.

Earth station transmitter power outputs range from a low of about 1 watt up to about 10 kilowatts. Transmitter efficiency does not rate the concern merited by the space segment of the system. Reliability, however, is important in that unattended, remotely controlled operation and very low maintenance requirements are a primary goal to be met in the earth segments of some systems. This suggests the desirability of reducing the required power level and utilizing an all-solid-state earth station system.

The earth station antenna aperture requirements range from 1/2 m for mobile vehicles to 30 m for large telephone trunking stations. These will usually be single antennas for both transmit and receive, with possibly an autotracking capability for large antennas and vehicles. Fixed station antennas with small to moderate apertures should require only boresight adjustment capability in lieu of dynamic tracking, since reasonable satellite stationkeeping capability will result in acceptable beam misalignment losses with these beamwidths. Mobile vehicle antennas must have either a very wide beamwidth or a tracking or automatic beam switching capability in order for the antenna beam to always be directed toward the satellite from the maneuvering vehicle. Since most applications will require only a single narrow bandwidth and a small wide angle beamwidth, the antenna should easily mount on top of the vehicle. The eventual application of a small phased array or multiple switched antennas should be considered. Additional detailed requirements are defined in par. 10.1.2, Link Calculations and Tradeoff Analyses.

These and other general background factors and interrelationships were considered in forecasting growth trends of the following technology parameters. The forecasting methodology is as defined in par. 7.1.

7.3.1 Spacecraft RF Power Generation

Thermionic, solid-state, and hybrid thermionic-solid-state devices are candidates for supplying the RF power output required in the satellite. Thermionic types considered were TWT, crossed-field amplifier, klystron, gridded tube, backward wave oscillator, and magnetron. The solid-state devices considered were transistor,

SPACE QUALIFIED TRANSMITTER POWER OUTPUT

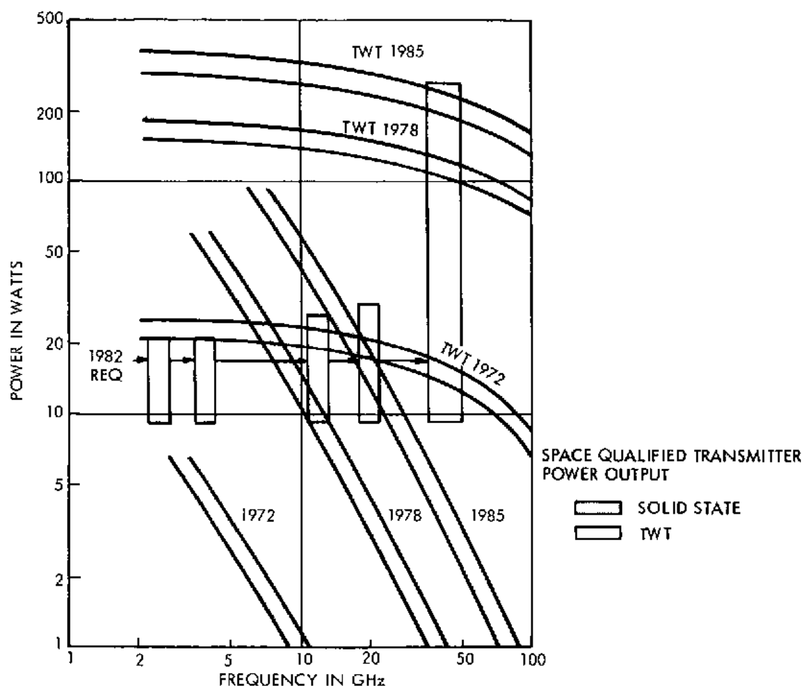


Fig. 7-12 Space-Qualified Transmitter Power Output

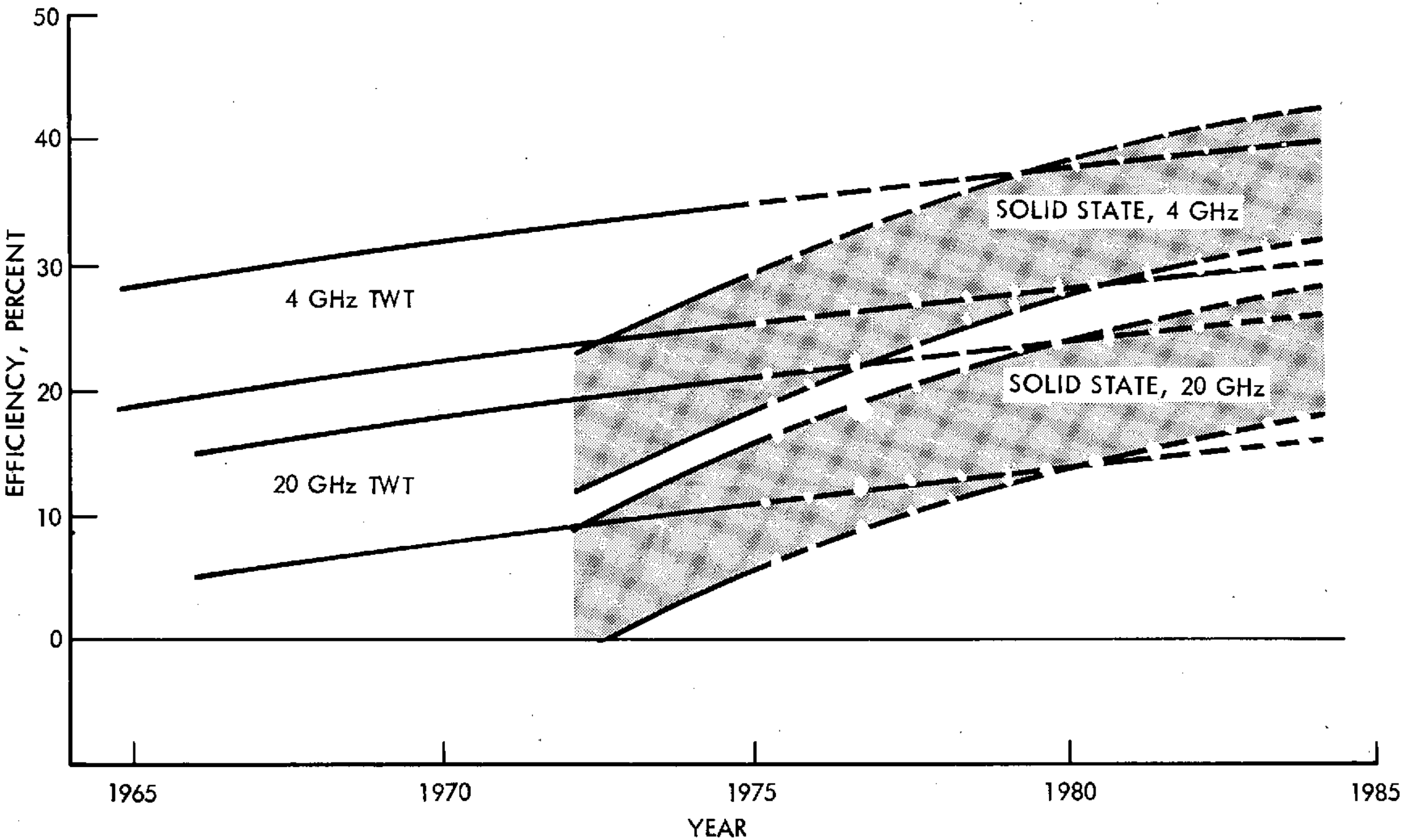


Fig. 7-13 Space-Qualified Transmitter Efficiency

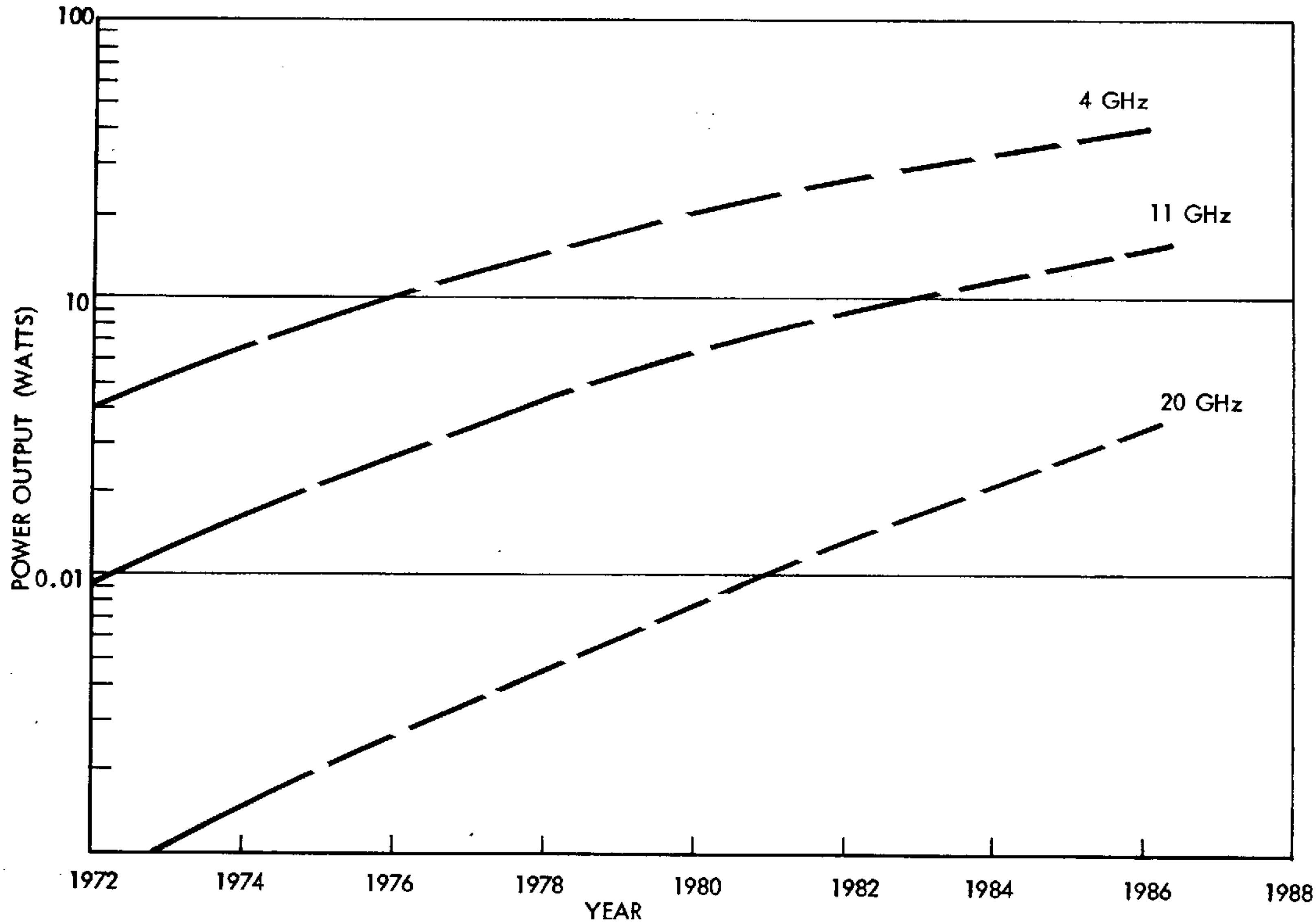


Fig. 7-14 Transistor Transmitter Power Output Growth as Function of Time

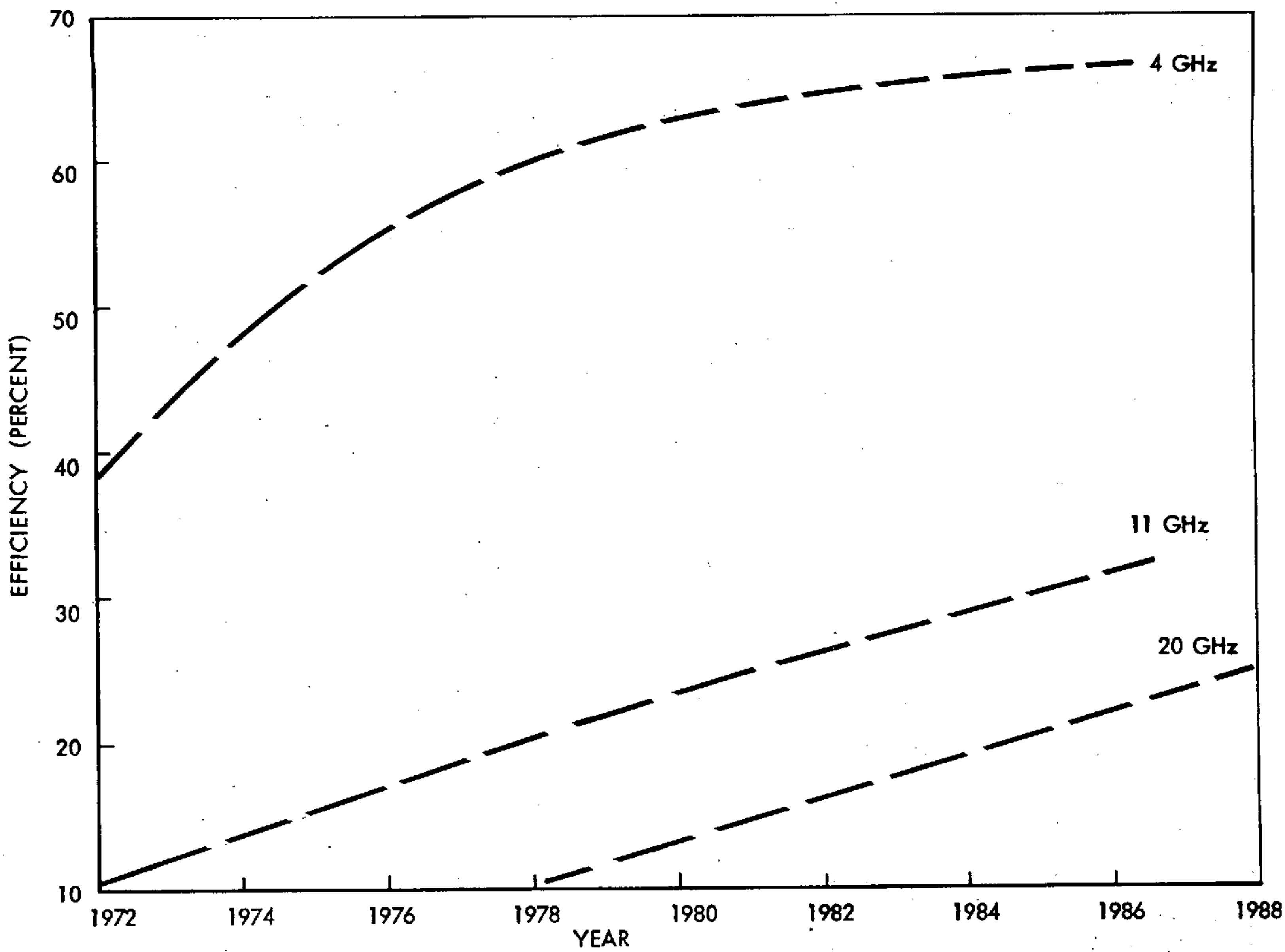


Fig. 7-15 Transistor Transmitter Efficiency Growth as Function of Time

IMPATT, Gunn, TRAPPAT, and LSA. The hybrid device considered was the electron beam semiconductor. While all devices have merits, only the TWT, the transistor, and solid-state devices such as IMPATT and Gunn warranted detailed examination. Current technical literature and manufacturers' literature were used to define the present state of the art of these devices and recent parameter technology improvement. Estimates were made of the probable state of the art in the years through 1980.

Power output as a function of time for a space-qualified TWT is shown in Fig. 7-12. The power output capability at 4 and 11 GHz is about the same, and the power capability for 20 GHz is somewhat lower. The general DC-to-RF power conversion efficiency growth for the three frequencies is given in Fig. 7-13. These forecasts are substantiated by data from Refs 50 through 71.

Each of the reference data points were analyzed and plotted on working charts. Corresponding power output and efficiency growth curves for transistors are given in Figs. 7-14 and 7-15. The development of efficient transistors for 20 GHz appears quite problematical at this time.

Data on a number of other solid-state devices were examined. The transfer electron device (TED) was chosen from this group for special scrutiny because of its somewhat greater power generating capability. Due to the embryonic state of the group as a whole, it is not known which devices will prove superior in the future. Figure 7-16 shows power output and Fig. 7-17 shows efficiency growth at various frequencies for TED or Gunn devices.

These trend curves indicate that we may reasonably expect the following capabilities by 1985 from transponders using transfer electron devices:

1. 40 watts of power output with 35 percent conversion efficiency at 4 GHz
2. 30 watts of power output with 35 percent conversion efficiency at 11 GHz
3. 15 watts of power output with 27 percent RF power conversion efficiency at 20 GHz

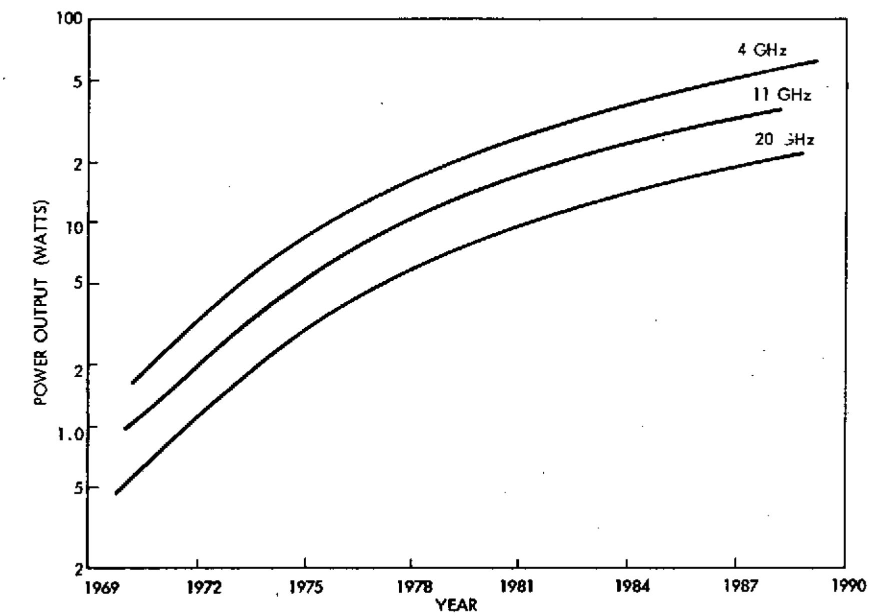


Fig. 7-16 Transfer-Electron-Device Amplifier Power Output Growth as Function of Time

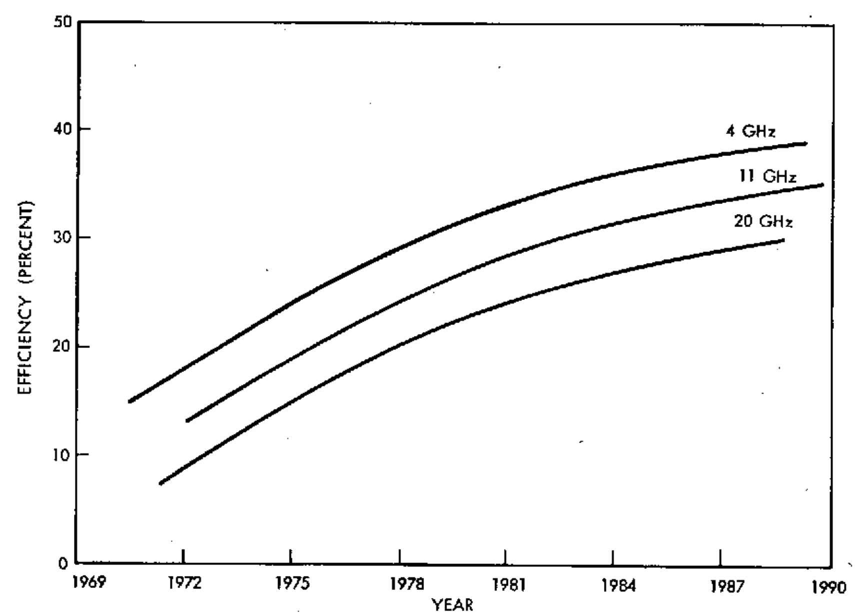


Fig. 7-17 Transfer-Electron-Device Efficiency Growth as Function of Time

7.3.2 Spacecraft Antennas

Reflectors, lenses, and phased-array antennas were considered for spacecraft application. Reflector types were subdivided into paraboloidal and cylindrical, and lenses were subdivided into Luneberg and plano-convex types. The types were minimized by a preliminary screening that eliminated the cylindrical reflector and Luneberg lens and cast doubt on the general use of the phased array. Cylindrical antennas can give a desirable pattern shape for some type of area coverage and can have somewhat better mechanical compatibility of multiple feeds, but they have somewhat limited beam-shaping properties and may require unusual feed-radiating properties compared to the paraboloidal reflector. The Luneberg lens has essentially the same multiple-feed capabilities as the plano-convex lens; however, its disadvantages are weight, power, loss, and high sidelobes compared to the plano-convex. Figure 7-18 shows the forecast trend of weight for various types of antennas. The phased array's

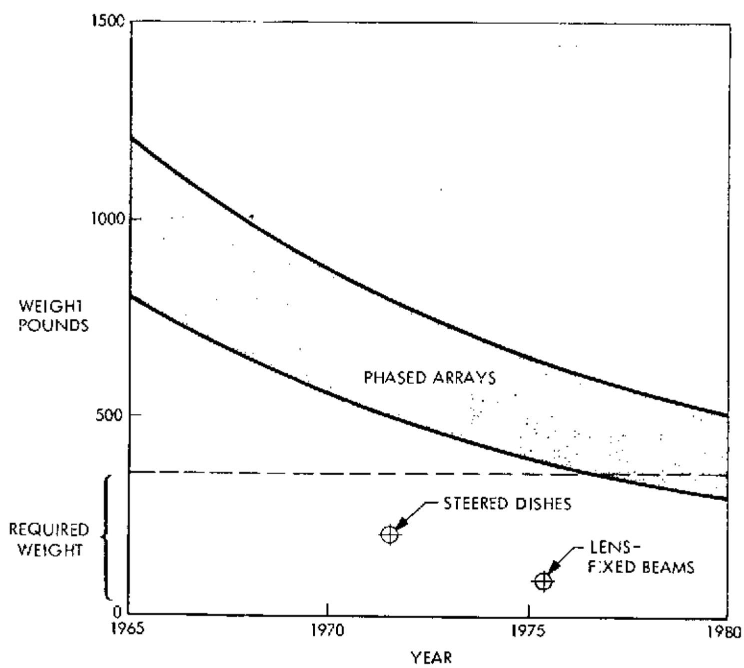


Fig. 7-18 Weight Trends of 12 GHz Systems – Eight 1-Deg Beams Receive and Transmit

attractive features become muted by bandwidth and phase-control limitations, the complexity attendant to multiple-beam operation, and the heavy weight required.

The sensitivity analysis shows that narrow beamwidths requiring large apertures with many beams are necessary for some applications. Either a paraboloid or plano-convex lens can be used for the less stringent applications; however, existing technology favors the paraboloid antennas. The paraboloid is also favored for moderately large apertures with few feeds. The number of feeds and the beam separation are limited by aperture blockage and off-axis coma. This forces the employment of numerous apertures for generating many beams when paraboloids are used. In contrast, use of many feeds, with a consequent reduction of the number of apertures, is possible with a lens, and with no aperture blockage or coma. The lens presently has the disadvantage of weight and loss compared to a paraboloid when a solid dielectric is employed. The principal problems attendant to lens application is that modern design data in greater depth are needed to minimize the amount of cut-and-try experimental work required. There is a dearth of computer-assisted design information available compared to the paraboloidal type. Also, artificial dielectric materials, which can materially reduce weight and losses, require further development effort to improve their properties and increase the magnitude of the dielectric constant. An increased number of competitive sources of supply is also required.

In summary, area coverage applications or point coverage with few beams favor the application of paraboloidal reflectors. Point coverage with many beams will probably require a complex array of paraboloidal reflectors with a relatively small number of feeds per aperture for near-term application. Lens antennas appear very favorable if adequate development effort is performed. Subsequent to about 1976, it is expected that a relatively small number of plano-convex lenses with a relatively large number of feeds per aperture will supplant the paraboloidal array for multibeam point coverage. The performance achievable on beam-to-beam isolation of each aperture type is anticipated to follow this same trend. Beam-to-beam isolation is reasonably satisfactory with either aperture type for present applications, although approximately 10 dB better isolation is attainable with the lens. It is anticipated that the beam-to-beam isolation of the parabola will increase to only about 25 dB by 1985, whereas the lens can be expected to increase to about 40 dB, which is expected to meet the more severe requirement of that time frame.

7.3.3 Spacecraft Receivers

The receiver noise figure affects the earth station transmitter power required for a specified signal-to-noise ratio. The noise figure and bandwidth are the key parameters of the satellite receiver. The receiver input stage is critical to the performance of these parameters. Input stage types considered were diode mixer, traveling wave tube, transistor, tunnel diode, and parametric amplifier. Expected noise-temperature improvement as a function of time for each of these input stage types is shown in Figs. 7-19 through 7-21 for frequencies of 6, 14, and 30 GHz. A curve for a cooled parametric amplifier is shown for comparison, although it is unlikely one would be used for this type of application. Figure 7-22 shows the typical percentage bandwidth improvement expected by year. The symbols shown indicate typical reference data points.

7.3.4 Power Subsystem Development

The weight and cost of power system components are based on power delivered to a synchronous equatorial satellite at the end of a 7-year mission. The power range considered is from 1,000 to 10,000 watts.

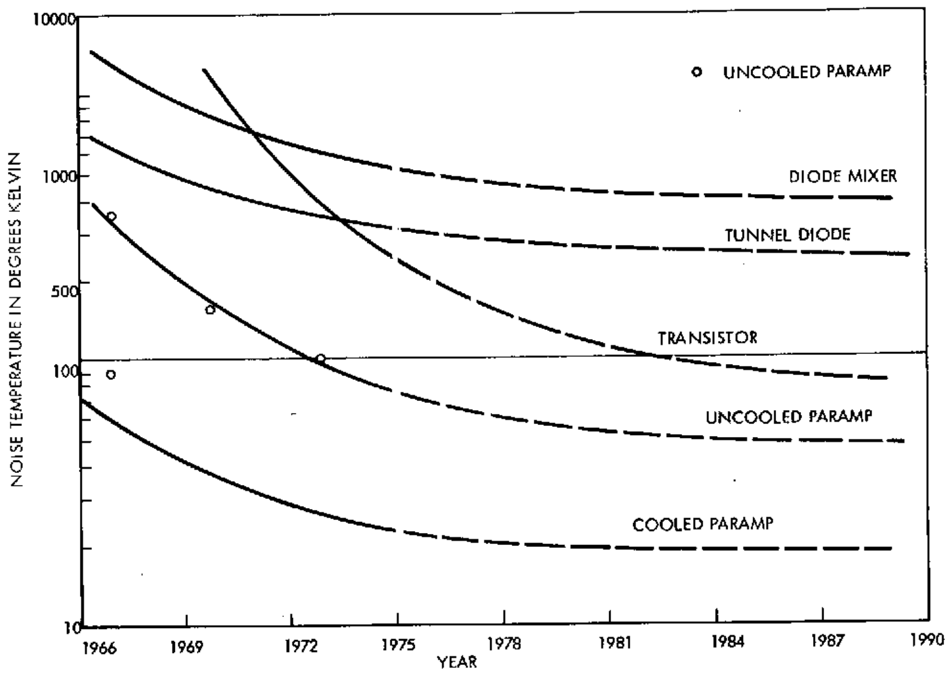


Fig. 7-19 Trend of Receiver Noise Temperature at 6 GHz

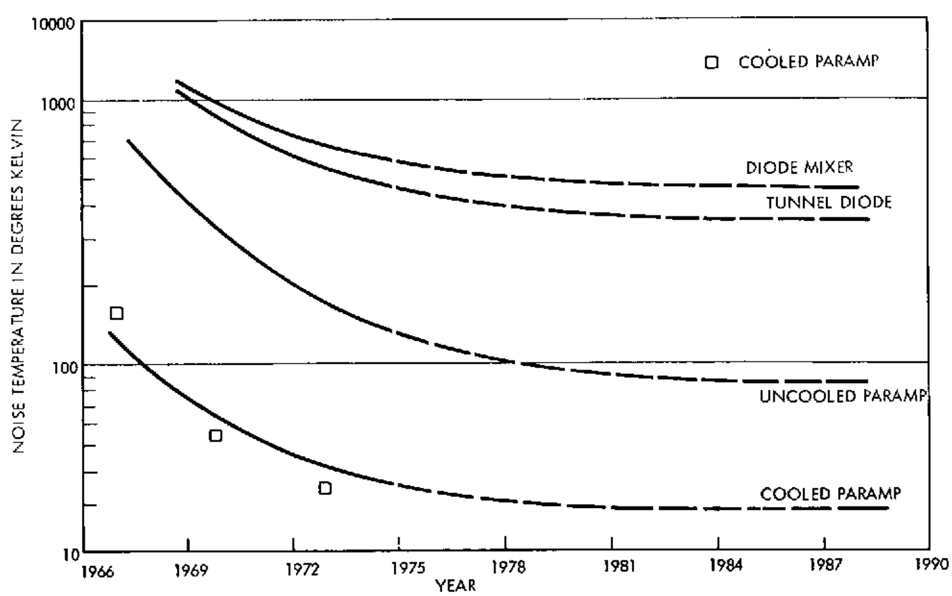


Fig. 7-20 Trend of Receiver Noise Temperature at 14 GHz

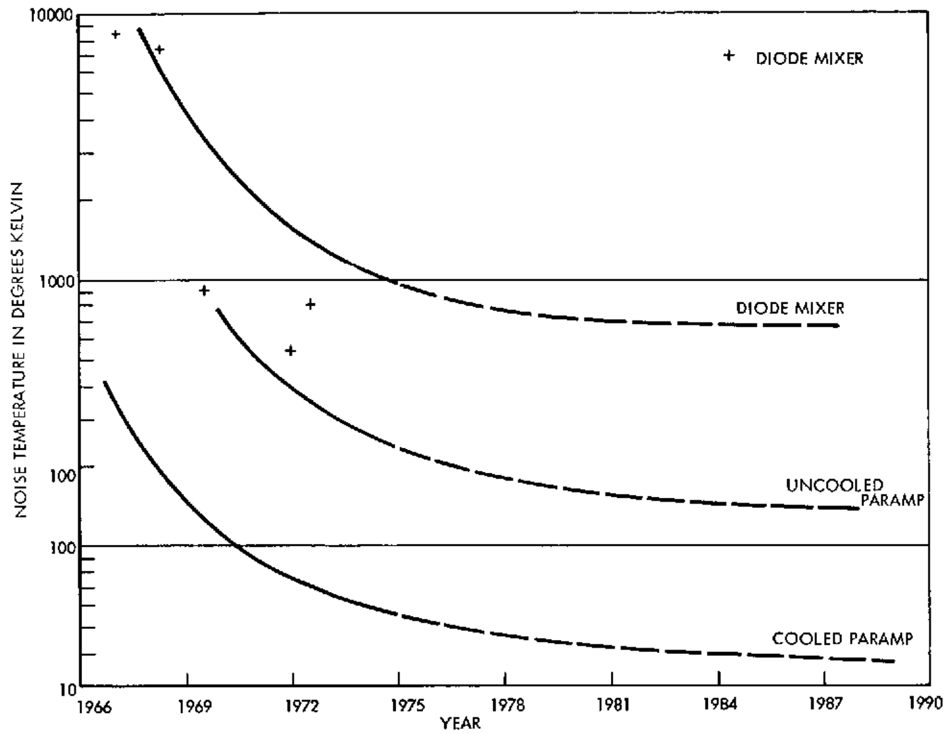


Fig. 7-21 Trend of Receiver Noise Temperature at 30 GHz

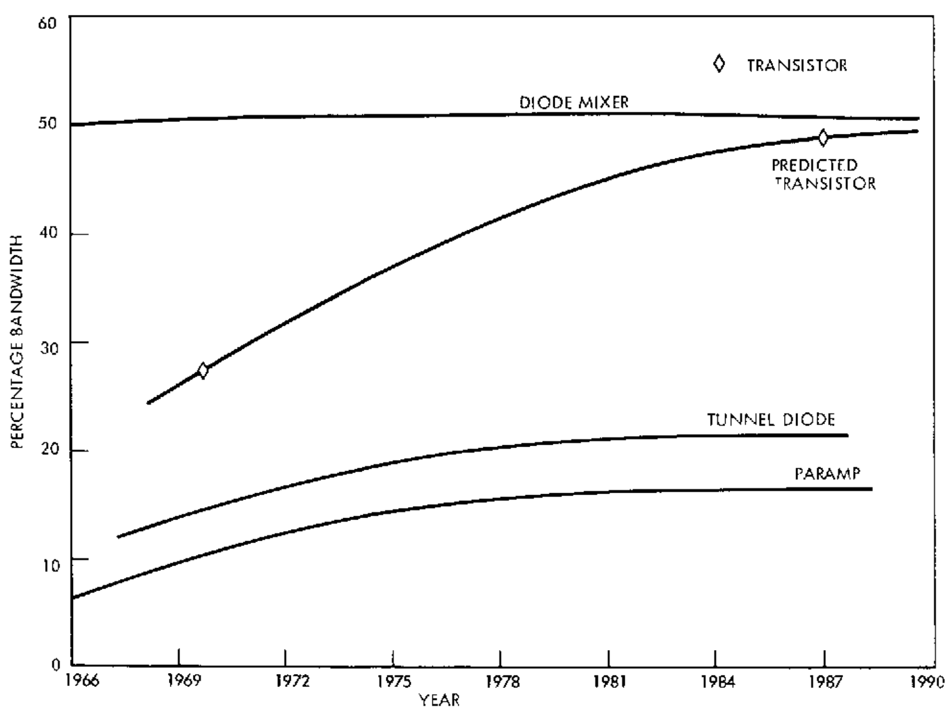


Fig. 7-22 Trend of 6 GHz Receiver Bandwidth Growth

The primary data sought were the nonrecurring and recurring cost and the weight of solar array/battery and nuclear electrical power systems. At power levels above 1 kW, the sun-tracking array is more cost effective than a spinning array.

The solar array/battery system required is a single-axis tracking deployed solar array. The system was broken into the following four components for detailed analysis:

1. Solar array, including stowage and deployment
2. Energy storage batteries
3. Array tracking and power transfer system
4. Power conditioning and distribution, including battery charge control

Solar array costs are highly dependent upon array area. The cost and weight data for present deployed array areas were correlated with the end-of-life (7-year) synchronous equatorial mission power by use of the following system design assumptions:

Battery system charge and discharge efficiency	70 percent
Degradation of cell power due to radiation	25 percent
Power transfer and distribution loss	3 percent
Power conditioning loss	5 percent
Cell cover transmission loss and thermal cycling effects	2 percent

Assuming a beginning-of-life array power of 10 watts/ft^2 at operating temperature and a normal illumination at 1 AU, the end-of-life array power is 6.3 watts/ft^2.

In Figs. 7-23 and 7-24, the cost and weight data for the solar array/battery and nuclear power system components were plotted against power to the vehicle and summed for the complete power subsystem.

The detailed analysis showed that solar arrays and batteries will continue to be more cost effective than the various types of nuclear power systems unless about $100 million

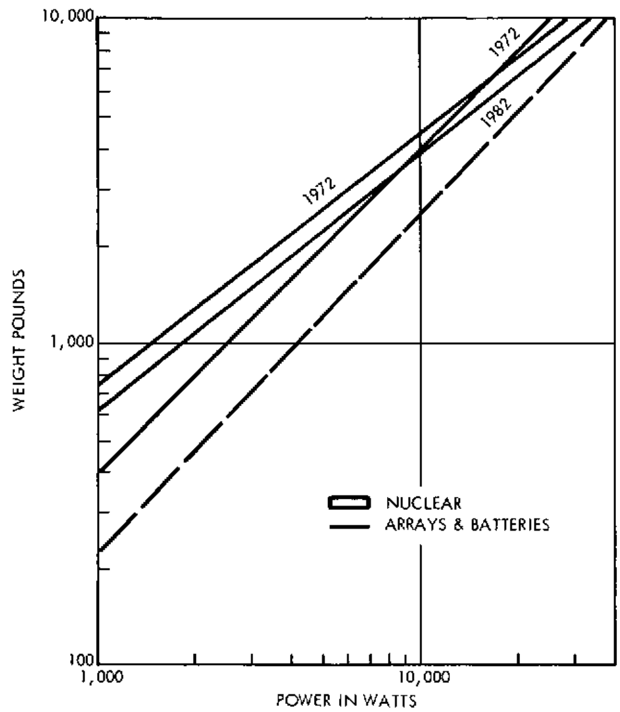


Fig. 7-23 Power System Weight

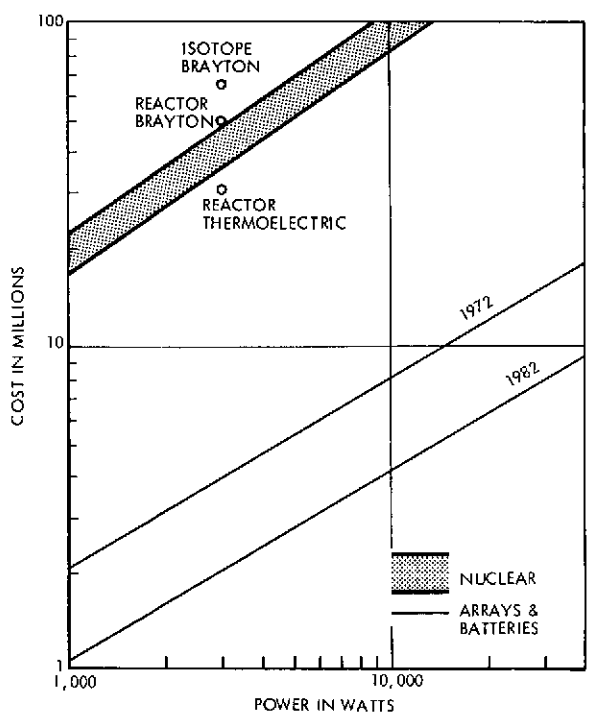


Fig. 7-24 Power System Development Costs

is expended for development of a satellite nuclear power system or an unexpected breakthrough occurs in nuclear power generation. Figure 7-24 shows the development cost trend for various nuclear systems. Nuclear systems are not considered further because of this high development cost, although once developed to expected levels of capability, the analysis showed that they could be competitive with solar array/battery systems.

The forecasted recurring costs of array and battery subsystems in 1982 would be about the same as the development costs for arrays and batteries shown in Fig. 7-24.

Figure 7-25 shows the relationship between cell thickness (which affects array weight) and cell cost from 1958 to 1974. Presently available 2 x 4 cm cells costing approximately $6.00 provide four times more power than a 1 x 2 cm cell that cost $6.00 in 1958.

The present recurring costs for an array and battery system are approximately $2 million for a 1 kW system capable of full power operation during 70 minutes of solar occultation and weighing 400 lb. By 1982, a replacement system will cost approximately half as much in constant 1972 dollars and require 40 percent less weight. Weight is generally proportional to total power output for systems in the 1 to 20 kW range. Doubling the required power, however, increases the subsystem recurring cost by only some 50 percent, provided that subsystem weight is not severely constrained. The forecast trends of solar array and battery technology show that substantial progress is being made. The forecasted level of technology development for 1982-1985 appears to be adequate to meet the expected 1985-1995 era communications satellite power requirements at reasonable cost. Further improvement over the forecast capabilities will be very beneficial. This conclusion, however, is based on the expected long-term continued support of array and battery system development by NASA and the US Air Force in order to better meet on-going requirements of specific space missions.

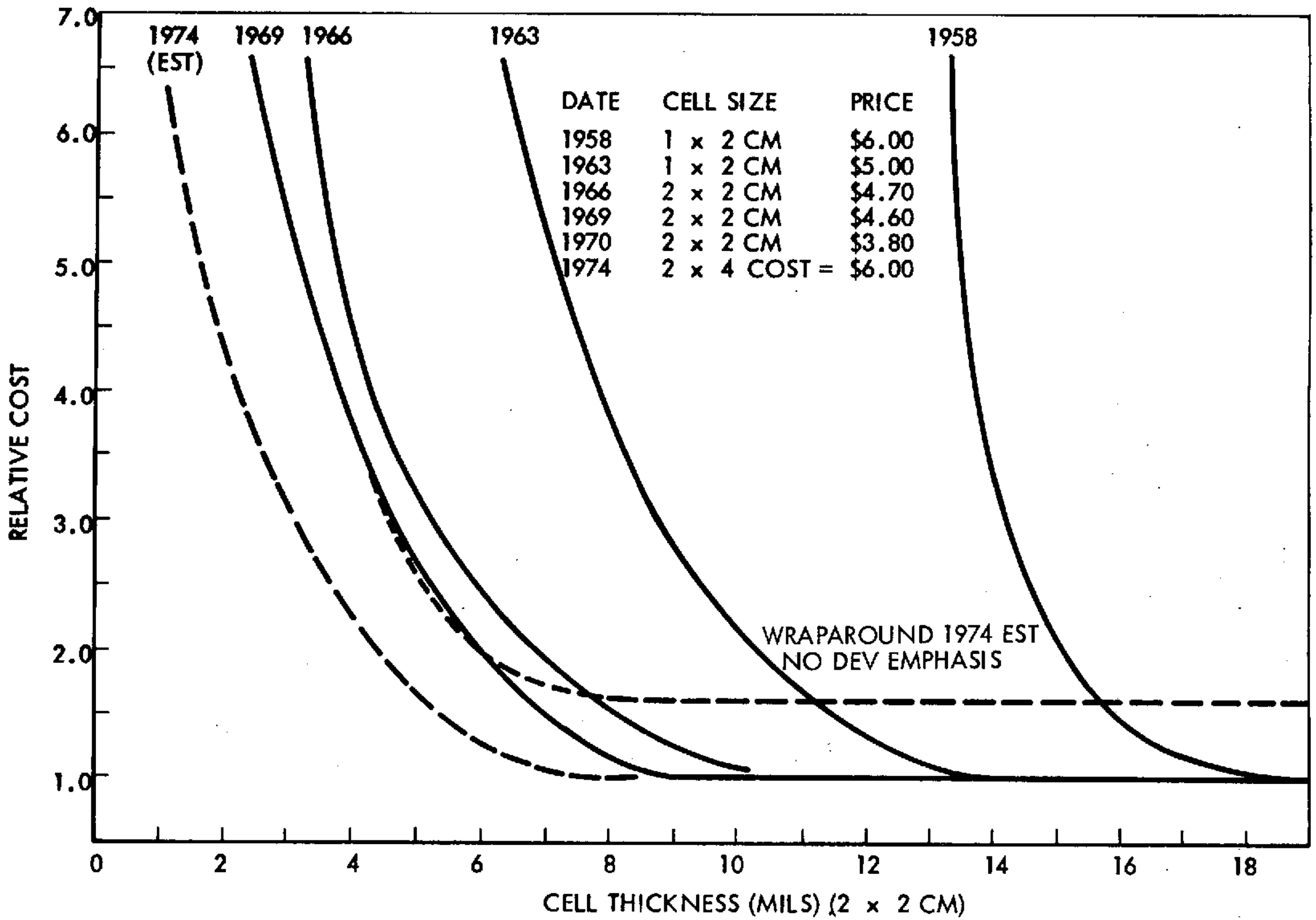


Fig. 7-25 Trend of Solar Cell Costs

Important areas of technology developments worthy of special attention are presented in Section 11, Options for Stimulation of Technology Growth. References 71 through 88 of this report were used in the detailed analysis.

7.3.5 Attitude Stabilization Subsystem Development

The available and forecasted future three-axis attitude stabilization technology appears adequate for meeting the pointing accuracy, reliability, weight, and power constraints of communications satellites. Present technology is capable of providing stabilization systems with the following general capabilities for a 24-transponder Domestic Satellite weighing about 1,000 lb:

- Pointing accuracy, 0.1 deg in pitch and roll, 0.3 deg in yaw
- Weight, on the order of 37 lb
- Expected operating life, 10 years
- Reliability, 0.97 for 7-year life
- power, 30 watts

Attitude stabilization subsystem weight, power, and cost do not increase proportionally with total spacecraft weight; this is due to several essentially fixed elements of the subsystem. The attitude sensors and control electronics weight, for example, are sensitive to required pointing accuracy and fairly insensitive to satellite weight. Required momentum or reaction wheel weight increases as a function of satellite weight and unbalanced satellite area projected toward the sun about the satellite center of gravity. The estimated stabilization subsystem weight for a 1,800 kg satellite, for example, is about 70 kg. Expected improvements in sensors, integrated logic circuits, momentum wheels, and momentum wheel actuators are expected to reduce the weight and cost in fixed 1972 dollars of subsystems meeting present performance requirements. The 1985-era satellites using 0.5 degree antenna beams will require pointing accuracies on the order of 0.05 degree in pitch and roll and 0.1 degree in yaw. These requirements will be attainable.

7.3.6 Development of Propulsion Subsystem Technology

Table 7-3 shows the necessary total propulsion impulse required for a 7-year-life, 450 kg satellite requiring stationkeeping within ±0.1 deg of longitude and latitude.

Table 7-3

REQUIRED PROPULSION IMPULSE

	Total Impulse in Newton-sec for 450-lb Satellite
N-S stationkeeping (70 m/sec/yr)	14.6×10^4
E-W corrections (3 m/sec/yr)	$.6 \times 10^4$
Repositioning (70 m/sec, one time)	2.1×10^4
Three-axis stabilization (momentum wheel backup)	$.06 \times 10^4$

The impulse required for north-south stationkeeping is five times greater than the total of the three other requirements. A television distribution or marine communications satellite, for example, which did not require accurate north-south stationkeeping or repositioning would require about 13 kg of hydrazine propellant for a 7-year-life, 450 kg satellite. The total on-orbit propulsion subsystem weight required would be about 23 kg if available catalytic hydrazine technology were used.

Required weight for a 7-year, 450 kg satellite requiring accurate north-south stationkeeping would be about 114 kg, of which 86 kg would be hydrazine propellant. The hydrazine on-orbit propulsion subsystem used by most 1975-era satellites therefore requires about 25 percent of the total satellite weight. Bipropellants and other propellants offer a slight potential weight savings because of the higher specific impulse, as shown in Fig. 7-26. Most systems are more complex and presently less reliable than the catalytic hydrazine subsystems.

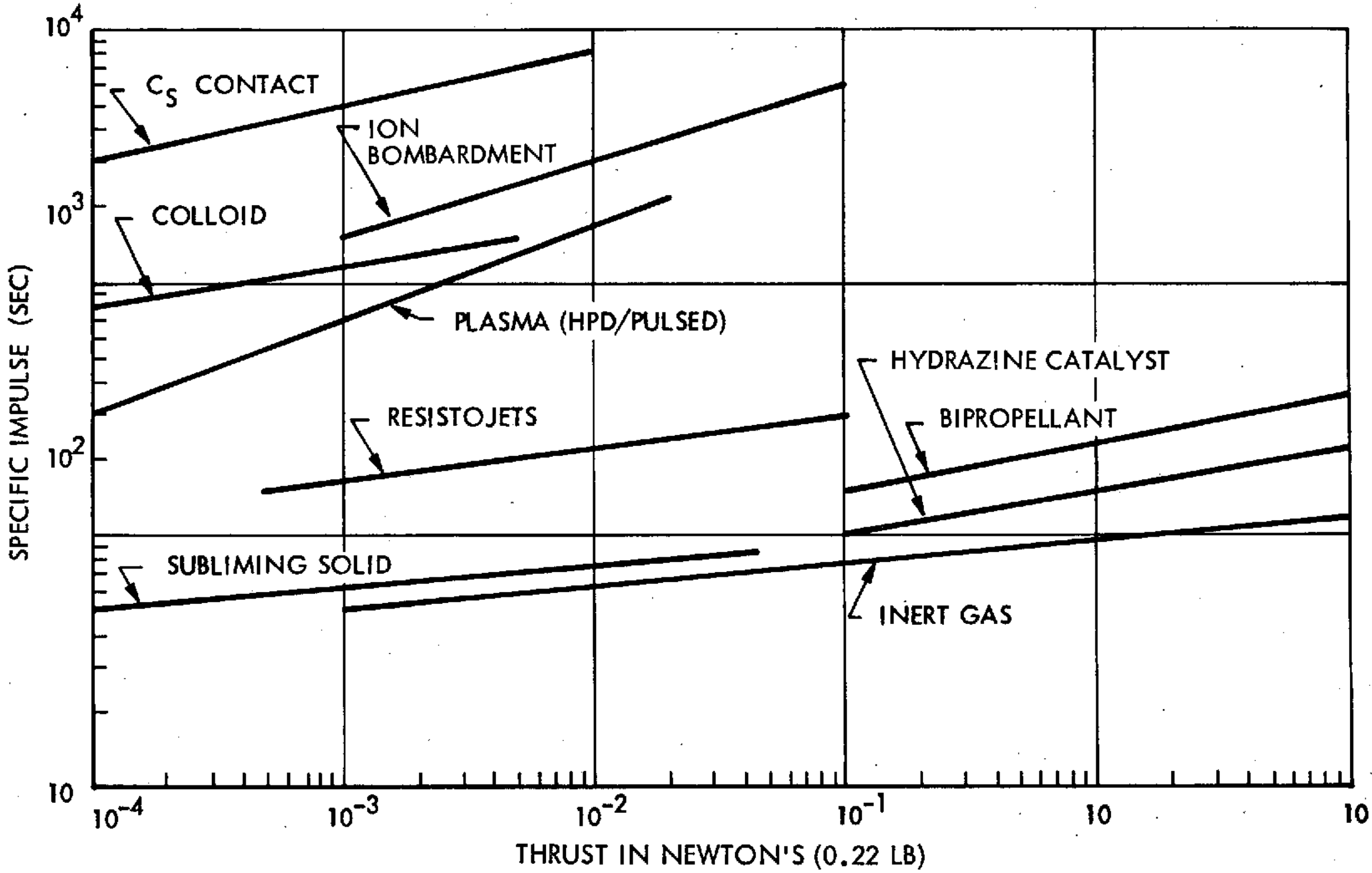


Fig. 7-26 I_{SP} and Thrust Range of Possible On-Orbit Propulsion Subsystems

Detailed analysis and trade studies show that reliable, flight-proven ion propulsion with a specific impulse on the order of 2,000 seconds is needed to reduce the propulsion subsystem weight for satellites requiring accurate north-south stationkeeping (Ref 40, pp 1-18 and 2-136 through -181). The required subsystem weight for a 7-year-life, 450 kg satellite using ion propulsion for north-south stationkeeping and hydrazine propulsion for all other functions is about 45 kg. The required weight for a 1800 kg satellite would be about 90 kg. Most of the required weight increase would be due to added propellant, tank volume, and line lengths.

The flight of ATS F is expected to provide a much needed flight demonstration of on-orbit ion propulsion for communications satellites. Although ion engines have been flight-tested and extensive ground testing has been performed, there is considerable hesitancy to commit a commercial operational satellite to full use of ion propulsion until an operational satellite system such as ATS F has flight-proven the concept.

7.3.7 Structures and Thermal Control Technology Developments

The structure and thermal control subsystems are required to support the other subsystem components and provide the required temperature environment during launch, ascent, and orbit operation. Ideally, the structure and thermal control components should be as simple, lightweight, and inexpensive as possible. Although the structure presently constitutes approximately 8 percent and thermal control 2 percent of the total on-orbit weight, it accounts for only about 4 percent of the allocated spacecraft cost. Generally, the structure is required to have good thermal conductivity to provide a heat sink and radiator for equipment temperature control, and good electrical conductivity for electromagnetic interference control. In addition, the structure should be reliable, inexpensive to build, and provide good accessibility to spacecraft equipment for ease of final assembly, test, repair, and launch-support.

The following three types of structure were studied to determine which was best for near-term spacecraft design (Ref 48, pp 3 and 13):

1. Bonded structure made up of 0.02-inch-thick sheet and hat sections
2. Welded spaceframe structure covered with sheetmetal skin for environmental control

3. Riveted sheetmetal and extruded stiffener spaceframe based on conventional airframe technology

As part of this analysis, each of the three different types of structures were used for tentative designs required to provide essentially the same structural capabilities of support, environment control, and accessibility. The riveted sheetmetal structure based on airframe technology proved to be most cost effective, provided exotic materials such as beryllium and composites were not required.

Advanced composites and stress analysis techniques are forecasted to allow a 10 percent reduction of structural weight of airframes by 1985 (Ref 49, pp 25 and 46). The potential expected reduction of communications satellite structural weight resulting from improved materials and thermal control technology developments is about 5 to 10 percent. This improvement is highly dependent on thermal control technology. Structural weight reduction is expected from reduction of ascent loads by elimination of the high-thrust solid-rocket apogee kickstage in the 1980s. The development of more efficient transmitters for the 4/6 and 12/14 GHz frequencies is expected to reduce the thermal control problems, and the use of 20 GHz frequencies requiring higher transmitter power at lower efficiency is expected to increase the thermal control problems. The 20-GHz frequencies will probably be used with narrow spot beams to reduce the total power required and the heat loads.

7.3.8 Tracking, Telemetry, and Control Subsystem Technology Development

The tracking, telemetry, and control (TT&C) subsystem has the most stringent reliability requirements of any subsystem. Loss of command control capability amounts to loss of the spacecraft. Great progress has been made over the last 10 years in improving the performance and reducing the size and weight of command and telemetry subsystems. There have been significant improvements in reliability and in size reduction of building-block components such as multiplexers and receivers. Command and telemetry systems have gone from analog to pulse code modulation.

Present tracking, telemetry, and command subsystem weight for Intelsat IV is 22 kg and accounts for approximately 4 percent of the on-orbit weight and an estimated 6 percent of the total program cost.

Most of the TT&C weight is in the encoders, decoders, command receivers, transmitters, and beacon transmitters. The subsystem weight and cost are fairly insensitive to a doubling of the number of commands and telemetry points required for a larger satellite.

A command and control subsystem based on use of present technology for a 2000 kg satellite with a 2000-command capability, 10-year operating life and all required telemetry points for 48 transponders and spacecraft control would weigh about 35 kg. Future solid-state and microminiature integrated circuitry technology are expected to further reduce the size and cost of the subsystem hardware. The present technology capability, the trend of technology growth, and subsystem standardization appear adequate for meeting future communications satellite system requirements. It is expected that by 1985 most major components such as transponders and the attitude stabilization electronics package will contain serial digital encoders and decoders for interfacing with the central clock and multiplexers of the subsystem. The total subsystem weight, and particularly the command and telemetry cabling weight, will be reduced. Future subsystem components will have standardized integrated electronics chips, wafers, and flat packs designed into the major subsystem components with full redundancy for use for flight, component acceptance, and subsystem testing. The increasing reliability and capability of the TT&C subsystem is progressively eliminating the need for all but the most basic functions from the spacecraft umbilical connection.

7.4 TREND OF EARTH STATION TECHNOLOGY GROWTH

The key earth station components are examined here as a necessary part of the overall space communication system.

7.4.1 RF Power Generation

Although only thermionic power amplifiers can presently supply the RF power levels required for earth stations, both thermionic and solid-state amplifiers were considered for possible future application. A large number of available tube types can furnish the expected power levels; however, the types that are expected to best fill the needs from the standpoint of transmission properties as well as power output are the traveling wave tube and the multiple cavity klystron. Of these two, the TWT appears better suited because of its bandwidth and other transmission properties as compared to the klystron.

Traveling wave tube bandwidths are typically 15 percent or more of the operating frequency, but bandwidths for multiple cavity klystrons are only a few percent. Thus, the TWT can pass any allocated RF channel bandwidth but the klystron is restricted to at best a few RF channels.

Growth curves of power output and efficiency for a TWT are given in Figs. 7-27 and 7-28. A wide range of power output capability is available from TWT designs for earth-station application. These curves show the growth trend for high-powered TWTs of the type being considered for contemporary earth-station design. Future increases in efficiency are expected through more widespread application of the tapered helix pitch and depressed collector operation concepts.

As with the satellite transmitter, transistors or Gunn devices are the solid-state candidates that appear to offer the best potential to satisfy future earth-station power-generation requirements. Trends of transistor power output and efficiency for frequencies of 6 and 14 GHz are given in Figs. 7-29 and 7-30. Some of the amplifiers are composed of multipled devices. Recent work has shown that this is a possible way of deriving a considerable amount of power from a solid-state transmitter, although the bandwidth capabilities of such a configuration may be somewhat limited.

Curves for Gunn or transfer-electrion-device amplifier power output and efficiency growth are given in Figs. 7-31 and 7-32. Multiple devices are not shown, since the power levels are reasonably higher than for the transistor devices.

7.4.2 Antennas

Present technology requires no appreciable advancement in the area of earth station antennas to meet the technological requirements of future satellite systems. Antennas of sufficient aperture, surface tolerance, and stability are presently available to meet

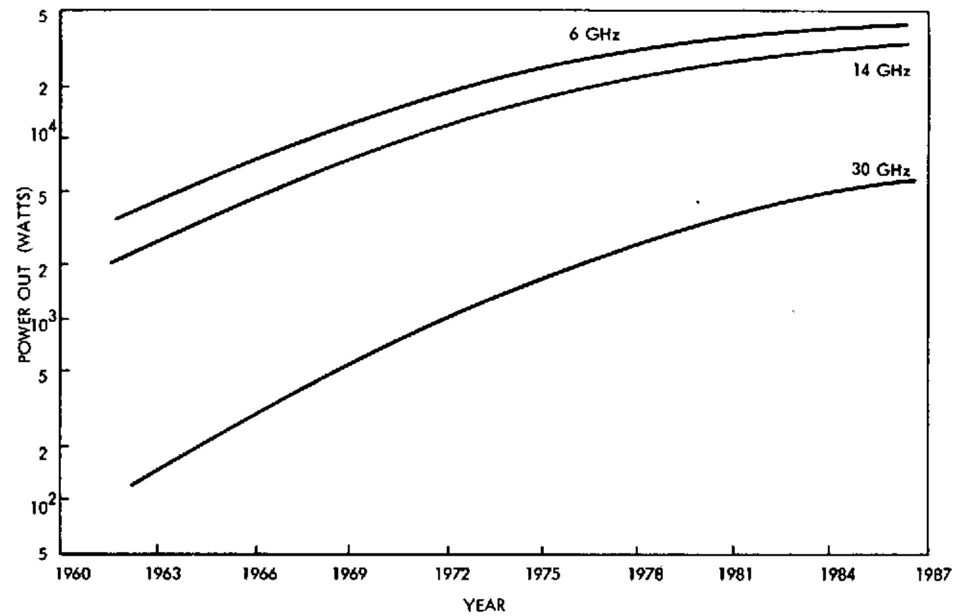


Fig. 7-27 Earth Station TWT Power Output Capability

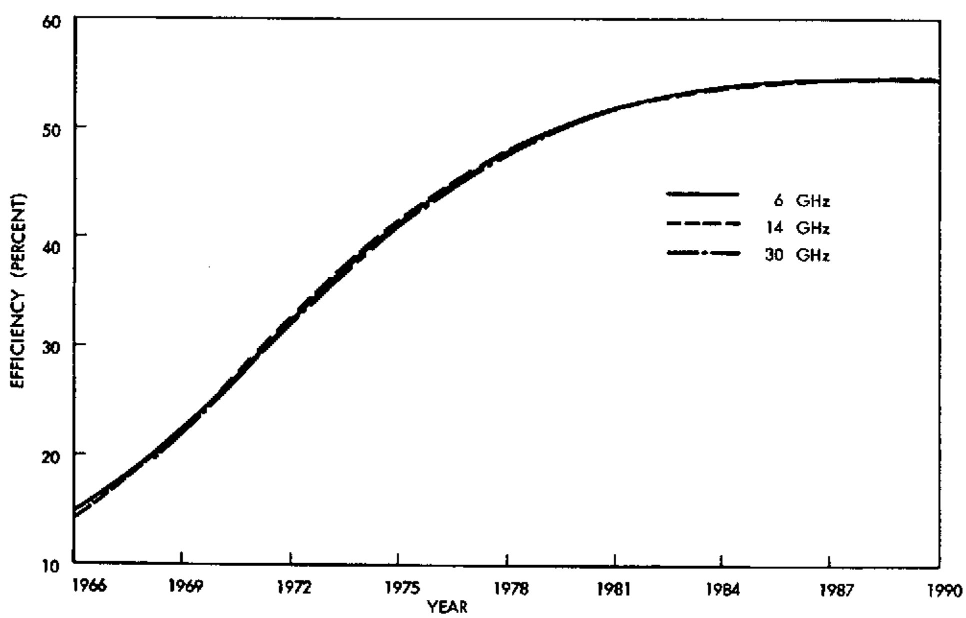


Fig. 7-28 Earth Station TWT Efficiency

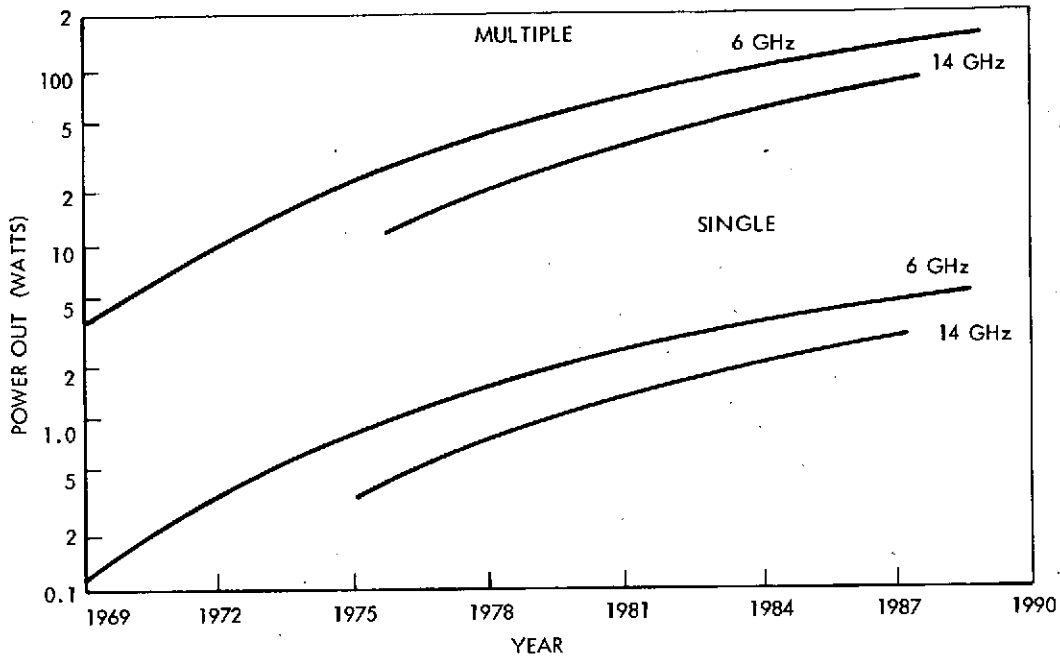


Fig. 7-29 Transistor-Amplifier Power Output

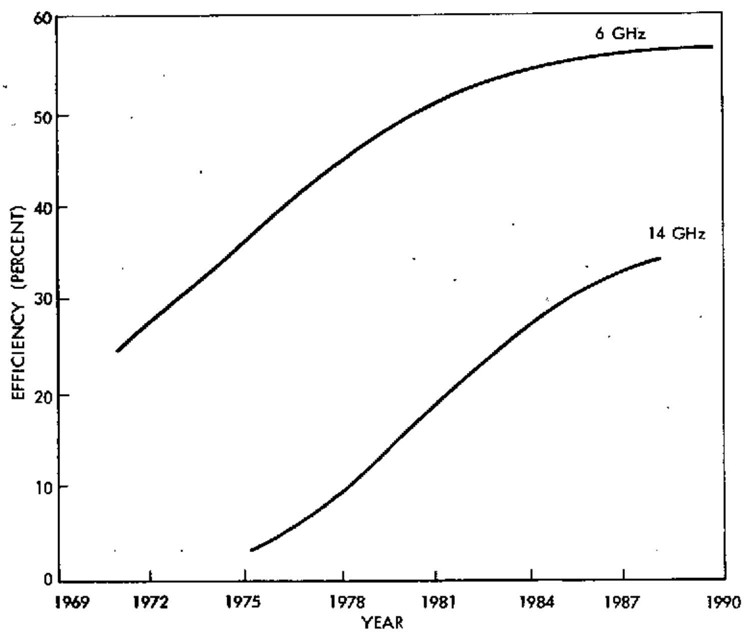


Fig. 7-30 Transistor-Amplifier Efficiency

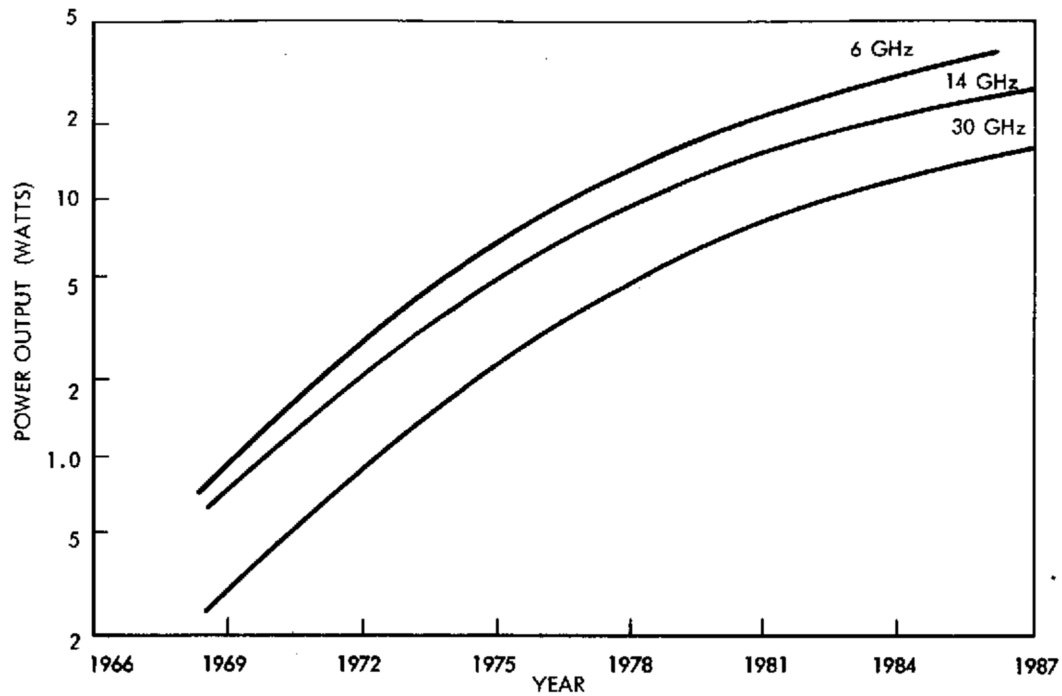


Fig. 7-31 Transfer-Electron-Device Power Output

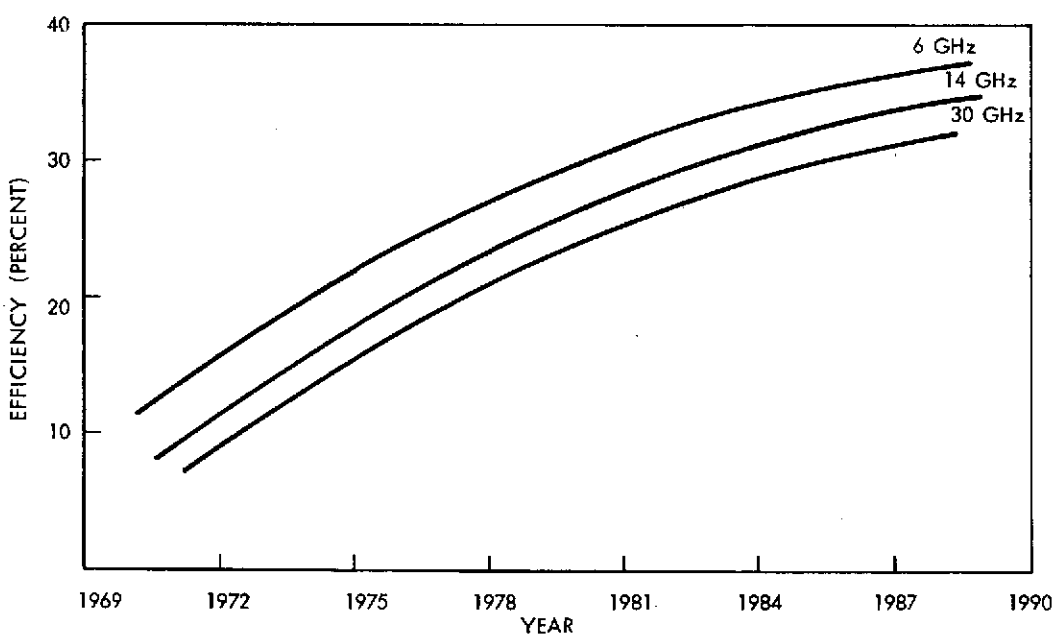


Fig. 7-32 Transfer-Electron-Device Efficiency

any foreseeable future needs, particularly since it appears that earth-station aperture needs are likely to decrease rather than increase. But, since future systems are likely to require a multiplicity of earth antenna beams, economic rather than technological factors are likely to add importance to switched or steered beam antennas. Thus, new fabrication methods and new materials application for existing technology with the goal of decreasing antenna cost will be of paramount importance.

7.4.3 Receivers

The input amplifier is the critical item in the performance of the earth-station receiver. Its noise temperature, bandwidth, and reliability are important performance factors. Both cooled and uncooled parametric amplifiers and possibly tunnel diodes or diode mixers may find application as input amplifiers. Both from the standpoint of cost and maintenance, the uncooled devices are preferable to the cooled amplifier; however, the cooled amplifier's considerably lower noise temperature may require its use in some applications. The noise temperature and bandwidth of these devices as a function of time are similar, as shown in Figs. 7-19 through 7-21 for various frequency ranges. The noise temperature curves are relatively flat beyond 1973 because of a lack of a significant effort in varactor diode development at present. Thus, the achievement of significantly lower noise temperatures is not likely until improved solid-state pumps are developed for the parametric amplifier. Tunnel diode and mixer performance are such that they are presently not competitive with the parametric amplifier.

It appears that the present device bandwidth of about 600 MHz at both 4 and 11 GHz and about 1000 MHz at 20 GHz will show only a small growth with time. The bandwidth at 4 GHz can be covered with one receiver; the 11 GHz bandwidth receivers may not be sufficient for total band coverage because of a split frequency allocation on the downlink assignments. The 20-GHz bandwidth receiver is insufficient for total band coverage. Total band coverage may not necessarily be required for a given system application; it is often beneficial but not critical.

Section 8
FORECAST OF TERRESTRIAL COMMUNICATIONS GROWTH

The future growth and viability of satellite systems for meeting the requirements of the needs model is dependent on how well satellites perform in comparison with terrestrial modes of information transfer. Determining the key technologies required for 1985 era satellites requires an understanding and knowledge of future terrestrial capabilities in order to determine how future satellites and terrestrial systems can best complement one another to provide the most cost effective total system of maximum benefit to the user population. The trend of terrestrial communications growth into the 1985-1995 time frame is defined to determine the baseline against which potential future satellite applications will be measured. The objective of this study to determine the key technology requirements for viable new services is dependent on a comparison between costs and services provided by terrestrial and satellite systems.

The results of this section of the study show that terrestrial communications will continue to grow, provide new improved services, and remain the dominant mode of communication for over 90% of the nation's population. Inherent limitations of terrestrial systems for broad coverage and operating flexibility provide ample opportunities for increased application of improved communications satellite systems.

The needs model presented three levels of service requirements, 1972 to 1975, 1975 to 1985, and 1985 to 1995. The improving levels of service are based upon forecasts performed in this section and in previous studies from which the basic needs model was obtained. Levels of future service demand defined by the functional and technical requirements of Section 5.0 are substantiated by the trends of communication service growth forecast in this section. Domestic terrestrial communications statistics are used for forecasting the growth trend of all domestic communications because they provide the best available applicable data. The historical trend data define the past rates of communication growth to meet growing demands and new needs. Satellite systems are a new means of providing better more cost effective services for certain long distance communication needs. Similarly, the coax cable supplemented the open wire telephone trunk systems, and the radio relay system supplemented and in some cases supplant coax cable systems. So the space satellites will supplement and supplant some terrestrial systems. The forecast trends of demestic communications growth presented are for the total demand for terrestrial and space satellite communications growth as evidenced by the historical past, the present developing capabilities, and the demands of a service oriented society.

The factors considered in para 7.1.1, Basic Considerations and Rationale for Forecasting, were applied for determining the trend of terrestrial communications growth and development. These forecasting techniques plus published statistics, plans, and technology data from the telephone company, technical journals, and technical society papers provide a clear indication of the expected trend of terrestrial technology growth and the problems and goals of the telephone, cable TV, and broadcast companies. AT&T's Bell System carries over 90 percent of the nation's domestic terrestrial communications, exclusive of commercial broadcasting. AT&T services include mobile telephone, picture phone, TV distribution, computer data communication, and two-way (telephone) voice communications by wire and radio. A comparison between the Bell System and conceptual independent satellite systems for leased long-distance telephone communication and distribution of TV service is presented in Section 9, Cost Effectiveness of Domestic Satellites.

8.1 TREND OF TELEPHONE SYSTEM GROWTH

8.1.1 Overview and Summary

The telephone industry is actively developing improved terrestrial communications technology and facilities for carrying the growing traffic load forecasted in Fig. 8-1 at a lower cost per channel-mile and providing a wider range of improved services such as Picturephone, high-speed data channels, better TV distribution, and faster-switching circuits. The prime areas of technology advancement are all-digital long-distance communications, computerized stored memory switching systems which will reduce costs and improve service, and improved cable systems. Such technologies

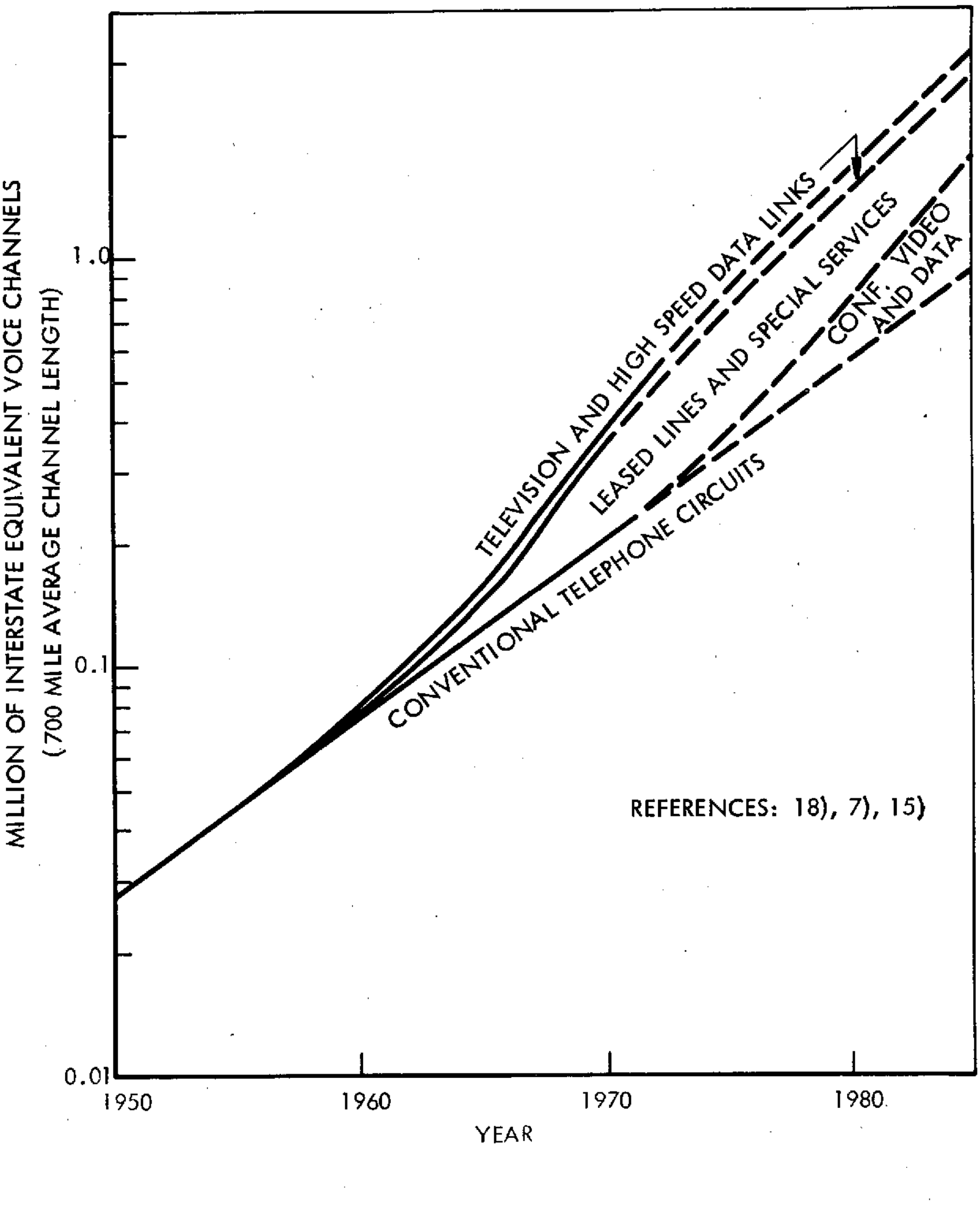


Fig. 8-1 Growth in Interstate Telephone Channels

provide the means for carrying the growing traffic load at lower cost, improving system flexibility, and improving service quality. The telephone system is motivated to develop improved, automated switching because switching and associated operating expenses account for most of the cost of a long-distance telephone toll call. The trend toward a predominately digital, synchronized, time-division multiplexed network with automated solid-state switching will reduce fixed operating and switching costs per channel.

Figure 8-2 shows the trend of long-distance toll rates and forcasted rate decreases by 1990 in equivalent 1958 dollars. Figure 8-3 shows a comparison between these prime-time long distance toll charges versus the prorated hourly cost for a leased line based on 75 percent utilization (7 hours a day, 150 hours a month). The rate structure is such that a leased line provides only a 20 percent savings if there is a 75 percent utilization for one 7-hour shift a day. The forecasted 1990 leased line rates resulting from technology improvements and a competitive market show that long-distance communications costs will become progressively less sensitive to distance and similar to satellite cost versus distance rate structures. Leased long-distance lines become increasingly more attractive with increased utilization rate. High usage is needed to justify leasing. The recent development of improved modems capable of communicating at 9600 BPS and costing several thousand dollars will make it more economical for many computer communications users to switch from leased lines to direct dialing if the line quality is adequate and the rate structure is revised to encourage direct dialing by machine for call durations of several seconds. The trend toward low cost, short duration direct dial calls may be an effective means of restricting the leased service market for communications satellite companies.

8.1.2 Growth Trend of Long-Distance Communications

Figure 8-1 shows the forecasted growth trend of long-distance telephone circuits from approximately 500,000 interstate equivalent voice circuits in 1972 to about 3,500,000 circuits in 1985 (Ref 18, p 148). Note that there is a need for only 1,000,000 actual voice/data circuits. Figure 8-4 indicates the relationship between gross national product and toll calls per day, which are two of the prime forces affecting the growth

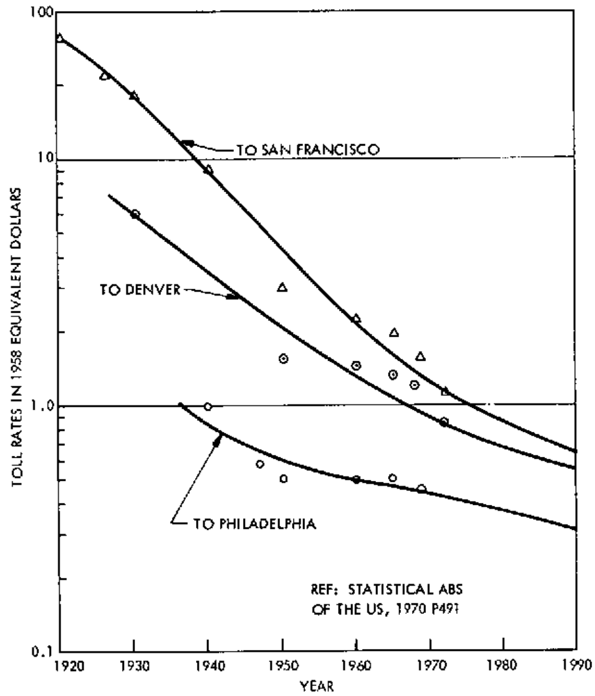


Fig. 8-2 Toll Rates from New York

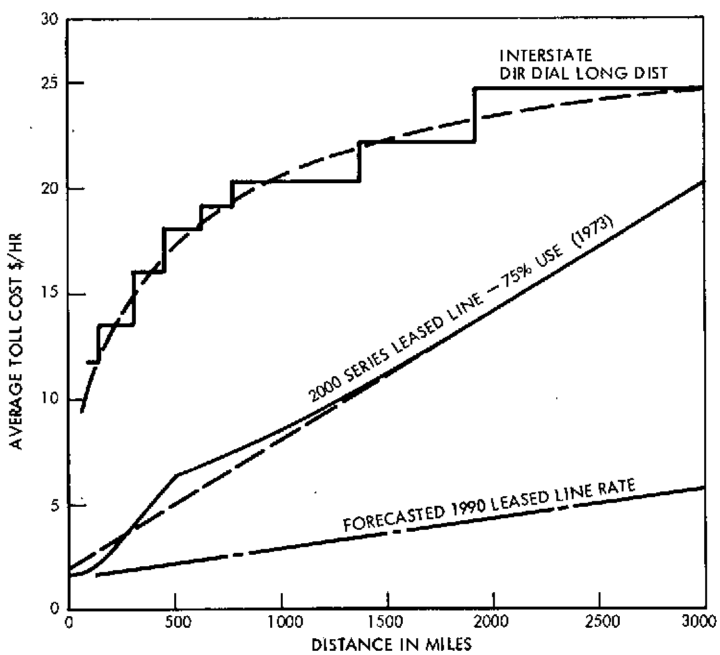


Fig. 8-3 Toll Charges Versus Distance

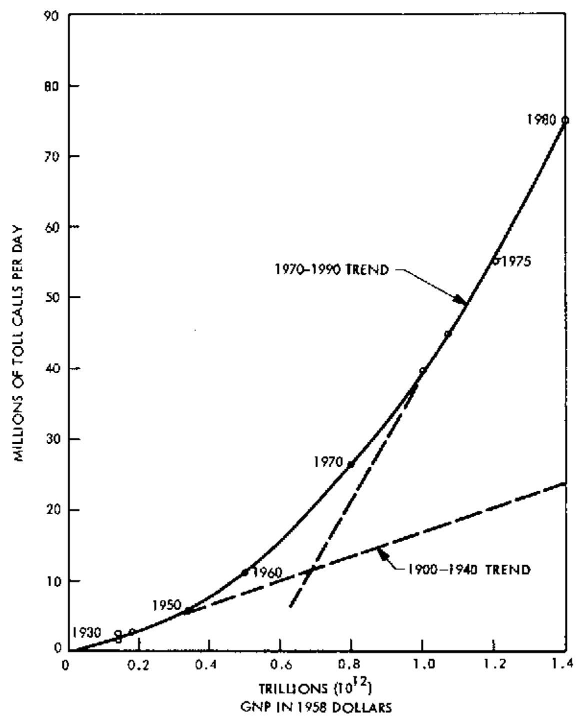


Fig. 8-4 Growth of Toll Traffic Versus Gross National Product

trend of long-distance communications. An important aspect of this figure is the change of the correlation ratio between GNP and toll calls between the 1900 to 1950 era and the post-1950 era, when the nation increasingly changed from a basically manufacturing-oriented society to a more service-oriented society with a mature semiautomated production capability for producing most of the needed goods and hardware.

Telephone companies and electronic equipment suppliers are presently developing the technology for meeting the forecast traffic growth for communications services (Ref 15, p C6). AT&T is fulfilling much of the near-term traffic growth by refining existing equipment and developing new systems such as the L-5 long-distance cable, planned for operation in 1973, to carry 90,000 voice channels at a per-channel cost 30 percent less than for existing systems. Waveguide systems being developed for possible installation in the late 1970s will be capable of carrying 230,000 digitized two-way voice/data channels (Ref 16, p 5). Installation of a 6,000-mile millimeter waveguide backbone system of the type shown in Fig. 5-1 between the 22 major metropolitan areas would provide 1.4 billion channel miles of long-distance communications capability and would fulfill forecasted long-distance trunk-growth requirements of the nation's telephone system through 1981 (Ref 5, p 66). The installation of such a system in the late 1970s would cost an estimated $2 to $3 billion and would be a reasonable investment for upgrading a system with projected 1976 operation revenues of approximately $30 billion and projected 1976 plant investment cost of $100 billion.

One alternative to a millimeter waveguide trunk is a satellite system with 5 to 10 million voice channels to provide the equivalent communications capability of a 1.4 billion channel-mile cable system. The average message communication distance in a 6,000 mile backbone terrestrial communication system is approximately 700 miles, and the equivalent satellite system therefore needs about ten times more channel capacity than the end-to-end terrestrial system. Terrestrial and satellite systems will each carry part of the total communications traffic load. Terrestrial cable systems will carry the bulk of the short-distance and conventional telephone load. How much of the total long-distance wide-bandwidth traffic is carried by satellite is partially dependent on technology developments, which will determine the relative economics of cable versus satellite systems.

Satellites are well suited to carry a portion of the nation's long-distance leased telephone traffic plus special traffic such as public service broadcast program distribution, biomedical network teleconferencing, and general teleconferencing, which require a minimum of switching. Such special services are not specifically identified as part of the forecasted telephone system traffic shown in Figs. 8-1 and 8-4 but are included as part of the television and Picturephone growth. Figure 7-1 shows the chronologic growth of long-distance communications system capability in bits per second resulting from developments such as wire telephone lines, coaxial cable, microwave radio links, waveguides, communications satellites, and lasers (Ref 28, p 342). The trend line of communications technology growth curves upward because of the accelerating pace of innovation and development in the environment described in para 7.1.1.

The rapid development of improved communications satellites poses a limited threat to established long-distance terrestrial systems. The threat is being countered by accelerating the development of improved microwave and laser cable systems. Laser communication over optical cables or light pipes is a promising area for new development because of the high theoretically attainable communications capacity of light waves;

light waves have a higher frequency and a much broader available bandwidth. Lasers operating at the 1-micron wave length with a frequency of 10^{14} Hz can theoretically carry on the order of 10,000 times more information than a microwave carrier at 10^{10} Hz.

The present rate of development of lasers and light pipes indicates that optical fiber cables will revolutionize communications and supersede coaxial cables and wave guides by 1985. Technology is available for transmitting hundreds of television or Picturephone channels through an optical cable. The key technical problems at present are the manufacture of suitable long-length fibers at low cost and the splicing of optical cables. Table 8-1 indicates the pace of laser and optical cable technology development.

Table 8-1

TREND OF DEVELOPMENT OF LASERS AND FIBERS OPTICS

Year	Lasers	Fiber Optics
1950		Development of fiber optics strands
1955	Maser invented	1000 dB/kilometer light attenuation
1960	Laser invented	
1962	Semiconductor lasers	
1965	Laser beam communications systems commercially available	
1970	Laser beamed to moon	14 dB/kilometer loss fibers at 1.08 microns
	Forecasted operational satellite laser systems	Planned optical cable installations
1973		4 dB/kilometer loss
1980	Extensive commercial applications	
1985		Extensive use of optical cables

At the 1972 state of development, light pipes required a repeater amplifier every 2 to 6 kilometers. Due to a recent technology development reducing the loss of fiber optics to 4 dB/kilometer, repeater spacing will probably be on the order of 10 kilometers. The theoretically attainable glass attenuation losses are on the order of tenths of a decibel per kilometer. Improved lasers and light detectors will help to increase both the distance between repeaters and the capacity of optical cables. If light pipes are not perfected, the present development trend of improving coax cables, repeaters, and wave guides will enable the telephone system to meet the nation's present and future long-distance communication requirements for voice, data, and television program distribution. The demand for long-distance communications is expected to grow at a 15 percent per year rate, as shown in Fig. 8-1 (Ref 15, p 66; Ref 17, p 148; Ref 18, p 37; Ref 9, p 27; Ref 7, pp 11, 15, 20, 21, and 22). The growth rate forecasted is based on continued use of the existing AT&T and GTE systems, with evolutionary modifications to improve services. The development trend and future market forecasts for the terrestrial systems tend to become self-fulfilling without the impetus of competitive communications satellite systems because the demand tends to grow in proportion to the new facilities installed on the basis of a planned investment rate. The investment rate may not reflect total needs.

8.1.3 Trend Toward Digital Telephone System

The trend toward a predominantly digital telephone system capable of carrying the growing data and telephone traffic load is well under way. Over 15 million trunk-miles of T-1 cable designed for data communications have been placed in service. This amounts to on the order of 100,000 T-1 cable-wire-pair terminals, with each terminal capable of carrying 24 one-way voice channels or 1.5 megabits of data. Each wire-pair terminal of the new T-2 trunk developed to replace the older T-1 system can carry either 96 voice circuits, a Picturephone channel, or a 6.3-megabit data stream per wire pair of the cable. The T-2 cable has been carefully developed to increase the range of economically feasible communications to 500 miles. The limit for the T-1 cable is 50 miles. A T-4 cable has been developed to carry three encoded television channels of 92.5 megabits each or a combination of up to 32 multiplexed T-2 lines. Terminals have been developed for converting TD-2B radio microwave relay channels to 20-megabit-per-second data streams instead of the original 1200 voice channels per carrier. Similarly L-4 and L-5 coaxial cable systems have been converted to carry 13 megabits per second over channels originally designed to carry a master group of 600 analog voice channels. The Bell System's strategy is to convert TD-2B radio and coaxial cable channels to 20 and 13 megabit digital channels in order to carry most of the growing intercity digital trunk traffic over the next 5 to 10 years by means of the existing plant (Ref 12, p 284).

Long-distance millimeter wave guides and optical cables capable of carrying on the order of 100,000 to 200,000 voice channels or gigabit data streams are planned for the later part of the 1970s and early 1980s. Digital modulation of the cables is required to help overcome inherent transmission imperfections such as multipath effects (Ref 16, p 5). Digital modulation will provide the following additional advantages:

1. The PCM-coded digital technique used by the telephone system has high immunity to noise. New, all-digital systems can provide essentially distortion-free communications and low bit error rates over long distances when the total system is digital and adequate signal-to-noise ratios are used. Much of the present telephone system was not designed to handle thousand-bit-per-second digital data streams. Bit error rates of the order of 10^{-5} or worse occur as a result of noisy lines and switches. The effects of nonlinear distortions and delays increase as bit rates are increased.
2. Digital bit regenerators can be relatively simple nonlinear devices in comparison with linear broadband repeater amplifiers required for long-distance analog circuits.
3. Voice, Picturephone, television, and digital data signals can be interleaved into a data stream and carried in any combination within a high-speed data channel without introducing significant intermodulation crosstalk between adjacent signals.
4. Digital systems work well with time-division switching and multiplexing, which increase total system flexibility and can reduce switching costs.
5. End-to-end digital systems are the ideal means of carrying the growing digital computer and data terminal traffic.
6. Time-division multiplexed digital systems can accept, transmit, and switch data streams of various bit rates and from various sources such as computers, television, Picturephone, or voice telephone if adequate system capacity exists to handle the total traffic. There is no difference within the communication system trunk channels between digital bits from widely varying sources. Consequently, the system has the capacity to handle fluctuating traffic loads and varying traffic mixes in a straightforward manner without the need for special conditioning. All signals are digital and equal within the system.

The disadvantage of the digital system has been that a greater RF carrier bandwidth was required to transmit television or Picturephone signals in digital format rather than analog signal format. This disadvantage is being overcome by means of signal compression techniques. The same advantages and disadvantages apply generally to both terrestrial and satellite common carrier systems. Consequently, common carrier satellite system communications will be predominantly digital in the 1980s. The development of millimeter waveguides and optical cable systems with bit rate capabilities on the order of hundreds of gigabits (10^{11}) will lead to all-digital long-distance communications systems.

8.1.4 Trend of Increased Cost Effectiveness of Computer and Data Terminal Communications

The cost effectiveness of using voice telephone circuits for digital communications is improving. This is due to both the increasing digital bit rate per voice circuit and toll rate reduction (based upon constant value dollars). Figure 8-5 shows the general trend of digital bit rate increasing with time and approaching a fixed limit of 56,000 bits per

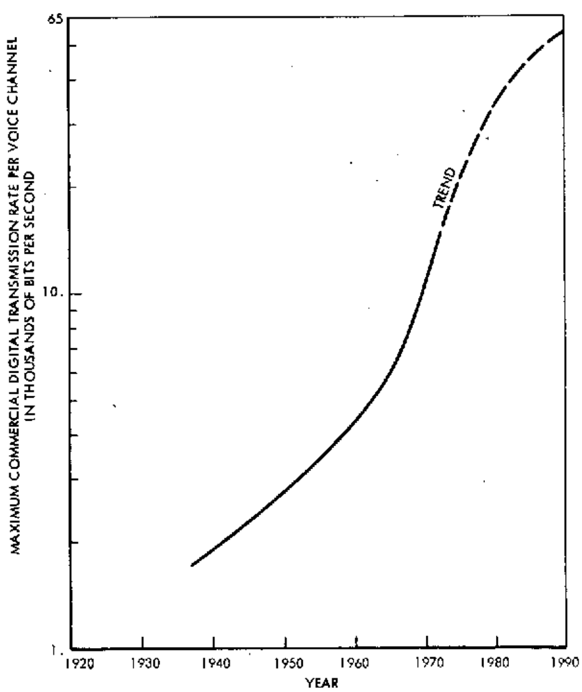


Fig. 8-5 Digital Transmission Rate per Voice Channel

second in 1990. This limit is due to the 64,000-bit-per-second digital system format adopted by the telephone system (AT&T) for converting 4 kHz analog voice channels to 64 KBPS digital channels so that both voice and digital communications can be easily accommodated in an all-digital time-division multiplex (TDM) system (Ref 12, p 281). The limit of a 64-KBPS digitized voice channel is 56 KBPS, because every eighth bit is required for addressing and control. Data terminals will have a 50-KBPS capability by eliminating the analog-to-digital conversion step and providing buffered data inputs direct to the telephone system in the proper digital form. Conversion to a 50-KBPS capability for long-distance voice channels will occur gradually during the 1970s. Figure 8-6 shows the forecasted increase in cost effectiveness from reductions in long-distance tolls and the increase in digital data rate per voice channel. By 1990, a full 700-page text could be transmitted coast-to-coast in less than 3 minutes for less than a $1 toll charge during prime time. A 50-KBPS digital rate would allow one multiplexed channel to serve approximately 30 timeshare computer terminals simultaneously at a prorated cost of approximately 30 cents an hour per terminal at the 1000-mile lease rate for 1973 shown in Fig. 7-3.

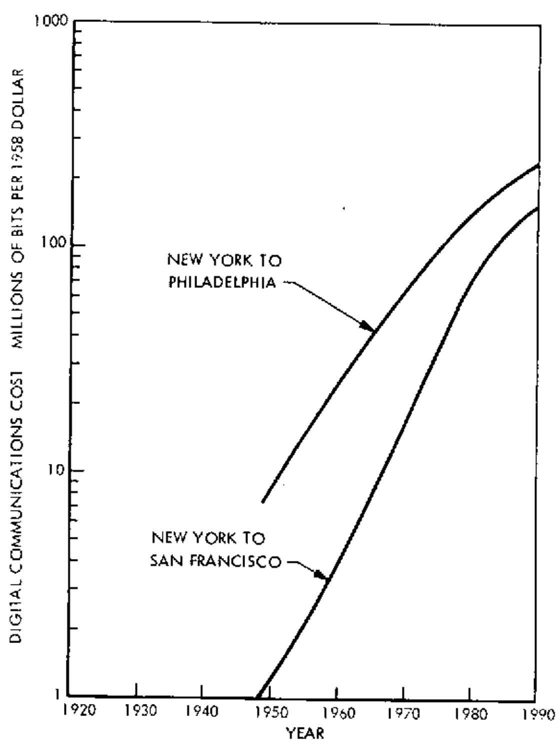


Fig. 8-6 Effective Digital Communications Costs

8.1.5 Growth of Computer and Data Terminal Communications

The growing use of digital computers tends to accelerate the growth of digital traffic. But the trend of declining costs for computer processor and memory units tends to favor the development of improved local computer capabilities and reduced use of long-distance timeshare communications networks. Forecasted future costs of mass storage are as low as 10 million bits per dollar of storage system cost by 1980 (Ref 3, p 14; Ref 4, p 71). Such a low cost for memory units favors the use of local and regional data files over the use of a single central data file system accessed by long-distance communications channels.

Figure 8-7 shows the forecasted trend of logic gates per dollar for computer manufacture. The machine capability, which costs $1 million today, is expected to cost $100,000 by 1980 (Ref 4, p 71). The cost of a programmable minicomputer will be reduced from several thousand dollars to several hundred dollars. This trend toward low-cost computers will result in the more efficient use of digital communications

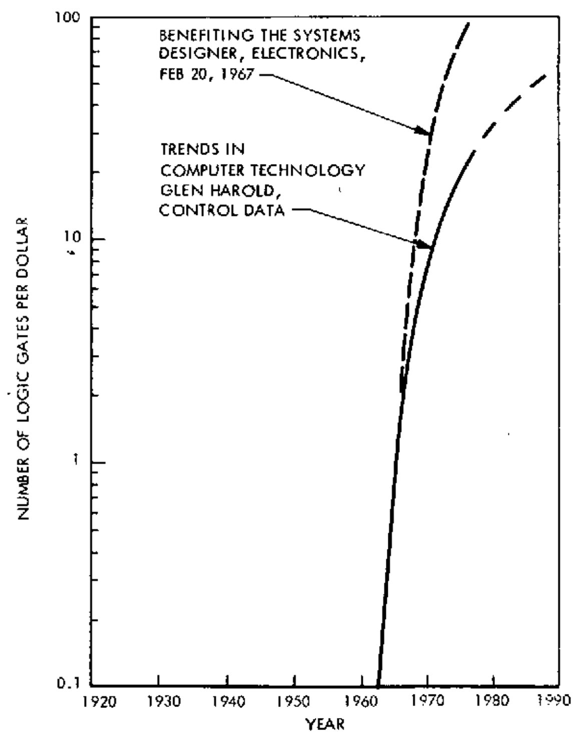


Fig. 8-7 An Indicator of the Trend of Computer Capability Versus Cost

channels. Regional data files of billions of bits located at data centers will be updated periodically when there are lulls in the communications channel usage. The number of data terminals connected to telephone systems and eventually to home service cable systems will continue to grow, as shown in Fig. 8-8 (Ref 15, p C5). The trend is for data terminals to have multiple capabilities, including input, output, display, printout, buffering, storage, and multiplexing in order to provide greater convenience and to make more efficient use of communications channels.

By 1980 most data terminals will be integrated with computers capable of performing programmable logic operations, storing programs, compressing data, and automatically accessing larger remote computer systems containing needed data, files, programs, and problem solving capabilities. Figure 8-9 shows data rates required for today's data terminals. Maximum core-to-core data rates are expected to increase by a factor of ten. Figure 8-10 shows the estimated future increased computer instruction rates. A 92.5-megabit-per-second digital television channel data rate is considered adequate for the highest speed commercial computers in the 1990s. Special purpose computers, such as for earth resources data input will require higher data rates.

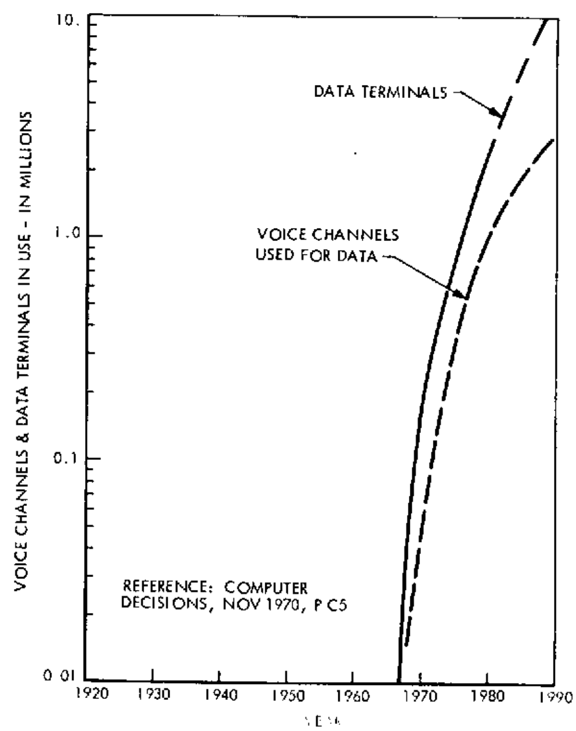


Fig. 8-8 Number of Data Terminals

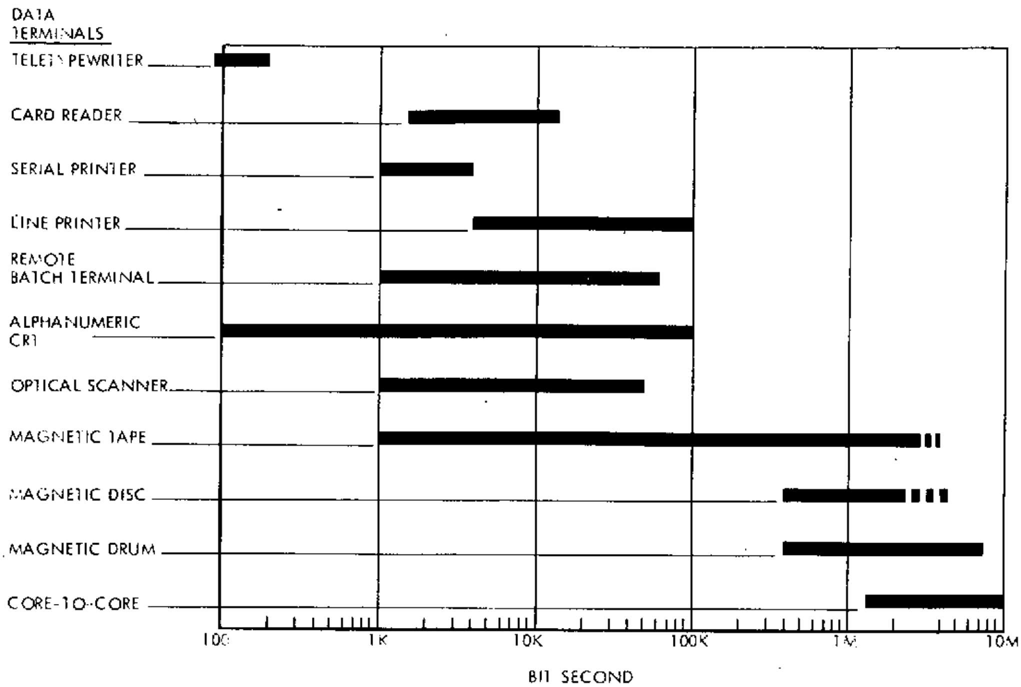


Fig. 8-9 Data Rates for Major Types of Data Terminals

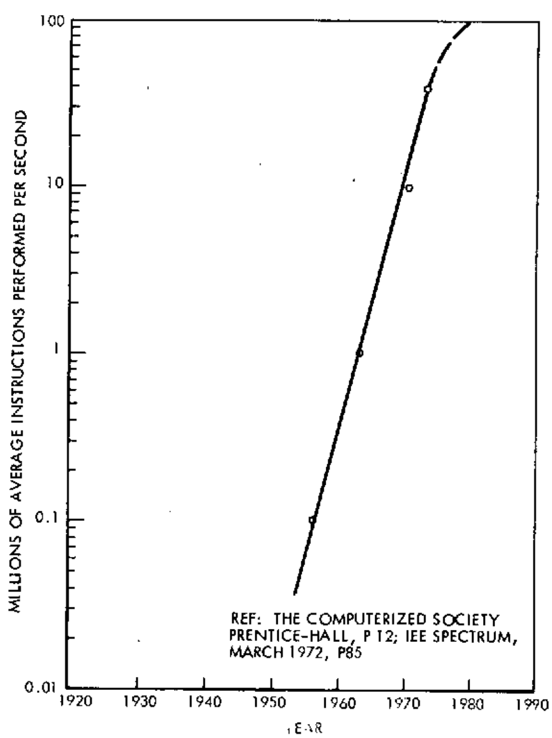


Fig. 8-10 Computer Performance

The 56-KBPS digital voice channels, 1 MBPS T-1 channels, and 6 MBPS Picturephone channels are expected to fulfill the bulk of the future data communications requirements. If half of the one million interstate voice channels forecasted to be leased by 1985 were utilized for carrying digital computer and records data at a 75-percent utilization rate at 50,000 BPS, the system would be capable of transmitting the equivalent of 200 pages (or video display frames) of text per 8-hour day for every adult in the nation. The system could provide over two thousand pages of computer printout or display per day for each manager, scientist, supervisor, engineer, and proprietor in the nation. A system capable of providing one million digitized long-distance voice lines should adequately fulfill the nation's need for long-distance leased voice and data communications during the 1980s. About 3.7 billion telephone calls were made over the toll call circuits for data transmission in 1970 (Ref 15, p C8). A significant amount of the nation's future total data communications traffic will be effectively handled by means of toll traffic over direct-dial, all-digital communications systems that will not require acoustic couplers or line equalizers. The growing use of toll calls for data as well as voice communications will generate a total need for approximately one million long-distance voice-grade toll circuits by 1985. About one-third of the nation's total long-distance telephone network capability will be dedicated to leased voice/data, one-third to regular toll voice/data traffic, and one-third to TV and Picturephone/data traffic. The average channel transmission distance will be approximately 700 miles (Ref 7, Exhibit 1).

8.1.6 Future Growth of Picturephone

There is a trend toward telephone service with a video diaplay. AT&T's Picturephone provides real-time two-way video images and uses 6.3 MBPS or a 1 MHz analog bandwidth. The Bell System is being modified in an evolutionary manner to provide nationwide Picturephone service in the 1980s. Future plans for Picturephone are presented in the May-June 1971 Special Picturephone Issue of the Bell Laboratories' Record. Many of the on-going developments of improved telephone system switching and signal transmission are directly aimed toward providing economically attractive Picturephone or 6 MBPS digital data service capability. An important reason for AT&T's present effort in developing small-diameter fiber-optic cables for transmission of laser light beams over several miles distance without a repeater amplifier is to provide the means for upgrading voice telephone service to Picturephone service. Existing runs of wire and cabling would be replaced by low-cost flexible plastic fiber optic cables smaller in diameter than a pair of 22-gauge copper wires, but providing a hundredfold increase in bandwidth capability with relative immunity to radiated electromagnetic waves and moisture along the cable run. Potential problems due to phase-shift and multipath effects will probably be resolved with digital modulation techniques.

Picturephone was developed as a visual computer readout terminal as well as for two-way visual personal communications. Picturephone is seen as one of the major markets and greatest potential uses of long-distance communication bandwidth in the future. The forecasted number of Picturephone toll calls a day will equal one toll call a day for 1 percent of the nation's population by 1985. Some Picturephone toll calls will be made by automated, direct-dialing computer systems exchanging data over the 6.3 megabit Picturephone channel. Most of the Picturephone traffic will be for personal communications or man-machine interfacing. Digital data compression will ultimately be used to reduce the bit rates required for long-distance Picturephone transmission from 6.3 megabits to 1.2 megabits.

The increased digital rate provided by digital voice/data and Picturephone/data channels plus improved computer systems will increase the cost effectiveness of machine-controlled toll calls so that fewer or shorter time-duration connections will be required to meet the nation's requirements for digital information. No new technology developments are foreseen, however, that will significantly alter the basic need for person-to-person communications, as defined in para 4.1, Background Considerations for the Needs Model. The introduction of Picturephone in place of regular telephone increases the minimum required communications channel bandwidth from 4 KHz to 1 MHz in order to improve the effectiveness and attractiveness of person-to-person communications. As the nation continues to move toward an affluent service economy, with greater importance placed on human values, there will be a continuing need for improved long-distance person-to-person communications by means of Picturephone and two-way video systems. Such communications will be increasingly used to save travel time normally required to bring together people who are working on the same task, or for common purposes at widely separated locations.

Lower-cost digital logic and memory units (Fig. 8-7) will make automated switching and data compression of Picturephone and television channels an economically attractive means of reducing long-distance Picturephone toll rates. Digital transmission of images has been studied for over 15 years, and redundancy removal techniques have yielded data compression ratios of 5 to 1 (Ref 20, p 39). Television will probably be transmitted at rates on the order of 12 to 20 MBPS over video conference systems, which would be scheduled for short-term meetings or leased for limited periods of use.

Recent development of slow-scan video systems that transmit an image every 40 seconds over a normal voice telephone channel for fixed image viewing also provides an important step forward in the trend toward visual augmentation of the telephone communications. Such systems are expected to be used extensively in the future as low-cost substitutes for Picturephone and two-way interactive television.

8.2 CABLE TELEVISION GROWTH

Cable TV is presently growing by about 20 percent a year, as shown in Fig. 8-11. By 1985, about 90 percent of all residences will be served by cable television. Recently developed cable systems can carry some 80 television channels or a mixture of television, voice, and data channels. Cable systems are expected to provide a variety of local communications services such as education and instructional television, library reference, biomedical education, consultation and diagnosis, shopping news, continuous weather and news service, meetings and discussions, cultural programs, and home access to timeshare computer networks. Special closed-circuit digital video channels will provide security for specialized customers such as doctors, dentists, law enforcement officers, and special schools. Digital signals will be coded and decoded by means of such devices as shift registers that will be inexpensive and easily changed or replaced. Video communications sets of the future can be provided with code card receptacles so that a doctor, for example, could use any of several sets provided at various

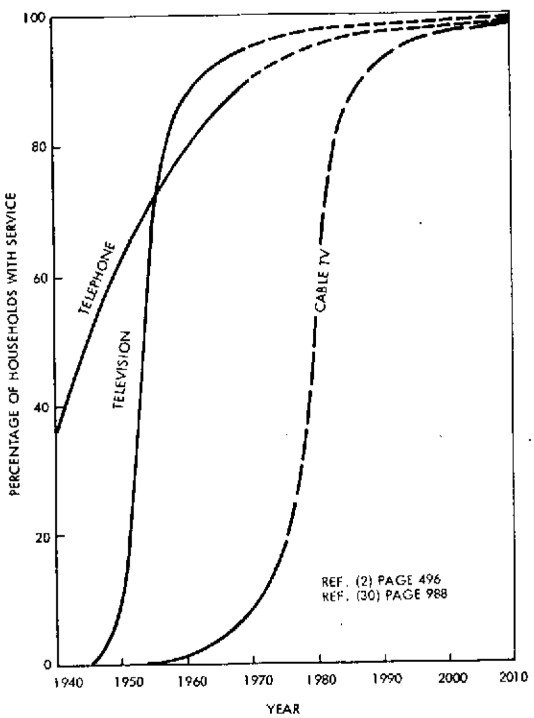


Fig. 8-11 Household Services

locations by insertion of a small decoder key card that would enable him to have access to a biomedical network when at home, in the office, at medical center, or when visiting a medical facility. Existing cable systems will be upgraded in the future by adding additional cables and using compression techniques to expand the number of available channels (Ref 24, p 1026).

Technology breakthroughs will accelerate the development of cable TV home communications centers. The potential development of these services by means of cable TV systems will generate long-distance traffic for telephone systems and communications common carriers, but will pose a challenge to local telephone systems. Picturephone and home data terminal systems will be developed to operate over the telephone system to provide service options in competition with cable TV services (Ref 24, p 966).

8.3 RADIO SERVICES GROWTH

Police and special service radios have grown from 650 thousand stations in 1960 to nearly 1.8 million stations in 1967 (Ref 2, p 495). Growth trends of special radio stations for aviation, marine industry, public safety, and citizens' band users are shown in Fig. 8-12. Crowding of available radio communications channels is restraining present growth trends. Techniques are being developed to increase the capacity of the available RF spectrum. Pressure is growing to allocate more of the RF spectrum for mobile communications.

The mobile radio telephone system has a 4 to 5 year waiting list for mobile telephones. Bell Telephone Laboratories has proposed a new mobile radio telephone system that can increase capacity and lower the average service charge from $50 a month to $40 a month as subscriber density increases. The system uses the 75 MHz band from 806 to 881 MHz. The system can provide 800 channels to supplement the present system,

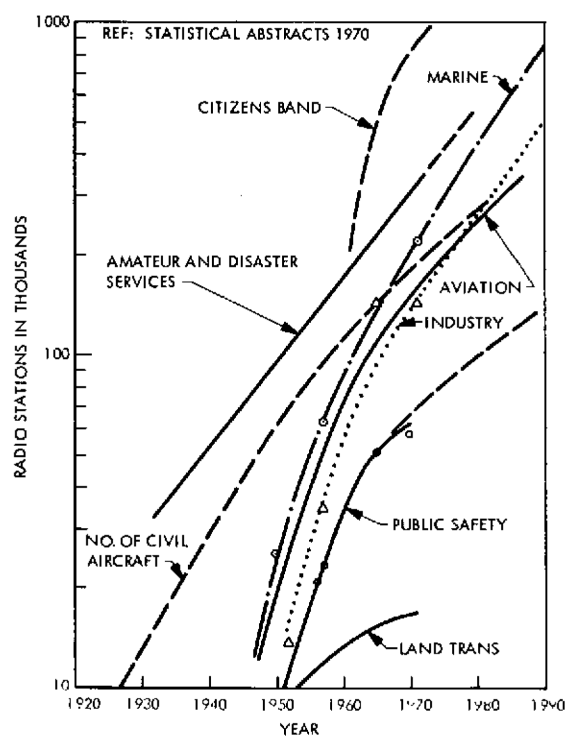


Fig. 8-12 Growth of Radio Communications

which provides 12 channels with 30 to 40 customers per channel. Estimated capacity of the new system is 300 users operating within a 600 square mile area. Such a system could handle 300,000 users operating in 100 metropolitan areas. A recent study shows that 7-1/2 percent of the population of the United States, or 15 million people, are interested in obtaining a mobile communications system if the cost is approximately $40 a month (Ref 23, p 42). Additional RF spectrum allocations and new technology developments are needed to meet the future demands. New frequency allocations and technology improvements that provide more channels at lower user cost will stimulate demand for special service radios such as citizens band, amateur and disaster warning, marine, industry, public safety, and land transport. There is a growing trend toward installation of mobile public telephones in public transportation units such as aircraft, trains, and buses.

Future applications of available technology will produce lighter-weight personal two-way radio systems. Batteries are the major item limiting weight and performance of present two-way personal radios. The mobile radio range is generally limited to local line-of-sight operation within 20 to 40 miles, depending on the frequencies used and the power output. Satellite relays with narrow beams covering 200 to 400 mile radius areas could provide two-way communications throughout the beam coverage area and allow emergency communications to remote stations. Use of 1 GHz of frequency bandwidth in the 19 GHz band could provide on the order of one million voice channels because of frequency reuse in different areas. Mobile users could use either satellites or local stations by switching antennas and frequencies when beyond the range of a fixed ground-relay station. A hybrid system using satellites and ground-relay stations could provide mobile communications throughout the nation. Future systems will incorporate means for automatic position location and special channels for emergency aid. Conceivably every automotive vehicle may eventually contain a two-way mobile radio.

Section 9

COST EFFECTIVENESS OF DOMESTIC SATELLITES

This section presents a comparison between satellite and terrestrial communications in order to indicate the viability and extent to which satellites can compete with the terrestrial communications networks described in Section 8. Satellites have inherent advantages for special services such as aircraft communications over oceans, and television program distribution. Recent studies and plans for Aerosats and the development of satellites for Canadian television distribution show that satellites are viable for such special services. Comparison of satellite systems with the established AT&T terrestrial network rates presents a critical test of the cost effectiveness and viability of domestic satellite systems. The AT&T system presently provides extensive and generally acceptable services throughout the nation. A meaningful comparison with the AT&T system is dependent upon numerous factors such as average communications distance, service bandwidth, service reliability and outages, networking structure (point-to-point or multipoint), and network size. There are additional pertinent factors such as the amount of switching required as discussed in Section 4.0. The effects of all of these factors are not described in detail. Only a summary comparison of various possible types of satellite networks with the AT&T network's rates are presented. Comparisons are made on the basis of the minimum distance, for a typical mix of likely narrow bandwidth services, at which satellite systems can compete with the terrestrial system. The distance is called the crossover or equivalence distance.

Satellites compare more favorably for wide bandwidth services such as video than for narrow bandwidth services such as voice circuits due to the present AT&T rate structure for voice and video services. Also, the existing terrestrial networks do not provide as extensive capabilities for carrying wide bandwidth services because they were developed primarily for analog voice service. Comparison on the basis of a narrow bandwidth mix weights the comparison in favor of the present terrestrial system. Satellites are not considered for extensive direct house-to-house switched communications. Such a service by satellite for the urban and surburban population is not viable.

The crossover distance is an established means for comparing satellite and other types of communication services. The comparison is misleading when improper comparisons are made. The concept of the crossover distance is that satellite communication costs are essentially insensitive to distance. Therefore, satellite services are less expensive than terrestrial services at distances greater than the crossover distance. The crossover distance, however, has little meaning unless systems designed for similar purposes are compared. It is erroneous, for example, to use the crossover distance between global communications satellites (Intelsats) and local or regional terrestrial networks as a means of comparison. Such results only show that global satellite communications will not be very competitive with regional systems. Regional networks should be compared with satellites providing regional coverage and designed to provide optimum cost effectiveness for the particular region and service needs. A regional satellite directs its radiated energy over a limited area or country and is more cost effective for short haul distances than a global coverage satellite. The domestic satellite systems analyzed make use of established terrestrial facilities to improve total cost effectiveness. This is similar to airlines and railroads using trucks to provide final delivery to user facilities by means of existing roads.

Results of the analysis show that satellites using present technology can compete at distances of only 200 miles if customers will accept short 8 to 15 minute outages once a day for about 20 days per year. Such outages affecting only one earth station at a time due to sun and storm conditions are expected to be acceptable to many users desiring lower rates. Outages occur in the present telephone network due to busy lines, storm damage and emergency conditions.

Which of the five spacecraft configurations presented is best depends on the service objectives and risk limitations imposed by the financial resources of the operating organization. The spacecraft with 48 transponders can provide the most cost effective communications – if adequate markets and traffic can be developed. Therefore, 48 transponder spacecraft are used as a basis for the voice/data (telephone) system in the sensitivity analysis in Section 10.

The forecasted trend of increased cost effectiveness for satellite systems presented in Section 7.0 indicates that satellites will be competitive into the 1990s. The trend of satellite cost effectiveness improvement is greater than the forecasted trend of terrestrial telephone system toll and leased line rate reduction presented in Section 8. The ability of satellite systems to profitably operate in conjunction with and also to supplement established terrestrial communications indicates the viability of the conceptual systems defined in Section 10. Satellites are viable for common carrier and leased services and also for services not now provided by established terrestrial networks.

9.1 BACKGROUND CONSIDERATIONS

This analysis was performed to determine the communications distances (crossover points), satellite size, and conditions in which independent communications satellite companies could best compete with terrestrial communications systems for a share of the nation's leased voice and data network market. Independent satellite communications companies, attempting to capture a portion of the national market, have an inherently different problem of applying communications satellites than do AT&T and GTE. Consideration of this difference is an important factor affecting the analysis and conclusions.

Established terrestrial carriers must protect their markets and make the best use of existing terrestrial networks developed to serve the full range of the domestic market. Communications satellites, light pipes, and improved coaxial cable systems provide means for improving the existing long-distance coaxial cable and microwave relay networks. Satellites can improve system flexibility, reduce costs for very long-distance circuits, and provide point-to-multipoint distribution for broadcast network programs.

The existing long-distance trunks can provide backup communications for satellites during storms, solar occultation, and sun outage (when the sun is directly behind the satellite and within the earth station antenna's field of view). Consequently, the best type of satellite and the best utilization of satellites by AT&T and GTE will be different from the type of satellites and utilization that will be most advantageous for a satellite communications company.

Satellite companies must develop or lease the required terrestrial circuits between satellite earth stations and customer facilities, but the satellite system must provide the major means for developing an extensive competitive network. Consequently, the network must be developed for the maximum use of the inherent capabilities of satellites and minimize the need for supporting long-distance terrestrial circuits requiring extensive right-of-way and investment. The satellite system should be optimized for the market objectives and designed to provide the best competitive advantage against the long-distance terrestrial networks, rather than be designed to complement the existing network. The objective of the analysis performed was to determine the optimum conceptual satellite configuration for independent satellite communications companies. Such a satellite will have broader possible applications for area support of developing countries and for fulfilling many civil needs. Sun outage or other causes of interruption of satellite services are of prime concern for the type of system considered in order to eliminate the need for terrestrial long-distance circuits for backup communications. Two approaches to this problem are considered: first, the use of two satellites in orbit to allow switching between satellites to prevent interruption of service from sun outage and, second, to offer reduced rates for customer acceptance of sun outage interruptions that last for approximately 8 minutes a day, 20 days a year.

9.2 SUMMARY OF ANALYSIS

The crossover distances at which various-size satellites with 35 ground stations and 85 percent loading of satellite transponders can profitably compete with AT&T at the leased-circuit rate structure shown in Table 9-3 are as follows:

- Thor-Delta launched Anik type satellite, 12 transponders, with sun outage allowed, 650 miles; without sun permitting outage, 2000 miles
- Atlas/Centaur launched INTELSAT IVA type satellite, 24 transponders, with sun outage allowed, 800 miles; without permitting sun outage, 2200 miles
- Titan IIIC launched INTELSAT V type satellite, 48 transponders, with sun outage allowed, 200 miles; with sun outage not allowed, 700 miles.

Table 9-1 shows the typical traffic mix per obtainable revenue per transponder for AT&T rates for several distances. This traffic mix is used for the required revenue

Table 9-1

SATELLITE TRANSPONDER REVENUES
OBTAINABLE FROM AT&T RATES

AVERAGE TRAFFIC MIX PER TRANSPONDER		CIRCUIT DISTANCE					
		500 MILES		700 MILES		1000 MILES	
NUMBER OF CIRCUITS	TYPE DUPLEX CIRCUITS	ATT 500 MILE RATE $K/MO CIRCUIT	REV/ TRANSP $K/MO	ATT 700 MILE RATE $K/MO CIRCUIT	REV/ TRANSP $K/MO	ATT 1000 MILE RATE $K/MO CIRCUIT	REV/ TRANSP $K/MO
10	50 KBPS	7.20	72.0	9.50	95.0	11.00	110.0
100	4.8 KBPS	1.25	125.0	1.43	143.0	1.68	168.0
70 (70)	SERIES 2000 (1 VC)	0.82	57.4	0.95	66.5	1.24	86.8
4.2 (50)	8000 (12 VC)	0.56	23.0	0.72	36.0	0.87	43.5
0.3 (20)	5700 (60 VC)	0.28	5.6	0.38	7.6	0.54	10.8
REVENUE PER TRANSPONDER			273.0		348.1		419.1
AVERAGE REV/EVC			0.81		0.995		1.20

per EVC (equivalent duplex 4 KC voice channel) for satellites with 12, 24, 36, and 48 transponders in Table 9-3. Costs assumed for the ground stations and links between cities are listed in Table 9-2.

The required revenues for systems using only 10 to 15 ground stations to reach about 85 percent of the market included costs for leased intercity trunks. These were costed to service 25 percent of the system's traffic from locations averaging 100 miles away from the cities having ground stations. With lower rates available to this large market segment, it is expected that transponder loading will increase to the required 50 to 75 percent of capacity.

Increased traffic, increased transponder utilization, and increased revenue is justification for increasing the number of ground stations. Table 9-3 shows the required revenue per EVC for the baseline system and for a 35-ground-station system. Figure 9-1 shows the forecasted leased circuit market in terms of 36 MHz satellite transponder capacity based on a Booz-Allan-Hamilton study. The number of leased circuits

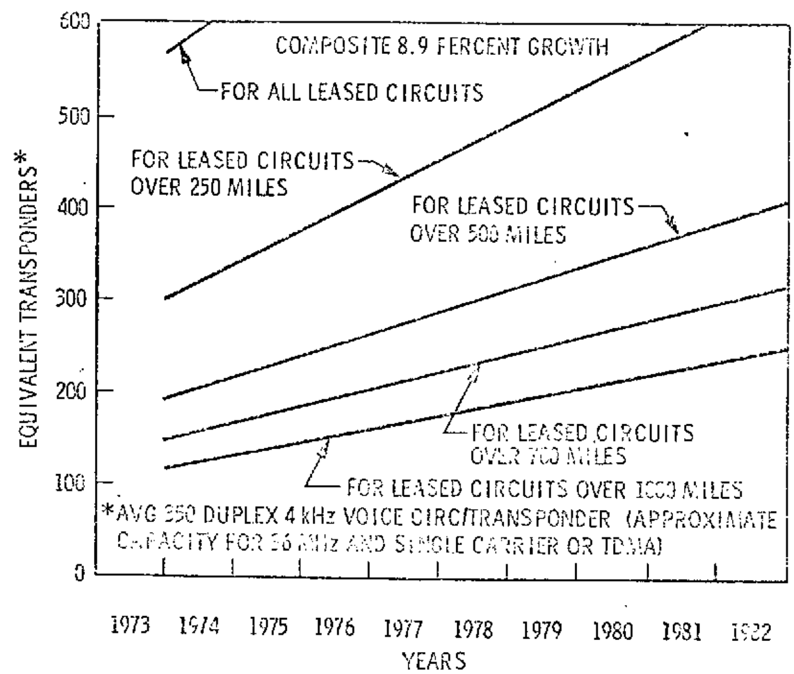


Fig. 9-1 Leased Circuit Market

Table 9-2

COSTING FACTORS

Ground Stations	
4/6 or 12/14 GHz ground station capital cost (exclusive of TDMA)	\$1.2M
TDMA cost per ground station	\$0.5M
Ground station O&M cost (each)	\$0.375 M/yr
Terrestrial Interconnects	
Local loop, user to central terminal, for fully loaded transponder capacity	\$0.497 M/yr/loop
4/6 GHz trunk from central terminal to remote ground station	
For ground stations in over 30 primary and secondary cities, per fully loaded transponder	\$0.870 M/yr
For ground stations in 5 to 15 primary cities, per fully loaded transponder	\$1.188 M/yr
Intercity trunks (to service 30+ cities from 10 to 15 ground stations), per fully loaded transponder	\$0.381 M/yr
General Cost Factors	
Rate of return on investment after taxes	11%
G&A selling expense and product/market development expense	15% of sales
Earth station depreciation time (except 4/6 GHz) span	10 years
4/6 GHz earth station depreciation time span	Space segment life or 10 years
Space segment depreciation span	Life
Inflation rate	4%/yr
Preoperational and training cost (15 ground stations)	\$10M
Additional preoperational/training cost (additional five ground stations)	\$2M
Preoperational capital cost depreciation span	5 years

Table 9-2 (Cont)

Space Segment

12 transponders: 7-yr life – 4/6 GHz		
Satellite (4/6 GHz) (two launches)		$33M
Launch vehicles (two Thor/Delta/AKMs)		$16M
Insurance and reserves for launch failures		$11M
	Total	$60M
24 transponders: 10-yr life – 4/6 GHz or 7-yr life – 12/14 GHz		
Satellite (4/6 GHz) (two launches)		$63M
Launch vehicles (two Atlas/Centaur/AKMs)		$34M
Insurance and reserves for launch failures		$24M
	Total	$121M
24 transponders: 10-yr life (12 transponders at 4/6 and 12/14 GHz)		
Satellite (two launches)		$83M
Launch vehicles (two Titan IIICs)		$59M
Insurance and reserves for launch failures		$11M
	Total	$153M
48 transponders: 7-yr life (24 transponders at 4/6 GHz and 12/14 GHz)		
Satellite (two launches)		$102M
Launch vehicles (two Titan IIICs)		$59M
Insurance and reserves for launch failures		$13M
	Total	$174M

Table 9-3

REQUIRED REVENUE AND CROSSOVER BETWEEN SATELLITE SYSTEM REQUIRED RATES AND AT&T COMPOSITE RATES

				Baseline System			Effect of Having 35 Ground Stations					
Operating Frequencies	Launch Vehicle/ Satellite Derivation	No. of Sats/ No. of Transp Per Satellite/ Avg No. Fully Loaded Transp	Sun Outage Permitted	Baseline No. of Ground Stations(1)	Baseline Required Rev Per EVC $K/Mo	X-Over(2)	No. Addl Ground Stations/ Sets of TDMA Equip.(3)	Annual Equiv Addl Captl Invest. Reqd $M/Yr	Addl O&M $M/Yr	Credit for Omitting Intercity Trunks ($M/Yr)	Revised Reqd Rev Per EVC $K/Mo	X-Over
4/6 GHz	Thor-Delta/ Anik	2/12/11.66	No	10	1.26	1100	25/35	7.7	22.5	(4.4)	1.93	2000
		2/12/23.22	Yes	10	0.62	300	25/35	7.7	22.5	(8.8)		650
12/14 GHz	Atlas-Centaur/ Intelsat IV	2/12/11.66	No	10	1.42	1300	25/35	7.7	16.9	(4.4)	2.02	2200
		2/12/23.22	Yes	10	0.82	500	25/35	7.7	16.9	(8.8)	1.07	800
4/6 GHz	Atlas-Centaur/ Intelsat IV-A	2/24/20.16	No	15	1.07	800	20/20	5.3	18.0	(7.7)	1.32	1200
		2/24/40.32	Yes	15	0.52	200	20/20	5.3	18.0	(15.4)	0.60	300
4/6 and 12/14 GHz	Titan IIIC/ Intelsat V	2/36/30.24	No	15	1.14	900	20/20	5.3	13.5	(11.5)	1.21	1000
		2/36/60.48	Yes	15	0.60	300	20/20	5.3	13.5	(23.0)	0.55	250
4/6 and 12/14 GHz	Titan IIIC/ Intelsat V	2/48/40.32	No	15	0.96	650	20/35	7.0	13.5	(15.4)	0.99	700
		2/48/80.64	Yes	15	0.53	200	20/35	7.0	13.5	(30.8)	0.50	200

(1) Average annual O&M costs for large stations

Freq (GHz)	O&M ($M/Yr)
4/6	0.900
12/14	0.675

(2) Crossover distance in miles between satellite system and AT&T for composite traffic mix and rates.

(3) $0.7M/ground station
$0.5M/TDMA installation

required for over 250 miles correspond with the forecasted lease circuits shown in Figure 8-1, Growth in Interstate Telephone Channels. A 54 percent loading of two 48-transponder satellites requires capture of only 8 percent of the total available leased circuit market over 250 miles. If "no sun outage allowed" type service is required, 17 percent of the market over 700 miles would have to be captured to compete with AT&T's rates.

The possible use of two 24-transponder satellites in place of one 48-transponder satellite to accommodate traffic growth may require two additional antennas per large ground station requiring access to both satellites and to the on-orbit backup or spare satellite. The total investment cost of the system would be substantially increased. Conceivably, two 24-transponder satellites could be operated within one orbital station area to synthesize a 48-transponder satellite so that both satellites could operate at different frequencies through a common antenna at each ground station.

The cost data of Table 9-2 show that space segment investment costs are about $500,000 per transponder year. Analysis shows that a satellite radiating some 20 watts over the 48 states can provide good quality TV service 99 percent of the time to remote earth stations costing several thousand dollars each at present, and potentially only several hundred dollars by 1980. This forecast is based on technology developments that will provide low-cost, low-noise amplifiers for $200 to $300 in volumes of several hundred thousand. It may be at least 20 years before the telephone system will be able to offer comparable service at competitive costs to rural areas that can be easily serviced with low-cost satellite ground stations. The Canadian TELSAT system presently using an ANIK satellite proves the feasibility and cost effectiveness of satellites to provide wideband communications to remote rural areas.

9.3 CONCLUSIONS

Satellite systems can compete with terrestrial communications even for leased voice telephone line services and at distances of 200 miles. The AT&T rate structure is not expected to change drastically in the future. The forecasted future rate structure presented in Figs. 8-2 and 8-3 indicate that satellite systems will be able to effectively compete with the telephone system in the 1980s. This conclusion is based on the following premises:

1. The domestic telephone system is so extensive that it cannot be easily modified. Some 10 to 20 years are required for extensive implementation of new technologies, such as light pipes, to an extent that could seriously impact profitable satellite operation. Great progress will be made in satellite communications over the next 20 years, as shown in Fig. 7-11. The telephone system cannot make extensive changes as quickly, because it employs nearly one million people who must be retrained and it operates some 628 million circuit miles that cannot be quickly replaced (Ref 45, p 492).

2. The installation of new cables and switching for long-distance communications over the nation's backbone trunk circuits, as presented in Fig. 5-1, will make the telephone system cost effective for the market between major metropolitan areas.

3. The telephone system will gradually restructure its long-distance rates, as forecasted, and will operate satellites. Individual subscribers' monthly and local call rates may be increased to reduce the prorated charges for long-distance service.

4. The cost effectiveness of satellite systems, independent of earth station data compression, will increase by a factor of at least 3 over the next 10 to 15 years, as shown in Fig. 7-11.

5. Improvements in Time Division Multiple Access techniques and data compression will be equally beneficial to terrestrial and satellite communications systems.

6. Marketing efforts by satellite companies as well as reduced rates will stimulate the growth of such special communications services as closed-circuit coverage of conventions and biomedical consultation services. Such services are specially adaptable to satellite communications.

Section 10
SENSITIVITY ANALYSIS

The sensitivity analysis is the focus of the analyses and forecasts of the previous sections. The purpose of the needs model refinement, the development of functional and technical requirements, the technology forecasting, and the analyses of communications cost effectiveness is to provide the required insight and background data for determining the key technologies. The overall study methodology has been developed to provide the clearest and most viable possible determination of the key technologies and the relationships between technologies and basic human needs (refer to para 4.2). The systems and sensitivity analyses procedures can readily be adapted to modify the focus of the study as desired. Minor changes of the needs model should not change the study results, which are essentially based on seven different analyses for seven categories of service needs. The methodology provides a means for quantizing the worth of possible technology improvements within such definable areas of technology specialization as antennas, transmitters, or solar cell efficiency.

Determining the various detailed technologies (within each area of specialization) that are most worthy of special attention is a logical course for future study. Such studies are needed to explore limited areas of key technologies and develop detailed plans and means of best meeting the key functional and technical requirements for improving the cost effectiveness of communications satellites.

Computerized optimization of conceptual satellite systems and evaluation of finite technology improvements were not used for the following three reasons.

First, the likely satellite configurations and optimum concepts can be adequately determined from available study results and the analysis of trends of satellite development and growth. A computer program sufficient to simulate all required conceptual communications systems to the degree of systems sophistication applied in the analyses would be complex and expensive because of the number of runs needed to test each technology.

Second, the results of the computer runs would be dependent on the program mechanization and inputs. Such results are less clear and viable than the results obtained by the explanatory methodology used.

Third, the forecasts of technology growth are a critical element of the analysis. There is, for example, little point in special stimulation of technology capabilities which are essentially developed or which can be developed as needed. The results of precisely quantitized computer sensitivity values are no more accurate than the forecasts of technology capabilities and achievable improvements in technology obtainable for a finite investment in research and development. It is not possible to accurately determine a specific finite advancement in technology for a fixed funding in research and development. It is possible, however, to forecast the likely levels of technology improvement for an approximate level of funding. The level of technology improvement obtained versus total funding is dependent on time phasing, funding levels, exploration of alternate approaches, and the capabilities of the doing and directing organizations.

The sensitivity analysis therefore indicates the key technologies on the basis of the improvements of technology parameters defined in para 10.6. The recommendations and development plans define the general areas of research and development, the time spans, and the funding levels that can reasonably be expected to provide the desired levels of attainable technology improvement.

10.1 METHODOLOGY AND BACKGROUND CONSIDERATIONS

The sensitivity analysis was performed by a five-step process, described below:

10.1.1 Available Frequency Bandwidth

Available frequencies and bandwidths for fulfilling the communications needs of the 1980s were first evaluated. Then it was determined whether there was sufficient bandwidth to meet the needs if the spectrum were properly used. This part of the analysis is presented in para 10.2.

10.1.2 Link Calculations and Tradeoff Analyses

Technical requirements for proper use of the allocated frequencies and for formulation of conceptual spacecraft systems were determined from communications link calculations. Tradeoff analyses based on link calculations were performed to determine the best compromises between spacecraft and earth-station antenna sizes, transmitted power levels, receiver sensitivities, channel capacity, and quality of communications service for meeting the function requirements for each of the seven categories of service needs. The tradeoff analyses were based on use of present and near-term technology forecasts presented in Section 7 and demonstrated by prototype units. This part of the analysis is presented in para 10.3.

10.1.3 Cost Model

A relatively simple but fairly accurate cost model for communications satellites was formulated as a tool for costing the conceptual spacecraft formulated. The cost model was derived from historical data and tested against detailed cost estimates for future spacecraft. The cost model is defined in para 10.4.

10.1.4 Formulation of Conceptual Spacecraft and Networks

Conceptual spacecraft and communications networks were formulated for each of the seven categories of service needs for the 1975 to 1980 and 1980 to 1985 time frames. The 1975-era systems are based on present technologies and proposed system designs and therefore provide a baseline from which to formulate the 1980 to 1985 era spacecraft. The 1980 to 1985 era spacecraft were formulated on the basis of forecasted trends of spacecraft development and technology growth presented in Section 7. To bias the sensitivity analysis on the conservative side, minimal technology growth forecasts were used for formulating the 1980 to 1985 era spacecraft. Use of optimistic technology growth forecasts would lead to the conclusion that many important technologies would be sufficiently developed by 1985 and that development stimulation is not required. The results would then tend to be self-defeating.

Formulation of conceptual systems showed that domestic common-carrier and high-speed data relay spacecraft and systems were sufficiently similar and that only one representative system need be considered. Sufficient differences exist between aeronautical support satellites and ground vehicle support satellites that two separate systems were formulated and evaluated in appropriate parts of the sensitivity analysis.

Conceptual spacecraft were developed in sufficient detail to provide finite values of cost, weight, and reliability for each major subsystem. The trend of technology growth is such that the 1980 to 1985 era needs could be effectively met with a 3914 series Delta boost vehicle. This approach was used for formulating the 1980 to 1985 era spacecraft, even though the Space Shuttle would be in operation, to provide continuity of the conceptual spacecraft with the 1975 to 1980 era baseline spacecraft, and with the historic trend of spacecraft development. The results of the sensitivity analysis are therefore related to a 3914 series Delta-launched spacecraft and must be adjusted for the expected impact of the Space Shuttle on spacecraft design concepts. Paragraphs 7.2.3, Correlation Between Transportation and Satellite Costs, and 7.2.4, Impact of Transportation Costs and Capabilities on Satellite Size and Cost, provide the basis for adjusting the results of the sensitivity analysis for use of various possible types of booster or transportation systems.

10.1.5 Reliability Considerations

The conceptual spacecraft designs have adequate reliability to fulfill the functional requirements and be cost-effective in comparison with future terrestrial systems. Therefore, providing adequate reliability capability of each conceptual system, and showing the sensitivity of reliability to spacecraft weight (Fig. 7-8), are the basis for not including detailed reliability evaluations within the sensitivity analysis. Sensitivity analysis of reliability would reiterate the facts presented in Fig. 7-8 – that reliability can be significantly improved to meet requirements over a minimum weight design by means of selective addition of redundant components, requiring about a 10 percent increase in spacecraft weight. The weight increase, valued at some $2 million per spacecraft for total spacecraft and booster costs, increases the reliability from near-zero to 0.7 for a 7-year operating life. The trend of technology growth is toward lighter-weight components of increased reliability. The reliability sensitivity values would be conservative. A 25 percent reduction of component failure rates provides a value within the range of improvements of the structure and thermal control technology shown by the results of the sensitivity analysis. To show that spacecraft reliability improvement is not a key technology need now or in the post-1985 era allows the sensitivity analysis to be reduced to basic parameters of cost, weight, and efficiency.

Use of the Space Shuttle in the 1985-era reduces the sensitivity of system cost to reliability by reducing the weight and transportation cost constraints, which presently limit the amount and degree of redundancy that can be used to approach the ideal spacecraft operating reliability and design life. The modularized spacecraft design concepts for allowing on-orbit refurbishment to prevent permanent loss from a failure are partially justified on the premise of reducing spacecraft costs by reducing presently specified component reliability goals. On this basis the attainable reliability values for the conceptual spacecraft designs exceed the possible 1985-era reliability requirements.

10.1.6 Sensitivity Analysis Methodology

The sensitivity analysis is based on determining cost savings due to technology improvements for 1985 to 1995 spacecraft. The improvements would reduce the costs and increase the capabilities of the 1980 to 1985 time frame spacecraft presented in Tables 10-6 through 10-11. Costs for these conceptual 1980-1985 systems are summarized in Table 10-13. Section 11 presents specific options for technology improvements which can provide the improvements of technology parameters evaluated.

The parameters selected for evaluation cover each subsystem of each of the seven functional types of spacecraft. The cost saving obtained due to improvement of a parameter for a particular spacecraft application indicates the relative importance of the parameter. Comparison of cost savings due to various parameters indicates the relative importance of each parameter for each type of spacecraft.

Adding the cost savings for all eight types of spacecraft due to improvement of a parameter provides a general ranking of technology parameters for communications satellite applications in general. The same detailed technology cannot be used for improving the same parameter for each type of spacecraft. Different spacecraft have different power, attitude control, transponder, antenna, life and reliability requirements. The methodology and parameters used allow generalization of important parameters for all seven types of spacecraft and reveal relative importance of the parameter for each spacecraft. The functional and technical requirements of Section 5 and the conceptual spacecraft defined in this section, indicate technologies to be improved for improving a particular service. The methodology of this study can be adapted to develop detailed evaluations of a particular technology for a specific application. The parameters and methodology were selected with the objective of determining key technologies and recommended plans for benefiting all seven types of spacecraft in the 1985 to 1995 era in a clear viable manner. The objective of determining universally key technologies and viability requires considerable simplification and generalization of the sensitivity analysis without loss of insight into important basic relationships and causative factors which determine the key technologies.

The parameters and methodology were selected on the basis of results and conclusions of the previous sections. The important factors to be considered in selecting the parameters and methodology for determing the key technologies which need developed for the future are:

1. The future requirements can be met with the available and developing technology without special stimulation as shown by the conceptual spacecraft and system costs presented in Tables 10-6 through 10-13. Section 7 presents the forecasted impact of technology improvement on satellite system cost effectiveness, ref Fig. 7-10. Sections 8 and 9 show that satellite systems will be viable and competitive with terrestrial systems for long distance communications (over 200 miles).
2. Paragraph 10.5, Conceptual Satellite Systems, shows that there is adequate allocated frequency spectrum for meeting the forecast 1985-1995 demands, if properly utilized. The conceptual systems are based upon proper utilization of the available frequencies. The key fact which influenced the sensitivity methodology is that the 1985-1995 demands can be met with the available frequencies and developing technologies.

3. Reliability is not a key factor or technology parameter for the reason presented in para 10.1.5. The conceptual spacecraft for the 1975-1980 time frame have complete redundancy except for the apogee rocket motor, structure and transponders. The only single point failures which could cause a complete spacecraft failure are a booster system failure, apogee motor failure, or structure failure. A transponder failure results in loss of capacity of one transponder. Probabilities given for transponders are for 80 percent of all transponders operating at end of life. Conceptual designs allow for transponder failures.

   Conceptual spacecraft for the 1980-1985 time frame have complete redundancy or spare units except for the structure which is based on a conservative design margin. Use of Space Shuttle can provide as significant an improvement of total system reliability as any possible reliability improvement of a subsystem with adequate redundancy provided for in the conceptual designs. Subsystem reliability is a design tradeoff parameter. The required reliability is obtained by allocating the weight and money needed to provide the required reliability which is in balance with the total spacecraft and system design objective.

   Reliability is such an important parameter of spacecraft design that a brief example is provided to show why reliability is not a considered parameter. A 20 percent reduction of the power subsystem 7-year reliability for a television satellite (Table 10-6) would increase the expected reliability from 0.960 to 0.968. The seven-year spacecraft operating reliability would be increased from 0.7155 to 0.7215. The increased reliability for a 6 spacecraft program costing $105 million is worth $630 thousand. Reducing the weight of the power system would in contrast save 43 kilograms of weight values at $22,000 per kilogram. The weight savings for a 6 spacecraft program is worth $5.676 million. The 20 percent subsystem reliability improvement is about one tenth as important as a 20 percentage weight reduction for an optimum designed system without overly severe weight constraints.

4. Each subsystem will be capable of meeting the 1985 performance requirements. The antenna subsystem for some spacecraft has performance requirements which have an important bearing upon the total system cost, service quality, frequency reuse; and, therefore, frequencies used.

   Therefore, the unique functional requirements of antennas are utilized as the technology parameters evaluated. Antenna weight and cost are important, but the critical parameters are more important than slight incremental weight savings of antennas lacking in the desired capabilities. The importance of antenna characteristics such as beam shaping and multiple spot beams is developed in the functional and technical requirements presented in Section 5 and the link calculations of paragraph 10.3. Similarly, special requirements for earth terminal antennas and data compression were determined and included as sensitivity parameters to determine the worth of the parameter.

5. The key cost effectiveness parameters for most subsystems are weight and cost; provided the subsystem meets the performance requirements, has adequate reliability, and meets the booster constraints for the total spacecraft. Therefore, the subsystem weight and cost are the technology parameters used for evaluating spacecraft subsystems. Weight savings are translated into equivalent cost of a $22,000 per kilogram on the basis of Delta and Atlas/Centaur booster costs per kilogram placed in synchronous orbit. Except for the antennas, each subsystem is tested for a 20% incremental reduction weight and cost. This approach is based on determining where the costs and weight of future spacecraft will be allocated and evaluating the worth of a degree of improvement which is attainable.

6. Transponders are one of the largest users of spacecraft power. Improvement of transponder efficiency can allow significant reductions of required weight and cost of the power subsystem. Therefore, transponder efficiency is included as a technology parameter.

The technology parameters selected for evaluation on the basis of the 6 factors just presented are listed below. Each of these parameters were varied or tested singly without improvement of any other parameter. Each parameter was tested for each of several conceptual spacecraft. Total cost savings determined for improvement of a parameter for a conceptual spacecraft are for one network utilizing the total number of spacecraft listed in Table 10-13.

The sensitivity analysis savings determined from the parameters listed apply to the conceptual Delta launched spacecraft. Savings values obtained can be determined for a Space Shuttle/Tug launched conceptual spacecraft configuration if allowance is made for Shuttle/Tug transportation costs. The Shuttle/Tug transportation cost used is $6,500 per kilogram.

The parameters used for the final sensitivity analysis are as listed:

Transponder Technology

- Improve efficiency by 10%
- Reduce weight by 20%
- Reduce costs by 20%

Antenna Technology

- Improved shaped beams
- Reduce side lobes
- Improve switched or steered beams

Power Subsystem Technology

- Reduce costs 20%
- Reduce weight 20%

Attitude Control Technology

- Reduce costs 20%
- Reduce weight 20%

On-Orbit Propulsion Subsystem Technology

- Reduce costs 20%
- Reduce weight 20%

Spacecraft Structure and Thermal Control Technology

- Reduce costs 20%
- Reduce weight 20%

Tracking, Telemetry, and Command Subsystem Technology

- Reduce costs 20%
- Reduce weight 20%

Earth-Station Technology

Lower-cost steered beam antenna

Multiple steered or switched beam antenna

Data compression

10.2 AVAILABLE FREQUENCIES

The technology requirements and related link calculations are based on the availability and use of the frequency bands listed for satellite communications as specified in Federal Communications Commission Docket No. 19547, which was adopted July 18, 1972. This docket pertains to the International Radio Regulations as revised by the World Administrative Radio Conference in Geneva, Switzerland, on June 7, 1971. Only the key downlink frequencies pertinent to the bulk of civil satellite communications applications are listed in the interest of briefness:

1. Broadcast satellite service (direct reception by general public):

   0.620 – 0.790 GHz

   2.50 – 2.69 GHz domestic and regional

   11.7 – 12.2 GHz

   41.0 – 43.0 GHz

   84.0 – 86.0 GHz

2. Fixed-satellite services (data, telephone, TV distribution):

   2.5 – 2.535 GHz common carrier

   3.5 – 4.2 GHz

   6.625 – 7.125 GHz domestic

   10.75 – 11.2 GHz international only

   11.45 – 11.7 GHz international only

   11.7 – 12.2 GHz domestic only

   17.7 – 19.7 GHz

   19.7 – 21.2 GHz

   40.0 – 41.0 GHz

   102. – 105 GHz

   150. – 152.0 GHz

   220.0 – 230.0 GHz

   265.0 – 2750 GHz

3. Inter-satellite communications service:

   54.8 – 58.2 GHz

   59 – 64 GHz

   105 – 130 GHz

   170 – 182 GHz

   185 – 190 GHz

4. Aeronautical and maritime-satellite services:

   1535 – 1542.5 MHz, maritime

   1542.5 – 1543.5 MHz, aeronautical/maritime

   1543.5 – 1558.5 MHz, aeronautical

   4.2 – 4.4 GHz aeronautical

   5.0 – 5.25 GHz, aeronautical

   15.4 – 15.7 GHz, aeronautical

   157 MHz, distress frequencies

   43 – 48 GHz, aeronautical mobile-satellite

   66 – 71 GHz, navigation satellite

5. Earth resources satellite services:

   401 – 403 MHz uplink

   460 – 470 MHz downlink

   1.67 – 1.7 GHz downlink

   2.025 – 2.12 GHz uplink

   8.025 – 8.4 GHz downlink

   21.2 – 22.0 GHz downlink

6. Space research service:

   2.2 – 2.3 GHz downlink

   8.4 – 8.5 GHz

   14.4 – 15.35 GHz

10.3 LINK CALCULATIONS FOR SERVICE NETWORKS

Table 10-1 summarizes the basic communications link parameters calculated for conceptual satellite systems that meet the functional requirements of the needs model.

Table 10-1

COMMUNICATIONS LINK PARAMETERS

	Video	Digital and Voice	High-Speed Data Network	Mobile Voice and Data	Space Tracking and Data Relay Network	Earth Resources and Ocean Data Monitoring	RF Environment Monitoring
Frequency Range	12 GHz	12 GHz	20 GHz	43 GHz	40 GHz	147 MHz	43 GHz
Bandwidth	29 MH	36 MHz	1 GHz	20 KHz	1 GHz	2 KHz	1 GHz
Capacity	1 Ch	35 MBPS	1000 MBPS	Voice/ 2 KB	1 GBPS	200 BPS	1 GHz
Spacecraft Antenna Gain	32 dB	32 dB	55 dB	47 dB	60 dB	18 dB	60 dB
Antenna Size (Meters)	1	1	4	1	4	10	4
Radiated Power (Watts)	13	100	25	2*	25	5	25
Earth Station Antenna Gain, dBW	55	60	64	32	65	0	65
Antenna Size (Meters)	7	13	2	~1	7	0.2	7
Receiver Noise Temperature	330^{o}K	50^{o}K	300^{o}K	330^{o}K	50^{o}K	1150^{o}K	50^{o}K
Carrier-to-Noise Ratio	10 dB	16 dB	14 dB	10 dB	10 dB	16 dB	10 dB
Coverage	Natl	Natl	Natl Internatl	Area	Global	Global	Global & Regional
Average Outage	0.1%	0.01%	0.04%	0.2%	0.2%	0.01%	0.2%

*Clear weather condition

The high end of the frequency spectrum and broadest bandwidth requirements consistent with functional requirements were used to determine reasonably stringent technical requirements. Such higher frequencies must eventually be used as lower frequency bands become saturated.

A major problem limiting the use of 12 GHz and higher frequencies is rain and cloud attenuation. High effective-radiated-power levels are required to maintain a normally acceptable 10 dB threshold carrier-to-noise ratio and limit outage to less than 0.1 percent of the time. The communication link calculations show that the higher frequencies are well suited to carrying high bit rates on spot beams with moderate power levels. A space tracking and data relay network satellite, for example, with a 1 GHz bandwidth beam operating at 40 GHz could relay a gigabit data stream to earth with 25 watts of transponder radiated power, a 4-meter-diameter antenna on the relay satellite, and 7-meter earth station antenna. Communications outage will probably occur from rain distorting the carrier polarization and attenuating the carrier.

The earth-station 7-meter-diameter antenna is state-of-the-art capability but is costly because of the precision reflector or lens need for the 40 GHz frequency. If the transponder power level were increased to 40 watts, the ground station antenna could be reduced to a 5-meter diameter. The optimum design point is dependent on specific technology capabilities at the time of project go-ahead and also on the availability of qualified transponders and antennas that might be used. The communications link parameters of Table 10-1 indicate present and near-term technical capabilities and the general relationships between satellite transponder power, antenna size, carrier-to-noise ratio, channel capacity, and average expected outage for domestic satellite systems. Actual satellites will use various combinations of frequencies and generally lower allocated frequencies other than those that are presented as worst-case requirements.

The link calculations were prepared for each of the seven categories of service networks as part of the sensitivity analysis to show the basic communication parameters required for providing the communications services of the needs model. The calculations provide a basis for evaluating and trading off communications parameters. Several categories of service have unique functional requirements that require unique communications for providing services. The calculations are based on the best-available technology and on conservative estimates of available 1980 technology for fulfilling requirements during the 1980 to 1990 era.

10.3.1 Video Networks

10.3.1.1 Summary of Video Link and Earth Station Cost Analysis. The video link calculations are based on the conditions and rationale described below, which show that, by effective use of available technology, community cable TV and dedicated TV services can be distributed nationally with a 12-GHz carrier, about 20 watts of transmitted output power, and FM modulation. Digital modulation will significantly reduce the spacecraft radiated power requirements.

The cost of a typical receive-only ground station would cost on the order of $15,000 today. A private home installation where community TV is not available would cost on the order of $600.00 by 1985 (on the following basis). A cost comparison for television reception equipment by terrestrial versus satellite service to the home is as follows:

	Terrestrial-to-Fringe-Area Homes	Satellite-to-Home
Antenna	90	200* (2 meter dish, 45 dB gain)
Pre-amp	40	300* (330°K)
Rotor	30	–
Mast or mount	50	40
Cable and misc	10	10
Labor	80	80
Subtotal	$300	$630
TV set	300	370
Total	$600	$1000

*Based on 45 dB EIRP at 12 GHz (16-watt radiated power for 48-state coverage, 1 percent outage). Cost based on a volume of 1 million units in 1985.

The home system would provide a 45-db signal-to-noise ratio signal in clear weather. The community or institutional TV ground station would provide a 45-dB signal-to-noise ratio (TASO Grade 1) with 10 mm/hr of rainfall and approximately 52 dB signal-to-noise ratio in clear weather. Outage due to local weather conditions would be on the order of 0.1 percent. Equivalent operation at 20 GHz would require 95 watts of satellite transponder power for 48-state coverage and approximately 20 watts of transponder radiated power for coverage of a time zone.

The link calculations show that there is not a need for developing high power transponders capable of generating kilowatts of RF power or high-voltage solar arrays operating at kilovolts for direct broadcast communications satellites. The video distribution system defined is near optimum for economical program distribution for the following reasons:

1. By 1985 over 80 percent of all residences may have cable television, as shown by the trend curve of Fig. 8-11. Less than 3 percent of all households will be without television services. Therefore, the need for a direct broadcast satellite would be to provide services to less than 3 million households.

2. The total cost of providing service includes the cost of the television set as well as the cost of the receiving antenna, parametric amplifier, and installation. The present cost for a fringe area TV system antenna, antenna amplifier, cable, antenna rotor, mast, and labor is on the order of $300. Therefore, a cost of $630 for a satellite antenna in 1985 seems in balance with the total system cost and present costs for fringe area antenna systems. Many fringe-area installations provide much less than the 45-dB signal-to-noise ratio that could be obtained with a 2-meter home television-reception antenna.

3. The total cost for a large satellite system requiring the minimum home equipment for home reception with 1 kW of radiated power for each of five channels will be on the order of $600 million. This amounts to an investment of approximately $200 per household served, if there were 100-percent acceptance. With 100-percent acceptance, there could be on the order of a $600 million total savings due to the reduced costs for home antennas. Fifty percent acceptance is the estimated breakeven point for a kilowatt of radiated power per channel.

4. $300 of the $630 cost of a home antenna installation for a low-powered satellite is due to the cost of a low-noise parametric amplifier with a 150 MHz bandwidth and a 330^{o}K noise temperature. An expected breakthrough allowing a significant cost reduction in low-noise amplifiers will strongly favor the use of low-power-per-channel (20-watt) video distribution satellites for the United States. Canada, however, will require a higher power level because of the large area and low antenna elevation angle for Northern Canada.

5. The sharing of an antenna by several households in a remote area further favors the low-power satellite system concept by reducing the number of ground antennas required.

10.3.1.2 Basis of Link Calculation and Cost Estimates for Video Services. The video link calculations for institutional users and cable TV networks are based on the following factors:

1. The required peak-to-peak video signal-to-noise ratio required is 45 dB at the user's video set. Thus, the required signal-to-noise ratio at the output of the ground antenna for a community cable TV system, school district, university, hospital, etc., should be about 48 dB under worst conditions. This is an important point, because signal attenuation due to TV broadcasting is on the order of -55 to -95 dB, and a possible -2 to -3 dB for small cable TV networks. TV broadcast restrictions result in about a 44 dB signal-to-noise ratio at about 60 miles distance and a 10 dB receiver antenna gain.
2. The allowable time for degradation and outage due to weather conditions is about 1 percent for low-cost community cable TV or public school TV — not on the order of 0.01 percent as is required for commercial TV distribution to broadcasting stations. An outage of 0.1 percent is used because of the critical nature of biomedical communications.
3. A 5-meter-diameter parabolic antenna is recommended for low-cost applications because it is about the largest size "dish" that can be conveniently transported in one piece on most roads, and it provides a sufficiently narrowbeam to be compatible with frequency reuse and relatively close satellite spacing. A one-piece mass-produced antenna is less expensive and more reliable than a two-piece antenna. Antennas larger than 5 meters create increased problems because of wind loads, roof-top mounting, etc. The estimated cost for the 5-meter antenna and fixed mounting are presented below. 70% antenna efficiency is expected by 1985. The 5-meter-diameter antenna is shown to be the most cost-effective for carrying up to 40 channels at 4/6 GHz by Burton I. Edelson, Director of Comsat Laboratories in a technical article, "Small Earth Terminals for Satellite Communications," page 45, in the June 1973 issue of Astronautics and Aeronautics.
4. The link calculations for community and institution ground stations are based on use of available pumped parametric amplifiers with a 300°K noise temperature at 12 GHz and a 500 MHz bandwidth. A 100°K noise temperature is added because of the antenna temperature during a 10 mm/hr rain (Ref 32, p 545).

   Suitable parametric amplifiers which presently cost on the order of $4,000 for small quantities are forecast to cost $300 by 1985 if a market is developed on the order of a million units.

5. The video carrier could be frequency-modulated with a modulation index of 2.4 and require a 29 MHz bandwidth per channel with approximately a 3 MHz guard band spacing between channels. This bandwidth minimizes the transmitter power needed to satisfy the 10 dB threshold and signal to noise requirements. A modulation index of 2.2 to 2.4 will provide the required signal-to-noise ratio (Ref 30, p 493 and Ref 33, p 6). FM demodulation and threshold extension is not a serious problem for the TV receiver modification. Use of FM provides significant savings in the satellite power because of the signal-to-noise improvement with increasing modulation index. Similar performance could be obtained with the COMSAT Corporation Digital Television Communication system with pulse code modulation.

6. The following losses are assumed:

   1 dB carrier to noise ratio degradation due to transponder receiver noise temperature

   4 dB ground antenna pointing and position loss, by being on the satellite antenna -3 dB contour

   2 dB design margin

   0.1 dB polarization loss for linear polarization

   3 dB rain loss at 12 GHz (10 dB at 20 GHz) for 0.19 outages

   206 free space loss for synchronous orbit and 12 GHz operating frequency.

7. The link calculations are based on a 10-dB carrier-to-noise ratio under rain conditions of 10 mm/hr and a required minimum 48 dB peak-to-peak signal-to-noise ratio.

10.3.1.3 Link Equations for Video Services. Link calculations are based on the following formulas for carrier-to-noise ratios expressed in decibels:

$$\frac{C}{N} = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Dm - Pl - P$$

C/N = Carrier to noise ratio

Pt = Transmitter power

Gr = Transmitter antenna gain

Nr = Receiver noise, Nr = KTeB

Nt = Effect due to satellite transponder noise

K = Boltzmann's constant, 1.38×10^{-23}

B = Receiver bandwidth

Te = Effective noise temperature in degrees Kelvin

Lfs = Free space loss plus atmospheric attenuation

Lr = Allowable loss due to rain

Dm = Design margin

Pl = Polarization loss

Pp = Receiving antenna pointing and position losses

10.3.1.4 Signal-to-Noise Equations. Signal-to-noise ratio improvement over carrier-to-noise ratio for frequency modulation is as follows:

$$\frac{S}{N} = \frac{C}{N}(8)\ 3\ m^2\ (m + 1)\ (\text{Pew})\ (d)$$

$\frac{C}{N}$ = Carrier to noise, rms ratio

m = Modulation index

Pew = Preemphasis and weighting

d = Delta factor

8 = Conversion factor rms to peak-to-peak

$3m^2\ (m + 1)$ = S/N versus C/N improvement factor for FM above the threshold

10.3.1.5 Downlink, 12 GHz, Community and Institutional Ground Stations.

$$\frac{C}{N} = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Dm - Pl - Pp$$

$$\frac{C}{N} = 13 + 32 + 55 - 1 + 127.5 - 206 - 3 - 2 - 0.1 - 4$$

$\frac{C}{N}$ = 11.4 dB (for 20 watts radiated power and 48-state coverage)

Pew = 13 dB

$$Nr = (1.38 \times 10^{-23})\ (330^{o}K\ \text{amp} + 100^{o}K\ \text{ant})\ (30 \times 10^{6}\ \text{dW})$$

$$Nr = 228.6\ dB + 26.3\ dB + 74.8\ dB = 127.5$$

Nt = -1 dB, Transponder noise

$$\frac{S}{N} = \frac{C}{N} (8) \; (3m^2 \; (m + 1) \; (Pew); \; m = 2.4)$$

$\frac{S}{N}$ = 11 + 9 + 17 + 13 = 50 dB for 7-meter antenna, 47 dB for 5-meter antenna with threshold extension receiver

10.3.1.6 Downlink, 20 GHz.

$$\frac{C}{N} = Pt + Gt + Gr - Nt - nr - Lfs - Lr - Dm - Pl - Pp$$

With the same modulation index and ground antenna diameter as for the 12 GHz case for community and institutional TV:

$$\frac{C}{N} = 20 + 32 + 60 - 1 + 126 - 208 - 10 - 2 - 1 - 5$$

Approximately 100 watts (20 dB) of RF radiated power is required for 48-state coverage, and approximately 25 watts for time zone coverage. The important differences affecting the increased power for 20 GHz versus 12 GHz are as follows:

1. 10 dB rain loss versus 3 dB for 12 GHz
2. 2 dB increase in antenna pointing error due to narrower beam
3. 2 dB increase in parametric amplifier noise temperature to 575°K (although a 330°K noise temperature is highly probable by 1985 and would reduce required satellite power)

10.3.1.7 Estimated Ground Station Costs. The estimated cost of a community TV or institutional ground station exclusive of receiver and transmitter costs is as follows:

Preparation of antenna base	$ 5K
Antenna base mount with tracking adjustment	$10K
Antenna, 5 meter diameter (53 dB gain)	$ 6K
Preamplifier, 1972 cost for limited number	$ 4K
Installation	$ 5K
Total	$30K

The antenna would have a three-point suspension. Two screw jacks operated open-loop by stepping motors and controlled from a low-bit-rate command signal could provide satellite tracking.

10.3.2 Common Carrier Networks

An important difference between the common carrier or digital service networks and the dedicated video networks is the number of ground stations required, the allowable outage, and the required carrier-to-noise ratio. Digital service networks will require on the order of 50 to 100 ground stations. Hundreds of earth stations are required for dedicated video networks. Digital trunk communications between large metropolitan areas are best served by antennas on the order of 10 to 30 meters in diameter, depending on the number of ground stations in the network, capacity per ground station, local site, and noise factors. The ground antenna position and pointing loss is reduced to -3 dB through use of a tracking antenna. Increased earth station antenna gain, space diversity and use of spot beams from the satellite can reduce the required satellite transponder radiated power. Conservative downlink calculation for a 35 MBPS quadri-phase shift-keyed 12 GHz link with a bit error rate of 10^{-7}, and operating through a 12-meter ground antenna receiving from a satellite antenna with 48-state coverage, are as follows:

$$C/N = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Dm - Pl - Pp$$

$$C/N = 20 + 32 + 60 - 1 + 125 - 206 - 12 - 2 - 0.1 - 3.0$$

$C/N = 13$ dB required for 10^{-7} bit error rate

The required 100 watts of radiated power can be reduced by one or a combination of the following means:

1. Use of satellite spot beams to increase satellite antenna gain at the expense of increased satellite switching or reduced satellite flexibility.
2. Increase ground station antenna gain at an increase in cost per ground station.
3. Use space diversity of ground station antennas to reduce required margin for rain storms.

4. Reduce the bandwidth per channel and use three transponders to transmit the 35 MBPS data rate. This will decrease the power per transponder but requires more transponders and increased transponder weight for the total data rate, and is not recommended.

The use of space diversity can allow reduction of the required power margin from 12 to 9 dB. Reduction of the required bit error rate during storms from 10^{-7} to 10^{-5} will allow a reduction of the required carrier-to-noise ratio from 13 dB to 12 dB during storm conditions (0.01 percent of operating time) (Ref 33, p 18). This approach permits a reduction of the satellite radiated transponder power from 100 to 40 watts. Forty watts is a high power level for cost-effective satellite design.

An alternative approach to the reduction of transponder power is to use multiple $1/2^{\circ}$ spot beams from the satellite to each major ground station. Satellite antenna gain would be increased from 32 to 50 dB and would accommodate an increase of the data rate from 35 to 100 MBPS with a simultaneous reduction of transponder radiated power from 100 to 5 watts. The 100 MBPS data rate could allow time-division multiplexing of data between three earth stations to provide the equivalent of three 35 MHz data channels. Operation at a 20 GHz downlink frequency would require 100 watts for a 100 MBPS data rate with a 22 dB rain margin. The 20 GHz frequency is practical if lower frequencies are used during local storm conditions.

The use of 4/6 GHz frequencies for 50-state coverage can be accomplished with only 6 watts of radiated power per 34 MHz bandwidth channel (35 MBPS) to provide an EIRP (effective isotropically radiated power) of 32 dBW at the beam edges. The system can provide commercial quality telephone, data, and video distribution communications by means of 11-meter-diameter ground station antennas. The EIRP for the 4-GHz downlink is restricted to approximately 40 dBW per 40 MHz bandwidth due to recommendations of the International Radio Consultive Committee to limit earth-surface flux density to (-152 + elevation angle/15) dBW/M^2.

10.3.3 Very High-Speed Data Relay Network

Very high-speed data links carrying on the order of a gigabit (10^9) data rate require gigahertz bandwidths. The required bandwidth will be obtained in the 20 and 30 GHz or higher frequency regions after the 4 and 6 GHz and the 12 and 14 GHz frequencies presently assigned for satellite communications are saturated. The 20 and 30 GHz frequency regions present technology requirements for 20 and 30 GHz transmitters, antennas, and low-noise receivers. The higher frequencies are compatible with the need for transfer of gigabit data rates only between major science and business centers. A very high-speed data network would interconnect on the order of 20 to 40 terminals by using high-gain antennas, kilowatt uplink transmitters, and low-noise satellite receivers. The rain losses for a 0.04 percent outage limit for the East Coast region and a 30 GHz uplink are 23 dB (Ref 40, p 11-64). A 0.049 percent outage for the East Coast at 20/30 GHz appears reasonable if several 4-6 GHz and 12-14 GHz channels with a 0.01 percent outage probability are available to carry top priority messages when the 20/30 GHz channels go out. The sample link calculations for a 30 GHz gigabit uplink are:

Uplink at 30 GHz

$$\frac{C}{N} = Pt + Gt + Gr - Nr - Lfs - Lr - Pl - Pb - Dm$$
$$= 30 + 67 + 57 + 110 - 213 - 23 - 0.1 - 3 - 2$$

$$\frac{C}{N} = 23 \text{ dB}$$

These calculations are based on a transmitting station with 1000 watts of transmitter power and a 11-meter antenna. The satellite requires a 3-meter-diameter antenna and a 720°K combined antenna and receiver noise temperature. The satellite receiver temperature would be about 320°K with a 1 GHz bandwidth. These values can be met, but most probably the transmitter power will be set at about 6000 watts to reduce the required satellite antenna gain and receiver noise temperature. Low-noise satellite receivers and high-gain antennas will probably be cost effective if flight-proven hardware and technology are available from satellite-to-satellite relay applications.

Downlink at 20 GHz

$$\frac{C}{N} = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Lp - Pp - Dm$$

$$\frac{C}{N} = 14 + 55 + 64 - 2 + 113 - 210 - 20 - 0.1 - 2 - 2$$

$$\frac{C}{N} = 10 \text{ dB}$$

These calculations are based on the use of a 20-GHz frequency and a 300^{o}K uncooled parametric earth station antenna amplifier with a 11-meter-diameter antenna. Twenty-five watts of radiated power on a 1 GHz bandwidth transponder with a 4-meter-diameter antenna provide a 10-dB carrier-to-noise ratio. Such a system places a heavy dependance on one satellite transponder. Redundant transponders or redundant switched transponder sections are required. Breaking the bandwidth into several segments such as five 200 MHz bandwidth channels using five transponders would reduce the required power required per transponder and allow more graceful degradation in the event of a transponder failure. The use of a single transponder, however, provides the advantage of system simplicity and a minimum of wave guide between transponder output power devices and the antenna feed switches.

10.3.4 Mobile Services

The key functional requirements for mobile services of this category are motion of the using vehicle and low data rates on the order of 100 BPS or voice to be transmitted over a narrow bandwidth channel. Vehicle movement requires the user antenna to have on the order of a 180^{o} beam width or be steered. The base bandwidth is on the order of 3 KHz. Mobile services will generally operate with satellite beams covering specific areas, such as a state or coastal area. The following link calculations are based on use of a $3/4^{o}$ satellite beam, which covers approximately a 300-mile diameter at 40^{o} latitude. A 43-GHz frequency allocated for mobile communications is considered as being the most stringent operating frequency. A 20-dB rain attenuation is used to allow for about 10 mm/hr of rainfall and a 30^{o} elevation look angle for the user antenna.

A steered beam antenna is required for the ground vehicle, because the power requirements are excessive for use of wide-angle fixed-beam antenna. On this basis the link calculation values are:

$$C/N = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Dm - Pl - Pp$$

$$C/N = 15 + 47 + 32 - 2 + 159 - 216 - 20 - 2 - 0.3 - 3 \text{ (for 43 GHz)}$$

$$C/N = 10 + 47 + 32 - 2 + 157 - 210 - 20 - 2 - 0.3 - 3 \text{ (for 20 GHz)}$$

$$C/N = 10$$

The required transmitter power per voice channel is 32 watts during rain. Less than 1 watt per channel is required in clear weather or for aircraft flying above the weather. A 200-watt transponder could provide 200 channels in clear weather. The ground vehicle requires a 4-degree beamwidth antenna providing a 32-dB maximum gain. The calculations indicate that about a 32-watt transmitter is required for each vehicle to transmit through a satellite having a 500^{o}K effective noise temperature due to the antenna looking at earth, plus approximately a 300^{o}K amplifier temperature.

The signal-to-noise ratio due to a 10 dB carrier-to-noise ratio and an FM modulation index of 2.2 is equal to:

S/N = C/N + RMS to P-P conversion + freq imp + preemphasis and weighing factors

$$S/N = 10 + 9 + 16.6 + 8$$

S/N = 43.6 dB under worst-case design conditions.

The 43-dB signal-to-noise ratio indicates that an intelligible quality voice channel could be maintained with a carrier noise ratio down to 6 dB (with threshold extension), which would allow up to 26 dB loss for weather conditions or other phenomena. The system would work with a 6-dB gain user antenna in clear weather.

The low power levels for transmission from the ground vehicle are only possible if a steered or switched narrow beam antenna is used. Use of an omnidirectional antenna with 3 dB gain requires nearly 1 kilowatt of radiated power per voice channel under worst-case rain conditions. The high-gain ground vehicle antenna beam would track a reference beacon signal broadcast by the satellite to all using vehicles. A phased array antenna could steer the antenna beam to obtain the maximum signal strength, or a switched beam antenna or lens would switch "on" the proper feed for looking at the satellite.

10.3.5 NASA Tracking and Data Relay Network

Relaying of data between ground tracking stations would be performed as described for digital service networks in para 10.3.3. Tracking of orbit and deep-space vehicles presents special requirements. Small satellites in low earth orbit may only require a 1 KBPS data rate. The Space Shuttle data bus is expected to require about a 50 KBPS data rate (Ref 35, p 7-4). The maximum data rate by 1985 could be on the order of gigabits but data rates of 200 to 400 MBPS are considered as the upper bound. For a 50 KBPS data rate for medium size satellites, link calculations for operation at S-Band (2.3 GHz) from the satellite to the TDRS (tracking and data relay satellite) are:

$$\frac{C}{N} = Pt + Gt + Gr - Nr - Lfs - Dm - Pl - Pp$$

$$\frac{C}{N} = 30 + 3 + 18 + 156 - 190 - 3 - 1.3 - 3$$

$$\frac{C}{N} = 10 \text{ dB}$$

The required satellite power is 1 kilowatt for use of a nearly omnidirectional antenna in conjunction with a global coverage antenna for the TDRS. The use of a 1^{o} tracking spot beam on the T&DRS reduces the required radiated power to about 3 watts. A 30-foot antenna is required to generate a 1^{o} beam at S-band.

A medium-size satellite with a 5 KBPS data rate would require about 1 watt of radiated power if the spot beam is used. The link calculations reveal that even for a 5 KBPS data rate at S-band, a tracking spot beam is required on the T&DRS to reduce the using vehicle's transmitter power requirements and allow an omnidirectional antenna to be used on the scientific satellite.

For a 50 KBPS data rate at 137 MHz frequency, the link calculations for use of a global coverage TDRS antenna beam are:

$$\frac{C}{N} = Pt + Gt + Gr - Nr - Lfs - Dm - Pl - Pp$$

$$\frac{C}{N} = 7 + 0 + 18 + 156 - 165 - 3 - 0.3 - 3$$

$$\frac{C}{N} = 10$$

Therefore, scientific satellites with 50 KBPS data rates would require 5 watts of radiated power with a fixed global coverage beam. Operation at 137 MHz allows the use of a simple system without tracking antennas for low data rates. Operation at higher frequencies will require the use of spot beams, even for small satellites. Spot beams will provide more immunity to interference and a more secure communications link at the expense of the complexity of a steered beam antenna. The expense, degree of risk, and complexity of a steered beam antenna are dependent on future technology development.

Data rates of 100 to 400 MBPS for Space Shuttle and manned space stations require the use of higher frequencies. The relaying of data from TDRS over the Indian or Pacific Oceans to a TDRS over the United States will possibly require data rates on the order of gigabits per second unless data compression techniques are used for digital video transmission. Use of a 60-GHz carrier frequency will present the most challenging communications hardware requirements. It is estimated that hardware for such a system will be available for satellite use by 1985. Link calculations for a 1-gigabit channel between synchronous satellites are as follows:

$$\frac{C}{N} = Pt + Gt + Gr - Nr - Lfs - Dm - Pl - Pp$$

$$\frac{C}{N} = 15 + 60 + 60 + 108 - 224 - 3 - 0.3 - 3$$

$$\frac{C}{N} = 13 \text{ dB}$$

The requirements are 32 watts of radiated power, a 1000°K receiver with a 1 GHz bandwidth, and 60 dB antennas. Such antennas would be on the order of 3 meters in diameter for 60-GHz carrier frequencies and have a 0.2-degree beam width. The technology for developing such links is available (Ref 36, p 82 and Ref 37, p 24). Laser links between spacecraft and satellites offer a second alternative. Clearly, the functional requirements can be met by 1985 with the present trend of technology development and laboratory demonstrations in laser systems (Ref 37, p 35). Lasers are not considered in detail because of limitations, caused by weather and cloud cover, on a laser downlink to the ground. The attenuation of a 40 GHz carrier through 10 mm/hr rain and 30° elevation angle is 23 dB (Ref 39, p 86). Link calculations for a 1 GHz per second data link using a 40 GHz carrier are:

$$\frac{C}{N} = Pt + Gt + Gr - Nt - Nr - Lfs - Lr - Dm - Pl - Pp$$

$$\frac{C}{N} = 14 + 60 + 65 + 116 - 216 - 23 - 2 - 0.3 - 3$$

$$\frac{C}{N} = 10 \text{ dB}$$

Twenty-five watts of radiated power and a 3-meter-diameter antenna can provide a 1 GHz data link to an earth station with a 7-meter antenna and 50°K noise temperature receiver. The system provides a 10 dB carrier-to-noise ratio to provide a 10^{-5} bit error rate with up to about 10 mm/hr of rain. The downlink to ground is not a critical problem for the TDRS, even if the allocated 40 GHz rather than 20 GHz frequency band must be used. The carrier-to-noise ratio should be over 30 dB for more than 99 percent of the time to give a low bit error rate.

There are several critical problems for full utilization of tracking to data relay satellites in the 1990s. One problem is to provide multiple steerable or switched antenna beams for communicating with satellites in low earth orbit. Five to 10 spot beams are required, each capable of accommodating 100 MBPS data rates from Space Shuttle vehicles, earth resources satellites, manned space stations, and orbiting observatory spacecraft. The second need is steered beams to relay gigabit data streams from distant TDRS to the central ground station and data terminal. Multiple steered or switched beam antennas will benefit command and data relay operations for medium-sized scientific satellites with 50 KBPS to 30 MBPS data rates. Steered beams will also be required for communication with deep-space probes.

A third need is for high gain ground antennas on the order of 13 meters in diameter and providing about 72 dB of gain at 40 GHz to reduce the 1 gigabit downlink satellite RF power required from 25 watts to about 5 watts. A fourth need is for a low noise parametric satellite receiver amplifier capable of reducing the effective noise temperature from 1150°K to about 500°K. This will reduce the satellite-to-relay-satellite RF power requirement from 32 to 16 watts.

10.3.6 Earth Resources Data Collection

Link calculations for a 200 BPS channel operating at 149 MHz are:

$$\frac{C}{N} = Pt + Gt + Gr - Nr - Lfs - Lr - Dm - Pl - Pp$$

$$= 7 + 0 + 18 + 165 - 168 - 2 - 1.3 - 3$$

$$\frac{C}{N} = 15.7$$

The calculations are based on the following:

1. Pt (transmitter power) of 5 watts radiated power at 149 MHz for approximately 2 to 60 seconds, four times per day (radiated by each fixed data platform)
2. A semi-omnidirectional antenna for moving stations such as ships and balloons
3. A satellite receiver antenna with full earth coverage (18 dB gain antenna for a 149 MHz frequency band would be on the order of 30 ft in diameter and would not require beam switching or steering.)
4. A channel base bandwidth of 200-250 Hz (The combined receiver and satellite antenna noise temperature are 1150°K.)
5. A design margin of 2 dB
6. A 1.3 allowance for polarization loss with a circular-to-circular antenna polarization
7. A 3 dB allowance for location of the ground station at the half-gain point of the satellite receiving antenna

The power required to command the platform station "on" from the satellite would be on the order of 20 watts for a 1150°K receiver noise temperature and a 10 dB margin to ensure an adequate reference frequency.

10.3.7 RF Environment Monitoring and Test Satellite

A satellite monitoring the space RF environment affecting communications satellite operations should be capable of determining the source of illegal or out-of-specification RF radiation. Therefore, the RF environment monitoring satellite will benefit by the use of narrow steered antenna beams capable of searching out the sources of radiation. Such beams must be able to sweep through large angles on the order of 30 to 60 degrees. The satellite should be capable of monitoring communications satellites in orbit as well as the earth's surface in view of the satellite. Wideband low-noise receivers are required to provide coverage of all communications satellite transmit and receive bands and adjacent operating frequency bands. The antenna gain for each frequency region should be compatible with any communications satellite in use to ensure the capability of detection of any energy sources capable of disrupting communications or degrading communications performance.

The satellite should be at least as sensitive to signals as operational satellites. One concept is the use of multiple low-noise receivers with switched filter bands or switching of receivers to downlink transmitters for frequency monitoring. The downlink to the earth station would be similar to the downlink for the tracking and data relay satellite 1 gigabit downlink.

10.3.8 Path Attenuation

Figure 10-1 shows the typical vertical attenuation for various weather conditions versus the higher frequencies that are significantly affected by atmospheric and rain attenuation. Figure 10-2 shows measured rain attenuation data at the location indicated. These data values are of the order of presently available data, which require refinement and expansion to support successful utilization of the frequencies above 10 GHz in the 1980s.

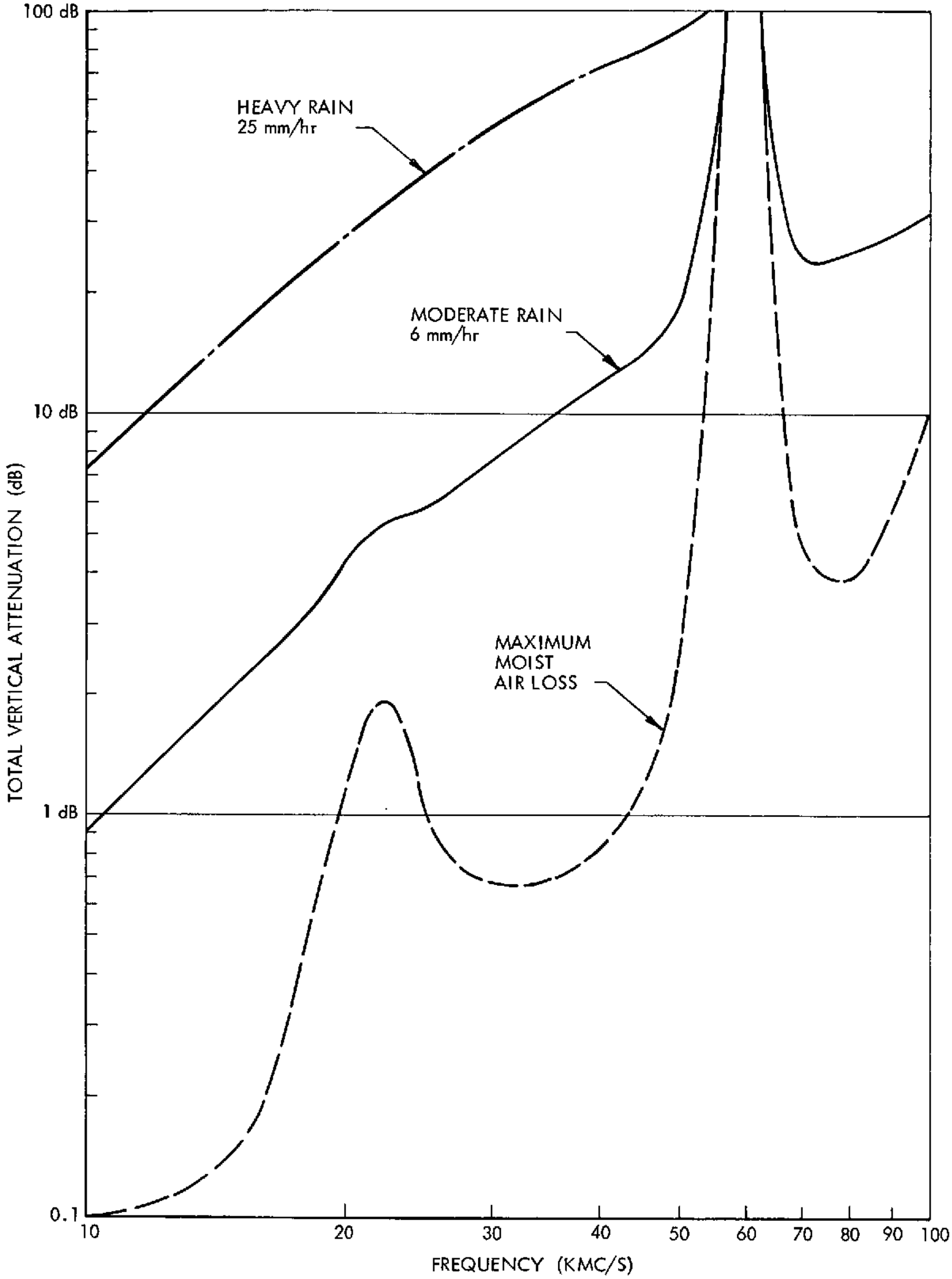


Fig. 10-1 Total Attenuation for Various Weather Conditions

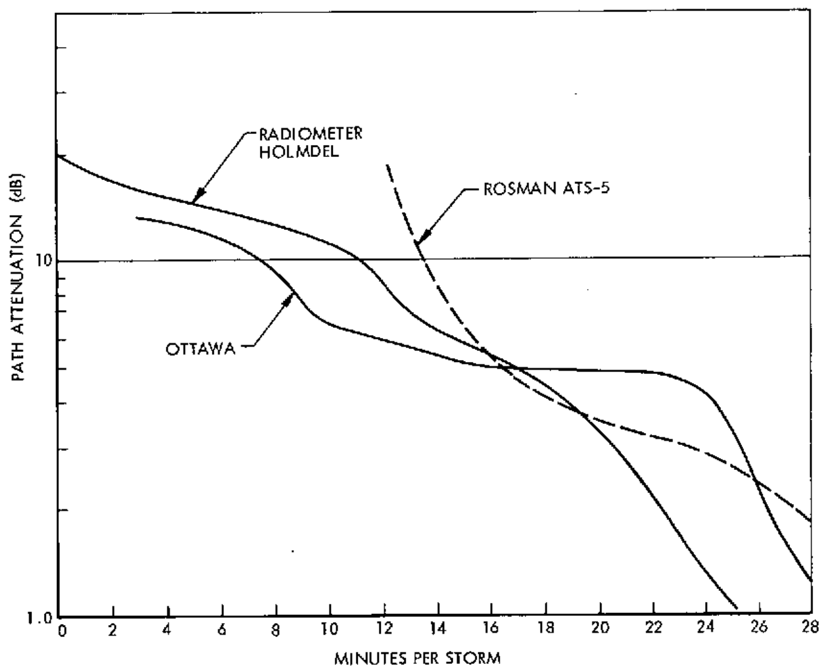


Fig. 10-2 12 GHz Storm Attenuation – Total Time That Attenuation Exceeds Ordinate

10.4 COST MODEL FOR CONCEPTUAL SYSTEMS

Since the available and developing satellite technologies can provide the quality and quantity of services needed for the 1985 to 1995 era, satellite system costs and technologies for reducing costs become important elements of systems cost effectiveness analysis. The trend of inflation presents a problem when defining costs because historic cost data must be adjusted for present dollar values. Also, quotes for equipment to be delivered are made on the basis of forecasted future inflation over the period of contract performance. Such costs must be adjusted in order to be comparable with available historic cost data. Cost data and all costing has been related to equivalent 1972 dollars as the most convenient dollar reference for this study.

An analysis of long-term inflation from 1920 plus forcasts to 1975 indicate that the average inflation rate is 4 percent per year. Historic and recent cost data have been adjusted for the inflation rates documented by the U.S. Department of Commerce.

10.4.1 Spacecraft Cost Model

Table 10-2 presents cost and cost-related data for eleven satellite programs. Costs of these programs can be quite accurately approximated in millions of 1972 dollars by means of the following simple cost model, based on satellite weight and number of transponders:

$$\text{Sat. Cost} \approx (\text{No Transponders}) \times \$0.5 + \$2 + (\text{Sat. Wt KG}) \times \$0.004$$

This recurring cost per satellite is sufficiently accurate for conceptual communications systems if the bandwidths per transponder, frequencies and power levels per transponder all fall within a reasonably close range of historical operating characteristics. The ratios of satellite primary power per hertz of bandwidth for the satellites listed in Table 10-2 vary by less than a factor of five. This means that if each satellite utilized antennas which provided equal areas of earth coverage, the effective radiated power per hertz of bandwidth would probably vary by less than 7 dBW. Transponder complexity and numbers of transponders is a major factor of satellite system cost. The more transponders of equal power and weight, the more electrical power, structure, thermal control, command, telemetry, and station-keeping propulsion expendables required. Link calculations show that the full range of service needs can generally be met with transponder radiated power levels between 5 to 100 watts. The type of transponder, whether solid-state or traveling wave tube, and radiated power level affect the transponder, power subsystem and total satellite system cost. These factors are taken into account when modeling satellite costs for each of the seven types of systems.

The cost model was adjusted for technology growth and used to determine the recurring costs of 1975-1980 era satellites in 1972 dollars. The 1980 cost per transponder was reduced 20 percent below the 1972 cost due to reductions in transponder and supporting subsystems resulting from technology growth and competition. The estimated satellite cost per transponder for the Earth Resources Data Collection satellite was adjusted to half of the cost per video service transponder because the VHF or UHF frequency and the narrow 50 KHz required bandwidth allow efficient, relatively simple, and easy to develop solid-state transponders. Cost per solid-state aerosat transponder was reduced 40 percent (to $0.3 million per transponder and required support equipment).

Table 10-2

COST DATA FOR SATELLITE PROGRAMS

Satellite	Weight in Pounds	Design Life/ Power in KW	No. of Operating Transponders and BW in MH	Sat Wt per Transponder kg	No. of Sats.	First Launch	Contractor	Development Factor	Modeled Cost per Satellite	Modeled Development Cost	Modeled Program Price in Millions of 1972 Dollars	Modeled Program Price Corrected to Flight Date	Published Program Price in Millions
Intelsat I	39	1.5/0.03	2/26	19	2	1965	Hughes	2	3.2	6.4	12.8	9.8	10
Intelsat II	87	3/0.1	1/126	87	5	1966	Hughes	2-1/2	2.9	7.3	21.8	17.4	18
Intelsat III	154	5/0.13	2/225	76	8	1968	TRW	3-1/2	3.7	13	42.5	52	56
TACSAT	730	2/0.9	2/400	350	1	1969	Hughes	2-1/2	6.2	15.5	21.7	18	15
Intelsat IV	915	7/0.6	12/36	60	8	1971	Hughes	2	11.2	22.4	112	123	112
Intelsat IVA	800	7/0.7	24/36	33	3	1975	Hughes	1-1/4	17.5	21.8	74.5	74.5	73
AT&T	1760	7/0.7	24/36	33	3	1975	Hughes	1-1/4	17.5	21.8	74.5	74.5	>70
Anik	270	7/0.3	10/36	27	3	1972	Hughes	1/2*	8.2	4.1*	28.7	~30	30
Western Union	270	7/0.3	10/36	27	3	1974	Hughes	1/2*	8.2	4.1*	28.7	22.6	25
GTE	270	7/0.3	10/36	27	3	1975	Hughes	1/2*	8.2	4.1*	28.7	22	25
DSCS II	510	7/0.3	2/50 1/125 1/185	17	6	1971	TRW	3-1/2	6.22	21.7	59	65	65

*2-1/2 prorated over 15 units

A cost factor of 1-1/2 times commercial spacecraft cost was used for NASA procured spacecraft (Ref 47, p 11).

The 1980 to 1985 era satellite costs were estimated on the basis of $0.3 million for each transponder and related support equipment; plus $2 million for management, integration, and system test; plus $2 million for basic systems capability such as attitude control; on-orbit propulsion; tracking, telemetry, and command; basic power elements; and basic structure and launch vehicle adapter. Transponder and related support equipment was estimated to cost only $0.2 million per transponder for Aerosat and Maritime satellites, and $0.1 million for Earth Resource Data Collection satellites.

The non-recurring costs for developing a new satellite system depend upon system requirements and how great an advancement in technology must be made over previously designed systems. Table 10-2 shows that development costs have been between 1-1/4 to 3-1/2 times the recurring cost of a flight spacecraft. Intelsat I, for example, had a low development factor due to similarities with Syncom. Intelsat III is believed to have a factor of 3-1/2 because it was the first commercial satellite with a mechanically despun antenna and had many additional innovations. Intelsat IVA has a development factor of only 1-1/4 because it is very similar to Intelsat IV. A development factor of 2-1/2 was used for each of the six types of spacecraft presented in Table 10-2. Development factors of two (2) were used for the Video, Common Carrier, and Aerosat satellites of Table 10-13 for the 1980 to 1985 era. The lower development factor was based upon expected continuity of development and availability of technology.

The NASA satellites for Space Tracking and Data Relay, Earth Resources, and RF Environment Monitoring and Testing were costed on the basis of a development factor of 2-1/2, due to the tendency to utilize more advanced technology for NASA satellites, and added experiments in support of related missions. Both the recurring and non-recurring costs of the NASA satellites were therefore increased by 50 percent (1-1/2 times) of the cost of commercial program satellite costs, due to the contractual reporting, testing, and management requirements usually required for scientific and research satellites.

Launch costs are based upon use of Delta boosters until 1985.

10.4.2 Factors Affecting Use of Cost Model

The conceptual spacecraft designs would be heavier and less costly per pound of satellite for utilization of the Space Shuttle/Tug system. Spacecraft costs would probably be reduced on the order of 20 percent to 30 percent and the cost per kilogram of spacecraft on orbit reduced by about 40 percent. The effects of Space Shuttle upon spacecraft costs are defined in paragraph 10.6.3.

Total space segment costs per transponder could be reduced by spreading development costs over 10 to 12 satellites, rather than over 3 to 6 as shown. The number of common spacecraft is dependent upon user requirements and specifications.

Future decisions to utilize fewer but higher-capacity spacecraft will increase the development costs per spacecraft. Each spacecraft will be larger and more complex, and fewer spacecraft will be required.

10.4.3 Earth Station and Operating Costs

Earth station costs are based upon the following:

1. A major earth terminal with a 30 meter dish costs on the order of \$5 million.
2. A domestic satellite common carrier satellite ground station with one 11 meter antenna costs on the order of \$1.2 million.
3. A small video ground station with a 5 meter antenna costs on the order of \$30K to \$50K.
4. A common carrier ground station with 5 meter antenna costs on the order of \$100,000 to \$150,000.
5. Annual amortization, operating, and maintenance expenses are about one-third of the ground station investment costs.
6. Satellite support and operating costs range from 3 to 5 million dollars per year based upon the number of satellites and complexity
7. Each aircraft and ship terminal is estimated to cost \$20,000 during the 1975-1980 era and \$2,000 during the post-1985 era.
8. Earth resources and data platform communications equipment is estimated to cost on the order of \$1500 dollars per set in 1975 and \$500 per set by 1985 – in equivalent 1972 dollars.

10.5 CONCEPTUAL SATELLITE SYSTEMS

Conceptual satellite systems have been formulated for meeting the needs of the seven typical categories of services. Table 10-3, Summary of Communications Requirements, lists the numbers of channels needed for each type of service, the total channel requirements for the 1985-1990 era, the RF bandwidth required, and the available RF bandwidth. The RF bandwidth requirements are based upon network channel requirements listed in Tables 5-5 and 5-6 and the link calculations. Table 10-3 shows that there is more than adequate available allocable bandwidth for fulfilling all forecasted needs if the available technologies and frequencies are properly utilized. Table 10-4 summarizes the minimum usable bandwidth for U.S. Domestic Coverage based upon FCC frequency allocations and use of the minimum effective antenna diameters for each frequency, as listed in Table 10-5 of required earth station antenna

Table 10-3

SUMMARY OF COMMUNICATIONS REQUIREMENTS, 1985-1995 ERA

	DEDICATED VIDEO SERVICE	COMMON CARRIER AND HIGH SPEED DATA	AERONAUTICAL AND MARINE	STATE AND GROUND VEHICLE	TRACKING AND DATA RELAY	RF ENVIRONMENTAL MONITOR
VIDEO CHANNELS						
GLOBAL	–	–			10 *	
NATIONAL	200	500 *			10 *	
REGIONAL	1,000	–			–	
VOICE/DATA CHANNELS						
GLOBAL	–	–	–	–	50	
NATIONAL	500	280,000	–	–	50	
REGIONAL	6,000	–	3,000	50,000	–	
HIGH SPEED DATA						
GLOBAL	–	–			2 GBps	5 GHz
NATIONAL	1 GBps	12 GBps			2 GBps	–
REGIONAL	1 GBps	–			–	–
TOTAL TRANSPONDERS	1,500	1,000	200	150	36	10
TOTAL PER REGION	300	–	30	10	12	–
REQ RF BANDWIDTH (MHz)	(60,000)	(34,000)	(80)	(500)	(5,000)	(5,000)
COMPRESSED BANDWIDTH (MHz)	(15,000)	(24,000)	(9)	(150)	(4,200)	(50)
BASE BANDWIDTH (MHz)	(1,210)	(15,000)	(9)	(150)	(4,100)	–
AVAILABLE BANDWIDTH (MHz)	(33,600)	(108,000)	(2,546)	(2,500)	(8,400	(2,000)

* VIDEO AND DATA CHANNELS

Table 10-4

SUMMARY OF AVAILABLE BANDWIDTHS, 1985-1995 ERA

SERVICE	ALLOCATED FREQUENCY IN GIGAHERTZ	USABLE BANDWIDTH IN MHz	DEGREES OF USABLE EQUATORIAL ARC	NUMBER OF SATELLITE SLOTS	TOTAL AVAILABLE BANDWIDTHS IN MEGAHERTZ
DEDICATED VIDEO SERVICES	0.7	340*	80	2 @ 30°	600
	2.5	380*	80	8 @ 10°	3,000
	11.7-12.2	1,000	90	30 @ 3°	30,000
					33,600
COMMON CARRIER AND HIGH SPEED DATA	3.5-4.2	1,000*	80	16 @ 5°	16,000
	6.625-7.125	1,000*	60	20 @ 3°	20,000
	17.7-19.7	2,000	20	20 @ 1°	40,000
	19.7-21.2	1,500	20	20 @ 1°	30,000
					106,000
AERONAUTICAL AND MARINE	1.5	23	80	2 @ 80°	46
	43.0-48.0	2,500	10	1 @ 10°	2,500
					2,546
GROUND VEHICLE	43.0-48.0	5,000/2	10	1 @ 10°	2,500
RF ENVIRONMENTAL MONITORING	40.0-41.0	4,000	10	10 @ 1°	2,000

*WITH ORTHOGONAL POLARIZATION

Table 10-5

EARTH STATION ANTENNA PARAMETERS

FREQUENCY (GHz)	BANDWIDTH PER CHANNEL	SERVICE	EARTH ANTENNA GAIN (dB)	EARTH ANTENNA APERTURE M	MAXIMUM BEAMWIDTH	SATELLITE RF POWER WATTS/ CHANNEL	SATELLITE ANTENNA GAIN (dB)
0.4	2 KHz	DATA COL	0	1	180°	7	18
0.7	30 MHz	TV	24	3	10°	13	32
1.5	25 KHz	AEROSAT	3	2	180°	20	32
2.5	30 MHz	ETV	35	3	3°	15	32
4.0	34 MHz	DOMSAT	43	5	1-1/2°	10	32
12.0	34 MHz	DOMSAT	55	7	0.3°	16	32
20.0	1 GHz	DATA	60	7	0.2°	100*	55
40.0	1 GHz	DATA	60	3	0.2°	32**	60
43.0	20 KHz	MOBILE	32	0.2	4°	32**	47

*10 dB RAIN MARGIN
**20 dB RAIN MARGIN

parameters. The approximate satellite radiated power and RF bandwidth per channel are important factors for frequency reuse. The numbers of satellite slots covering the 48 states and degrees of spacing between satellites are conservative. Satellites can be more closely spaced than indicated and a wider usable segment of the equatorial arc can be utilized for satellites covering limited regions such as the Eastern United States, Alaska, and the Pacific, for example. Also, the following constraints were applied:

1. Each frequency below 12 GHz used only twice for broadcast and fixed user services due to use of orthogonal polarization.
2. Frequency used once per major area for mobile users.

One orbit position or slot can accommodate several satellites utilizing the same frequencies if the satellites each utilize spot beams to illuminate separate areas, and there is sufficient isolation between beams. One satellite can also reuse the same frequency several times by means of isolated spot beams. Therefore, the available RF spectrum bandwidth can be much greater than calculated.

Tables 10-6 through 10-11 present the allocated weight, percent of cost, and allocated reliability for each major subsystem for six conceptual satellite systems for fulfilling the seven categories of required services. The common carrier (telephone) and high-speed data satellites use essentially the same conceptual satellite systems by 1985, and are therefore combined. Each table shows the required subsystem weight to provide the numbers of channels or bandwidth indicated for the 1975 and the 1985 eras.

Allocated costs for subsystems are based on relative subsystem cost and complexity, independent of the costs for program management, integration, systems testing, and launch support.

Allocated reliabilities are based upon achievable and forecasted reliabilities for meeting the needs for the 1985 era.

Tables 10-12 and 10-13 present cost summaries for the six types of satellite systems for the 1975-1980 era and the 1980-85 era. The cost items indicate the relative importance of each major part of a system. Tables 10-6 through 10-11 define conceptual systems capable of meeting the 1985-1990 era needs defined by the needs model and functional requirements, given the present and conservatively forecasted trend of technology development. The weights, costs, and reliability values are supported bv
dies as referenced in the tables.

Table 10-6

CONCEPTUAL DOMESTIC TELEVISION SATELLITE

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES)

SUBSYSTEM	WEIGHT IN KILOGRAMS 1975	WEIGHT IN KILOGRAMS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (NO TRANS, GHz FREQ)	60 (15,4/6)	123 (15, 4/6; 15, 12/14)	41	47	0.80	0.80
ANTENNAS	10	11	1	2	-	-
POWER (WATTS)	136 (800)	218 (2000)	17	19	0.96	0.96
STABILIZATION	36	27	15	10	0.87	0.97
PROPULSION AND STATIONKEEPING	136**	50*	12	12	0.99	0.99
STRUCTURES AND THERMAL CONTROL	68	52	6	5	0.99	0.99
COMMAND AND TELEMETRY	24	14	8	5	0.90	0.98
TOTAL	470	495	100%	100%	0.59	0.71

REFERENCE: LMSC-A968535, DOMESTIC TELEVISION DISTRIBUTION SATELLITE BY LOCKHEED MISSILES & SPACE COMPANY

*ION ENGINE STATIONKEEPING PLUS HYDRAZINE
**INCLUDES APOGEE KICK STAGE MOTOR CASING

Table 10-7

CONCEPTUAL DOMSAT (TELEPHONE AND HIGH-SPEED DATA NETWORK SATELLITE)

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES)

SUBSYSTEM	WEIGHT IN KILOGRAMS 1975	WEIGHT IN KILOGRAMS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (USABLE BANDWIDTH)	74 (1 GHz)	155 (3.5 GHz)	50	46	0.86	0.80
ANTENNAS	15	68	1	6	-	0.99
POWER (WATTS)	95 (600)	105 (1000)	12	16	0.98	0.96
STABILIZATION	36	32	14	11	0.87	0.97
PROPULSION AND STATIONKEEPING	135**	50*	11	10	0.99	0.96
STRUCTURES AND THERMAL	55	45	5	5	0.99	0.99
COMMAND AND TELEMETRY	25	15	7	6	0.90	0.98
TOTAL	435	470	100%	100%	0.66	0.69

REFERENCE: LMSC-D331345, 6 OCT 1972, EARLY VERSION INTELSAT V DESIGN STUDY BY LOCKHEED MISSILES & SPACE COMPANY

*ION ENGINE STATIONKEEPING PLUS HYDRAZINE
**INCLUDES APOGEE STAGE MOTOR CASING

Table 10-8

CONCEPTUAL AERONAUTICAL/MARINE SATELLITE

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES)

SUBSYSTEM	WEIGHT IN POUNDS 1975	WEIGHT IN POUNDS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (NO. TRANS/NO. VOICE CH)	65 (8/12)	122 (16/24)	20	27	0.90	0.90
ANTENNAS (L-BAND)	70	55	20	16	0.95	0.99
POWER (WATTS)	100 (600)	105 (1100)	15	21	0.96	0.96
STABILIZATION	35	28	18	12	0.87	0.97
PROPULSION AND STATIONKEEPING	90**	50*	12	11	0.99	0.96
STRUCTURES AND THERMAL	70	60	6	5	0.99	0.99
COMMAND AND TELEMETRY	23	15	9	8	0.95	0.98
TOTAL	453	435	100%	100%	0.66	0.77

REFERENCE: PROCEEDINGS OF THE IEEE, FAB 1971, APPLICATIONS SATELLITES F&G COMMUNICATIONS SUBSYSTEM

*ION PROPULSION AND HYDRAZINE BACKUP
**INCLUDES APOGEE STAGE MOTOR CASING

Table 10-9

CONCEPTUAL TRACKING AND DATA RELAY SATELLITE*

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES

SUBSYSTEM	WEIGHT IN POUNDS 1975	WEIGHT IN POUNDS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (NO. TRANSPONDERS)	65 (10)	125 (20)	27	45	0.90	0.85
ANTENNAS	90	160	16	14	0.95	0.93
POWER (WATTS)	55 (300)	70 (600)	12	11	0.98	0.98
STABILIZATION	35	30	17	10	0.87	0.97
PROPULSION AND STATIONKEEPING	90**	45***	12	11	0.99	0.96
STRUCTURES AND THERMAL	90	70	4	4	0.99	0.98
COMMAND AND TELEMETRY	25	15	9	5	0.95	0.96
TOTAL	450	515	100%	100%	0.68	0.68

*REFERENCE REQUIREMENTS AND S-BAND SYSTEM WEIGHTS; PROCEEDINGS OF THE IEEE, FEB 1971, PAGE 136, BY S. DURRANI AND D. LIPKE, COMSAT
**INCLUDES APOGEE STAGE MOTOR CASE
***ION PROPULSION

Table 10-10

CONCEPTUAL EARTH RESOURCES DATA COLLECTION SATELLITE*

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES)

SUBSYSTEM	WEIGHT IN POUNDS 1975	WEIGHT IN POUNDS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (NO. TRANSPONDERS)	45 (15)	80 (30)	20	30	0.95	0.95
ANTENNAS 20 FT, 137 MHz	45	40	10	9	0.98	0.98
POWER (WATTS)	45 (250)	45 (400)	15	13	0.98	0.98
STABILIZATION	35	27	22	20	0.87	0.97
PROPULSION	100**	50	17	15	0.99	0.99
STRUCTURES AND THERMAL CONTROL	60	33	6	5	-	-
COMMAND AND TELEMETRY	20 20	15 15	10	8	0.95	0.98
TOTAL	350	290	100%	100%	0.74	0.85

*REFERENCE, COLLECTION OF DATA FROM IN SITU SENSORS VIA SATELLITE; BY J. D. DORFMAN, HUGHES AIRCRAFT CO.; 1969 WESCON TECHNICAL PAPERS, SESSION 12

**INCLUDES APOGEE KICK STAGE ROCKET MOTOR WEIGHT

Table 10-11

CONCEPTUAL RF ENVIRONMENT MONITORING AND TEST SATELLITE

(FOR 1975 AND 1985 TECHNOLOGY CAPABILITIES)

SUBSYSTEM	WEIGHT IN POUNDS 1975	WEIGHT IN POUNDS 1985	ALLOCATED PERCENT COST 1975	ALLOCATED PERCENT COST 1985	ALLOCATED RELIABILITY FOR 7 YEARS 1975	ALLOCATED RELIABILITY FOR 7 YEARS 1985
COMMUNICATIONS (NO TRANSPONDERS)	90 (10)	135 (20)	62	62	0.90	0.90
ANTENNAS	135	135	15	15	0.99	0.98
POWER (WATTS)	45 (270)	45 (400)	6	6	0.98	0.98
STABILIZATION	35	30	6	6	0.87	0.95
PROPULSION AND STATIONKEEPING	90*	50**	5	5	0.99	0.99
STRUCTURES AND THERMAL CONTROL	60	40	3	3	0.99	0.99
COMMAND AND TELEMETRY	25	15	3	3	0.90	0.98
TOTAL	480	450	100%	100%	0.67	0.79

REFERENCE: NASA PAYLOAD DATA BOOK BY THE AEROSPACE CORPORATION, 31 JULY 1972; SORTIE COMMUNICATIONS MISSION: CODES NC2-52 NC2-53, NC2-54

*INCLUDES APOGEE STAGE MOTOR CASE

**ION PROPULSION

Table 10-12

COST ESTIMATES FOR 1975-1980 ERA

(IN MILLIONS OF 1972 DOLLARS)

	VIDEO NETWORKS BIOMED EDUCATION ETC.	COMMON CARRIER AND HIGH SPEED DATA	AEROSAT AND MARINE VOICE AND DATA	SPACE TRACKING AND DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR AND TEST
SATELLITE						
NO TRANSPONDERS	15	24	8	10	15	10
WEIGHT, KG	470	435	453	450	350	480
NO SAT + 1 SPARE	6	6	5	5	4	4
DEVELOPMENT COSTS	25	34	16	30	25	30
RECURRING COSTS	60	80	32	60	40	50
LAUNCH COSTS	50	50	40	40	30	30
8% DISCOUNT COST	96	117	63	94	67	78
EARTH STATIONS						
7 YR OPERATION AND AMORTIZATION COST	55	105	105	45	105	45
COVERAGE	NATIONAL	NATIONAL	NATIONAL	GLOBAL	GLOBAL	GLOBAL
NUMBER	210	30	1,000	3	20,000	3
INVESTMENT	15	40	40	10	40	10
TOTAL COST FOR SEVEN YEARS	286	386	256	269	267	233
COST PER TRANSPONDER/YEAR	0.54	0.46	1.1	0.97	0.85	1.1

Table 10-13

COST ESTIMATES FOR 1980-1985 ERA

(IN MILLIONS OF 1972 DOLLARS)

	VIDEO NETWORKS BIOMED EDUCATION ETC.	COMMON CARRIER AND HIGH SPEED DATA	AEROSAT AND MARINE VOICE AND DATA	SPACE TRACKING AND DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR AND TEST
SATELLITE						
NO TRANSPONDERS	30	48	16	20	30	20
WEIGHT, KG	495	470	435	515	290	450
NO SAT + 1 SPARE	6	6	5	5	4	4
DEVELOPMENT COSTS	25	35	15	35	22	35
RECURRING COSTS	80	110	35	75	35	60
LAUNCH COSTS	50	50	40	40	30	30
8% DISCOUNT COST	110	140	64	107	62	90
EARTH STATIONS						
7 YR OPERATION AND AMORTIZATION COST	80	125	180	45	105	45
COVERAGE	NATIONAL	NATIONAL	NATIONAL	GLOBAL	BLOBAL	GLOBAL
NUMBER	410	50	30,000	3	60,010	3
COST	25	50	70	10	40	10
TOTAL COST FOR SEVEN YEARS	345	360	334	303	254	260
COST PER TRANSPONDER/YEAR	0.33	0.21	0.75	0.54	0.40	0.62

10.6 SENSITIVITY ANALYSIS

Potential cost savings are determined for attainable technology improvements over the minimal technology capabilities forecasted for 1985. Cost savings are not determined for implementing key technologies such as time division multiplexing or ion propulsion capabilities which are available and forecasted to be extensively utilized by 1985. Potential savings are determined for technology improvements of each of the spacecraft subsystems and key earth terminal technologies. Since the available and developing technology is capable of fulfilling the basic communications needs, the sensitivity analysis must be based upon cost savings which improve system cost effectiveness by increasing efficiency, reducing required spacecraft weight, increasing capacity, or providing a direct cost saving.

Generally a technology improvement provides options for reducing spacecraft weight or utilizing weight savings to improve total system capacity and reliability. Figure 7-6, Correlation Between Transportation Costs and Satellite Costs, shows that satellites using the existing booster systems have nearly similar costs per pound of spacecraft weight. The conceptual spacecraft systems formulated for the sensitivity analysis reflect this factor. Technology improvements providing weight savings are considered as providing direct cost savings valued at $22,000 in 1972 dollars per kilogram of weight reduction for each spacecraft of a network. Cost per kilogram is based upon Delta and Atlas/Centaur booster transportation costs. This approach has been taken to prevent complication of the sensitivity analysis which would result from converting weight savings into increased service capacity, and then determining the value due to the increase. Converting weight savings into increased capacity can result in a greater value due to technology improvements but the results are less clear than savings based directly upon weight reduction and an assigned value per kilogram. The conceptual spacecraft can fulfill the 1985 needs through use of numerous dedicated networks of the types defined. By 1985 there may be several dedicated video networks of the type defined in Table 10-13 for separate needs such as Education Television, Biomedical Communications Networks, Teleconferencing, and Public Service Broadcasting.

Technology improvement is primarily motivated by potential cost reduction if the basic functional requirements can be met. Therefore technology improvements are evaluated for providing cost reductions of components and subsystems, such as transponders.

Several technologies such as data compression are evaluated which provide means for directly increasing spacecraft capacity. Such technologies are evaluated on the basis of increased communications capacity per spacecraft, and savings are based upon the numbers or portions of a spacecraft of the network which could be eliminated. Where transponders can be eliminated, savings are based upon the cost per transponder and associated support equipment for each of the spacecraft of a network as presented in par. 10.1.3 defining the cost model used for the conceptual spacecraft.

10.6.1 Summary of Savings From Technology Improvement, Delta-Launched Spacecraft

Table 10-14 summarizes the potential savings due to possible technology improvements of each subsystem and key earth terminal components for each of the seven different types of networks. Values listed are savings obtainable by reduction of the total systems costs presented in Table 10-13 for each type of dedicated network. Savings for a particular type of network are dependent upon the total number of spacecraft or earth stations listed for providing the required services. Each kilogram of weight savings for example is multiplied by $22,000 per kilogram to provide the savings value per spacecraft due to reduced booster costs. Total savings due to weight reduction, reduction of subsystem costs and savings due to capacity improvement are added together and then multiplied by the number of spacecraft for one network to give the savings per subsystem listed in Table 10-14.

10.6.2 Effect of Booster Cost On Cost Savings

The conceptual spacecraft are based on use of the Delta booster to provide continuity between the baseline 1975 era systems defined in Table 10-12, and historic trend data.

Table 10-14

SUMMARY OF POTENTIAL SAVINGS

(IN MILLIONS FOR 1985 ERA SATELLITES)

SPACECRAFT	VIDEO	COMM CARRIER DIGITAL AND VOICE	HIGH SPEED DATA	EARTH VEHICLE VOICE AND DATA	AEROSAT AND MARINE	SPACE TRACKING DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR AND TEST	TOTAL
TRANSPONDERS	16	21	21	16	6	10	4	13	107
ANTENNAS	20	37	37	25	25	10	0	8	162
POWER	9	7	7	9	4	3	2	2	43
STABILIZATION	2	3	3	3	2	3	2	2	20
PROPULSION*	3.3	2.5	2.5	3.3	2.0	3.0	2.3	1.5	20.4
STRUCTURES AND THERMAL	2.2	2.3	2.3	2.3	1.7	2.3	1.0	1.2	15.3
COMMAND AND TELEMETRY	1.2	1.8	1.8	1.2	0.9	1.2	0.9	0.9	9.9
EARTH TERMINAL									
ANTENNAS	10	4	4	100	100	0	0	0	218
DATA COMPRESSION	30	20	0	0	0	0	0	0	50
TOTAL	93.7	98.6	78.6	159.8	141.6	32.5	12.2	28.6	645.6

*BASED UPON OPERATIONAL USE OF ION PROPULSION BEFORE 1980.

The $22,000 boost vehicle cost per kilogram of spacecraft weight would also hold true if the Atlas/Centaur or Titan III C boosters were used for the conceptual spacecraft due to factors presented in par. 7.2.3. Correlation between transportation and satellite costs show that costs for developing and producing spacecraft are partially related to booster costs per kilogram placed in orbit for a Delta, Atlas/Centaur or Titan III C booster. The cost per transponder on orbit is reduced as the booster size and spacecraft weight increase because many elements of spacecraft cost such as attitude control costs, systems management, and testing do not increase proportionately with the numbers of transponders per satellite. This fact is reflected in the cost model, reference par. 10.1.3.

10.6.3 Effect of Shuttle/Tug on Cost Savings From Technology Improvement

The cost savings listed in Table 10-14 for technology improvement for spacecraft using Delta boosters must be reduced if Shuttle/Tug is used due to reduced transportation costs $6,500 per kilogram placed in synchronous orbit. Changing the conceptual spacecraft from a Delta to Shuttle launched vehicle will cause an estimated 20 percent to 30 percent reduction of total spacecraft recurring and non-recurring cost and a 50 percent increase in total spacecraft weight. Savings due to technology improvement and use of the Shuttle/Tug transportation are based upon all of the same criteria as for Delta launched spacecraft, only the value per kilogram of weight savings is reduced from $22,000 to $6,500.

10.6.4 Impact of Space Shuttle/Tug on Systems Costs

The expected impact of using Space Shuttle/Tug upon the cost of the conceptual spacecraft of Table 10-13 is due to a reduction of conceptual spacecraft launch costs to $6,500 per kilogram plus a 20 percent reduction of total spacecraft costs and 50 percent weight increase. These differences will provide the following cost savings per network for each type of service.

Video Networks	$ 83 Million
Common Carrier	$119 Million
High Speed Data	$119 Million
State and Earth Vehicles	$ 83 Million
Aerosat and Marine	$ 56 Million
Tracking and Data Relay	$ 72 Million
Earth Resources Data Collection	$ 56 Million
RF Environment Monitoring and Test	$ 62 Million
Total Savings	$650 Million

These savings are based upon nearly 100 percent utilization of the Shuttle/Tug capacity to inject multiple spacecraft into orbit at a transportation cost of $6,500 per kilogram, or 50 percent utilization of capacity capability at a $3,250 cost per kilogram. On the basis of these estimates, the Shuttle/Tug system will provide greater potential cost savings than the technology improvements summarized in Table 10-14. These savings are attainable without modularized spacecraft designs, use of on-orbit refurbishment and without use of technologies other than those forecasted to be developed by 1985. The Shuttle provides an average savings of $15 million per spacecraft. Six million of the savings is due to the 8-percent cost or interest for money invested in a spacecraft.

Table 10-15

TRANSPONDER TECHNOLGOY SAVINGS

(IN MILLIONS FOR 1985 ERA SATELLITES)

	VIDEO NETWORKS	DIGITAL AND VOICE NETWORKS	HIGH SPEED DATA NETWORKS	EARTH VEHICLES	AERO-NAUTICAL AND MARINE	SPACE TRACKING DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR	TOTAL
IMPROVE EFFICIENCY	7.8	6.0	6.0	8.0	1.5	1.0	0.6	0.8	31.7
REDUCE WEIGHT 20 PERCENT	3.2	4.2	4.2	3.0	2.5	2.5	2.2	2.4	24.2
REDUCE COSTS 20 PERCENT	4.5	10.6	10.6	5.0	1.6	6.0	1.2	9.8	49.7
TOTAL	15.5	20.8	20.8	16.0	5.6	9.5	4.0	3.0	105.6

10.6.5 Spacecraft Transponder Technology

Table 10-15 summarizes the cost savings due to technology improvements to increase transponder efficiency 10 percent, reduce weight by 20 percent, and reduce costs 20 percent. The incremental 10 percent improvement in efficiency amounts to increasing a 30 percent overall DC power to RF power conversion efficiency to 40 percent efficiency. Minor improvements are possible for aeronautical and marine satellites, and earth resources data collection satellites, because the conceptual designs are based upon use of all solid-state transponders. Significant savings may be realized by development of solid-state 12 GHz transponders for video, digital and voice common carrier, and high-speed data networks. Present traveling wave tube amplifiers have approximately a 15 percent power loss due to the required high voltage regulated power supply, which could be reduced if a suitable solid-state transponder is developed.

10.6.5.1 Potential savings from transponder technology improvement for television satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (+10 percent)	1.3	60	7.8
Weight (20 percent)	0.54	24	3.2
Cost (20 percent)	0.75		4.5
		Total	15.5

The transponders require 60 to 85 percent of the satellite power. Increasing end-to-end transponder efficiency from 30 percent to 40 percent would reduce total required satellite power by 25 percent for a 2.0 kilowatt satellite with 30 transponders. Satellite weight could be reduced 16 percent or total cost reduced by some 6 percent. Capacity could be increased by 15 percent at a slight increase in total cost. The net result of increasing capacity is about 15 percent improvement in total space segment cost effectiveness ratio of capacity to cost. This level of improvement is worth $12 million dollars in cost savings for a six vehicle program. The trend of technology development indicates that it will be possible to develop 4 GHz solid state transponders with 40 percent to 50 percent end-to-end efficiencies by 1980. Development work toward this end is being conducted in industry. A 12 GHz all solid-state transponder may be developed before 1985 but the overall efficiency is in doubt. The need is for better efficiency and increased reliability with low distortion and weight. These are the important factors rather than whether achieved by means of tubes or solid-state devices. Adequate reliability is attainable with present technology. The potential benefits and cost savings due to increased efficiency and reduced weight justify some development effort.

10.6.5.2 Potential savings from transponder technology improvement for common carrier and high speed data networks.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (10 percent)	1.0	95	6.0
Weight (20 percent)	0.7	32	4.2
Cost (20 percent)	1.8		10.6
		Total	20.8

The common carrier and high-speed data network satellites of the 1985 era will be more sensitive to improved antennas and switching and much less sensitive to transponder efficiency. Satellite cost effectiveness and capacity will be improved by utilization of spot beams between the limited number of high capacity earth stations. Spacecraft power required per data bit transmitted will be reduced. Universal use of all digital PCM channels and time division multiplexing will reduce intermodulation distortion effects and improve transponder and multiple access operation. Transponder weight could account for one third of total satellite weight and half of the system cost by 1985. There has been a 4 to 1 reduction of effective transponder weight over the past five years. The trend of technology development indicates, therefore, that lighter-weight transponders will be developed.

Total cost savings are based on transponder improvement of: efficiency, weight reduction, operating characteristics and cost. Present capabilities of traveling wave tubes appear adequate for meeting future power level, bandwidth and frequency requirements. Experimental transponders have been assembled and tested to prove the feasibility of utilizing the 20 GHz and 30 GHz frequencies.

A 10 percent improvement in efficiency could provide a 13 percent increase in satellite capacity. The cost of six additional transponders consumes a part of the value of increased capacity. Providing more power per transponder due to increased efficiency, and increasing bandwidth per transponder provides a 13 percent increase in capacity valued at some $15 million. The 13 percent increase in capacity could be attained by increasing the power system by some 200 watts and increasing the power capacity and bandwidth of the transponders. Common carrier and high-speed data network satellites become less sensitive to transponder technology improvements to increase efficiency as narrower antenna beams reduce RF power output requirements and improved power systems reduce the weight required and cost per watt of primary power.

10.6.5.3 Potential savings from transponder technology improvement for earth vehicle communications and state communications satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (+10 percent)	1.6	73	8
Weight (20 percent)	0.6	27	3
Cost (20 percent)	1.0		5
		Total	16

If such services are provided for state-wide communications networks operating at 20 GHz and 43 GHz, transponder efficiency will be important to conserve primary satellite power and provide adequate power for reliable service with low cost earth terminals. The conceptual satellite is similar to the video satellites due to the required power per transponder and providing video services for a state. Earth coverage per transponder is limited to a 200 to 400 mile radius through use of spot beams. The cost savings are based upon the use of four satellites, each having 25 transponders with an average of 15 watts radiated power. Total savings are based upon a program using 5 spacecraft.

10.6.5.4 Potential savings from transponder technology improvement for aeronautical/marine satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (+10 percent)	0.3	14	1.5
Weight (20 percent)	0.5	25	2.5
Cost (20 percent)	0.35		1.6
		Total	5.6

An adequate aeronautical/marine satellite system can be developed with available technology as shown by the ATS-F satellite PLACE experiment equipment and present plans for maritime satellites by the U.S. Navy. The conceptual system is based on all solid-state transponders with a 50 percent end-to-end efficiency. Higher efficiency would allow increased capacity. But, with directional aircraft and ship antennas, capacity will be more limited by available frequency and use of spot beams than by satellite capacity. Transponder weight is not a major problem and will be less critical with the Space Shuttle. Total transponder cost is not a major factor and accounts for only 20 percent of allocated spacecraft cost. Maximum savings are based upon a 5 spacecraft program.

10.6.5.5 Potential savings from transponder technology improvement for tracking data relay satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (+10 percent)	0.2	9	1.0
Weight (20 percent)	0.5	25	2.5
Cost (20 percent)	1.2		6.0
		Total	9.5

The 1985 conceptual satellite is expected to use about 75 percent of the available primary power output for powering transponders. Use of high frequencies such as 8 GHz, 54.8 to 58.2 GHz, and 21.2 to 22.0 GHz are expected to result in an average power conversion efficiency of 30 percent or less. A 10 percent improvement in efficiency would be worth one million dollars for a program having 5 spacecraft. This value is not based upon improvement in satellite communications capacity or increased operational reliability. If the 20 transponder capacity is fully adequate and no additional capacity is required, then the efficiency improvement is worth about $200,000 per spacecraft or $1.0 million in program cost savings due to reduce spacecraft weight and power requirements. Reduced costs for the power subsystem are due to a 100 watt reduction in required satellite power.

10.6.5.6 Potential savings due to transponder technology improvement for earth resources data collection

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (10 percent)	0.15	7	0.6
Weight (20 percent)	0.55	25	2.2
Cost (20 percent)	0.3		1.2
		Total	4.0

The Earth Resources Data Collection Satellite collects low-speed data from balloons, ocean buoys and earth-mounted data platforms. The 200 BPs data rate and allocated frequencies are such that available all solid-state transponders can be utilized. Only minor improvement in effectiveness or cost reduction can be obtained by means of improved transponder technology.

10.6.5.7 Potential savings due to transponder technology improvement for RF environment monitoring and test satellite.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Efficiency (+10 percent)	0.2	9	0.8
Weight (20 percent)	0.6	27	2.4
Cost (20 percent)	2.4		9.8
		Total	13.0

The RF Environment Monitoring and Test Satellite is similar to the Tracking and Data Relay Satellite. Each has 20 transponders with transponders operating in the VHF, UHF, and SHF frequencies. The spacecraft receivers detect RF environment conditions and collect data. The T&DR satellite collects and relays data from orbital spacecraft. The major differences are in receivers, bandwidths, and directions of communications. An adequate technology base is available for development of an effective RF Environment Monitoring and Test Satellite. Low-noise, uncooled receiver technology is important for increasing satellite sensitivity or reducing antenna requirements.

10.6.6 Antenna Technology

Table 10-16 summarizes the attainable savings from spacecraft antenna technology improvement.

Table 10-16

ANTENNA TECHNOLOGY SAVINGS

(IN MILLIONS FOR 1985 ERA SATELLITES)

	VIDEO	DIGITAL AND VOICE	HIGH SPEED DATA	MOBILE VOICE AND DATA	AERO-NAUTICAL AND MARINE	SPACE TRACKING AND DATA RELAY	EARTH RE-SOURCES DATA COLL	RF ENVIR MONITOR	TO AL
SHAPED BEAMS	5	4	4	5	5	-	-	-	23
REDUCE SIDE LOBES	7.8	3	3	20	20	-	-	-	54
SWITCHED OR STEERED MULTIPLE BEAMS	7.2	30	30	-	-	10	-	8	85
TOTAL	20	37	37	25	25	10	-	8	162

10.6.6.1 Potential savings from antenna technology improvement for television satellites.

Technology Parameters	Value of Increased Capacity $M	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Reduced Earth Sta. Cost $M	Maximum Savings Per Network $M
Shaped beams				5	5.0
Reduced Side Lobes		1.3	60		7.8
Switched or Steered Multiple Beams	1.2	0.5	23		7.2
				Total	20.0

Savings from use of shaped beams are based on a $10,000 saving for each of 500 earth stations located in the fringe areas of antenna coverage. Shaped beams will distribute power and gain to minimize overall system cost by providing gain and power where it will be most needed. Shaping of beams should also act to limit interference between beams.

Reduced side lobes are needed to limit interference between spot beams and facilitate frequency reuse. Greater reuse capability will allow greater use of the lower frequencies, which require less power and weight, per channel. For the same area coverage and user antenna diameter, the 11 GHz frequencies generally require twice as much power as the 4 GHz frequency; this is due to rain attenuation. The total power for the conceptual satellite system could be reduced an estimated 25 percent or 500 watts. A savings of $1.3 million per satellite or $7.8 million for six satellites would be possible by reducing the required power plus other savings. The reuse of low frequency and width of orbit shots as the RF frequencies become crowded will depend upon side lobe characteristics.

Switched or steerable multiple beam antennas will allow selective illumination of regions and provide increased operational flexibility. Channels could be switched from one area to another, or shared. Also, spot beams could be used to increase radiated power to regions suffering signal degradation due to local weather conditions. Such modes of operation and increased flexibility are estimated to be capable of increasing the network utilization of available channels by 5 percent and possibly reducing the power required for frequencies above 10 GHz by 50 percent.

10.6.6.2 Potential savings from antenna technology improvements for common carrier and high-speed data networks.

Technology Parameters	Value of Increased Capacity $M	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Reduced Earth Sta. Cost $M	Maximum Savings Per Network $M
Shaped Beams Improve beam isolation				4	4
Reduced Side Lobes		0.5	23		3
Switched or Steered Multiple Beams	5	5.0			30
				Total	37

Shaped beams for covering large areas will help rural users and small networks by improved distribution of EIRP to aid small and medium-sized earth stations with weather attenuation problems or lying on the edge of the beam and having a low elevation angle. Shaped beam techniques can be used to modify spot beams so that adjacent areas can operate through a common transponder and spot beam.

Services can be improved by providing beams that cover the limited or irregular area of interest with improved energy distribution. Beams covering only the prime computer utilization areas of a region, such as the Los Angeles basin and the San Francisco bay area, are typical of the advantages of shaped beams. Such types of shaped beams will reduce the beam-to-beam switching load. Ground station costs will be reduced 5 percent with an additional savings in maintenance costs amounting to 2 percent of total operating and maintenance costs.

Beam switching will allow satellite time-division multiplexing of high bit rate data streams between multiple spot beams. The mode of operation and the types of antennas utilized would be as described in par. 11.2, Satellite Antennas, and 11.5, Satellite Beam or Transponder Switching. Switching satellite beams between transponders or time-division switching of received data between transponders can conserve satellite power by allowing better use of transponders and greater system flexibility.

An estimated 20 improvements in satellite capacity should be possible by means of high speed switching of transponders or beams and improved multiple beam antennas providing several spot beams. Each beam should be capable of being steered or switched to alternate orientations to meet changing traffic patterns.

Antenna weight will be important for systems with large antennas and multiple spot beams. Antenna weight may consume 10 percent of the total satellite weight. Multiple spot beams are one of the most effective means of reducing required transponder and earth station power, as shown by the link calculation. Lighter-weight multiple-beam antennas are being developed.

Improved lens antennas with high gains, sharper beams, and low side lobes will permit further reductions in satellite transponder power. Improved side lobe suppression and increased beam isolation will increase capacity by allowing greater reuse of lower frequencies by satellites. Such reuse of low frequencies below 20 GHz is important to conserve satellite power and limit outage caused by weather conditions. An estimated saving of $0.5 million per spacecraft is possible through allowing a 30 percent greater use of lower frequencies due to improved antennas with lower side lobes.

10.6.6.3 Potential savings from antenna technology improvement for aeronautical maritime satellites

Technology Parameters	Value of Increased Capacity $M	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Shaped Beams		1.0	45	5
Reduced Side Lobes	4			20
Switched or Steered Multiple Beams				
			Total	25

Shaped beams and reduced side lobes will allow increased reuse of the allocated VHF and 1.550 MHz L-Band frequencies. Shaped beams will allow selective coverage of aircraft flight routes and shipping lanes. One large satellite can provide multiple area coverage and allow reuse of frequencies. Otherwise, several widely separated satellites will be required and highly directional earth-vehicle antennas will be required to allow communication through one satellite without interference from other satellites operating at the same frequencies.

Only the allocated VHF and 1550 MHz L-Band frequencies ensure all weather operation. The 43 GHz frequency band, for example, can have a rain attenuation on the order of 60 dB. The 15 GHz frequencies can have on the order of 20 dB attenuation during heavy storm conditions. Reuse of the 1550 MHz frequencies is vital to ensuring adequate all-weather communications capability for ships and aircraft. A possible $30 million saving which is not tabulated is based upon satellite cost savings due to being able to double the satellite all-weather capacity by means of frequency reuse, and reduced power per channel due to use of area coverage patterns.

The factors affecting aeronautical and maritime satellites also affect earth vehicles. Shaped beams are needed to provide uniform service to states such as California, Texas, and Florida with irregular shape. Reduced side lobes will allow extensive reuse of frequencies near 12 GHz and 20 GHz rather than force use of 40 GHz frequencies.

10.6.6.4 Potential savings from antenna technology improvement for tracking and data relay satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Shaped Beams			
Reduced Side Lobes			
Switched or Steered Multiple Beam Antenna	2.0	90	10
		Total	10

The conceptual satellite is based on use of switched or steered beams for tracking manned space stations and the Space Shuttle vehicle. Only slow-speed beam steering or switching from spot beam to spot beam is required. It appears that adequate technology is being developed for meeting the future requirements for tracking and data relay support of small satellites. Reliable high frequency, high data rate satellite-to-earth links can best be provided by means of space diversified earth stations to reduce satellite power required. Available technology can provide adequate 40 GHz satellite antennas and transponders. Savings are based upon improved multiple beam antennas with individual beam steering or switching to save spacecraft weight.

10.6.6.5 Potential savings from antenna technology improvement for earth resources data collection.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Shaped Beams			
Reduced Side Lobes			
Switched Multiple Beams			
		Total	-0-

The present technology is capable of meeting the needs for Earth Resources Data Collection Satellites. There is adequate bandwidth available to meet needs and communications requirements of such systems, which would collect low speed data (about 200 BPS) from balloons, ocean buoys, and earth data platforms.

10.6.6.6 Potential savings from antenna technology improvement for RF environment monitoring and test satellite.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Shaped Beams			
Reduced Side Lobes			
Switched or Steered Multiple Beams	2	90	8
		Total	8

A single antenna capable of providing switched or steered multiple beams at different frequencies will allow weight savings estimated at 90 kg. The total savings for a four satellite program is $8 million.

10.6.7 Power Subsystem Technology

The power subsystems of each of the conceptual spacecrafts are similar. Each subsystem is sized to provide the required total power during periods of solar illumination and solar occultation which occurs at local midnight during a 44-day period about the Vernal equinox, and for a 44-day period about the Autumnal equinox. Occultation lasts for a maximum of 72 minutes during which the satellite is within the shadow of the earth. Requirements for satellite communications between 23:30 to 00:30 at the satellite location strongly affect the required battery capacity. Therefore, satellites requiring full operation and having power requirements of several kilowatts or more will be most sensitive to improvements of battery technology.

Spinning satellites are quite competitive with three axis-stabilized satellites having sun tracking array at power levels below 1 Kw. Spinning satellites are limited in power by the diameter and length of the spinning drum which can be accommodated by the launch vehicle and will be stable on orbit. A 10 ft diameter by 10 ft length drum, providing on the order of 1 Kw, is the practical power limit for simple spinning satellite configurations. Spinners also require about three times more solar cells for the same power output, due to part of the drum always being shaded. The conceptual spacecraft configurations and technology improvements are based upon three-axis oriented satellites with sun tracking solar arrays, which can most efficiently provide from 1 to 10 Kw of power. The most important power subsystem technologies for spinning satellites are solar cell efficiency improvements to increase the total available power and reduced battery weight per kilowatt-hour in order to reduce total spacecraft weight.

10.6.7.1 Potential savings from power subsystem technology improvement for television and earth vehicle communications.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Cost (20 percent)	0.5		3.0
Weight (20 percent)	0.46	44	6.0
		Total	9.0

The trend of technology development is expected to provide solar array and battery systems weighing on the order of 200 lb per kilowatt. The power subsystem cost for television satellites is forecasted to contribute less than 20 percent of total satellite program costs allocated for providing subsystems. The present trend of development should continue, with effort directed to increasing solar cell efficiency, reducing solar array weight, and lowering cost per watt. Battery weight is expected to be reduced from 1 pound per 10 watt-hours to 1 pound per 35 watt-hours. Subsystem distribution and control weight will be reduced by increased application of integrated circuitry technology and advancements in solid-state technology. Cabling weight will be reduced by development of improved cables, such as flat printed circuit cables, and reducing cabling requirements through greater use of integrated design, thereby reducing satellite weight. Command and telemetry cabling will be reduced by greater use of digital technology, with remote encoders and decoders designed into such integrated subsystem components as transponder modules and attitude stabilization and power subsystem control modules. Power cabling weight will be reduced through distribution on a common semiregulated voltage.

Most subsystems and major components will use separate integrated circuit power regulation modules to better regulate voltages and frequency at the point of use and to aid in the control of electromagnetic interference.

10.6.7.2 Potential savings from power subsystem technology improvement for domestic common carrier, high-speed data networks.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Cost (20 percent)	0.6		3.7
Weight (20 percent)	0.46	21	3.0
		Total	6.7

The power subsystem accounts for 22 percent of satellite weight for a 48-transponder-channel common-carrier satellite. The spacecraft has approximately 1-kilowatt of primary power and about 50 percent operating capacity during solar occultation, although a companion satellite could carry full load when one satellite is in the earth's shadow. The spacecraft is about 30 percent less sensitive to power subsystem performance than the video service satellites. Therefore, the available and developing technology will sufficiently meet mission requirements.

10.6.7.3 Potential savings from power subsystem technology improvement for aeronautical/maritime satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Cost (20 percent)	0.33		1.7
Weight (20 percent)	0.46	21	2.3
		Total	4.0

10.6.7.4 Potential savings from power subsystems technology improvements for tracking and data relay satellites.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Cost (20 percent)	0.5		2.0
Weight (20 percent)	0.3	14	1.2
		Total	3.2

10.6.7.5 Potential savings from power subsystem technology improvement for earth resources data collection satellite.

Technology Parameters	Reduce Sat. Cost $M	Reduce Sat. Weight kg	Maximum Savings Per Network $M
Cost (20 percent)	0.5		1.0
Weight (20 percent)	0.2	9	0.8
		Total	1.8

Each of these satellites has similar power subsystem requirements. The 1985 conceptual satellites require 400 watts. The power subsystems should consume less than 15 percent of total satellite weight, and less than 11 percent of total program cost. These types of satellites are less sensitive to power subsystem technology improvements than the common carrier, high-speed data relay, and aeronautical/ marine satellites.

10.6.8 Stabilization Subsystem Technology

Cost savings presented in Table 10-15 are based upon a 20 percent reduction in weight and cost for each conceptual spacecraft's attitude control subsystem. Differences in savings are due to varying accuracy of attitude required for each type of spacecraft. The most accurate requirements are for high-speed data relay satellites.

10.6.9 On-orbit Propulsion Subsystem Technology

Cost savings presented in Table 10-15 were derived on the basis of a 20 percent reduction in weight and cost of the on-orbit ion propulsion subsystem. Differences in potential savings are due to varying requirements. The greatest savings are possible for the video service satellites which require the most accurate stationkeeping.

10.6.10 Structure and Thermal Control Subsystem Technology

Cost savings presented in Table 10-15 are based upon possible technology improvements to effect a 20 percent reduction of weight and a 20 percent reduction of subsystem costs.

The percentage of structural and thermal control weight (for the 1975 era) spacecraft can be reduced more by lessening ascent loads imposed by high thrust level solid propellant rocket motors than by development of a 20 percent higher strength structural material, or improved thermal insulation, or conducting material. Use of Space Shuttle should therefore allow a significant reduction of structural and thermal control cost and weight. A major portion of present satellite thermal control weight and cost is required to provide the thermal control of the apogee rocket motor during up to 96 hours of transfer orbit time, and to protect the satellite during and immediately after rocket motor firing. The apogee motor also induces high stress loads due to the high thrust and G loads. Space Shuttle, by reducing orbit transportation costs per pound, reducing loads, and providing increased volume during ascent can allow a greater cost savings for structures and thermal control than is believed obtainable by attempts to improve basic structural and thermal control technology.

Structures and thermal control costs can also be effectively reduced by development of a common communications base structure which has a standard Space Shuttle interface and can be easily modified for use with numerous possible communications payload modules for various types of missions. Such a structure would be designed for a range of solar array and battery modules ranging from one to about six kilowatts end-of-life power capability. Development of such a structure should be a normal communication satellite program development function.

10.6.11 Command Telemetry Technology

Cost savings presented in Table 10-15 are based upon a 70 percent reduction of subsystem cost and weight.

The present command and telemetry technology is capable of meeting the requirements for 1985 era communications satellites. The trend of technology is such that by 1985 command and telemetry will require only 3 percent or less of satellite weight and require only 5 percent to 8 percent of the total program allocated costs for spacecraft development and assembly subsystems.

10.6.12 Earth Terminal Technologies

Earth terminal costs are generally less sensitive to technology improvement than spacecraft, for several reasons. There is essentially no weight penalty for equipment or antennas except for aircraft, ships, and land vehicle. Link calculations show that 5 and 11 meter antennas are adequate for many networks. Therefore cost savings must be based upon increasing service capacity with a given satellite system, or reducing earth station operating or equipment costs. Earth station operating costs are fairly insensitive to transmitter and receiver power requirements. Except for mobile and earth resources data terminals, power can be inexpensively purchased from local power companies. Therefore, there is little point in increasing transnsmitter efficiency from 30 percent to 40 percent, even for most mobile users. An effective means of reducing power requirements for mobile and earth resources data terminals is to reduce the required RF bandwidth, use modulation which provides a significant signal-to-noise ratio improvement factor, and utilize as high a gain transmitting antenna as practically possible.

Available commercial quality equipment technology can easily meet the requirements for earth terminal transmitters, receivers, digital encoders, and decoders, demodulators, and other such equipment. Figure 8-12 indicates the growing use of radio communications which is driving the commercial development of technologies which can be almost directly applied to communications satellite earth terminals. Present crowding of terrestrial communications frequencies is stimulating the development of technology for transmitting voice and data over narrower bandwidths with improved resistance to interference.

10.6.12.1 Potential savings from earth station technology improvement for television satellites.

Technology Parameters	Savings Per Network $M
Low cost Steered Beam	6
Steered or Switched Multiple Beam Antenna	4
Data Compression	30

A low cost steered beam antenna within the price allocated for ground station antennas could save some $6 million by reducing the need for accurate satellite stationkeeping. Multiple steered beams would not only eliminate the need for accurate stationkeeping, but would eliminate the need for alternate antennas for access to a second or third satellite.

The development of data compression electronics costing on the order of $50,000 and capable of a 4:1 compression of ten video channels covered effect a $70 million reduction in the network cost by elimination of 3 of the 5 satellites. The net savings after investment and maintenance of compression electronics would be on the order of $30 million. If the cost per earth station were $100,000 for compression electronics, there would be no significant savings.

10.6.12.2 Potential savings from earth station technology improvements for common carrier and high speed data network satellites.

Technology Parameters	Savings Per Network $M
Low Cost Steered Beam	
Switched Multiple Beams Antenna	4
Data Compression	20*

*Not applicable to data networks due to present data compression capabilities

Cost savings are based upon eliminating the need for a second antenna by use of multiple steered beams. Common carrier and data network satellites will require accurate stationkeeping to insure optimum global coverage. Savings due to data compression are based upon a demand for 500 video channels, and a network with 50 earth terminals having an equipment investment of $100,000 per earth station plus a 15 percent year cost for maintenance.

10.6.12.3 Potential savings from earth station technology improvements for earth vehicle, aerosat, and marine network.

Technology Parameters	Savings Per Network $M
Low Cost Steered Beam Antennas	100
Steered Multiple Beams	
Data Compression	

The service is not feasible by use of the allocated 43 GHz frequency band without a steered or switched beam antenna capable of locking onto or autotracking the satellite. The capacity of the conceptual spacecraft L-Band frequencies can be increased by a factor of three with a slight increase in spacecraft cost and weight, due to allowing greater frequency reuse and less power per voice/data channel. Therefore, a savings of $100 million is possible by use of 5 satellites with earth vehicle steered beam antennas to provide the same capacity as 20 satellites if omnidirectional earth vehicle antennas are used.

Present commercial quality equipment technology is adequate for the earth vehicle terminal transmitters, receivers, and ancillary equipment.

10.6.12.4 Potential savings from user terminal technology improvement for tracking and data relay satellite systems. The potential savings are essentially zero because available technology is adequate. The use of data compression could allow a reduction of transponders, but such transponders should be retained for backup operation or to allow increased capacity if needed. Earth station antennas, receivers, and spacecraft command and telemetry hardware will be similar to that required for the RF monitor and test satellite earth stations. Space Tracking and Data Relay satellite earth stations will require numerous transmitters that can be developed with existing technology. Further rationale for a zero cost savings is presented in par. 10.6.12.6.

10.6.12.5 Potential savings from earth station improvement for earth resources data collection satellites. Available technology is adequate for the needs of low-speed earth resources data collection satellite earth stations. Future improvements in low cost printed circuit antenna technology, large scale integration, and integrated miniaturized solid-state transmitters and receivers will substantially reduce the costs for small autonomous earth resources data collection stations. Future improvements in slow-scan video and data compression will make remote environment viewing practical and cost effective. Continued cost reductions of solar cells and rechargeable batteries will provide lower cost, non-polluting power sources which will not disturb the environment. Low cost earth repeater stations will allow formation of repeater grids for determining location and status of animals within cells of the grid pattern. It will be possible to implant devices within animals which will relay data several miles in a low electron-magnetic noise environment to several relay stations for data recording and transmittal to the relay satellite. The expected savings due to special stimulation of the developing commercial and aerospace technology is therefore essentially zero.

10.6.12.6 Potential savings from RF environment monitoring and test satellite. The satellite will monitor the environment and carry test devices for communications and navigation satellite system development. The one or two required earth stations will be similar to the Space Tracking and Data Relay satellites. Present technology is adequate for the earth station requirements. Technology growth will further reduce earth costs. Technology stimulation can not provide significant savings due to weight savings for earth station equipment, or justify special development cost to reduce the equipment costs for several earth stations. Therefore, the expected savings due to technology stimulation or special development efforts are minor. Cost saving developments will be performed by component suppliers forced to reduce costs or improve equipment in order to survive in a competitive market.

Section 11
OPTIONS FOR STIMULATION OF TECHNOLOGY GROWTH

In forecasting the future trends of technology growth, the options presented in this section for stimulation of technology became apparent. These options are in general agreement with the results of the sensitivity analysis, because the forecasts of technology growth, the sensitivity analysis, and the options are based on technical and functional needs for fulfilling future demands for communications services. The options are broader in scope than the plans and recommendations resulting from the sensitivity analysis, because the options are derived primarily on the basis of what could be done to improve each important technology parameter or subsystem. Options derived in this manner represent a "wish list" of the technical possibilities of importance for designing and developing improved operational spacecraft for future communications satellite networks. The trends of space technology growth do not necessarily conform to the ideal or wished-for growth trends that would be of most benefit to a particular application of the technology. Technology growth is the result of multiple efforts directed toward the achievement of different objectives by the various funding groups. The options therefore represent the desired general direction of future development independent of other applications.

11.1 SATELLITE RF POWER GENERATION

Possible areas in which to stimulate development are indicated in the link calculations and the basic network constraints. One important need is to generate some 10 to 20 watts of power at as high an efficiency as possible. It is also desirable to have an all-solid-state transmitter. Figure 6-12 shows that at present or in the near future the required power for each of the frequency bands can be generated with reasonable efficiency by a traveling wave tube. The ability to meet the satellite requirements with solid-state devices varies considerably. It appears that the transistor will be able to meet the requirements at 4 GHz in the 1977-1979 time frame with normal growth, but will be unable to meet the requirement at the higher frequencies.

The IMPATT should meet the requirement at 4 GHz in the 1976-1978 time frame, at 11 GHz in the 1978-1980 time frame, and at 20 GHz in the 1981-1988 time frame, all at an efficiency of 24 to 35 percent.

Since the 4 GHz band does not offer a significant prospect of allowing additional growth in the future, it does not appear prudent to stimulate developmental work at this frequency, particularly since normal growth will probably fulfill the needs. Since an all-solid-state transmitter is an important objective, stimulation of development of solid-state devices at 11 and 20 GHz, particularly from the standpoint of efficiency improvement, is recommended. Not only would both areas benefit from this stimulation, but potential benefits would also be applicable to other uses. It is recommended that the stimulus be moderate, since a backup in the form of the TWT will be available.

11.2 SATELLITE ANTENNAS

A requirement for some systems is the generation, from a limited number of physical apertures, of a multiplicity of independently steerable or switchable, narrow-width spot beams with a high degree of interbeam isolation. Such designs are not presently possible except with an unacceptably large number of physical apertures, and it appears unlikely that satisfactory designs will evolve naturally until 1980 at the earliest, and possibly much later.

Improvements are required in beam isolation for the paraboloidal antenna. However, because of the inherent limitations due to aperture blockage and coma, it probably will not be too advantageous to stimulate a capability for this type of antenna. Conversely, the considerably less-mature lens technology, with its potentially greater ability to satisfy developing system requirements, offers a fruitful field for stimulation. Significant advances are required to develop the lens to its fullest capability. The underlying technology of lens design has been quite dormant for the past decade. Excellent design criteria with associated computer design programs are required to minimize the amount of experimental cut-and-try during the design phases of the antenna. Additionally, the availability of suitable artificial dielectrics to use for fabrication is very limited as to types of properties and sources. Artificial dielectrics are required that will have a higher dielectric constant, possess a lower loss factor, and be lighter in weight than those now available. Thus, moderate stimulation of lens design technology and artificial dielectric fabrication capability is recommended to meet system requirements within the anticipated need period.

11.3 SATELLITE RECEIVERS

Comparison of expected technology growth of satellite receiver front ends with the requirements shows that, in general, the requirements will be met reasonably well at reasonable time periods in the future at 6 and 14 GHz. Even at 30 GHz, the state of the art will probably be satisfactory by the time that this band is actively considered for application. Some justification exists for a very small stimulation to improve the technology of parametric amplifiers at this frequency to lower the noise temperature moderately and to increase the bandwidth capability.

11.4 RF SATELLITE ATTITUDE SENSING

A recent study has shown that several methods of RF attitude sensing show promise of providing accuracies considerably better than present-day IR systems and at lower weight, volume, and power and at a higher reliability. It is recommended that RF sensing technologies be moderately stimulated to ensure that improved attitude sensing can be obtained.

11.5 SATELLITE BEAM OR TRANSPONDER SWITCHING

High-speed data networks carrying on the order of 100 MBPS to 1 GBPS of data on multiple narrow beam links can benefit from programmable switching developments. The system would repeatedly switch the bit stream on a beam from an earth station in a properly timed sequence so that packets of data would be switched to the proper transponder or antenna beam serving the area for which the data are addressed. Conceivably, the 22 major metropolitan areas of the nation could be served with a satellite having 22 beams of on the order of 0.5-deg beam width. The earth station in each area could, for example, transmit or receive a gigabit data stream on a 20 GHz frequency. The satellite would require a 10-ft-diameter antenna and 35 watts of radiated power for an average 0.04 percent allowed outage. The ground station would require a 30-ft or larger antenna with a 0.1-deg beam width. A well balanced network could allow a high percentage of effective total link capacity utilization by optimum switching and interleaving of data pockets into the downlinks.

COMSAT Corporation is presently planning experiments with onboard switching. This area of technology is important for trunked digital networks and could be utilized for teleconferencing and distribution of compressed digitized video channels.

11.6 ONBOARD DATA PROCESSING AND MEMORY

Onboard data processing and memory is principally applicable to such user spacecraft as the Earth Resource Satellites, which may need to store and perform preliminary data processing prior to transmittal to an earth station or relay satellite. Data communications between relay satellites will probably require bit error correction checking or correcting of codes and onboard memories to reduce bit errors.

11.7 SATELLITE-TO-SATELLITE COMMUNICATIONS

The large demand for satellite communications will initially saturate the 4/6-GHz bands and then the 12/14-GHz bands. Use of the 20-GHz band presents problems associated with rain attenuation. The reuse of frequencies is limited because of the spacing required between satellites to minimize interference and the restricted longitudinal arc along the equator from which a satellite can service all 50 states. This usable synchronous equatorial orbit length can be expanded and, consequently, the reuse of frequencies can be increased by use of pairs of satellites with satellite-to-satellite communications capability. The satellite would be positioned beyond the two ends of the zone for single-satellite coverage of the 50 states. The satellite-to-satellite communications would aid in allowing the two satellites to function essentially as a single system for missions such as elementary school video distribution and air traffic control. The satellite-to-satellite communications link would eliminate the need for the transfer of data between satellites through an earth relay station and, consequently, conserve allocated satellite-to-earth frequencies.

Such a system could enhance network performance by providing better coverage of such areas as Alaska and New England, which tend to be on the fringes of single-satellite coverage.

Satellite-to-satellite communications will also be of benefit for global networks services such as air traffic control, marine communications, NASA space operations, and United Nations communication.

Development of satellite-to-satellite communications should be stimulated before the 12/14-GHz bands are saturated and all orbit slots for 4/6 GHz and 12/14 GHz fully allocated.

11.8 EARTH STATION RF POWER GENERATION

Vacuum tube technology for earth station RF power generation needs no significant advancement from that available today, as long as operation is on the basis of one RF channel of moderate bandwidth per transmitter. Areas that can benefit from improvement are an increase in the life and reliability of the amplifier and a decrease in the cost, since each earth station usually requires a multiplicity of transmitters.

Consistent with the philosophy of high reliability and low maintenance, stimulation of solid-state technology should be done to increase the likelihood that solid-state devices will replace vacuum tube amplifiers in this application. In addition to stimulation of the growth of the power output capabilities of a single device, attention needs to be given to the multiple operation of such devices with transmission bandwidths sufficient to support future system requirements. The importance of the possibility of very significant gains in the reduction of system costs in this area suggest the appropriateness of strong stimulation of this technology.

11.9 EARTH STATION ANTENNAS

The requirements for earth station antennas are so modest that existing technology is presently adequate to fulfill most system needs from the electromagnetic standpoint. Benefits may be obtained from lighter-weight designs to enable mounting on existing buildings without building design alteration. Also, development of more economical fabrication methods will represent considerable system savings when large numbers of earth stations are employed. Some development effort is needed for low-cost mobile user antennas.

11.10 EARTH STATION RECEIVERS

Available receiver input noise temperatures will meet system requirements adequately. Some increase in bandwidth at 20 GHz would possibly be beneficial. Principal system benefits will accrue from an increase in reliability and a decrease in first cost. The development of improved solid-state pumps for parametric amplifiers would benefit both satellites and earth stations. At most, probably only a very modest stimulation will be required in this area.

11.11 EARTH STATION DATA COMPRESSION

Data compression is important because, as discussed in par. 7.4, a possible 5 to 1 compression of video channels would essentially allow a given satellite's capacity to be increased by a factor of 5. The overall effect is equivalent to having a fivefold increase in satellite efficiency.

The data compression system to use is dependent on the amount of compression obtainable versus the cost of the processing equipment at each earth station. High data compression ratios will probably require digital memories capable of storing two or three video frames so that only differences between frames need be transmitted. Such a system will require a memory of on the order of 10 million bits at each earth terminal. The important technologies to be stimulated are therefore methods of data compression for use with low-cost earth stations, and low-cost memories that are reliable and can operate in a normal room environment.

11.12 SOLAR ARRAYS

Lightweight flexible substrate arrays are being developed and are expected to replace rigid substrate deployed arrays.

The forecasted reduction of solar array nonrecurring or development costs by 1982 is based on:

- Standardization of qualified solar cell design so that no cell development will be required
- Reduction of the cost of development and qualification hardware resulting from reduction in fabrication and component costs

- Qualified array designs with proven thermal cycling capability that will reduce development testing

The predicted reduction of solar array recurring costs is based on:

- Silicon Solar Cell Efficiency. Attainment of beginning-of-life efficiencies up to 22 percent are theoretically possible, but a practical limit of 18 percent is predicted for 1982. This will reduce the number of cells and therefore the cost and weight per watt.
- Radiation Degradation of Cells. The 7-year degradation of present designs is about 25 percent. This value will be halved by 1982 to about 12.5 percent by the addition of dopants to silicon cells or the development of more radiation resistant cells of types other than silicon, such as gallium arsenide.
- Wraparound Contact Cell. Development of backside contact cells should reduce the cost of solar arrays by as much as $30/watt by reducing the complexity of panel assembly.
- Standardization of Solar Cell Specifications. Standardization will reduce the cost of cell manufacture and quality control. The relaxation of cosmetic requirements will increase manufacturing yields. The acceptance of a larger fraction of the manufactured lot at some weight per watt expense will reduce costs.
- Optical Filter. Lower reflectance and higher transmission of antireflection coatings with lower degradation in orbit will increase array output. An improved red filter will produce an 8 percent increase in power output resulting from cell temperature reduction.
- Cell Covers. The development of FEP Teflon or other cell-cover materials will provide less expensive covers than the presently used separately fused silica coverglasses.
- Mechanization of Solar Panel Assembly. The reduction of slow and costly manual fabrication operations by use of automated techniques will reduce array costs.

11.13 BATTERY TECHNOLOGY DEVELOPMENT

Present battery acquisition costs are very sensitive to the specification used, particularly with regard to (1) testing and documentation required during component manufacture and (2) battery testing prior to launch. The present nonrecurring cost of a 1,000 watt-hours Ni-Cd battery is approximately $30,000. Battery system development costs increase with system capacity due to more complex temperature control required in high-power minimum volume systems. Reduction of satellite weight and volume constraints will therefore effect cost savings. The costs are correlated with power to vehicle by assuming present maximum allowable depth of discharge (DOD) to be 50 percent. Each watt supplied to the vehicle during the maximum 1.2 hours of eclipse requires 1.28 watt-hours of power from the battery system to compensate for diode and distribution losses. The battery capacity required at 50 percent DOD is then 2.56 watt-hours per watt to the vehicle. Increasing the allowable depth of discharge could therefore reduce battery costs and weight.

The predicted reduction in battery nonrecurring costs is based on:

- Standardization of battery cell specifications, reducing the need for development tests
- Standardization of battery case design requirements and the establishment of proven thermal control designs

The recurring cost of Ni-Cd batteries is expected to be reduced to $8,000/1,000 watt-hour battery by 1982 due to improvements in:

- Quality Control of Fabrication. Standardization of battery specifications and characterization of important fabrication parameters will improve quality.
- Charge Control. Improved charge control techniques will permit discharges to greater depths, reducing installed capacity and therefore cost. Improved temperature control and the use of third electrodes will increase battery life.
- Battery Testing. The reduction of battery testing, with shipment of the battery direct from the manufacturer to the launch facility, will reduce costs.

The recurring and nonrecurring cost for regenerative fuel cell systems (H_2-O_2) and metal-gas systems presently undergoing technology development are predicted to become competitive with NiCd batteries by 1982.

11.14 SATELLITE STABILIZATION

The most important technology developments for improvement of communications satellite stabilization subsystems are improved attitude sensors and improved momentum wheel control gimbal actuators.

11.15 ON-ORBIT PROPULSION TECHNOLOGY

Improved on-orbit propulsion subsystem equipment and components need to be developed and flight proven to reduce the satellite weight required for accurate stationkeeping. Although ion propulsion is the prime candidate for potential weight reduction, there are numerous other viable candidates that offer promise. Figure 7-26 shows the attainable specific impulse and thrust range of various types of thrusters.

The ideal thruster would be a standardized modular unit containing power conditioning, thrust vector control, command control functions, sequential digital telemetry readout with clock pulse and readout command inputs, and internal propellant tankage. Such a module would be designed to be mounted on the spacecraft as a functional subsystem unit requiring only proper orientation and interconnection with power, command, and telemetry cabling to provide a functional on-orbit thruster. Such a modular unit is particularly needed at present because of the high weight penalty and subsequent cost of using hydrazine for precise north-south stationkeeping. Availability of the Space Shuttle will tend to reduce the need for weight savings due to the reduction of transporttation cost from a present $22,000 per kg to an estimated $6,500 per kg. The expected growth of satellite weight due to use of the Shuttle will make development of improved on-orbit propulsion systems attractive because of the cost of transporting the required weight of hydrazine into synchronous orbit. Transport cost for 90 kg of hydrazine required for a 450 kg satellite launched into orbit with a Delta booster would be $1.9 million. If the 1985 replacement satellite grows to 1800 kg due to increased communications capability and reduced weight constraints, the required transportation cost for 370 kg of hydrazine is $2.4 million in 1972 dollars if Shuttle is used.

11.16 STRUCTURAL AND THERMAL CONTROL

The most likely option for structural and thermal control are the development of improved lower cost thermal control coatings and materials which will reduce the cost and improve the capability for passive thermal control.

Structural weight could be significantly reduced by reduction of the ascent acceleration and vibration-induced loads.

11.17 TRACKING, TELEMETRY, AND CONTROL

No special technology stimulation is required. The present trend of technology development plus development of a Space Tracking and Data Relay satellite will fulfill future technical and functional requirements.

Section 12

RECOMMENDATIONS

Results of the sensitivity analysis indicate the priorities and worth of technology improvement for each subsystem and key components of the eight types of communication networks listed in Table 10-14. Estimates of savings are due to the impact of technology improvements on each of the eight networks listed in Table 10-14. The savings reduce the total 7-year costs listed in Table 10-13 but do not include a factor for discounting the future value of money.

The recommendations and plans presented are based upon a conservatively estimated one-time savings due to technology improvements of only 42 satellites during the 1980 to 1990 time frame. The following list of 11 civil communications satellite networks in the Western hemisphere shows a requirement for a total of 39 satellites during the 1975 to 1980 time frame, indicating that the number of communications satellites in operation by 1985 will substantially exceed the 42 satellite baseline used for substantiation of the recommended plans and funding levels.

Network	Number of Spacecraft
Telestar (Canadian)	3 (Anik)
Western Union	3 (Westar)
National Satellite Service (Hughes/STE)	3
American Satellite Corp	3
CML (Comsat/MCI/Lockheed)	3
RCA	3
Intelsat (Comsat)	8
Brazil	3
Maritime Satellites	3
Aeronautical Satellites	4
Tracking and Data Relay Network (NASA)	3
Total	39

The recommended plans for stimulation of technology growth are based on the minimum practical expenditures. Plans and funding are based upon prudent and highly effective direction and development of new technology such that the cost savings will exceed the required costs of development. Significant expenditures in excess of the recommendation can be justified due to the conservative methodology and base line used for determining minimum savings.

Each of the options for technology development defined in Section 11 are worthy of development effort and funding. The options define detailed capabilities and improvements which should be developed in each of the key areas of technology for which stimulation and development of improved capabilities are recommended.

The sources of funding and technology development are not defined. These are matters of policy and not technical requirements. Planning is based upon the expectation that funding and development efforts by NASA, DoD, satellite communications companies, aerospace contractors, universities working under grants, equipment vendors, parts suppliers, and research and development institutes will continue in the future.

12.1 KEY TECHNOLOGIES FOR COMMUNICATION SATELLITES

Improvements of the key technologies and components defined are expected to provide the most significant improvements of communications satellite cost effectiveness. Present and forecasted future technology growth is capable of meeting all of the requirements of the needs model as defined in Section 4. Some very important technologies such as time-division multiplexing are not recommended for special attention because demonstrated capabilities and the trend of technology growth indicate that no special stimulation or development is required. Technologies are not considered if the major thrust of future development will be provided by the terrestrial telephone and radio communications industries which have combined annual revenues of over $30 million. Key technologies recommended for special attention and stimulation of technology growth to improve the cost effectiveness of communications satellite networks are listed below in the order of recommended priority.

1. Develop technologies for improving the following antenna characteristics.

   - Provide 20 to 30 steerable or switched beams from one lighweight antenna
   - Provide improved antenna beam shaping to allow more controlled distribution of radiated energy and gain distribution
   - Provide -30 dB or greater isolation between adjacent beams of a spacecraft
   - Reduce antenna side lobes by more than -25 dB with lightweight antennas
   - Develop improved high speed switching of antenna beams and transponders

2. Develop solid-state transponders for 12 GHz and possibly higher frequencies with the following improved characteristics.

   - Increased DC to RF power conversion efficiency
   - Reduced transponder costs
   - Reduced weight for required reliability and life

3. Develop switched or steered beam antennas with 10 dB or higher gain for aircraft.

4. Continue development of improved video channel compression technologies and hardware.

5. Continue development funding for spacecraft technologies such as:

   - Ion propulsion
   - Power subsystems and components utilizing solar power
   - Attitude control
   - Thermal control
   - Integrated micro-electronics
   - Laser communications
   - On-orbit chemical thrusters and propulsion
   - Tracking, telemetry and control components
   - Built in automated control and test capabilities for spacecraft and earth terminal components

12.2 RECOMMENDED DEVELOPMENT PLANS

The main objective of the development plans outlined is to develop the key technologies and hardware at minimum cost to provide high practical payoffs. Development funding should result in cost saving operational hardware which can be developed and applied with a minimum risk of failure or cost over-run. A second objective is to maintain expertise and leadership in communications satellite technology.

Technical expertise is dependent upon the available capabilities of people in developing and applying technology to solve problems. Efficient stimulation of technology growth is dependent upon the proper phasing and funding of development programs to best utilize the available talent. Recommended time spans are sufficient for the logical evaluation and development of the required basic theories, material and components from which improved systems can be produced. Reiteration is inevitable as initial approaches prove less promising than hoped, or test results indicate a need for modification or redirection. The time spans considered allow for the normal development phases and reiterations inherent in developing new technologies. Planned long term funding is needed in order to maintain a continued development of key technologies and to ensure continued technical excellence. The recommended plans includes funding for further development of technologies such as ion propulsion which are forecasted to be utilized, and are very beneficial but are not considered as key technologies.

Research and development has been performed in each of the key technical areas in the past and is expected to continue to some degree in the future by government and industry. The recommended development plans and funding levels presented are based on development of the required capabilities within one organization or by means of closely coordinated joint efforts between several organizations.

The minimum recommended plans and funding levels will probably be exceeded over the next ten years due to the present competitive development of communications satellites. Hardware will probably exceed the minimum required key technology capabilities listed in par. 12.1. Benefits should be in proportion to the value of the recommended development plan for providing the general levels of technology improvement defined in the sensitivity analysis, ref. 10.1.6. Plans and funding levels are presented below in order of recommended priority for maximum benefit of communications satellites in general. Specific priorities for specific spacecraft applications are indicated by the summary of the sensitivity analysis presented in Table 10-14.

Improved Spacecraft Antenna Technology. An estimated $30 million should be funded between 1973 to 1980 to develop the needed technologies, produce and test prototype antennas of the types described. Additional funding on the order of $10 million should be used to provide flight test articles by 1977 to 1979 if a flight test program is funded.

Antennas for Aircraft. $5 million should be funded between 1974 to 1977 to develop a low profile steered or switched beam antenna. One approach may be to switch or phase shift slot antennas.

Funding on the order of $10 million from 1976 to 1980 is recommended for research and development of an improved antenna capable of being retrofitted to existing aircraft with a minimum of change to the basic structure. Such an antenna might be developed as a replacement wing tip or fillet for example. Development should be started and maintained at a level of between $0.2 to $0.5 million per year until it is determined that such an acceptable antenna can be produced and building block components are "bread-boarded" or there is a firm technology base from which to attempt the development of an antenna with a reasonable expectation of meeting most of the requirements. The initial problem should be studied by several groups. Prototype development of a flight test antenna will probably cost on the order of $10 million.

Solid-State Transponders. Solid-state transponders are of sufficient importance and the requirements so basic that a long term level of funding should be provided. There should not be a concerned effort to develop a solid state 12 GHz transponder by a given date but rather to investigate promising improvements and refinement of basic devices and material for operation and switching at 12 GHz.

Funding should include refinement and development of low noise terrestrial receivers for spacecraft. Refinement and use of developed solid state terrestrial communications devices applicable to space operations should be the main thrust of study. Prototypes of promising devices and components should be developed and tested. There should not be a major effort to hunt for, discover or create a revolutionary new device or materials specifically for communications. Maximum use should be made instead of the development funding by the semiconductor and terrestrial communications industry for improved devices for RF power generation, switching, oscillator and other ancilliary components required for transponders and switching. Prototype transponder development should be funded when the basic components have been developed to a state that there is a possibility of approaching traveling wave tube transponder efficiency with on the order of one watt output. The funding should be on the order of $1 to $2 million per year for sustaining and preliminary development and $10 million in 1975 to 1980 for development of a prototype transponders.

Steered or Switched Multiple Beam Earth Station Antenna. Technology required and developed for spacecraft antennas and aircraft antennas should prove adequate for fixed earth station antennas.

Video Compression. Funding of up to $1 million per year should be expended for basic study, work and experiments on data compression theory, techniques, laboratory work and tests. Funding on the order of $10 million should be expended as required if a determination is made that a breakthrough can be achieved in video or data compression techniques and earth terminal hardware. Prototype hardware development should be focused on low cost earth terminals costing $50,000 or less.

Funding for Sustaining Development. Funding of at least $10 million per year should be utilized for maintaining growth of technology and expertise in critical technologies. Continuing development effort should be performed in the following areas:

Ion propulsion
Power subsystems and components
Attitude stabilization and control components
Thermal control

Integrated microelectronics

Laser communication

On-orbit chemical thruster and propulsion

Tracking, telemetry and control components

Built in automatic control and test capability for spacecraft and earth terminal equipment

Flight Testing. Flight testing and demonstration of technology capabilities is highly desirable. The present status of communication satellite technology and application for global and domestic systems would not have been realized were it not for the NASA flight testing and demonstration of technology. ATS-F and the Canadian Technology Satellite should not be the last satellites developed to test and demonstrate significant technology improvements. On-going commercial satellite programs will, however, continue to development proprietary technical refinements, and may carry equipment on operational spacecraft.

There is a long term need for continued development and flight testing of new and hopefully revolutionary technologies such as LASERs which might penetrate cloud cover. Such experiments may be outside of the scope of interest of commercial communications satellite programs. Advanced technology experiments could be carried out by means of a simple, low-cost, Shuttle launched standardized test-bed satellites. Such satellites could be developed from available technology and make maximum use of available hardware to reduce costs. The standardized spacecraft would be used to support a variety of experimental modules. Experimental modules would be developed to be relatively simple, and compatible with the standard test spacecraft. Such an approach would reduce the development costs and total costs for experimental test programs.

The experiment test spacecraft would not demonstrate the future generation of communications spacecraft as the ATS spacecraft have done. Instead, the experiment test spacecraft would test components, concepts, and possibly experimental subsystems which would be modularized for on-orbit testing and evaluation. Such modules could be used for future spacecraft. Ideally, test data and results would be documented and reported for use by operational programs to improve the cost effectiveness of all types of spacecraft and satellite systems.

12.3 VALUE OF THE DEVELOPMENT PLAN

The cost of the recommended development plan for stimulation and sustaining development of key technologies is $100 million. Additional funding for general sustaining technology development costs $70 million over seven years. The total plan costing $170 million includes funding which is part of present on-going development for space programs. The minimum value of the development plan and expenditures amounts to $587 million over a seven year period with the use of the Space Shuttle/Tug transportation system (The minimum value without Space Shuttle is some $645 million). The minimum payoff on the recommended plan is 3.5 to 1, based on technology utilization for 42 spacecraft. The actual payoff may be 5 to 1 if communications networks grow to include some 60 satellites by 1985.

Present annual funding by NASA for communication satellite research and development to develop improved technologies is $2.6 million (Ref 90 page 874). The total annual NASA budget for space technology research and development is given as $64.8 million (Ref 90 page 70). The recommended plan would cost on the order of $25 million per year. The benefits of most of the technology improvements would not be limited to communication satellites, but would aid other applications of space technology.

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