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40 AND 80 GHz TECHNOLOGY ASSESSMENT AND FORECAST

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NATIONAL SCIENTIFIC LABORATORIES
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Project Manager, Grady H. Stevens, Space Flight Systems Study Office, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

The results of a survey to determine current demand and to forecast growth in demand for use of the 40 and 80 GHz bands during the 1980-2000 time period are given. The current state-of-the-art is presented, as well as the technology requirements of current and projected services. Potential developments were identified and a forecast is made. The impacts of atmospheric attenuation in the 40 and 80 GHz bands were estimated for both with and without diversity. Three services for the 1980-2000 time period -- interactive television, high quality three stereo pair audio, and 30 MB data -- are given with system requirements and up and down-link calculations.

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SECTION 1

INTRODUCTION

1. Background

The 40 and 80 GHz Technology Assessment and Forecast study was performed by the National Scientific Laboratories Division of Systematics General Corporation, McLean, Virginia under Contract NAS 3-19724 for the National Aeronautics and Space Administration, Lewis Research Center. The study was initiated on June 18, 1975 and all technical study efforts were scheduled for completion in nine months.

2. Study Objectives

The objectives of the 40 and 80 GHz Technology Assessment and Forecast project were divided into the following basic tasks:

1) Survey the communications industry to establish the current demand for services and to forecast the growth in demand for these services through 1980-2000.

2) Establish the state-of-the-art in 40 and 80 GHz technology.

3) Forecast potential developments in 40 and 80 GHz technology.

4) Estimate the impact of atmospheric attenuation on the 40 and 80 GHz bands.

5) Identify the technology requirements for support of current and projected services in the 40 and 80 GHz bands.

6) By examining the state-of-the-art technology and projected technology developments, establish those requirements which could be realized in 1980-2000 and hence, which services could be provided by 40 and 80 GHz technology in that time frame.

The study objectives listed above are not independent, but form a logical and interrelated sequence of tasks which were undertaken in performing this study. Conducting a study relating to the 40 and 80 GHz frequency bands for satellite communications services involved pursuing a domain where limited technology development has occurred and where no experiments in communications have been performed. These frequencies of the spectrum are virtually untapped from the standpoint of communications systems usage. However, the communications systems are feasible and technology realizable if the demand warrants development at these frequencies.

3. Study Approach

In meeting the objectives of the program, a survey was conducted of various publications, user organizations, the communications and aerospace industry, and various Government agencies. This survey concentrated on new applications or services which could be served by satellite communications, the existing and potential terrestrial communications market which might be transferred to satellite systems, the domestic satellite industry which may be the primary carrier, and the technology development status and potential.

The survey revealed several studies previously conducted regarding satellite communications in the 1980's. Other data obtained provided details on a number of Government-sponsored studies relating to the use of satellites for information transfer. Analyses of the information provided the basis for identifying current demands for services and forecasts of new applications and growth potentials for the future.

Contacts were made throughout the communications and aerospace industry and at selected Government agencies to determine the state-of-the-art in 40 and 80 GHz technology. Some work has been done in these frequency regions and above; however, some key components or subsystems required for such a system have to be developed. The consensus obtained indicates that the potential exists for providing all of these subsystems if sufficient time and funding were available and demands warrant pursuit of systems in the 40 and 80 GHz regions.

In estimating the impact of atmospheric attenuation, detailed literature surveys were made to identify key propagation experiments and other detailed statistical, theoretical or postulated data on the effects of the atmosphere at 40 and 80 GHz. Much propagation work has been done in lower frequency regions but data at 40 and 80 GHz was scarce. The estimation of the effects of attenuation in the atmosphere is a key factor in establishing the requirements and potential for services in this frequency region. Analyses of these impacts and results are described in detail in Section 6 of this report.

Detailed analyses of all the information collected through personal contact, literature survey, telephone conversation, and correspondence provided the basis for postulating, projecting, and determining the capabilities and services realizable at 40 and 80 GHz. Thus, from a large number of potential services initially identified, through analysis of technology status, and atmospheric attenuation projections and link calculations, a selection was made of several services which could be provided in the future.

4. Study Environment

The transfer of information using terrestrial and space communications systems has increased at a rapid rate over the past several years as Government, industry, and other users have sought new, improved, and more cost effective ways to pass information from place to place. This increase has been fueled by demands for new services and by advancements in the technology state-of-the-art. Accordingly, a steady growth in terrestrial communications links and satellite communications systems has resulted. A continuation of this trend is expected for many years into the future.

The growth in the terrestrial communications field is exemplified by the emergence of the Specialized Common Carrier (SCC) industry that followed the Federal Communications Commission (FCC) decision in June 1971, which allowed competition to be introduced into limited sectors of the communications market. As a result of the decision, over thirty companies applied to the FCC for licenses to operate SCC's over routes spanning 40,000 miles. Subsequently, over 2000 applications for new microwave stations were received by the FCC (ref. 1). Today, a large number of companies are offering point-to-point communications channels for voice, data, facsimile and various wideband applications across the country although the growth has not been as rapid as anticipated.

In parallel with the terrestrial systems development, space communications and the attendant technology have increased accordingly. The acceptance and widespread use of satellite communications as a new means for transfering information from point-to-point grew out of the success of the first TELSTAR, Relay, and Syncom Satellites. Since 1965, the Intelsat series of satellites has come into being and has been providing international point-to-point communication service. Another significant growth in the industry came with the launch of the first United States and Canadian commercial domestic satellite services - the WESTAR and Telesat (ANIK) series. The first of the RCA/Globcom satellites (Satcom) has been launched to provide additional satellite communications capability to meet the growing demand. Demands for services, along with increases in the number of domestic satellites in the U. S. and abroad, are inevitable as many countries throughout the world plan to launch their own domestic satellites.

Although the entrants into the domestic satellite arena are increasing in number and the technology is being developed at various levels, the market potential in domestic communications is yet to be fully realized. The "conventional" markets served by Common Carriers and Specialized Common Carriers are well-defined. However, satellites are being employed in these areas to the extent that their economic viability and operational effectiveness has been demonstrated to be competitive with terrestrial means.

The advantages of satellites in satisfying needs usually served by Common Carriers and Specialized Common Carriers are: 1) the cost and lead-time for rerouting and expansion of service is dependent primarily on the cost-time factors for installing new earth terminals; and 2) for a given satellite system capacity, costs are almost independent of distance.

In addition to the conventional markets, there is a large new market in the area generally categorized as social services communications, but which includes communications for educational, health/medical and social needs. These users have been served by the carriers to the extent that facilities have been available. However, these services are most needed, most appropriate, and most effective in rural areas and isolated areas, far from the main routes of common and specialized carriers, which can be reached by satellite quicker and cheaper than by terrestrial means.

A number of Government agencies, industrial organizations and other user groups have conducted or are conducting studies which may lead to the widespread use of satellite communications. Some of the applications which are being investigated and may become operational in the near future include:

- Electronic Mail System
- Law Enforcement Telecommunications
- Industry Internal Communications
- Value Transactions
- Satellite Instructional Television
- Health and Social Services
- Satellite Teleconferencing
- Interactive Education
- Disaster Warning
- Data Collection Satellites
- Rural Broadcast Services

Experiments have been conducted by NASA and various user agencies in many of these areas on the experimental Applications Technology Satellite and others are planned for the joint U.S. - Canadian Communications Technology Satellite. Results of the satellite experiments conducted to date indicate that these applications can successfully utilize the capabilities offered by satellites.

However, several factors heavily influence the path of future trends. There is the consideration of the current investment, both in satellite and ground station technology and hardware at the present frequencies of 6 GHz and 4 GHz, and the consideration of the capability of expansion of current capacity at these frequencies. Opportunities for expansion at these frequencies lie in two approaches: 1) use of spot beams and subsequent frequency reuse, and 2) use of horizontal and vertical polarization separation and subsequent frequency reuse. Either approach is an attempt to increase capacity within a fixed spectrum limitation.

Of even greater significance in the domestic satellite services is the orbital spacing limitation where there are only a certain number of desirable orbital assignments in the usable orbital arc. Such assignments are limited because of: 1) satellite antenna footprint requirements, 2) adjacent satellite interference, and 3) spacing needed to minimize sun outage. The cost of the launch vehicle and its weight capability, which determine the number of transponders that can be powered and carried per satellite, are other economic factors that also must be considered.

Of the 120,000 telephone channels* that might be available in orbit prior to 1980, there are predictions that even these will not be sufficient to meet the demand. Therefore, it is logical to presume that new markets will force consideration of alternative frequencies. Investigations are already underway to exploit new frequency regions. For example, experimentation is being carried out at 14 and 12 GHz using the joint U.S. - Canadian

* This number represents all telephone service and does not consider reservation of capacity for television or space channels.

Communications Technology Satellite and the Japanese Broadcast Satellite. Comsat/IBM/Aetna is planning for a satellite with 12 and 14 GHz transponders while making use of an interim system leasing 6 and 4 GHz transponders. Additionally, AT&T and Hughes Aircraft Company are considering the 30 and 20 GHz frequency regions for future satellites and the use of diversity stations to minimize rain outage which occurs at these frequencies. This is partly a result of the success of the AT&T Holmdel measurements conducted utilizing ATS-5 and ATS-6.

Thus, the evolution of the use of new frequency spectra is following a consistent pattern and is being influenced by technology capability and the desire to gain natural "squatters rights" in a new frequency domain.

Two of the areas which might offer some relief to the spectrum crowding problem and can provide a means for new communications services is the 40-43 GHz and 80-84 GHz frequency bands. The 40-43 GHz band has been allocated by the International Telecommunications Union to the Fixed Satellite (space to Earth) service and the Broadcasting satellite service. The 80-84 GHz (space to Earth) region has yet to be allocated, but the 84-86 GHz (space to Earth) region has been allocated to Broadcasting satellites (ref. 2).

The use of these bands to relieve the crowding conditions is possible, provided the technology can be developed to make systems in these bands feasible. However, this study indicates that the 40 GHz band is marginally viable while the 80 GHz band is not viable for Earth-to-space-to-Earth communications. Consequently, the candidate new services have been sized for the 40 GHz region. Prior to developing these new areas of the spectrum, it is necessary to investigate the potential, problems, impacts and the technology required to implement systems operating in the millimeter wave frequency region.

This report describes the methodology employed in meeting the objectives of the 40 and 80 GHz Technology Assessment and Forecast project and summarizes the data and results of the parametric analyses leading to the determination of which potential services may be available in the 1980-2000 time period.

SECTION 2

SURVEY OF CURRENT COMMUNICATIONS MARKETS

1. Introduction

This initial task was one of the most important efforts in meeting the objectives of the project since the market information obtained formed the basis for subsequent analyses. Furthermore, in order to acquire the needed data, it was necessary to employ several different types of survey methods, to survey many organizations and agencies for the same data, and to make contacts at a variety of working levels. It was only through this multi-faceted survey approach that data essential for making decisions regarding present markets, future applications, and the potential for using the 40 and 80 GHz frequency bands could be obtained.

The survey methodology commenced with an extensive literature search which was performed at a number of libraries primarily in the Washington area. Technical data, periodicals, reports, technical articles, papers, and documents such as filings at the Federal Communications Commission were reviewed and copies obtained. Data was collected on topics such as terrestrial and space communications, markets, information transfer, data collection systems, broadcasting, and various applications and services which were of concern to the program. Libraries such as the National Aeronautics and Space Administration Headquarters and Goddard Space Flight Center, the Health, Education and Welfare, the FCC, Office of Telecommunications Policy, and the Corporation for Public Broadcasting were contacted and a document search conducted. Surveys were made of technical report indexes such as those published in NASA Scientific and Technical Aerospace Reports (STAR) documents, Department of Commerce Technical Information abstracts, and Commerce Clearing House publications. Copies of appropriate documents were obtained from virtually every source surveyed.

In parallel with the literature search, another survey effort was conducted by means of correspondence, telephone and personal contact. Various Government agencies, communication users, and other organizations were contacted in this phase of the study to obtain current markets and information on applications for satellite communications. A list of primary contacts and markets of interest is given in Table 1. A large number of other contacts were made but no relevant information was obtained.

The search revealed that numerous studies of advanced communications systems, which will carry future services, have been conducted by various agencies and organizations. Table 2 lists some of the typical studies along with the application and the agency or organization performing the study. Copies of each of these documents were obtained for detailed analysis.

TABLE 1

TYPICAL CONTACTS AND MARKETS OF INTEREST

Contact	Interest
Dept. of HEW Office of Telecommunications Policy	• Social Services Satellite • Health/Medical Services • Educational Telecommunications
U.S. Postal Service Office of Distribution Systems and Advanced Plans and Development	• Electronic Mail Systems
Lister Hill National Center for Biomedical Communications	• Biomedical Communications • CTS Experiments • ATS Experiments
Social Security Administration	• Social Security Administration Data Acquisition and Response System (SSADARS) • Direct Check Deposits
National Library of Medicine	• Telecommunications for Social Needs
Law Enforcement Assistance Administration, National Crime Justice Center	• National Crime Information Center and Nationwide System (NALECOM)
Federation of Rocky Mountain States	• Public Service Satellite System
Corporation for Public Broadcasting	• Public Broadcasting System and National Public Radio
Musak Corporation	• Audio Distribution Systems (Stereo)
NASA Headquarters	• Space Communications Systems • ATS-6 Experiments • CTS Experiments • Teleconferencing
NASA Goddard Space Flight Center	• Satellite Data Collection Systems • Disaster Warning • Search and Rescue • Tracking and Data Relay • ATS-6 Experiments

TABLE 1 (cont.)

TYPICAL CONTACTS AND MARKETS OF INTEREST

Contact	Interest
Federal Reserve System	• Federal Reserve Bank Communication System • Direct Payroll Deposits
Federal Communications Commission	• Domsat and Common Carrier Markets
Rapidfax Corporation 3M Corporation Xerox Corporation	• Facsimile Systems
Western Union Corporation	• Electronic Mailgram System
Bank Americard, Inc. Local Banks	• Credit Transactions • Transaction Telephone System • Electronic Fund Transfer

TABLE 2

TYPICAL AGENCY STUDIES OF COMMUNICATIONS SYSTEMS

APPLICATION	PERFORMING AGENCY	STUDY
Data Collection	Goddard Space Flight Center	Data Collection User Requirements, May 1975
Education	Center for Development Technology, Washington University for NASA	Early Childhood Education: Status, Trends, and Issues Related to Electronic Delivery, May 1973
Education	Center for Development Technology, Washington University for NASA	Planning Alternative Organizational Frameworks for a Large Scale Edcational Telecommunciations System Served by Fixed/Broadcast Satellites, June 1973
Electronic Mail Services	U. S. Department of Commerce for U. S. Postal Service	Study of Satellite Frequency Requirements for the U. S. Postal Service Electronic Mail System, February 1974
Information Transfer	The President's Domestic Council	Communications for Social Needs: Technological Opportunities, September 1971
Inforamtion Transfer	Lockheed Missiles & Space Company, Inc. for Ames Research Center	Technology Requirements for Post-1985 Communications Satellites, October 1973

TABLE 2 (cont)

TYPICAL AGENCY STUDIES OF COMMUNICATIONS SYSTEMS

Information Transfer	Space Applications Board of the Assembly of Engineering National Research Council	Practical Applications of Space System, 1975
Information Transfer	Convair Aerospace Division of General Dynamics for NASA	Information Transfer Satellite Concept Study, May 1971
Information Transfer	Lockheed Missiles and Space Company for NASA	Information Transfer Systems Requirement Study, March 1970
Health Care	Abt. Associates, Inc. for DHEW	Telecommunications and Health Services, January 1974
Health Care	DHEW, for the President's Domestic Council	Telecommunications for Improved Health Care, August 1971
Law Enforcement	Jet Propulsion Laboratory	National Law Enforecement Telecommunications Network Functional Requirements, June 1974

TABLE 2 (cont)

TYPICAL AGENCY STUDIES OF COMMUNICATIONS SYSTEMS

Law Enforcement	Jet Propulsion Laboratory for U. S. Department of Justice	National Law Enforcement Telecommunications Network Analysis - Final Reports, Phase II, February 1975
Law Enforcement	Rockwell International for Jet Propulsion Laboratory	NALECOM Satellite Usage Study, February 1975
Law Enforcement	Jet Propulsion Laboratory	National Criminal Justice Telecommunications Requirements, Preliminary - January 1974, Rev. A - June 1974, Review and Update - February 1975
Rural Broadcasting	Federation of Rocky Mountain States	Market Survey of Public Service Satellite Covering Prediction of Traffic and Potential Use, 1975
Teleconferencing	University of Wisconsin for NASA	Teleconferencing in Wisconsin, October 1971
Teleconferencing	University of Wisconsin for NASA	Legal Aspects of Satellite Teleconferencing, October 1971
Teleconferencing	Stanford University for NASA	Teleconferencing: Cost Optimization of Satellite and Ground Systems for Continuing Professional Education and Medical Services, May 1972

TABLE 2 (cont)

TYPICAL AGENCY STUDIES OF COMMUNICATIONS SYSTEMS

Value Transactions	Federal Reserve System Communications System Expansion Task Force	Federal Reserve System Communication-System Development Study, November 1974
Value Transactions	Arthur D. Little, Inc. for National Science Foundation	The Consequences of Electronic Funds Transfer, June 1975

During the course of this task, a large number of market candidates were identified, but those having the most potential application to satellites as well as the greatest information bandwidth requirements were given further consideration. The markets which appeared to offer the greatest potential on a national basis are given below:

- Health/Medical Services Telecommunications
- Educational Telecommunications
- Value Transactions
- Law Enforcement
- Satellite Mail Delivery Systems
- Industry Internal Communications
- Teleconferencing
- Commercial Broadcast
- Intersatellite Data Relay
- Specialized Audio Service
- Cable Television
- Public Broadcasting Service

Following initial identification and screening of the potential markets, the effort was concentrated on obtaining as much information as possible on the services and applications through research and further contact with the appropriate sources. Table 3 lists the primary potential satellite markets of a national nature and a number of typical future applications. The paragraphs in the following pages summarize the key market, possible growth and current activities in each of these markets.

TABLE 3

POTENTIAL SATELLITE MARKETS AND APPLICATIONS

Potential Market	Typical Future Applications
Health/Medical Services Telecommunications	• Biomedical Communications • Distribution of Library Information • Specialized Information Request • Public Health Information Dissemination • Record Transmission and Inventory Control • Remote Area Medical and Diagnostic Services • Dial Access System • Telelecture • Medical Education
Educational Telecommunications	• Medical Training • Large Electronic Delivery of Early Childhood and Higher Education • Continuing Education or Extended Learning • Education to Rural and Remote Areas • Instructional TV
Value Transactions	• Check and Credit Transactions • Direct Payroll and Payment Deposits • Automated Check Handling • Security Transfers
Law Enforcement	• Criminal Histories • Fingerprint Transmission • Criminal Justice Planning Information • Criminalistic Information • Criminal Intelligence • Video Circuits

TABLE 3 (cont.)

POTENTIAL SATELLITE MARKETS AND APPLICATIONS

Potential Market	Typical Future Applications
Satellite Mail Delivery Systems	• General Correspondence • Advertising • Magazines and Newspapers Delivery • Value Transactions
Industry Internal Communications	• Public Telephone • Business Telephone Network • Transaction Telephone • Video Telephone • Facsimile • Data Transmission • Facsimile of Newspapers and Magazines • Computer Telecommunications
Teleconferencing	• Audio and Video Transmission for Government and Business
Commercial Broadcast	• National Distribution of Commercial Audio and Video Programs
Intersatellite Data Relay	• Two-way Relay of Telecommunications Signals Between Ground Terminal(s) and a Number of Orbiting Spacecraft
Specialized Audio Service	• National Distribution of High Quality Audio and Stereo Data
Cable Television	• National Distribution Audio/ Video Programs and Material
Public Broadcasting Service	• Distribution of Public Services and Public Broadcasting Program Materials

2. Health/Medical Services Telecommunications

2.1 Introduction

Electronics, electrical engineering and telecommunications are assuming an increasingly important role in medical services. Medical service exhibits characteristics that require advancement of communications beyond the normal projection of conventional terrestrial services. The provision for adequate and efficient medical services depend upon communications. Communications provide the following essential services:

- Bring medical care to people in isolated communities that cannot be reached by the limited supply of doctors.
- Supply a quick response to specialized information requests.
- Means by which doctors can be informed of events, products, research, and procedures.
- A continuing medical education to members of the medical profession.
- Dissemination of medical information to non-medical audiences.

It is important to identify the categories of individuals who transmit and receive information. Obviously, the future systems under study are being influenced by the character of the audiences involved. To emphasize this point, the following listing presents a summarization of broad communications areas in the health field:

- Federal Health Agencies

  Intra-agency

  Interagency

  Armed Services/Veterans Administration/PHS Hospitals

- Intergovernmental

  Federal - State

  Federal - Regional

  Federal - Local

  State - Local

- Health Services Delivery

  Interinstitutional

  Intra-institutional

  Provider - Institution

  Provider - Patient

  Provider - Provider

- Health Education

  Federal - State - Institutions - Students

  Academic Societies - Practitioners

  Health Professionals - General Public

  Providers of Services - Consumers of Services

- Transmission of Research Results

  Scientist - Scientist

  Scientist - Practitioner

  Scientist - General Public

  Practitioner - General Public

  Health Professions - Legislative Bodies

This summary of broad communications areas illustrates two important facts: 1) the volume of traffic is very large in the total health industry; and 2) the nature and composition of the audiences involved are highly variable. Both items bear directly on the perspectives of telecommunications in health.

2.2 Information Services

The following categories of information transfer using modern telecommunication technology are anticipated for the future:

- Distribution of Library Information - This service is specifically for the medical community. The libraries would be located at a few regional centers as well as the National Library of Medicine. Types of circuits required would be teletype, telephone and television channels for remote viewing. The primary destinations for the library data would be hospitals. Other receiving points would be medical schools and clinics.

- Specialized Information Requests - This service is also specifically for the medical community whereby inquiries can be directed to centrally located data banks. The requests and responses are by means of digital data links.

- Public Health Information Dissemination - This service is primarily for the medically uninformed segment of the public. Information is conveyed by commercial quality television. Use would be made of existing educational TV broadcast stations eventually augmented and possibly superseded by a medical TV network covering the United States.

- Record Transmission and Inventory Control - This service pertains to the transfer of information about patient's records and transfer of information necessary to maintain inventory control of vital medical supplies such as blood banks and banks for organ transplants. Digital data links are required initially in metropolitan and regional areas with the ultimate use of a national network.

- Remote Area Medical and Diagnostic Services - This service would extend the service of a remote area by transmitting visual information via one-way or two-way TV and diagnostic monitoring data via telemetry from a remote site to a central location. Initially on a sectional basis and within states, this service could extend to regional and national areas.

- Dial Access Systems - Selectable tape recorded 4-6 minute lectures on current medical problems available by dial telephone by doctors in a state or regional area.

- Telelecture-System for doctor education that uses 2-way radio for lecture followed by a question and answer period. A variation uses radio for transmission only with questions from audience received via telephone.

In summary, information transfer requirements on which to base a national medical services network include teletype, video, voice and digital data links.

2.3 Applications

A key development in the use of telecommunications in the field of health is the creation of broadband communications links between and among central hospitals, outlying clinics, health centers, schools and colleges of medicine, institutions for the care of the mentally and emotionally disturbed, and other medical and health facilities. Such networks involve, singly or in combination, closed-circuit TV, cable TV systems, microwave transmission facilities, and even satellite transmission.

Medical education, including formal links between medical schools and health care facilities to expand the teaching capabilities of the schools, is a major use of many of the networks.

Another area of increasing activity is transmission of medical information to the public. TV or cable programs, produced by local medical associations or health care centers, have been launched. Some programs involve interaction with the public, who phone in questions on mental and emotional health to be answered by a professional on the staff of a local mental health center.

The National Center for Health Services Research and Development is supporting research and development in several areas of direct application to a medical data network. Included are programs to design and demonstrate a community health referral system, uniform hospital discharge abstract, automated medical interviewing (history), a prototype statewide health service data system, and the automation of a problem-oriented medical record.

Demonstrations and projects in telemedicine are being conducted in all parts of the United States. Major areas of experimental activity include teleconsultation, health education (for both professionals and patients), videotape as a medical/psychiatric tool, emergency medical networks, and computer applications in health care.

A common denominator in all these applications is the availability of a network of terminals (CRT, teletype, etc.) linked to appropriate automated data processing systems. The presence of terminals in the proper setting (hospitals, clinics, physician offices, etc.) would stimulate the development of additional programs designed to increase the efficiency and quality of the health delivery system.

Other applications are directed to problems of patient morale. On several systems, patients in hospitals or other health care facilities can talk to their families via TV or cable at specified hours each day.

As use of telecommunications in health care has increased, a number of uses have emerged that offer interesting and important advantages over existing methods and procedures. One such use is in medical education, with broadband links providing the dual advantage of expanding the inventory of teachers and teaching materials and lowering costs by decreasing the time requirements placed on instructors.

Other advantages lie in the use of video cameras and videotapes in live demonstrations of various medical and surgical procedures that could not be adequately viewed by a group of persons standing around the actual operation or activity. Delicate surgical procedures, eye operations, and dental surgery are among the types of activity that are now being "watched" by small TV cameras which transmit pictures to monitors that large numbers of persons can easily watch. Such operations are also being videotaped, both for future educational purposes and to enable the doctor to study techniques of others.

Videotape has been finding other uses, particularly in the field of psychiatry. Videotaped interviews with patients have increased the reliability of diagnosis through sharing of professional opinion among a number of professionals viewing the tapes. Tapes made of individuals and couples seeking marriage counseling often make dramatic differences in the speed with which the parties can view themselves and each other in a more accurate light.

2.4 Use of Satellites in Health/Medical Services Telecommunications

A brief description of a few of the proposed and operating systems of a telecommunications network and the application of satellite technology for health/medical service is given in the following paragraphs.

2.4.1 Communications Links for a Biomedical Communications Network (BCN)

The biomedical community consists of the approximately four million primary users of the network. This includes people and institutions devoted to providing medical services. Physicians, dentists, and nurses constitute the core of the community. Over 440,000 persons work as direct medical practitioners and over 1.5 million in related jobs. About 40,000 doctors per year graduate and enter the profession. There are

248,000 medical students and 400,000 students in related fields. Institutions number 1500 medical schools, 4500 schools teaching medical science as a part of their curricula, 3500 medical libraries, and 7000 hospitals. Table 4 shows how these groups are distributed among the 10 most populous states, along with distribution of population, hospitals, hospital beds, and health related professional schools (ref. 3).

TABLE 4. DISTRIBUTION OF POPULATION, MEDICAL PERSONNEL, AND HOSPITALS OF THE TEN MOST POPULATED STATES.

Rank Order	State	1967 Population (in thousands)	1975 Population (in thousands)	Number of Physicians	Number of Dentists	Number of Nurses	Hospitals	
							Number	Beds
1	California	19,153	24,129	33,604	11,573	55,240	638	140,020
2	New York	18,336	20,450	39,806	14,342	67,830	440	210,038
3	Pennsylvania	11,629	12,482	18,358	6,597	42,222	322	120,771
4	Illinois	10,893	12,141	14,810	6,285	29,371	325	106,906
5	Texas	10,869	11,840	12,284	3,890	17,448	565	72,459
6	Ohio	10,458	11,461	14,536	5,058	29,569	255	81,456
7	Michigan	8,584	9,259	12,462	4,334	21,322	260	73,702
8	New Jersey	7,003	8,156	9,808	4,268	22,101	141	54,933
9	Florida	5,995	7,720	9,042	2,941	16,432	179	39,053
10	Massachusetts	5,421	5,842	10,989	3,816	26,032	201	64,524
	TOTAL	108,341	123,480	175,699	63,104	327,567	3,326	963,862
	U.S. TOTAL	197,863	222,802	283,680	103,400	549,007	7,160	1,678,658
	Percentage	54.76	55.42	62	61	59.5	46.5	58

The geographical distribution of biomedical personnel and facilities in general tends to follow the distribution of population in the United States with the heaviest concentration of medical practitioners and facilities in the heavily populated areas. Also, large metropolitan areas serve as the sites for most medical, dental and other professional schools, research institutes, large hospitals, and medical societies. Figure 1 (ref. 3) shows this cluster pattern. Table 5 (ref. 3) shows distribution of personnel and facilities in principal metropolitan areas.

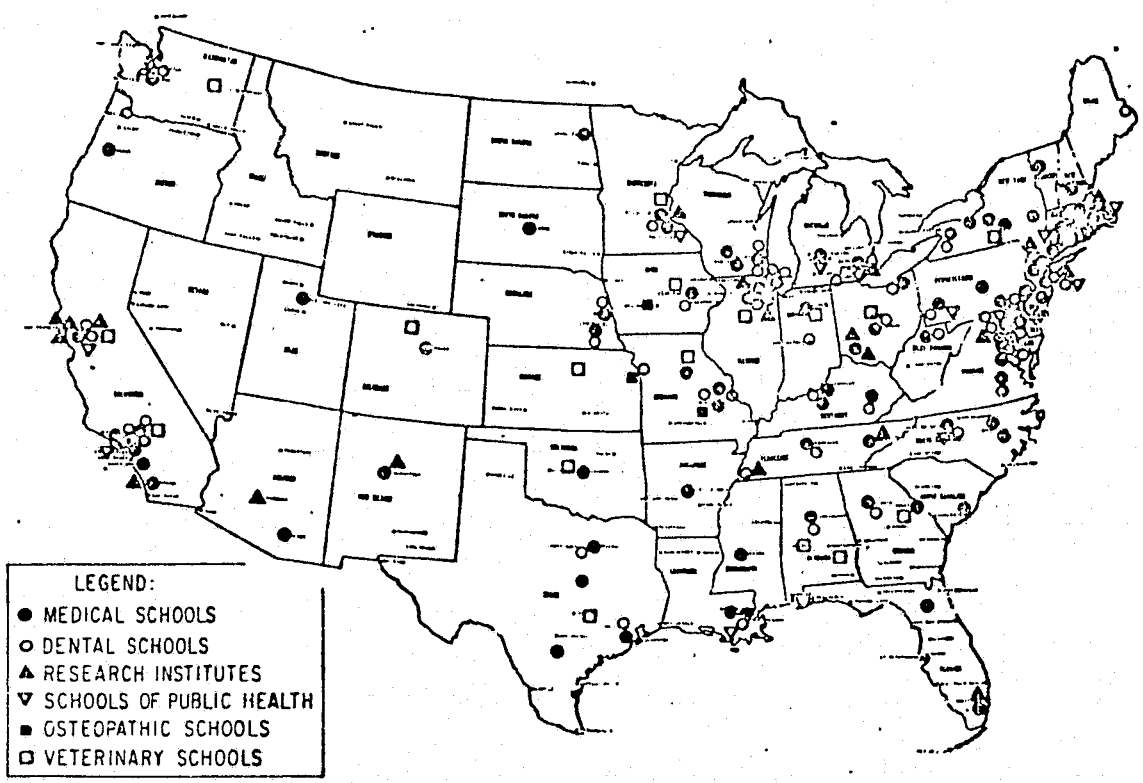

Figure 1. Medical educational institutions.

Because of the wide bandwidth required, television is considered the pacing requirement for the network. Real-time communications types such as telephone, teletype, facsimile and digital data are also required. The network would link major medical centers to the biomedical community.

A major emphasis of a BCN study, performed by Aerospace Corporation for the National Library of Medicine, dealt with an analysis of the types of transmission systems that could be considered for intercity connections and local distribution. The local distribution links, typically less than 10 miles, were

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TABLE 5. DISTRIBUTION OF HEALTH PERSONNEL AND FACILITIES OF 28 METROPOLITAN AREAS.

	Metropolitan Area	Projected 1980 Pop. (thousands)	Number of Physicians (thousands)	Number of Dentists (thousands)	Hospitals		Number of Medical and Dental Schools and Medical Research Centers
					Number	Beds	
1.	N.Y.-Newark	19,950	35.2	17.3	220	66.6	.15
2.	L.A.-San Bernardino	13,350	15.4	5.4	223	30.4	8
3.	Chicago	9,300	11.7	5.0	119	31.1	10
4.	Phil-Trent-Wil	6,650	11.3	3.7	103	26.3	9
5.	S. F.-Oak-San Jose	5,850	9.6	3.1	80	15.6	7
6.	Detroit	5,125	6.8	2.5	70	15.9	5
7.	Boston	4,200	9.0	2.9	101	18.6	9
8.	Washington	3,500	5.3	1.6	31	7.4	6
9.	Dallas-Ft. Worth	2,760	2.8	0.9	64	7.1	2
10.	St. Louis	2,775	3.4	1.3	43	10.8	4
11.	Houston	2,620	3.2	0.9	53	9.6	2
12.	Cleveland-Akron-Warren	2,715	6.0	2.3	53	16.6	2
13.	Miami-Ft. Lauderdale	2,350	3.4	1.0	31	6.8	2
14.	Baltimore	2,400	4.4	0.9	23	7.9	3
15.	Pittsburgh	2,500	3.4	1.5	45	13.9	2
16.	Minneapolis-St. Paul	2,150	2.8	1.3	35	9.4	3
17.	Seattle-Tacoma	1,975	3.0	2.2	40	5.6	2
18.	San Diego	1,815	1.9	0.7	27	3.4	2
19.	Atlanta	1,800	2.0	0.6	17	4.1	2
20.	Hartford-Springfield	1,725	2.2	0.8	22	5.4	1
21.	Cincinnati	1,690	2.1	0.5	18	5.0	3
22.	Buffalo-Niagra Falls	1,690	2.3	0.9	26	6.6	2
23.	Denver	1,525	2.5	0.8	21	4.8	1
24.	Milwaukee	1,540	2.3	1.1	29	6.4	2
25.	Kansas City	1,525	2.2	0.9	32	6.6	1
26.	New Orleans	1,420	2.4	0.6	23	6.1	3
27.	Tampa-St. Petersburg	1,350	1.2	0.5	17	3.1	--
28.	Phoenix	1,300	1.3	0.4	19	2.9	1
		107,050	159.1	58.3	1,585	251.7	106
	Total USA	242,307	283.7	103.4	7,160	1,678.6	173
	Percentage	44	56	57	22.2	15	62

considered "short haul" and the intercity links were classified as "long haul" with distances ranging from a few tenths of miles to a few thousand miles. The types of systems considered for intercity links were microwave relay, common carrier and communications satellites. The choices considered for local distribution were utilization of ETV, broadcast stations broadband coaxial transmission systems, microwave links, common carrier services, and direct reception from satellites. For intercity communications links an interesting and attractive method considered was a dedicated satellite to serve the communications needs of medical, scientific, engineering, educational, and other professional groups. It is proposed as a non-profit cooperative venture handling no commercial traffic in competition with commercial carriers. The system consists of a synchronous satellite located at 128°W longitude with one antenna beam covering the CONUS and three narrow beams illuminating three local areas of high user density - the East Coast, the Midwest and California. The proposed frequency plan was 15 GHz for the downlink and 12 GHz for the uplink.

While investigating satellite systems that could be received direct by individual users, four principal designs developed, each with several highly-directional beams covering 3 to 5 regions of the United States (Table 6, ref. 3). Power levels were sufficiently high to allow reception of television signals using an 8-foot diameter ground antenna.

TABLE 6. COMPARISON OF VARIOUS MODEL NETWORKS.

NETWORK	TOTAL ONE-WAY LINK MILEAGE	NUMBER OF CITIES SERVED
SMALL	4,400	11
NOMINAL	13,400	70
REGIONAL PLUS BACKBONE	21,000	70
EXTENDED REGIONAL PLUS BACKBONE	34,900	340

2.4.2 Physician Monitored Remote Areas

This proposed system is considered of significance because of its potential for providing medical service to remote areas and because it is the type of link that might be supplied by a satellite system. The purpose of this system is to provide for monitoring of patients at remote sites by a physician located at a centrally located medical center. The system would consist of a physician-monitored operation center and a report facility. It is proposed that there will be mobile units in addition to the fixed remote facilities.

2.4.3 Biomedical Communications Programs of U.S. Medical Schools

A number of medical schools provide various educational services that require communications links and therefore might be future candidates for the services of a dedicated domestic satellite communications system.

2.5 Current Satellite Health/Medical Services Experiments

The concept of using satellites for improving health/ medical services communications has been enhanced through demonstration experiments using the ATS-6 satellites. The following paragraphs summarize two key experiments as examples.

2.5.1 Regional Medical Education and Health Care Delivery

With the launching of the ATS-6 satellite in May 1974, the University of Washington School of Medicine tested the role that this communications technology could play in its regionalized experiment in medical education known as the WAMI Program (ref. 4). This program was embarked upon in an attempt to meet serious health education and health care needs of the states of Washington, Alaska, Montana and Idaho. This area, known as the WAMI territory (WAMI - an accronym for the participating states), encompasses 22 percent of the land mass of the United States but less than three percent of its people. Some communities in the WAMI territory are further apart than New York and Los Angeles and are scattered across five time zones. Some towns are accessible only by air or water transportation while some are completely isolated when weather conditions are unfavorable.

Experiments in administration, curriculum and patient care were conducted utilizing the full duplex color video capability of ATS-6 to communicate with medical students at the University of Alaska and half duplex black and white video to communicate with clinical students at a Family Medicine Clinic in a remote mountain community.

University faculty and administrators reported that satellite conferences facilitated the decision process. Admissions interviews can be successfully conducted via satellite if adequate discussion time is programmed. Students mastered selected segments of the basic science curriculum presented via satellite as well as those receiving instruction in the traditional classroom.

Clinical faculty reacted positively and few differences were noted between on site and satellite communication. The satellite was clearly preferable to the telephone but for most purposes the face-to-face communication had distinct advantages over the half duplex black and white telecommunication system. Dermatology consultations conducted via satellite were successful. Amplification of the image and frequency of follow-up contacts were viewed as advantages.

Medical educators involved in WAMI experiments agree that satellite communication can play a vital role in decentralized medical education and health care delivery.

2.5.2 Health Care in Alaska Via Satellite

The ATS-6 offered the Indian Health Service of the Department of Health, Education and Welfare the opportunity to test the feasibility of applying advanced communication and information system technology to the complex problems of health care delivery in the Alaska setting (ref. 5). The experiment involved for the first time the use of satellite telecommunications to permit physicians to provide consultation and health services, via two-way television, to Alaskans residing in remote areas served by paramedical personnel.

During the course of the experiment, a wide range of specialists located at the Alaska Native Medical Center in Anchorage were available to consult with physicians stationed at the Tanana Hospital. There were two unique features to this telemedicine experiment. The first was the fact that the technology was applied in a truly isolated and inaccessible environment. The second was that Community Health Aides were used in some cases to present the patients to the physicians via television. Thus, the experiment tested the usefulness of video in supporting outreach medicine through three types of para-professional workers: Community Health Aides, Physician's Assistants, and Nurses.

The results of the Alaska Satellite Health Care Experiment have shown that the capabilities provided by broadband satellite communications can be effectively used in the treatment and care of medical patients in remote and isolated areas such as Alaska. The experiment demonstrated that para-professional personnel, such as Community Health Aides, having limited medical and technical training, are capable of successfully presenting patients for telemedical consultation. The performance of the nurse at Fort Yukon was also outstanding, and demonstrated the extraordinary potential of nurse-practitioners in the telemedicine and health delivery systems of the future.

The experiment further indicated the advantages of video techniques in the area of continuing education for the health care team members. The knowledge gained by the Community Health Aides through such education and through participation in telemedicine transactions should result in a manifold increase in the effectiveness of these personnel. Furthermore, the experiment indicated that telecommunications contribute to the tying together of the far-flung health team into a cohesive, effective, and efficient unit.

The ATS-6 projects have demonstrated that there is sufficient potential to encourage the State of Alaska to plan for a satellite with two-way video capability within three years. However, before an operational system is implemented there is the need for an interim video telemedicine experiment to bridge the gap between the ATS-6 experiment and an operational system. Much more must be learned before the best possible operational system can be designed.

Alaskans have become convinced that the greatest contribution of satellite communications is in the support of health care. The Alaska Native Health Board has unanimously requested that every effort be made to continue the experiment on the ATS-6 when it returns to a position from which it can again support Alaska communications. The Indian Health Service is interested in a continuation and is investigating the possible use of the ATS-6 or the Communication Technology Satellite (CTS).

2.5.3 CTS Satellite Health Care Experiments

The Communications Technology Satellite launched in December 1975 also will be used to test several health/medical service experiments. Three experiments in this area are summarized as follows:

1) Health Communications. This experiment will conduct biomedical, clinical and continuing medical experiments among the 30 participating hospitals.

2) Biomedical Communications. The purpose of this experiment is to promote the distribution of information between research institutions and the medical community. The experiment will also evaluate broadband teleconference to support continuing education among health care professionals.

3) Communications Support for Decentralized Education. This experiment will define methods to improve techniques for administration and teaching, as well as procedures for decentralized medical education.

2.6 The Social Services Satellite System Concept

As evidenced from the preceding discussions there is an unfulfilled and growing need for more and better medical service communications and medical education which can be met by satellite communications technology. In a February 1975 article written by the Department of Health, Education and Welfare Office of Telecommunications Policy, (ref. 6) the potential for a "Social Services Satellite" is described and the following description of the simplest system is given.

The simplest system, which could remain at the heart of a later more complex system, would consist of a broadcasting satellite (or part of a satellite sharing a bus with other services) with one TV-grade channel and several audio-grade channels. One of a few video uplinks would originate programming going to thousands of receiving sites, a few percent of which would have audio uplinks. Operating the satellite, uplink transmitters and the originating stations' receivers might cost $1,000 per hour ($8,700,000 per year). For 1000 receivers, supporting the satellite and uplink could cost each participating institution $1 per hour. By comparison, distributing by video tape costs about $90 per hour per institution. Assuming a hundred or more individual users at each institution, the cost per user-hour would shrink to pennies or less. The cost for operating the local receiver is not included in this estimate. For one year, $5,000 should adequately cover the operation of a receiver and video tape unit, maintenance, and power. An audio link might raise the cost to $8,000. For 24 hours per day use, the cost would run about 60 cents per hour for each using institution. The cost per individual user-hour once again becomes pennies or less. In fact, a local station could be profitable with only one user for each program at a cost of 60 cents per hour.

It is interesting to compare the cost of the delivery system to the cost of the programming that it would carry. According to the article, programming of acceptable-to-professional quality costs from $10,000 per hour to over $100,000 per hour. Thus, programming costs far more than the satellite and uplink at $1,000 per hour. Since operating the receiving installation per hour costs approximately the same as the satellite and uplink, operating the complete satellite delivery system costs far less than the programming it delivers. This is not only appealing, it is necessary, if quality, worthwhile social service programming is ever to be made cost-effective on a per-user-hour basis. Expensive programming needs a large audience to reduce its per-user-hour costs to reasonable amounts, but this will mean little if marginal distribution costs remain high. Today the high costs, long time delays, and awkwardness of distribution systems present the main impediments to the massive use of quality audio-visuals for educational or social service uses.

In addition to delivering audio-visual programming, the basic system could link up with a wide variety of data processing, terminal, and storage devices. The video and audio bands could carry various data or other digital traffic part-time. Remote sites in certain regions could use one or two audio transponders for feedback or special purposes. In most areas, however, the telephone would serve adequately for most feedback. Interactive video is not anticipated as a major activity, although with several uplinks sharing the one TV transponder, a sort of shared circuit interactive TV would be possible for special purposes.

Much more work must go into conceptualizing and defining services which can exploit the reach and economic advantages of satellite delivery. HEW has begun working with knowledgeable professionals in the service areas themselves to optimize these concepts. It has already become clear that, in addition to satellite broadcasting delivery, operating systems would eventually include, or connect to, feedback circuits, either satellite- or land-based, one-way, two-way and pay-TV, video cable, computers and terminal equipment, signal-controlled or time-controlled video recorders, frame stoppers, learning systems (Ticcit, Plato), and perhaps other specialized systems to come.

Developing these systems and penetrating the markets which, though huge, may only slowly change their ways, will require much planning and effort on the part of the Federal government, the potential users, and industry. Such a disaggregated market is difficult for industry to deal with, since the satellite delivery system itself is a single whole. HEW is working toward the creation of a user consortium which could present industry with a single "customer" or at least act as a wholesaler of communication capacity. Meanwhile, the market represents an untapped but enormous potential for both service and profit which should both stimulate and challenge the satellite communications industry.

3. Educational Telecommunications

3.1 Introduction

The development of educational telecommunications through the use of the previously described social services satellite system concept or through other satellite systems would facilitate resource sharing and greater productivity in the education sector. It will also improve access to educational opportunity for those groups who are educationally deprived, including communities isolated by both geography and lack of communications.

There are currently numerous financial and social pressures at work on the education sector which may help to bring about large scale utilization of telecommunications. Among these are demands for 1) further equalization of educational opportunity regardless of residence or financial status; 2) education more responsive to the needs and abilities of the individual learner; 3) greater productivity; and 4) services to segments of the population previously not included as regular clients of the formal education system. These include people requiring job retraining; people needing continuous updating of knowledge in their career specialties; people preparing for occupational advancement; people seeking education for personal enrichment; and people confined to hospitals and prisons or handicapped people. These services, and some of their delivery mechanisms, are known as "non-traditional education." The spontaneously evolving adult-education, open-university, medical and professional extension courses, and corporate-training programs attest to the need for non-traditional education. Escalating energy and travel costs will increase this trend making it increasingly efficient to substitute communications for transportation and bring the learning to the student. The high cost of programming necessitates nationwide expense sharing.

3.2 Medical Education

Medical training demands current information and course material to keep the student and practitioner up-to-date with a rapidly expanding body of scientific knowledge. Furthermore, the knowledge gained in earning the professional degree no longer suffices for the lifetime of the practitioner. The medical worker must continue his medical education to maintain professional competence. Legislators and professional societies increasingly recognize this need in requirements for mandatory postgraduate training. At the same time, heavily burdened medical practitioners cannot, in most cases, interrupt their practices to attend conventional schools.

In fact, the unmet demand for medical services has exerted pressure for shortened degree programs, larger numbers of graduates, and increased paramedical training. Existing educational facilities and programs, the personal resources of potential students, and the efficiency of education limit fulfillment of the needs.

An unfulfilled and growing need for more and better medical education awaits a satellite service. A demonstrated interest and acceptance of audio-visual media and local or regional telecommunications delivery already exists. Maximum efficiencies, including high quality and low cost, could result from large-scale national or even international resource sharing. Medical science seems to lend itself to universally acceptable and valid educational materials. The Association of American Medical Colleges is gathering a national library of educational materials and establishing a Biomedical Communications Network.

3.3 Large-Scale Electronic Delivery of Early Childhood Education

Early childhood educational services may be delivered either to an institutional setting (including day care centers, pre-schools, or teacher training institutions) or to a home setting (an individual home or Family Day Care Home). Early childhood education may therefore be either a group or an individual experience.

Determination of a precise geographical coverage area is related to the notion of institutional control. Since the content of pre-school educational programs may vary among institutions if in a given locality, delineation of a distinct geographical coverage area may be difficult to ascertain. State-wide efforts to provide some degree of coordination on a higher level would provide manageable units.

A wide-ranging audience, bounded by common interest rather than geography, may be defined and attracted by programming designed to address itself to that audience. For early childhood education, three potential audiences may be defined:

1) preschoolers who would be the recipients of early childhood education;

2) parents of preschoolers who would receive training in maximizing effectiveness for encouraging learning and development if in the everyday environment, and

3) educators of preschoolers who might receive either initial training or continued training.

Technology applied to the field of early childhood education usually means television. Television appears to be the one medium of the broadly-based capabilities to transmit the type of programming needed for this market. Educational programming is available on both commercial and public television outlets to serve the preschool learning audience in some areas.

3.4 <u>Non-Traditional Education</u>

Traditional academic institutions display a widespread and growing interest in offering non-traditional learning and degree opportunities for several reasons:

- Many students cannot reach distant classrooms.
- Many students must study at their own convenience because of work or household duties.
- Many students cannot afford traditional education.
- Many students, particularly older ones, fear or dislike the traditional classroom setting and competing with youthful classmates.
- New traditional facilities are prohibitively expensive.
- Teachers are increasingly expensive.
- A general national commitment to equal opportunity for education has developed.
- A philosophy is spreading that learner-directed education is best.

Many colleges and universities have begun programs in open learning. Some use telecommunications to deliver part of the material, yet the concept is still new.

Libraries are developing into multimedia knowledge service operations. Distributing reference information, audio-visuals, and publications electronically would give every library access to almost unlimited knowledge resources.

3.5 Use of Satellites in Education

Not every educational telecommunications service will involve the use of satellites. The United States already has an elaborate telecommunications infrastructure, consisting of telephone lines, broadcasting, point-to-point and multipoint microwave and, more recently, cable. Satellites will have their greatest impact in providing services which accent the unique features of satellite technology, handling tasks which the terrestrial system can't handle or providing existing services more efficiently. In the total mix of services, satellites have four primary roles to play:

1) networking members of widely dispersed groups with common educational interests for distribution of materials from a central point or for teleconferencing over audio or video channels;

2) delivering high quality educational materials to small and remote users and providing return link capability for addressing information resource centers or computer-aided instruction centers;

3) interconnecting state and local networks with regional or national computing and instructional resource centers, including linking broadcasting stations and CATV systems with program centers; and

4) interconnecting local, state and regional networks among themselves for resource sharing, including

networking of public broadcasting stations for sub-national programming and feeds to program assembly centers; also including interconnection of libraries for interlibrary loans and other sharing applications.

The launch of the ATS-6 satellite by NASA provided new impetus for the use of satellites in education. The ATS-6 experiments included a series of Health, Education, Telecommunications (HET) Experiments. These experiments were designed to test the performance and effectiveness of the satellite relay of educational programming and health care delivery. This is the first time that satellite communications is used for the transmission of television and multiple voice channels to low-cost Earth stations. The experiment provides high performance reception utilizing fixed position parabolic antennas with a diameter of at least ten feet at the ground receiving stations.

The HET experiment consists of the following four components:

1) Applachian Regional Commission (ARC). The ARC will provide the results from a series of educational experiments where an Applachian educator will be able to receive course credit for taking a pre-taped televised course, submit questions via teletype transmission, obtain immediate feedback to the preceding pre-taped video course material, initiate computer and

manual searches for both educational materials designed to fit a particular student's needs and materials to guide students in career choices.

2) Veterans Administration (VA) Experiments. The VA experiments use the ATS-6 for biomedical communications in the categories of video seminars, outpatient clinic, consultation clinic, computer assisted instruction, and slow scan technical experiments.

3) Satellite Technology Demonstration. The Satellite Technology Demonstration was divided operationally into two sections -- Rocky Mountains East and Rocky Mountains West. It investigated the feasibility of broadcasting educational television and providing via satellite other media services to audiences in rural isolated areas.

4) Alaska Education Experiment. The objective of this experiment was to develop information needed to improve the quality of planning to meet specific telecommunications needs in the state. The topics selected in which to develop course material for broadcasting over the satellite are Instructional Programming, and Interactive Health, both on the elementary grade level, and Viewer Defined Programming and Public Broadcasting Service/National Public Radio Interconnection, both designed for the general population.

Subsequent experiments in the use of satellites in education are being pursued on the Communications Technology Satellite launched in December 1975 which is now in orbit. Five experiments were selected in this area and the objectives of each of these are given below:

1) College Curriculum Sharing. This experiment is designed to expand the scope of curriculum by sharing classes among universities and countries. It will demonstrate digital video compression techniques for bandwidth and power reduction.

2) Appalachian Educational Satellite Project II. The objective of this project is to strengthen the teaching system in Appalachia by improving teaching skills and increasing the information available to the students. The project will also allow for graduate courses and credit for the teachers.

3) Health Education Television. This experiment is designed to make available both live and pre-taped continuing health education programs for the use of health care facilities, no matter how remote.

4) Project Interchange. This project will serve teachers in scattered parts of the country. It will involve the continuing exchange of materials and teaching techniques related to computer aided instruction.

5) Satellite User Network (SUN). This experiment will investigate a telecommunications system requiring little human support. It will also provide data on counseling, job preparation, employment, and career development.

3.6 Educational Satellite System Components

A satellite-based educational delivery system will be a configuration of four basic components, as shown in Figure 2 (ref 7).

1) PROGRAM SOURCES
   a. Producers and Distributors
   b. Storage and Origination Points -- locations where software is collected, processed and loaded into the transmission system.

2) TRANSMISSION
   a. Satellite segment
   b. Earth terminals (receive only & receive/transmit)

3) LOCAL/REGIONAL DISTRIBUTION

   Communication links between satellite earth receiving terminals and final delivery points or between program storage/origination points and ground-to-satellite (up-link) transmitting stations.

4) USERS

   The term "user" is used to connote one or more individual learners; households; institutions where

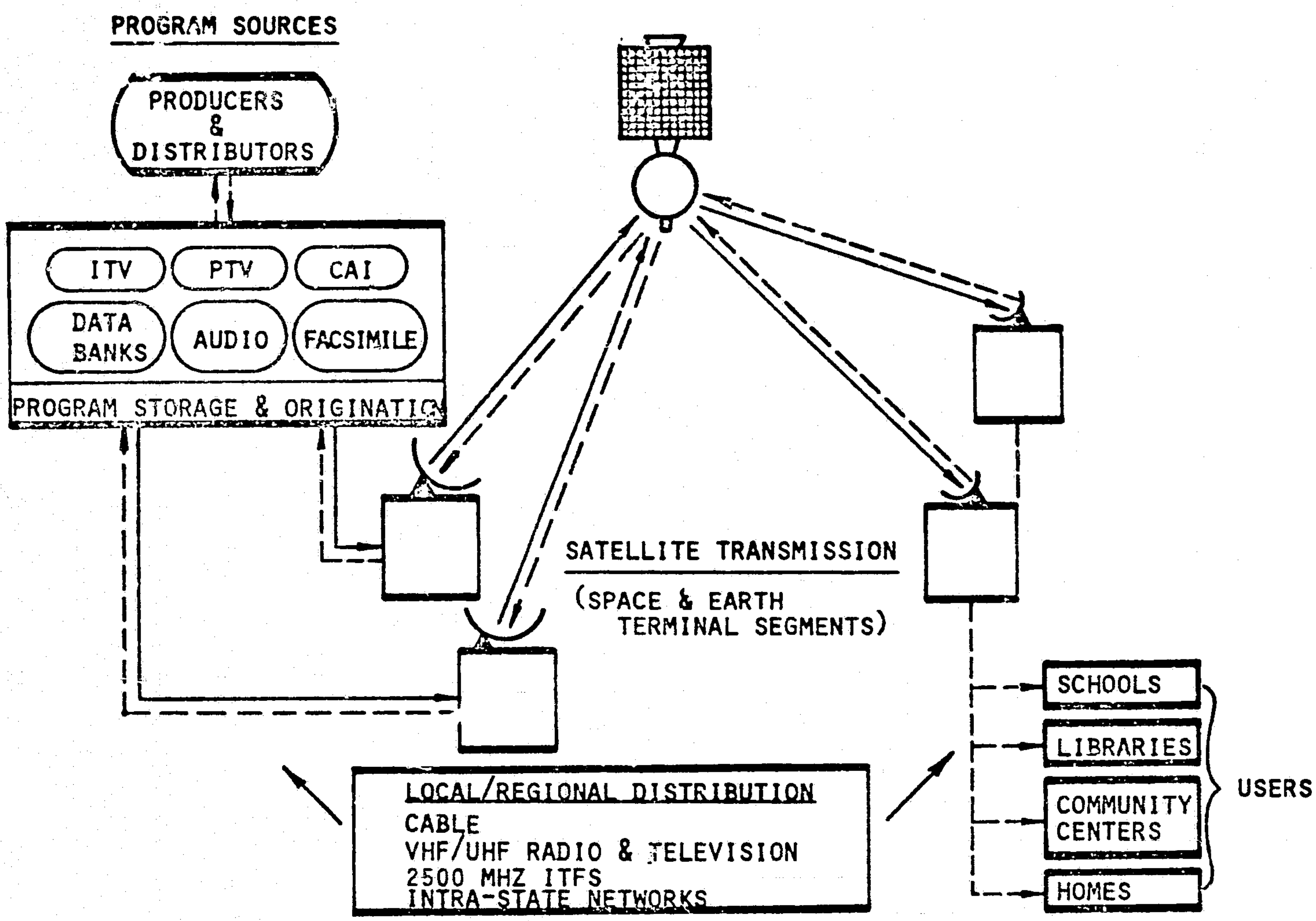

FIGURE 1
EDUCATIONAL SATELLITE SYSTEM COMPONENTS

Figure 2. Educational satellite system components

learners go to participate in the educational system (e.g., schools, libraries, community centers); organizations formed to coordinate system utilization by constituent groups and institutions.

4. Value Transactions

4.1 Introduction

The increasing volume of funds transfers processed each day, the Federal Reserve System's participation in automated clearing house (ACH) operations, the Air Force and Industry's Direct Payroll Deposit Projects, the Treasury's announced plans for the conversion of Government checks to electronic funds transfer items, the direct deposit of Social Security welfare checks and similar value transactions all presage a new generation of payments mechanism.

The Federal Reserve System as the central banking authority of the U. S. is playing a major role in this market. The FRS is using advanced technology to combat the problem of information flow by developing the Federal Reserve Communications System (FRCS) into a communications system capable of processing current applications as well as accommodating the gradual build-up of a high volume of transactions through the electronic funds transfer system (EFTS).

At the present time, the Federal Reserve member banks physically transfer checks from one region to another by airplane pouch. Banks within a region send checks by messenger to the head regional bank. This traffic usually take place between 6:00 p.m. and 8:00 a.m. Payroll checks of a repetitive nature (i.e., the Air Force payroll) are reprocessed into magnetic tapes by the regional member bank and then sent to other regional banks by airplane pouch.

Automated check handling is done through an association of banks. In some cases, a Federal Reserve branch bank processes the magnetic tapes and credits the receiving banks with a fund amount. Some regional ACH associations call on the Federal Reserve System for services. As an example, for banks located in the Mid-Atlantic states, the Middle Atlantic Automated Check Handling Association receives this service from the Baltimore branch of the Federal Reserve Bank.

4.2 The Existing System

The Federal Reserve Communications System, through its present notification procedures, provide the facility for the direct transfer of funds between member banks, anywhere in the United States, in a matter of minutes. The accounting and distribution of these transfers are accomplished in a large part by the regional Federal Reserve offices. If a transfer involves two Federal Reserve Districts, it is sent to the central message-switching center at Culpeper, Virginia, for transmission to the appropriate receiving Reserve Bank. Each Federal Reserve Bank has a computerized communications switching system with on-line terminals in large member banks and medium-speed data links to the central switching center at Culpeper.

The FRCS is designed to provide a high level of protection against lost messages or disruptions of communications services in the event of failure in key system components. Essential equipment and communications links are duplicated.

Communications system at Culpeper is the hub of the FRCS. All interdistrict message traffic flows through this system, which consists of four individual computers operating in a store-and-forward message-switching environment. The Culpeper switch receives a message, stores two copies of the message internally in separate places until the intended recipient is available, and then forwards the message to the addressee. The central switch also keeps file copies of all messages that pass through it, should future reference be necessary. The system is designed to rapidly handle the receiving and relaying of messages among th 2 Federal Reserve Banks, their 24 branches, the Federal Reserve Board, and the U. S. Treasury. Any type of message, whether quantitative or narrative, can be transmitted by the system.

An important feature of the system is that the kinds of terminal units located at each of the Federal Reserve offices can vary considerably. Standardization is achieved through the use of a universally adopted code in which all messages are phrased and transmitted. This code, which can be handled by several types of terminal gear, is ASCII, American Standard Code for Information Interchange. The code is a communications language which, in addition to actually transmitting information, executes its own internal check on the accuracy of the information transmitted.

The equipment at Culpeper and the District communications switches have considerable expansion capability and can accommodate additional communications circuitry. This will permit substantial growth in the volume of messages switched at Culpeper, including funds transfers, security transfers, and administrative-type messages. Thus, necessary growth can be achieved in an orderly fashion by exercising one of the many available expansion options as message volumes increase.

4.3 Message Categories

There are three basic types of messages:

1) Wire Transfers - These are used to transfer funds between Federal Reserve District Banks. Every inter-district transfer must go through the FRB's fund transfer system. A significant amount of each message constitutes message protection. In this instance protection refers to the use of accounting procedures and repetition for assurance of freedom from errors, rather than the use of security or secrecy procedures. Additional protection is provided by the equipment, which has parity techniques inherent in its mode of operation.

Timely processing and delivery of wire transfers is extremely important because of "float". Float is a phenomenon which occurs because the time actually taken to collect checks is often longer than that allowed in the schedules. This crediting frequently occurs before the account of the bank on which the check is drawn is debited. Float is sometimes sizeable and serves as a measure of the amount of Federal Reserve Credit generated by the national check collection process and available to the member banks.

2) Security Transfers - Security Transfers are transacted between Member Banks and between Federal Researve Banks. In addition to these usual Security Transfers, the Federal Reserve system also buys and sells securities in the open market as it accommodates seasonal demands for money and credit, attempts to offset cyclical economic swings, and supplies the bank reserves needed for long-term growth. The net change in its securities portfolio tends to be comparatively small over a year, but over the same period the

system undertakes a large volume of transactions, purchases and sales combined, in response to seasonal and other temporary variations in reserve availability.

Timely processing of security transfers is extremely important because of the fluctuation in value of the securities. The same system of message protection used for wire transfers is also used for security transfers.

3) General Administrative Correspondence - These messages are principally narrative in nature. For this type of traffic, message protection procedures are usually not applicable.

4.4 Projected Requirements

The adequacy of any communications system, or the need for its expansion, can be determined only if a clear description of future demands on such a system is available. The most significant increases in FRCS daily traffic will result from the electronic distribution of Treasury credit items and from automated payroll deposits for the Department of Defense.

A recent article in Money (ref. 8) stated that by 1980, an estimated 40% of the Government's $44 million monthly payroll will be automatically deposited into the employees' bank accounts. This will mean a savings of $25 million annually. Some companies, such as Hewlett-Packard, Xerox, Dow Chemical, and General Electric, presently deposit their employees payroll checks directly into their accounts.

The messages now being processed interregionally within the FRCS are either funds tranfers, securities transfers, and administrative messages. Projections for future growth of these types of messages are based on the following assumptions (ref. 9):

- Large dollar value transfers will continue to require priority transmission within the FRCS.
- The annual growth rate for this traffic will continue in the pattern established in 1972 and 1973 - that is, an annual growth rate of 20 percent for funds transfers and securities transfers and 6 percent for administrative messages.
- Message length will continue to average 225 characters.
- The remaining District communications switches will be installed during 1974, and most intradistrict message traffic will not be sent through the central switch at Culpeper after that time.

- The interdistrict distribution of these messages will remain in the same proportion between now and 1980.
- The current operating procedures for this type of traffic will be retained through 1980.

These assumptions were applied to the 1973 statistics and distribution patterns for the Culpeper center to produce volume projections for large-dollar transfers. The total volume of these transfers is projected to reach 50,000 messages a day (double the 1973 level) by 1978 and to exceed 75,000 daily by 1980.

4.4.1 Checks and Credit Transactions

As indicated in Figure 3 (ref. 10) the number of checks written in the United States, about 70 million each working day, is growing at a rate of approximately 6 percent per year. Credit transactions are growing at about 12 percent per year. All of these transactions are directly replaceable with some form of electronic funds transfer system. Summing both check and credit transactions, the potential number of items involved are 56 billion, 135 billion, and 340 billion transactions per year for 1970, 1980, and 1990, respectively. Converting these figures to bits per year at a rate of 50 characters/transactions and 8 bits/character yields 1.4×10^{14} bits/year in the year 1990.

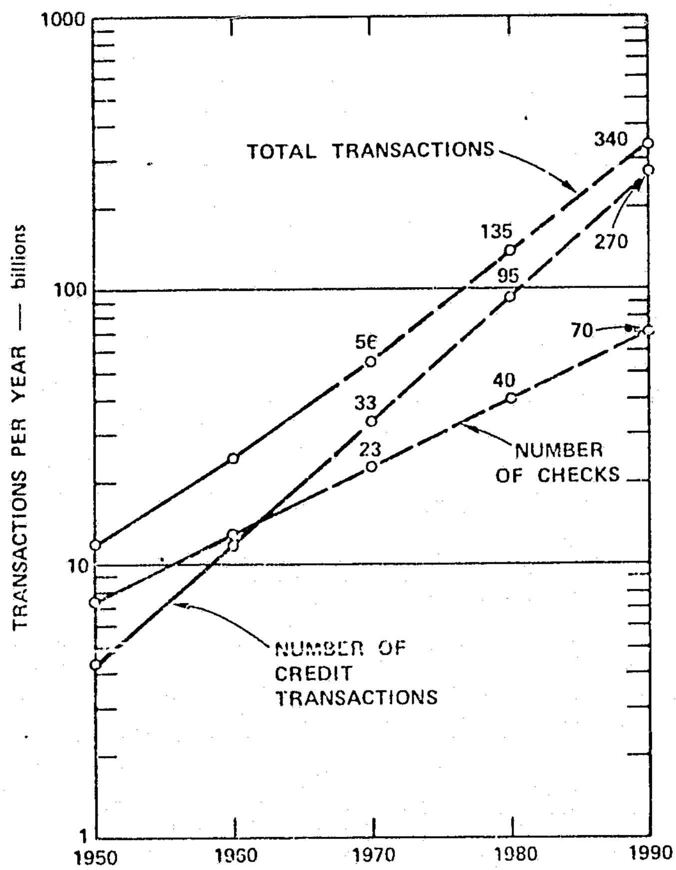

Figure 3. Check and credit transactions

4.4.2 Economic and Financial Data

The use of communications facilities for the collection and dissemination of economic and financial data will increase during the next few years. Currently, the data transmitted consists almost entirely of Transmission of Edited Deposits Series (TEDS) information. Projections for growth are based on the following assumptions (ref. 9):

- More than 90 percent of the economic and financial data will continue to flow between the Board of Governors and the Reserve Banks, with the remainder flowing between the Reserve Banks.
- The total volume of electronically transmitted economic and financial data will increase at a rate of 10 percent per year from present levels.
- The volume of time-critical information flows will not have a significant impact on daily communications requirements.
- Projections do not provide for any interactive applications.
- Use of the FRCS for interdistrict transfers between Federal Reserve operated ACHs will be initiated in 1977. There may be isolated cases where this will be started at an earlier date.

- The Federal Reserve will continue to process 40 percent of the national check volume.

- The proportion of Federal Reserve-operated ACH items that are interdistrict in nature will continue to be 26 percent.

- The nationwide distribution of payments items will continue to follow the patterns currently experienced.

- ACH payments transactions will follow traditional procedures, that is, all services, distributions, and organizational relationships and activities will remain constant.

- By 1977, Federal Reserve-operated ACHs will be processing 1,000,000 items per month, and generating 260,000 interdistrict items for transmission through the FRCS.

- The annual growth rate of total check volume will be 7 percent, resulting in a total check volume of 44 billion items in 1980.

- By 1980, 4.7 percent of the total number of checks written in the United States will be handled as ACH payments transactions.

- The proportion of interdistrict ACH items processed through the Federal Reserve's communications facilities will be 0.5 percent of all items in 1980.

These assumptions lead to an estimate that the average monthly volume of interdistrict ACH items processed by the Federal Reserve will reach 18 million items in 1980. An initial monthly volume of 260,000 interdistrict ACH items will be processed by the FRCS by 1977.

Consolidation of these estimates, as shown in Table 7 (ref. 9) indicates that applications involving electronic funds transfers will start in 1975 when the Federal Reserve will begin to process 250,000 electronic payments items per pay period to support the Air Force payroll. By 1977, the demands upon the system for this type of application will increase to 4.26 million items per month. The addition of interdistrict ACH items and growth in other areas will demand that the Federal Reserve process 44.5 million electronic payment items per month by 1980. Under the most favorable conditions - uniform distribution of volume throughout the month - the FRCS can anticipate an average daily processing volume of 2.1 million items in 1980; however, peaks substantially in excess of this number will occur.

TABLE 7. PROJECTED MONTHLY VOLUME OF NEW APPLICATIONS FOR THE FRCS

(In thousands)

Application	1975	1976	1977	1978	1979	1980
Department of Defense						
Items	500	750	1,000	1,260	1,530	1,800
Messages	178	267	356	448	544	641
Treasury						
Items		350	3,000	9,000	16,000	24,700
Messages		125	1,068	3,203	5,694	8,790
Inter—ACH						
Items			260	3,500	9,400	18,000
Messages			93	1,246	3,345	6,406
TOTAL						
Items	500	1,100	4,260	13,760	26,930	44,500
Messages	178	392	1,517	4,897	9,583	15,837

Figure 4 (ref. 9) shows the interdistrict portion of the projected traffic volume that the FRCS can be expected to process by 1980. It is apparent that the large volume and dynamic growth rates associated with the new electronic funds transfer applications present the most significant demands for communications service the Federal Reserve System will encounter between now and 1980.

4.5 Expansion Alternatives

A number of alternatives for expanding the FRCS are available to meet projected capacity requirements. Several of these alternatives are discussed in the following paragraphs.

Characteristically, increased capacity can be obtained through more efficient use of existing communications links or by means of small changes in network configuration. The modifications can be implemented in a minimum amount of time and with modest resources and will not change basic message-switching or transmission procedures.

For example, by the addition of direct communications lines between District processors, interdistrict capacity is increased with minor changes in message-switching programs or installed equipment. Bypassing the central switch at Culpeper relieves the the upper limit for interdistrict transfer volume imposed by the switch capacity. Retention of the same procedures for computer-to-computer exchange that are currently in use between Culpeper and the Districts minimizes the impact on individual District switches. Implementation of this alternative is readily available with current technology.

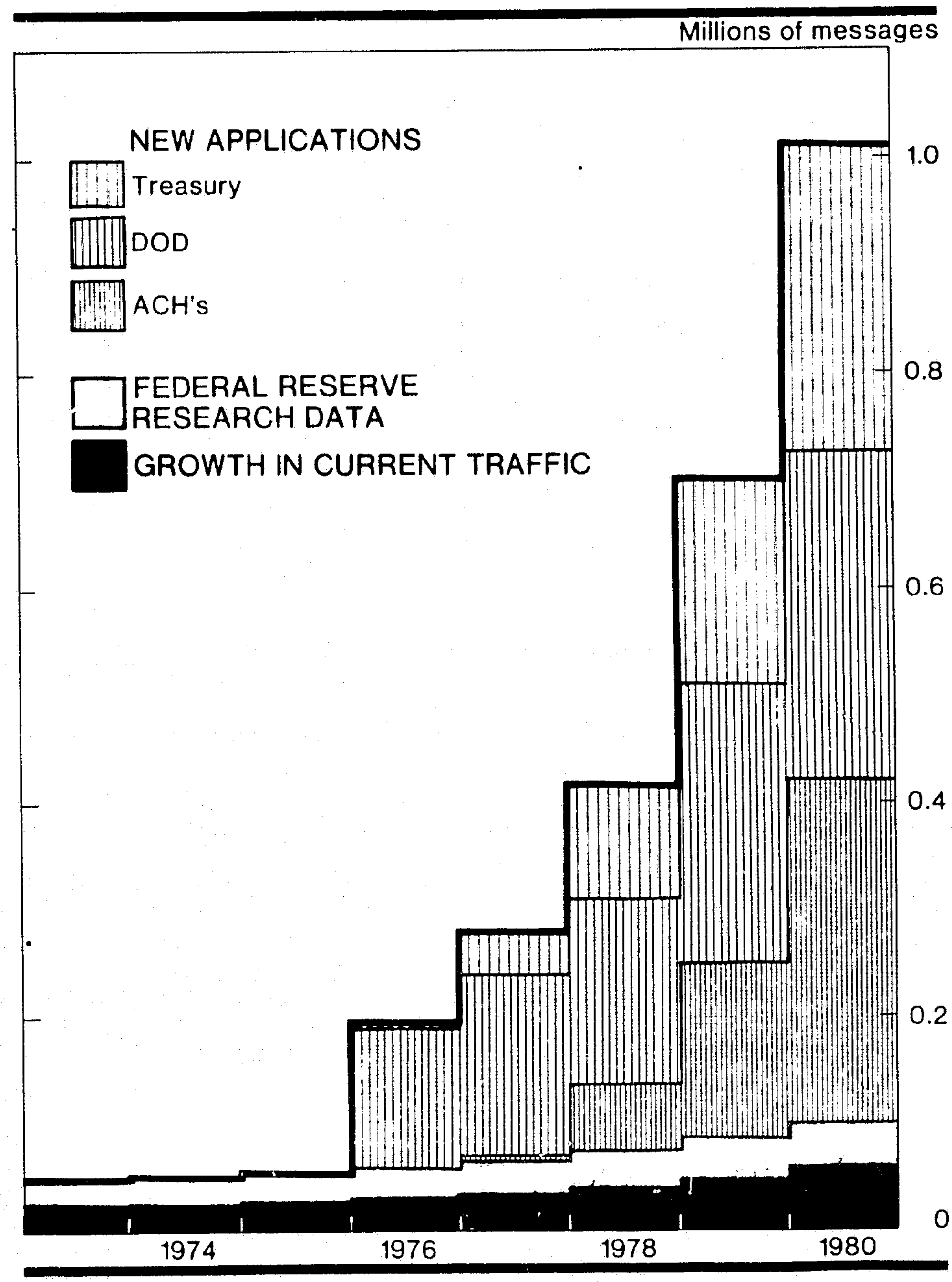

Figure 4. FRCS interdistrict volume projections for peak day

Another possibility for expansion is to increase the efficiency and utilization of existing components of the system. Established techniques in data communications, such as data compression or message batching, could be accomplished with modest investment of resources in the communications processors installed throughout the existing Federal Reserve Communications System. The implementation of these techniques would require careful coordination throughout the System. Nevertheless, existing operational procedures and management structure should be adequate to provide the required coordination and supervision to implement these improvements when the need arises.

Particularly effective improvements would result from the use of revised transmission procedures to accommodate the new electronic funds transfer applications. Inasmuch as the majority of the EFTS information will be computer generated, improved transmission efficiency can be achieved by exchanging interdistrict data in bulk form, as computer files, rather than as messages that must be independently formatted and transmitted. A suggested transmission procedure, incorporating compression message batching and bulk file transfer, is being developed.

Logically, the current investment in communications software and computers should be applied toward support of long-range communications requirements. The limitations that dictate change by 1978 stem from the current combination of computers, computer programs, and the communications network that connects them. A major change in any one of these areas could materially increase the usefulness and capacity of the Federal Reserve communications resources. Installing additional computers to share the processing load at Culpeper, reprogramming existing processors, or providing supplemental services such as dial-up data links would substantially expand the Federal Reserve aggregate interdistrict transmission capability.

The existing computer system at Culpeper can be modified to increase its capacity by replacing the present magnetic disks and disk packs with faster and larger capacity equipment, or by up-grading line termination equipment, to handle higher line speeds. In addition, the currently installed computers could be modified or replaced with new processors to increase the present capacity. In a report prepared in December 1972 (ref. 11), the Culpeper staff presented configurations of additional hardware that could be added to the Culpeper center and summarized the benefits and expenditures that would result. The report estimated that $800,000 of additional equipment would provide a 75 percent increase in processing capacity at Culpeper.

Another possibility for increasing interdistrict communications capability would be to leave Culpeper's current capacity unchanged and to procure independent, supplemental communications services to accommodate the excess volume of message traffic.

Several communications techniques other than the present FRCS operating concepts have been evaluated by the FRCS as potential supplemental transmission systems. The advantage of procuring such supplemental service is that it can be added in increments, as increased capacity is needed, without interfering with current system operations. The FRCS studies concluded that operation with multiple concepts and systems could lead to proliferation of equipment, inefficiency in operations, and a breakdown of system-wide accountability.

The possibility exists that the wisest long-range plan for the Federal Reserve System may be to completely replace the current system when its original design constraints are reached. If this course of action were pursued, the risk of deterioration within the existing system during changeover would be minimized. The system-wise planning, coordination, and resources required for the new system, however, would be of significant magnitude; sufficiently so, in fact, as to suggest that it may be unrealistic to assume a new system could be in place much before 1980. In view of this, the FRCS study noted that any system effort directed at replacement of the current FRCS should, at least in the initial stages, coincide with but not displace efforts directed at expansion of the existing facility.

The Federal Reserve has not conducted advanced studies relating to the potential use of satellite communications systems. Satellite systems could be used for this type of service although the data rate is not high enough to justify a dedicated satellite. Leased services might eventually prove to be cost effective.

5. Law Enforcement

5.1 Introduction

Crime in the United States is a phenomenon of national concern. Crime rates have increased over the past decade making it necessary to initiate programs at all levels of government (local, state and federal) to deter crime and to improve the effectiveness of the criminal justice system. Greater resources are being made available to the system for more personnel, modernization of facilities and equipment, and introduction of new hardware and operations technology.

Along with many other sectors, the criminal justice system is experiencing an "information" explosion with a greatly increased capability to gather, process and transmit information. This system is also under steadily increasing pressures for more information and reduced response times. For the effective administration of justice, information must be made available rapidly on the identity, location, characteristics and description of the offender. Improved officer safety and the increasingly stringent legal requirements to protect the rights of the individual place enormous demands on crime information systems. Information is required quickly and accurately not only for the apprehension of criminals but also because of the strong necessity to avoid the use of inaccurate information which can have adverse reactions in the form of legal actions against the law enforcement community.

In response to the need for improved information systems, local, state and federal law enforcement agencies have begun work on both specialized information storage and retrieval systems and telecommunication systems that will ensure user access to the information files and the exchange of administrative messages with other agencies.

The present interstate telecommunications systems must be modified or expanded to support larger traffic loads and the introduction of extended and new functions. There are few existing provisions for handling data on organized crime or interfacing with crime labs. The introduction of new data transmission requirements, such as the transmission of fingerprint information, will greatly increase the loading on the present networks and will require substantial upgrades.

5.2 Existing Information Systems and Communication Networks

Two major law enforcement information and communications networks are in use at the present time: the National Crime Information Center (NCIC) and the National Law Enforcement Telecommunications System (NLETS). NLETS provides a state-to-state administrative communication capability but has no central data files, whereas NCIC provides a state-to-national near real-time access to data files on stolen vehicles, stolen property, wanted persons, and criminal histories.

Other major law enforcement networks, such as the Kansas City, Missouri, ALERT System, Cincinnati CLEAR System, and several others, have been implemented on a regional basis. These networks provide service to many clients in the regions in which they operate and will be considered in the development of concepts for the NALECOM System.

5.2.1 NCIC

NCIC is a computerized information system established to provide a service to all law enforcement agencies at local, state, and federal levels. The system is essentially a computerized index to documented police information concerning crime and criminals of a nationwide interest. The FBI is responsible for operating NCIC, with data files and supporting equipment located in Washington, D. C.

The NCIC is presently capable of handling 48 134.5-baud terminals, 140 110-baud terminals, and 12 2400-baud terminals. Practically all these terminals are in use at the present time, and the NCIC is in the process of an upgrade to accommodate additional traffic.

Eight data files make up the NCIC data bank, including wanted persons, stolen vehicles, stolen license plates, stolen articles, stolen guns, stolen or missing securities, and criminal histories. There were over four million data and index references as of 1972, and it is anticipated that a substantial increase in the criminal history file will be experienced over the next several years.

A number of types of messages are permitted against each file including inquiries, tests, entries, clears, cancels, modifies, and locates. These message types are handled on line in real time; each receives a response from the computer on a one in, one out basis without priority.

The incoming messages are confined largely to inquiries (57%) and entries (8%). The average incoming message contains 50 characters, and the average outgoing message 85 characters. The latter can be expected to increase if the CCH files are built up at the national level since criminal history records typically contain several hundred characters per record.

The NCIC network was initiated in 1967, and transactions against the system in 1968 were approximately 7 million. The 1973 transactions are estimated at 37 million, based on June and July averages.

5.2.2 NLETS

The second major system, NLETS, is owned and operated as a nonprofit corporation by its participants, the law enforcement communications authorities of the fifty states. Beginning with a torn tape teletype system and upgraded to a low-speed computerized switching system with facilities in Phoenix, NLETS recently installed a fully computerized switch system at Phoenix.

The present configuration, which became operational in December 1973, provides a single dedicated line to each of the 48 contiguous states. It also provides communications capabilities to the FBI (NCIC) and the Treasury Enforcement Communications System (Bureau of Customs) for interconnection with state and local law enforcement agencies.

NLETS carries message traffic in accordance with the desires of its users. This message traffic consists primarily of vehicle and driver registration data and administrative messages.

Recent traffic volume (April 1974) is at the annual rate of 3.5 million messages with an average message length of 240 characters per message. By December 1974, 36 states, representing 85 percent of the nation's population, are expected to have computerized interface with NLETS.

Most of the data used in traffic projection analyses in the following paragraphs was derived from the previous configuration of NLETS and was taken from the JPL study on National Criminal Justice Telecommunications Requirements (ref. 12). Sufficient data from the new configuration was not available for inclusion in this report. For this reason, reference is sometimes made to "circuits," a concept which is not applicable to the present NLETS configuration.

5.3 Future Needs

A list of potential growth factors extracted from various master plans for criminal justice information systems prepared by state planning agencies is given in Table 8 (ref. 12). The list is divided into two main areas: 1) expanded access to existing data banks; and 2) expanded data types, services, and users. Expanded access includes the installation of additional terminals and the increased use of criminal history records. Expanded data types include a full implementation of the Computerized Criminal Histories (CCH) system. CCH traffic is assumed to start in early 1976 and reach full-scale usage by early 1980. Other new data types include fingerprint and video transmissions, general support for crime analysis, resource allocation, and other services. The National Law Enforcement Telecommunications System (NALECOM) network which has been under study by the Law Enforcement Assistance Administration (LEAA) is expected to meet these requirements.

5.3.1 NALECOM - The User Community

The purpose of the NALECOM network is to provide efficient telecommunications capable of transporting information between criminal justice agencies on a nationwide scale.

Agencies within the criminal justice system are generally divided by type of function and geographic jurisdiction. These are not unique divisions, and a great deal of overlap exists. The most common functional categories are:

TABLE 8. GROWTH FACTORS

- Expanded Access
  - Criminal Histories
    - Courts
    - Prosecutors
    - Probation/Parole
    - Corrections
  - Expanded In-Kind User Access (Added Terminals)
  - New Users
  - Mobile Digital Terminals
- Expanded Information Services
  - OBTS
  - Parole/Probation Data Centers
- Expanded Support Services
  - Crime Analysis
  - Criminal Intelligence Information
  - Criminalistics Information
- Expanded Identification Activities
  - Fingerprint Transmission and Identification
  - Video Transmission
- Reference Files

- Law enforcement
- Prosecution
- Adjudication (criminal courts)
- Probation and parole
- Correctional institutions
- Other, including crime labs and various criminal justice communications

Geographically, the system is divided by city, county, state and federal.

5.3.2 NALECOM - Analysis and Predicted Growth of Present Systems

The National Law Enforcement Telecommunications System (NALECOM) is envisioned as a combination of two functions: state-to-state communications including controlled automated access to state-based files and state-to-national traffic with automated access to a national crime data file. The states retain control over crime data and can determine which data can be given to the national file or retained within a state file.

NALECOM is expected to accommodate concepts involving both state and national crime data banks, using combinations of state-to-national and inter-state communication links. Regional switching centers or concentrators may be used to facilitate network linkage, but regional data banks are not believed desirable or feasible.

In order to develop traffic projections for NALECOM (Table 9, ref. 13) data was used from an existing state-to-national network (NCIC) and from a state-to-state network (NLETS). Since its inception in 1967, NCIC has accumulated comprehensive data records on traffic volumes, providing an excellent data base for NALECOM state-to-national projections. NLETS has not monitored system traffic at a detailed level, and a less substantial data base is available.

TABLE 9. SUMMARY OF NALECOM TRAFFIC PROJECTION FOR 1983*
(BEST ESTIMATE)

Item	State-to-State 1983			National 1983			1983 Total BPS (Averaged)
	Message Volume-10^6/Year	Average Characters/Message	Average BPS	Message Volume-10^6/Year	Average Characters/Message	Average BPS	
1. Current Uses Projected (Includes MDT)							
Inquiries } MDT	38.5	104	1,013	520.6	50	6,612	23,092
Responses } MDT	38.3	377	3,670	520.5	85	11,240	(66.5%)
Messages from non-MDT Terminals	7.7	286	557				
2. Criminal Histories (Case II)							
CII - Inquiries	0	N/A		11.2	70	199	
CII - "Hit" Responses	N/A	N/A		9.1	1,725	3,987	5,589
CS - Inquiries	2.1	130	69	7.5	70	133	(16.1%)
CS - "Hit" Responses	2.1	450	240	3.4	390	337	
"No-Hit" Responses	N/A***	N/A		4.1	70	73	
Updates	N/A	N/A		7.9	256	514	
"Pointer-Hit" Responses	N/A	N/A		2.1	70	37	
3. Fingerprints							
Booked Offenders				2.915	50,000 Bits	4,624	4,664
Latent Fingerprints				0.083	15,000 Bits	40	(13.4%)
4. Criminal Justice Planners							
GMIS - Inquiries				0.060	70	1.06	63
- Responses				0.060	1,725	26.16	(0.2%)
NCJSDB - Inquiries				0.156	50	1.94	
- Responses				0.156	500	19.76	
NCJRS - Inquiries				0.052	50	0.68	
- Responses				0.052	1,000	13.18	
5. Criminal Intelligence Information							
Administration				0.165	200	8.4	11
Inquiries				0.024	60	0.4	(<0.1%)
Responses				0.024	342	2.1	
Updates				0.01	1,000	0.1	
6. Crime Laboratories							
Facsimile	0.0078	300,000	595	0.0078	300,000	595	1,310
Bibliographic Data:							
Inquiries				0.1095	60	1.7	(3.8%)
Responses				0.1095	2,500	69.5	
Firearms Identification:							
Inquiries				0.1095	60	1.7	
Responses				0.1095	500	13.9	
Spectrographic Data:							
Inquiries				0.021	100	0.5	
Responses				0.021	700	3.6	
Administrative Response				0.2707	432	29.7	
Total BPS (Averaged)			6,144 (17.7%)			28,585 (82.3%)	34,729

*Uses for Courts, Prosecution, and Corrections have been accounted for under the estimates for Computerized Criminal Histories, Criminal Justice Planners, and Current Uses Projected.
**See National Pointer plus multistate offenders. (Note: 2 refers to Criminal History and CS to Criminal Summary.)
***Applicable.

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Growth trends projected by the traffic models (Figures 5 and 6, ref. 12) incorporated adjustments for the anticipated increase in traffic due to system automation.

5.3.3 NALECOM - New System Requirements

5.3.3.1 Criminal Histories

The need for speedy and reliable background information on defendants and suspects within the criminal justice system is well known. Determining the correct charge, setting bail, and many other activities can be justly done only if the background of the person in question is known. To meet this need, the concept of a Computerized Criminal History (CCH) was developed.

A national computerized criminal history file has been under development for the last several years. This effort was highlighted by the Project SEARCH experiments and the establishment of a CCH file in the NCIC system. As it currently exists, the CCH system of the FBI is a centralized data file into which the states place criminal records of offenders. Once in the file, any authorized terminal can access that record and retrieve a copy of the file. In most cases, a copy of the criminal history is not considered valid unless positive identification has been made (normally through the use of fingerprints), and thus the CCH record can be positively linked to the person in question. In this manner, the transmission of CCH's and fingerprint are directly related.

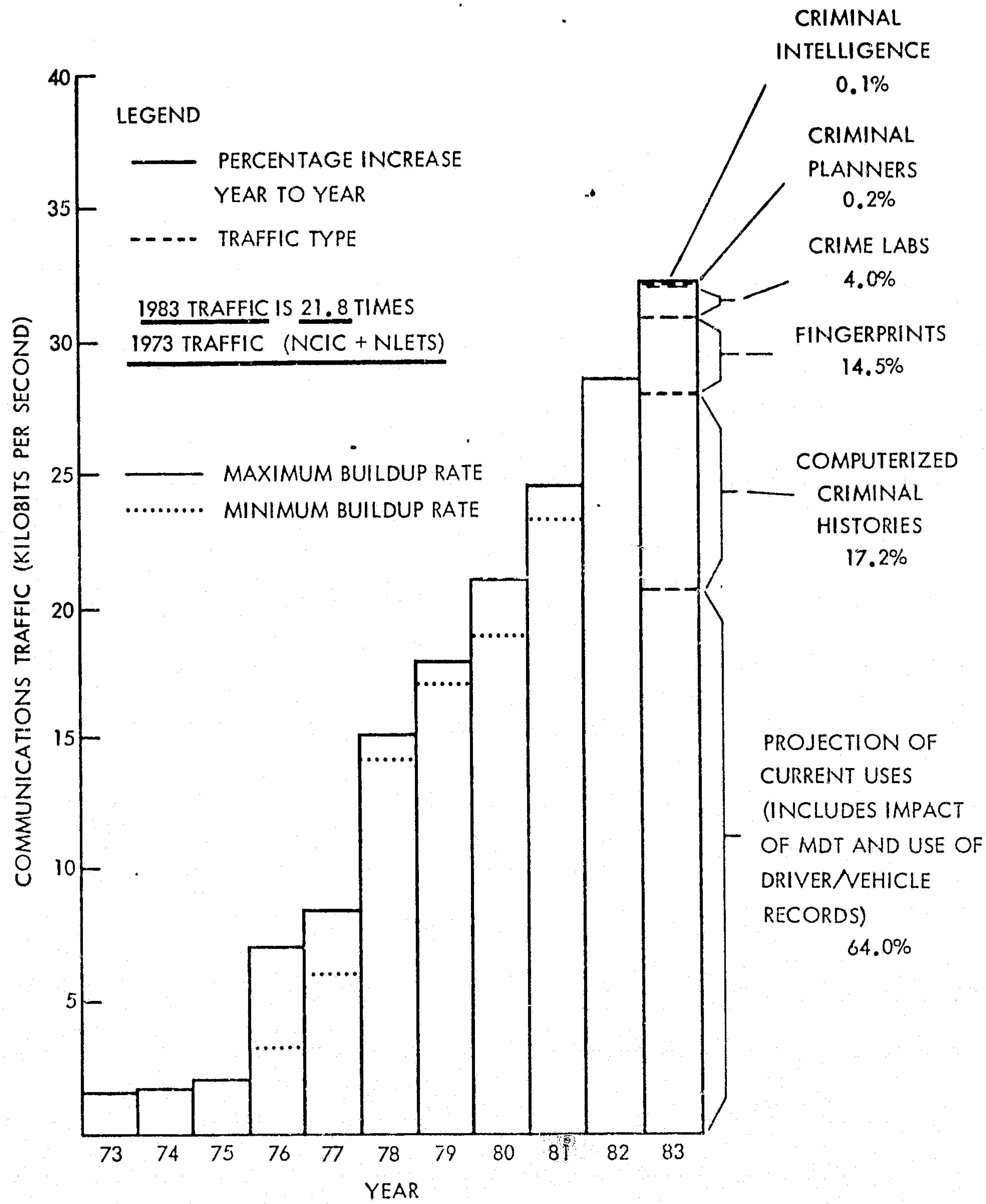

Figure 5. NALECOM potential annual traffic growth

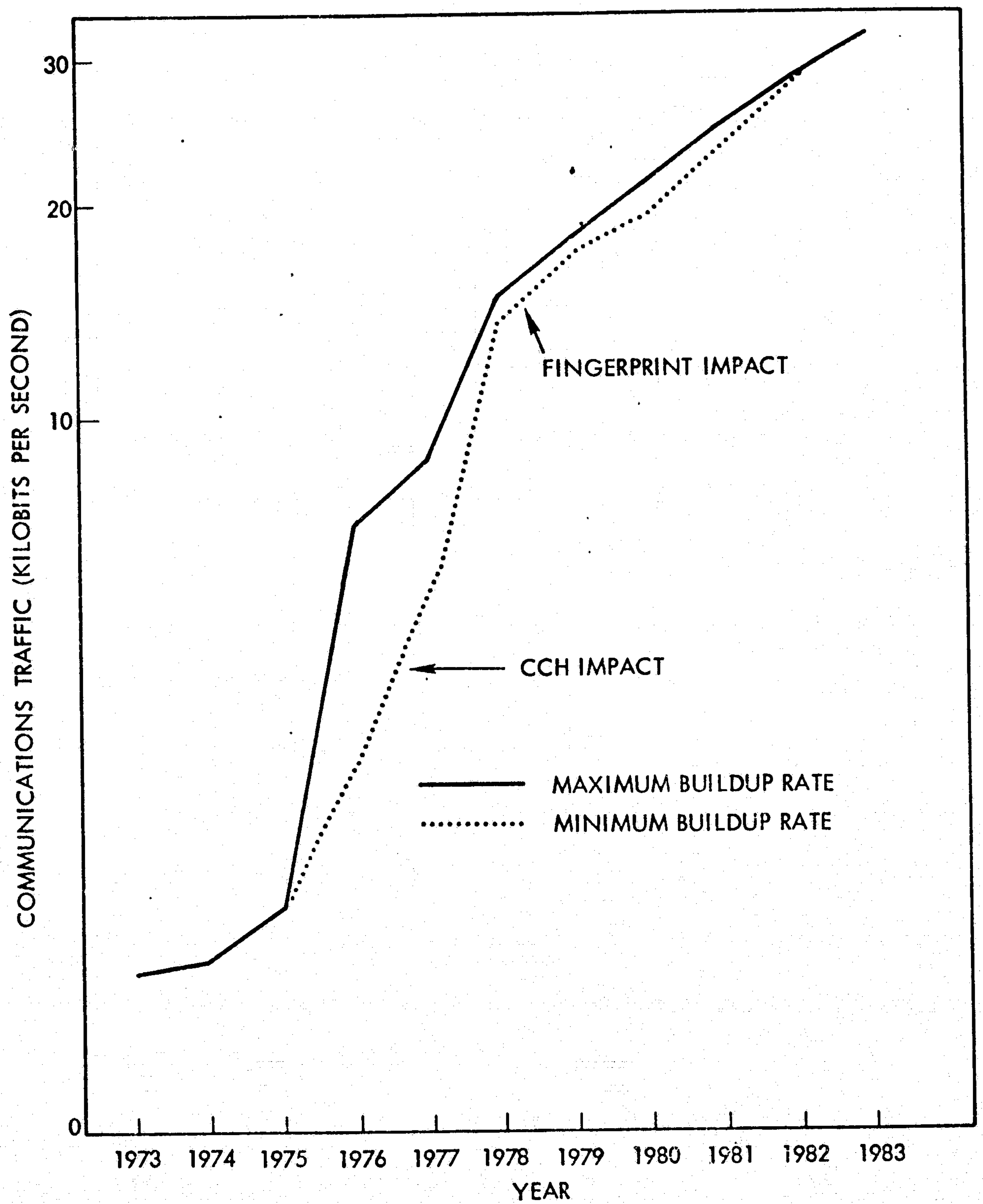

Figure 6. NALECOM traffic growth curve

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5.3.3.2 Fingerprint Transmission

Fingerprints are considered one of the most reliable means of distinguishing one person from another. With the growing volume of law enforcement data traffic and the increased number of arrests annually, there is an increasing demand for faster and more convenient methods of evaluating fingerprints.

The interstate transmission of fingerprints is associated with two specific activities:

1) Positive identification of booked offenders.
2) Identification of latent fingerprints found in the course of investigations.

Assuming that there would be a constant growth in requests at the national level each year and that the increasing level of expertise at the state and local level would absorb any increased growth in requests at the local level, an initial estimate for the years 1978 and 1983 is shown in Table 10 (ref. 12). It is assumed that on the average, latent fingerprints will require approximately 15,000 binary bits per transmission.

5.3.3.3 Courts and Prosecution

Information needs of courts are primarily of an intra-state nature; however, those of an interstate or national nature would involve Computerized Criminal Histories (CCH) of defendants, driving records of defendants, statute and case law related to the offense, and criminal justice research data from other jurisdictions.

TABLE 10. FINGERPRINT TRANSMISSION ESTIMATES

	1978	1983
Case 1. Booked Offenders		
Projected Arrests (A_i)	4,880,000	5,830,000
Proportion of Prints Sent to FBI	50%	50%
Total Fingerprint Requests to FBI	2,440,000	2,915,000
Bits per transmission	50,000	50,000
Average BPS Rate	3,870	4,624
Case 2. Latent Fingerprints	56,000	83,000
Bits per Transmission	15,000	15,000
Average BPS Rate	27	40
Total Average BPS (Bits per second)	3,897	4,664

A statute and case law retrieval system might require a state-to-national telecommunications capability. JURIS, a remote access information retrieval system being developed for U. S. Attorneys, and LEXIS, a privately contracted computer service, offer computer-assisted access to a national computer-based law library.

Use of a criminal justice data base would be from the standpoint of introducing new procedures or programs into the courts and prosecutor's offices in one jurisdiction based upon their history in another jurisdiction.

Other uses by the courts and prosecution would be largely of a management and/or administrative nature and therefore consist of local or intrastate transactions.

5.3.3.4 Corrections (Probation, Parole, Institutional Supervision)

Corrections encompasses the supervision of offenders, including pretrial detention, probation, parole, and institutional supervision.

Operationally, correctional agencies face the problems of: 1) gaining sufficient information on offenders to make program assignments; 2) keeping track of offenders as they shift from program to program and location to location; and 3) generating predictive data on post-release behavior. Offender classification is similar to material generated before court sentencing with respect to background and environmental conditions; the data are useful in determining treatment or program assignments based on interviews, testing, and observation.

The key functions of an information and statistics system for corrections include offender accounting, administrative decision making, ongoing research, and rapid response to additional questions. As to all functions but ongoing research, which includes planning and evaluation, information exchange would be primarily intrastate including offender-based transaction statistics and criminal history data. However, research, planning, and evaluation of state correctional system characteristics might involve interstate exchange of data which has been accounted for in the growth of interstate traffic and the growth in criminal justice planning traffic.

In the area of follow-up information on released offenders for determining common characteristics of those offenders who succeed on probation or parole, data probably would be gathered and retained at the local or state level because of security and privacy constraints. Furthermore, exchange of this data between state correction agencies probably would be limited to data in aggregate form.

Inquiries, responses, and updates of these data would rarely be of an urgent nature and would probably be assigned a low priority rating for transmission purposes.

5.3.3.5 Criminal Justice Planning Information

"Criminal Justice Planners" include planners and administrators at all levels and in all agencies of the criminal justice system. Although formal planning agencies are very important and require a great deal of information, most policy and procedural changes are made at the administrative level, and it is necessary to insure that this information be made available to all types of agencies at all levels of the system.

There are currently three federal programs designed in part to disseminate criminal justice planning information:

1) Grants Management Information Service (GMIS).
2) National Criminal Justice Statistics Data Base (NCJSDB).
3) National Criminal Justice Reference Service (NCJRS).

1978 and 1983 message volume estimates for these three programs were obtained by assuming that the number of inquiries will grow at a rate of 10 percent per year. The estimates are given in Table 11 (ref. 12).

TABLE 11. TRAFFIC VOLUME RELATED TO CRIMINAL JUSTIC PLANNERS

YEAR	MESSAGE TYPE	VOLUME (messages/yr)	AVERAGE LENGTH (characters)	BPS
1978	GMIS			
	Inquiries	37,100*	70	.66
	Responses	37,100	1725	16.26
	NCJSDB			
	Inquiries	96,700**	50	1.23
	Responses	96,700	500	12.28
	NCJRS			
	Inquiries	32,200***	50	.41
	Responses	32,200	1000	8.18
1978 TOTAL				39.02
1983	GMIS			
	Inquiries	59,700	70	1.06
	Responses	59,700	1725	26.16
	NCJSDB			
	Inquiries	155,600	50	1.94
	Responses	155,600	500	19.76
	NCJRS			
	Inquiries	51,900	50	.68
	Responses	51,900	1000	13.18
1983 TOTAL				62.78

*23,000/yr used as a 1973 base figure.

**60,000/yr used as a 1973 base figure.

***20,000/yr used as a 1973 base figure.

5.3.3.6 Criminalistics Information

Crime labs are playing an ever-increasing role in criminal investigations. To what extent a telecommunication system can aid in this field, however, is difficult to determine. In most cases, the mere communication of information is not sufficient, and it is necessary to transport the physical evidence to the laboratory for analysis. The types of transactions in this field include facsimile transmission, bibliographic data, firearms identification data, spectrographic data, and administrative messages.

A summary of criminalistics information traffic for each of these categories appears in Table 12 (ref. 12).

5.3.3.7 Criminal Intelligence Information

Intelligence units of numerous law enforcement agencies have been exchanging information for some time. To facilitate this exchange, an organization of Law Enforcement Intelligence Units (LEIU) is currently operating a pilot network of 30 terminals. This project, named the Interstate Organized Crime Index (IOCI), currently represents 223 agencies and plans to expand to 125 terminals in the future. IOCI currently operates in 2 major ways: 1) distribution of administrative messages; and 2) inquiries to a central data bank. IOCI is a telephone inquiry system. A grant is funding the project. At present, there is an involvement in the system design of a totally automated system to replace the manual/automatic system now in use.

TABLE 12. 1983 TRAFFIC ESTIMATES FOR CRIMINALISTICS INFORMATION

Message Type	Volume (Message/Yr)	Average Length (Characters)	Average BPS
Facsimile Transmission	15,600	300,000	1,189
Bibliographic Data			
Inquiries	109,500	60	1.7
Responses	109,500	2,500	69.5
Firearms Identification Data			
Inquiries	109,500	60	1.7
Responses	109,500	500	13.9
Spectragraphic Data			
Inquiries	20,500	100	.5
Responses	20,500	700	3.6
Administrative Messages	270,700	432	29.7
		Total	1,309.6

The future of the project is uncertain, as current legislation in Congress may greatly limit the distribution of information and perhaps outlaw it all together.

5.3.3.8 <u>Video Circuits</u>

The criminal justice applications of video circuits are numerous, but the use of video circuitry has not yet been fully exploited. Some of the current and potential applications are:

- Administration
- Intelligence:
  - traffic control
  - crowd control
  - riot control
  - high crime areas
- Surveillance in felony investigations
- Security
- Prosecution/courts
- Training/education
- Data transmission (pictorial, documentary, etc.)

It should be noted that, for NALECOM to be able to support video transmission, a channel with a 4.5 megahertz bandwidth would be required. Such a channel would have an equivalent 56 megabit single channel capacity which is approximately 1400 times the projected 1983 NALECOM traffic of about 35 kilobits.

The use of video for the education and training of criminal justice personnel via television instruction techniques is both feasible and practical. The needs for such training are sufficiently widespread and similar in nature to warrant nationwide distribution of any televised materials that are developed.

5.4 Use of Satellites in Law Enforcement

In 1975, Jet Propulsion Laboratory completed a study for the Law Enforcement Assistance Administration (ref. 14) which analyzed nine alternative approaches to the NALECOM network. These nine options ranged from existing configurations to multi-regional distributed networks.

One of the network options calls for an initial terrestrial configuration with the later addition of satellite data and video capability. The initial system would be a two-region network connected by terrestrial links with one switching center in Phoenix, Arizona handling traffic for western states and one switching center in Washington, D. C. handling traffic for eastern states. The enhancement of the network capabilities to provide satellite video and data-handling capability will take place in three phases.

In the first phase, inter-region lines will be replaced by a satellite link between Washington, D.C. and Phoenix for data transmission. Phase two calls for the installation of six more satellite ground stations. Terrestrial links between these stations will be replaced by satellite links and video capability will be provided. The final phase of implementation will provide six additional satellite ground stations. The western switching center located at Phoenix will be discontinued, and the eastern switching center at Washington, D. C. will serve the entire network. The projected operational date of this final phase would be between October 1979 and December 1983.

This option was the costliest of all nine options due to engineering costs and the installation and maintenance of microwave links and ground stations.

6. Satellite Mail Delivery Systems

6.1 Introduction

There has been a gradual worsening of mail service accompanied by an increase in postal rates. As the mail volume increases the present methods of mail handling and delivery are shown to be inadequate. Figure 7 (ref. 15) shows the total mail volume projections to 1990 based on the increase in mail volume from FY 1965 to FY 1970. Unless something is done, a complete breakdown in service is felt by authorities to be inevitable.

Several possibilities have been suggested as a means of providing improved mail service and a number of recent studies have been conducted on electronic mail delivery systems utilizing satellite communications technology. In the following paragraphs

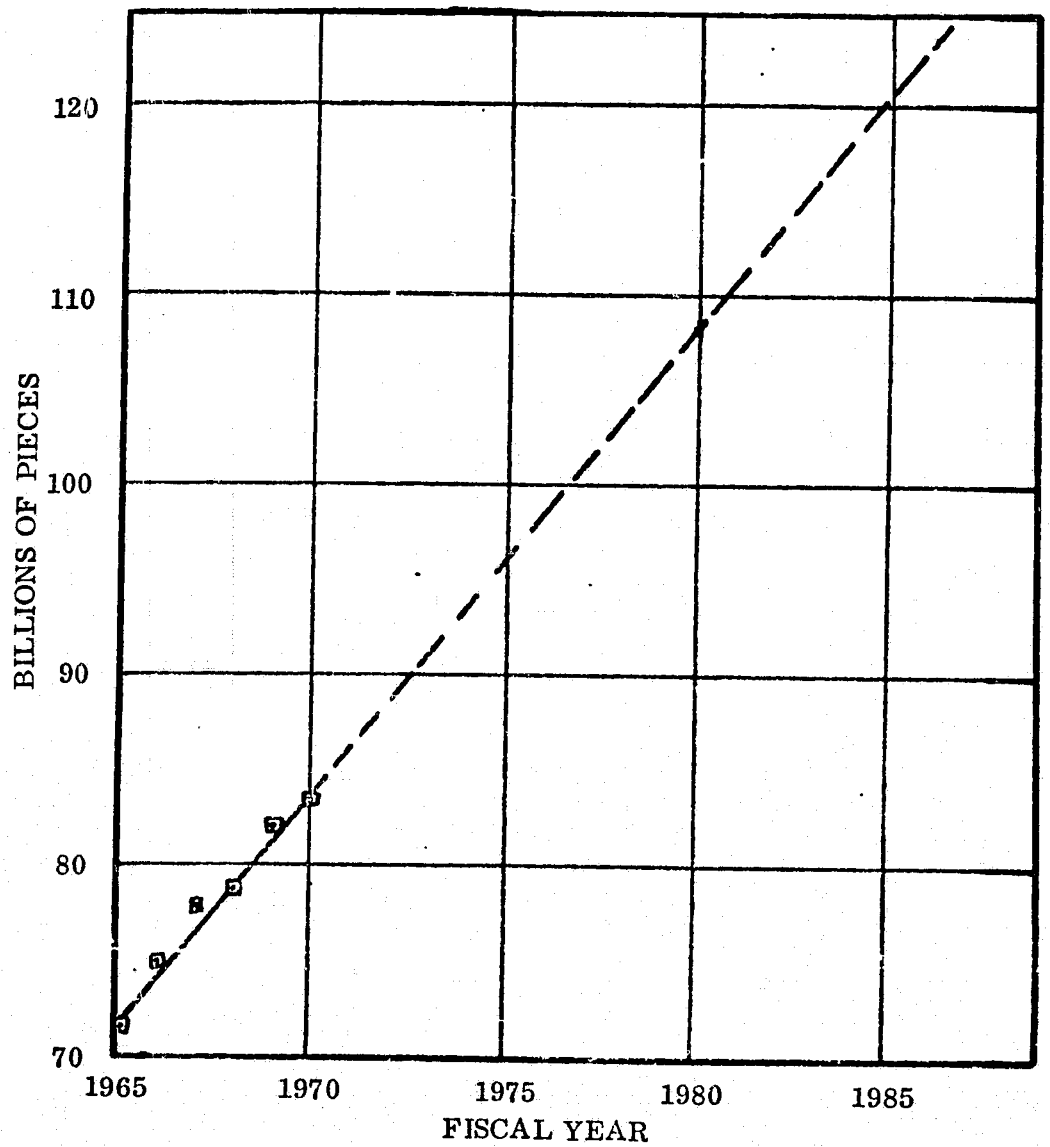


FIGURE 7. Total mail volume projections

the characteristics and growth of the mail from prior studies are described and some of the study results on future systems are discussed.

6.2 Composition of the Mail

In the early days of the postal service, correspondence between individuals undoubtedly dominated the mail flow. Gradually there has been a transition in mail usage so that today this type of mail represents only 7 percent of the mail volume, 14 percent if greeting cards are included. The mail has today become a principle means by which the nation's business is conducted. It is the primary vehicle for exchange of bills, orders, account statements, and checks. Approximately 70 percent of all magazines are delivered by mail. Arthur D. Little, Inc., in a special study for the Post Office Department, revealed the actual uses to which the mail is put. The results of this study were contained in a General Dynamics report for NASA (ref. 15), and are summarized below.

There are four principle classes of mail as defined by post office statutes: sealed letters, circulars and samples, publications and packages. The mail consists of transactions, advertising, magazines and newspapers, and correspondence.

Transactions comprise the greatest percentage of the total volume of mail. Flow shows that 80 percent of all transaction mail consists of business-to-business and business-to-household. The volume of transactions that involve transmission of money is particularly significant since in the future electronic means will probably be used to transfer funds.

Approximately 26 percent of all mail volume is made up of advertising material, of 5 percent sent from business-to-business and 21 percent from business-to-household.

The majority of general correspondence mail is sent from household-to-household. Although business-to-business messages have been considered to be a promising candidate for electronic mail transfer, they only make up 2 percent of the total mail volume.

6.3 The Future System

The Advanced Mail System Directorate of the United States Postal Service (U.S.P.S.) is actively engaged in an electronic mail handling program. The use of satellite telecommunications has been contemplated as one possible major transmission link between U.S.P.S. locations in the continental United States, Alaska, Hawaii, and Puerto Rico.

In substituting electronic mail transmission for traditional mail handling and delivery, it is important that there is not an accompanying compromise of those characteristics of the postal service that the public has traditionally expected and demanded, message privacy and dependability of mail delivery. Dependable and accurate message transmission and delivery requires that there be means to prevent loss and misdirection of messages and additions or deletions of any part of a message due to a noisy channel.

The Institute for Telecommunication Sciences (ITS) of the Department of Commerce conducted a program for the U.S.P.S. in support of the electronic mail handling program (ref. 16). The ITS program had two major objectives:

1) to recommend the optimum frequency range for a U.S.P.S. satellite telecommunications system which will support present and future traffice loads with regard to data transmissions from 125 representative sites, and

2) to document the evaluation of system parameters and corresponding engineering trade-offs to permit major policy determination by the U.S.P.S. and to support a position for the use of these frequencies.

6.3.1 Electronic Mail Traffic Requirements

Mail piece composition in terms of pages per mail piece and percentage of mail pieces which are large gray scale black-and-white and color graphics can have significant impact on the frequency allocation requirements as well as the system design requirements. The delivery time specified for the service can alleviate or increase queuing delays. Related to queuing delays and the required bandwidth, local stations hours of satellite transmission have a direct, quantitative effect on the required system digital bit rate and bandwidth.

The computation of bits per mail piece is very sensitive to the assumption of the number of pages per mail piece and equally sensitive to the assumed value for the scanning resolution, which affects the number of picture elements per page.

6.3.2 Network Configurations

In order to determine optimum frequency allocations, investigations of network configurations have a single purpose. The required bit rates must be estimated on the basis of feasible networks to include overhead bits required for system operation as well as electronic mail bits. These bit rates establish initial frequency bandwidth and system parameter requirements necessary for frequency allocation selection.

An important characteristic of the stations considered for the proposed U.S.P.S. network is the large differences in mail volumes each station must transmit and receive each day. These differences necessitate a more complex multiple access technique, a more sophisticated operating protocol (network rules of operation), and would require a more advanced satellite if satellite switching is considered. The optimum network configuration and operating protocol must have sufficient flexibility to accommodate this mail volume variation among stations.

6.3.3 System Bit Rate and Bandwidth Requirements

Bandwidth estimates are sensitive to a number of factors:

- the 12-hour daily transmission interval;
- the non-uniform bit rates among the different geographical zones;
- the standard deviation of the mail digital conversion variable, in bits per mail piece;

- the aggregation radius of 15 miles which, if increased to 25 miles, could increase mail volume by at least 2.5, and
- the omission of polarization diversity.

Polarization diversity may be necessary to achieve the 1×10^{-12} bit error rate performance level with the system parameters selected. If a bit error rate of 1×10^{-12} appears likely with the parameters selected, polarization diversity may then be used to further reduce the system bandwidth.

6.3.4 System Performance Objectives

To establish the feasibility of candidate systems operating at the indicated bit rates, bandwidths, and designated frequency allocations, a fundamental set of system performance objectives must be identified.

The four most important performance objectives which were considered in the Institute for Telecommunications Sciences (ITS) program are:

1) the bit error probability, desired to be 1×10^{-12};
2) the location of the earth station, desired to be as close to the U.S.P.S. station as possible;
3) the lost mail piece probability, desired to be as close to zero as possible; and
4) the satellite system outage time caused by signal attenuation and possible dispersion due to rain, desired to be small but not necessarily zero.

Two additional performance objectives must eventually be specified: 1) the probability that a network station will be delayed when it has a mail piece ready for transmission (access delay probability); and 2) the average access delay when a station is delayed.

6.3.5 Frequency Allocations and System Parameters

The ITS program concluded that feasible satellite electronic mail system designs could be developed, using present or near-future technology, for the frequency allocations from 4/6 GHz to 20/30 GHz based on the U.S.P.S. objectives presented. The system parameters calculated for the candidate systems included ground station antenna diameter, Effective Isotropic Radiated Power (EIRP), and total power.

An optimum choice of frequency allocation could not be made until the limitations due to sharing and interference were better defined. The ITS study indicated that a preference was possible within the government allocations and another preference was outlined within the non-government allocations. For the long-term, a slight preference was given to U.S.P.S. operation in a government allocation, even though the short-term preference would favor the non-government allocation.

Government Allocations

First Choice:	20.2 GHz-21.2 GHz Downlink and
	30.0 GHz-31.0 GHz Uplink
Second Choice:	7.25 GHz-7.75 GHz Downlink and
	7.90 GHz-8.40 GHz Uplink

Non-government Allocations

First Choice:	11.7 GHz-12.2 GHz Downlink and
	14.0 GHz-14.5 GHz Uplink
Second Choice:	19.7 GHz-20.2 GHz Downlink and
	29.5 GHz-30.0 GHz Uplink
Third Choice:	17.7 GHz-19.7 GHz Downlink an
	27.5 GHz-29.5 GHz Uplink
Fourth Choice:	3.700 GHz-4.200 GHz Downlink and
	5.925 GHz-6.425 GHz Uplink

The preference for the 20/30 GHz government allocation relative to the 7/8 GHz allocation was slight, and was based on the expectation that the sharing and interference limitations at 7/8 GHz will be more difficult to overcome than the technology developments required at 20/30 GHz. It is for this reason that studies of the 7/8 GHz allocation sharing and interference problems were recommended by ITS. The study noted that the rain-losses may be more severe than available data indicate. Thus, a measurement program to obtain reliable data relevant to sites of interest to the U.S.P.S. was recommended.

The non-government allocation preference for the 11/14 GHz allocation represented a balance between technology limitations and sharing problems. This allocation was expected to have less sharing-coordination problems than the 4/6 GHz allocation and less technology related problems, as well as rain-loss problems, than the two higher frequency allocations.

An important result of the ITS study was to establish that the U.S.P.S. has a wide range of options to explore. Technology limitations did not force the issue. Specific recommendations could not be made without detailed consideration of cost and relative costs associated with system development and operation in each of the preferred allocations.

In line with these results, the U. S. Postal Service issued a Request for Proposal (RFP 104-234-75-B-0233) in March 1975 to industry for a definition study for an advanced electronic mail system. Proposals received by the U.S.P.S. were still under evaluation in March 1976.

6.4 Western Union Mailgram

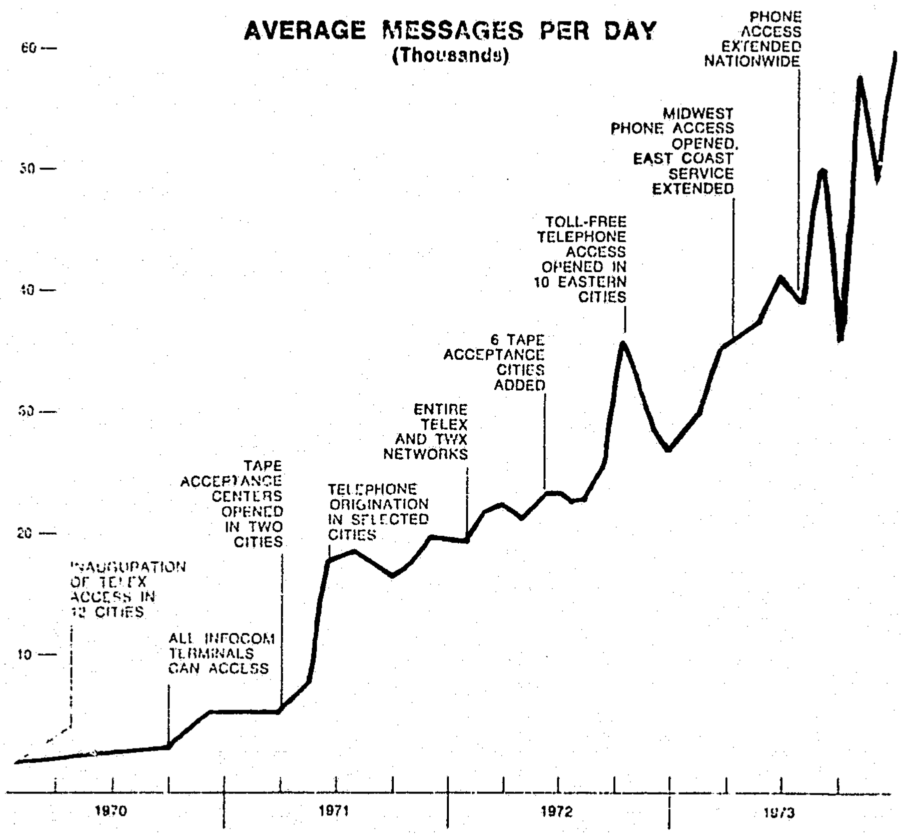
Mailgram is a modern electronic mail service operated jointly by the Western Union Telegraph Company and the U. S. Postal Service which uses the WESTAR satellite system for next business-day delivery to any location within the 49 continental states and Canada*. The mailgram service combines the message switching and transmission capabilities of Western Union with the delivery capability of the letter carriers of the U. S. Postal Service.

*Mailgram message service from Canada was inaugurated in late 1974, and to Canada in early 1975.

Some 40 million Mailgram messages have been handled since the service was introduced in January, 1970. During 1970, there were 370,000 Mailgram messages. This figure grew to 19,804,000 in 1974 (ref. 17). The growth of Mailgram service from 1970 to 1974 is illustrated in Figure 8 (ref. 18). These messages are being used for a wide variety of business transactions and personal messages.

A comprehensive package of new Mailgram services and rates was filed January 30, 1975. Under provisions of these new tariffs:

- An entire new population of more than 135,000 terminals, including facsimile, communicating typewriters and time-sharing terminals will be able to file Mailgram messages through the Central Telephone Bureaus.
- Senders of phone-originated Mailgram messages will be able to send the same message to multiple addressees at a discount from the single Mailgram message rate.
- Rate increases, as well as some decreases, will be instituted for the three classes of Mailgram messages.



Growth of Mailgram service has been marked—and made possible—by system expansion that has progressively added inputs and increased access options.

Figure 8. Growth of Mailgram service from 1970 to 1974

6.4.1 Mailgram's Network

The flexibility of the Mailgram network is largely responsible for the convenience as well as the speed with which Mailgrams can be sent. The five main input elements are:

1) Every telephone in the 48 coast-to-coast states and Alaska;

2) Every subscriber on the Telex or TWX teleprinter exchange networks;

3) 270 larger Western Union-operated Public Message offices;

4) 27 special offices for acceptance of bulk messages on computer tape; and

5) Any computer with an appropriate program and a communications controller. A growing number of these are located on the premises of individual organizations, including service bureaus which prepare and transmit Mailgram tapes for their customers.

At the output side are 119 Serving Post Offices, so designated by the U. S. Postal Service, and strategically located to feed the postal carrier delivery system which reaches every mail address in the 49 continental states.

The essential operating links between inputs and outputs are formed by Western Union's InfoMaster computer center at Middletown, Va., and the Company's nationwide microwave transmission channels. The InfoMaster Center, operating on a store-and-forward basis, performs the essential communications function of switching by zip code routing. It also validates incoming messages, generates all billing and message-retrieval information, and provides necessary input and output interfaces to accommodate the variety of terminal equipment it serves.

The auxiliary functions performed by the Western Union InfoMaster Center in connection with Mailgram service include the monitoring of the customer's message format and transmission for accuracy, the prompt creation of accurate billing information, and the maintenance of retrieval files for recovering any particular message on request. All are accomplished through software associated with InfoMaster.

6.4.2 Mailgram Revenues

Revenues from mailgram services increased by 75 percent in 1974, going from \$13.4 million in 1973 to \$23.5 million (see Figure 9, ref. 17).

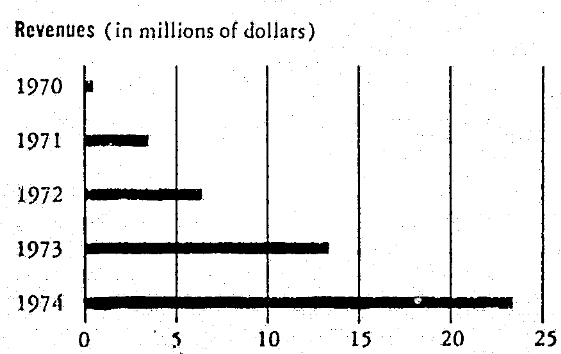


Figure 9. Mailgram services revenues

Mailgram message revenues fall into the following categories:

- Phone-originated Mailgrams - Messages can be sent by calling the Central Telephone Bureaus toll-free any hour of the day or night, or by handing a message over the counter at a Telegraph Company public public office. Revenues from these sources rose from $4.6 million in 1973 to almost $11 million in 1974.

- Terminal-originated Mailgrams - More than 100,000 Telex/TWX subscriber terminals, as well as InfoCom terminals, can be used to send a Mailgram message, by typing out the message on their teletypwriter keyboards and sending it directly to the InfoMaster Center for transmission to a Post Office near the addressee. Revenues in 1974 from this source remained at last year's level of approximately $6 million.

- Computer-originated Mailgrams - Large numbers of Mailgram messages can be sent by delivering a computer tape containing the message text and the address list to one of 27 special offices that accept bulk messages for computer transmission to the InfoMaster computer. Or customers may prepare bulk messages on their own computers and transmit directly to the InfoMaster computer. Revenues from this source more than doubled from $2.6 million in 1973 to $6.3 million in 1974.

- Associated Services - Mailgram message confirmation copies may be ordered for Telegram messages, international messages, and other Telegraph Company message forms, as well as for a Mailgram message itself. In 1974, this service was extended to Money Orders as a record that payment had been made. Also, senders of computer-originated Mailgram messages may request certified return receipts.

7. Industry Internal Communications

7.1 Introduction

There has been a rapid growth in the communications service needs of the business community. The service or market area referred to herein as Industry Internal Communications includes audio, video, facsimile and digital data services for industry of the business community. These services may provide for communications between separate divisions or groups within organizations, processing of business data, inventory and stock control, teleconferencing, credit card authorization, and other such services.

A number of prior studies by Stanford Research Institute (ref. 10), Lockheed Missile and Space Company (ref. 19), and the General Dynamics Corporation (ref. 20) have analyzed future and current status and future growth in the transfer of information by the business community. Some of the data from these previous studies and new information obtained during the market survey is included in the summaries of the various audio, video, facsimile and digital data services of concern in this market. Teleconferencing, which is a growing internal communications application in industry and government, is addressed separately in paragraph 8.

7.2 Public Telephone

The primary audio service used in industry for communications is the public telephone. Although data projections for the future are based on public telephone usage, much of the business and traffic flowing over these phones is from the business or industry community. The study performed in 1970 by Stanford Research Institute revealed that the long distance telephone system was expected to increase from 500,000 interstate equivalent voice circuits in 1972 to over 3 million 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 of 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. The nation's 22 major urban areas contain 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 would serve to interconnect some 60 smaller areas throughout the nation.

7.3 Business Telephone Networks

The functional requirements for the 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.

A number of specialized common carriers have been formed to offer services in competition with AT&T (See Section 3 of this report). These companies are expected to 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 technical need is 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 those 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.

The first U. S. domestic satellite system, WESTAR, has opened a new era in business communications since it was placed into operation by Western Union. For example, the American Can

Company joined the system after service began and is now using 16 private two-way telephone trunks between its East Coast headquarters and operations in the Los Angeles area. Studies conducted by the American Can Company on use of the satellite system indicate an annual savings of over $200,000 over the previous service.

7.4 Transaction Telephone

The Transaction Telephone service currently under experimentation by AT&T in the Cincinnati, Ohio area is a new application or service which may find widespread use in the business community. The Transaction Telephone enables merchants to instantly verify a customer's credit or bank balance for check cashing purposes and have a bank guarantee payment of checks. The system uses a magnetic coded credit card which is put into the Transaction Telephone. Impulses are sent to a bank or credit card company computer which verifies the credit or amount of cash on deposit. Indicating devices on the telephone show whether the customer has favorable credit or inadequate credit. The Transaction Telephone does not require private leased lines.

The telephone companies in the Washington, D.C. Metropolitan area are expected to begin marketing the Transaction Telephone this year. This service is the first step in electronic fund transfer in which the bank will automatically substract funds from a customer's account as purchases are made.

7.5 Video Telephone

The Video Telephone or Picturephone offered by the Bell System has been offered as a public communication service. Worldwide, very few video telephones are in use. According to the book entitled The Video Telephone, Impact of a New Era in Telecommunication by Edward M. Dickson and Raymond Bowers published in 1974, there are probably less than 1,000 video telephones in use today. It is expected that by the year 2000, a million video telephones may be in service with the majority being in the U. S.

The Picturephone, developed at Bell Laboratories for the Bell System of the American Telephone and Telegraph Company, is the best known video telephone. This device consists of a small television viewing screen, solid state video camera, and hands-free audio apparatus mounted in a single desk-top unit with all the necessary controls located on an attached pad. The picture is animated with 30 full frames per second, just as in broadcast television. Picture resolution obtained with Picturephone's 251 visible lines and 211 visible pels per line is markedly lower than that of broadcast television with its 485 lines and 640 equivalent pels per line. The Picturephone bandwidth of 1 MHz is correspondingly smaller than the 4.6 MHz of broadcast television.

Approximately 10 other video telephones have been developed in the U.S. and abroad. All are very similar to the Picturephone in concept, although at least one offers the option of using a 4MHz bandwidth to increase picture resolution. Since an audio telephone line has a bandwidth of only about 3 KHz, all animated video telephones require special transmission channels to handle the signal bandwidth of 1 MHz or more. This, alone, would be enough to necessitate high service rates for video telephones.

There are several video telephones with non-animated pictures on the market (such as RCA Globcom's Videovoice) or in development that can utilize existing audio telephone circuits. These so-called "slow-scan" video telephones send a picture with resolution comparable to broadcast television over the low bandwidth audio line by first freezing a single video frame and then slowly playing out the scan signal. At the receiver, the information is slowly accumulated to reconstruct the frame. Because of the large ratio between television bandwidth and audio telephone bandwidth, a considerable amount of time -- a half to a full minute -- is needed to send a single frame. Thus, in slow scan systems, there is no illusion of continuous movement as in animated television. Slow scan video telephones have the advantage over animated video telephones of being immediately useful anywhere because they require no special transmission facilities.

Present video telephones must therefore be regarded as just transitional devices that soon will be made obsolete by improved devices capable of handling graphic information satisfactorily. This process of change is being facilitated by the continuing and rapid progress in the technologies of telefacsimile, video recording, and remote computer time sharing terminals. It is anticipated that in about a decade a video telephone will be available that will offer an instantaneous selection between a low resolution animated and high resolution slow scan picture, a hard-wired facsimile paper copy output capability, pre-and post-transmission video storage, and a full alpha numeric keyboard. Consumer demand for video graphics communication seemingly makes the confluence of these technologies inevitable before video telephones can be taken seriously.

7.6 Facsimile

Facsimile communication systems have become an important business communication medium. The greatest usage of facsimile is in the area of convenience communications although the concept of graphic telecommunications in systems applications has made some headway in recent times.

Recent survey results obtained from the 3M Company Facsimile Department indicated that the smaller the company, the less likely they are to be using facsimile. This trend is particularly noticeable among manufacturing companies. Additional results of the 3M survey are given below:

- Respondents feel that there is a place for facsimile in their industries, although no industry segment emerged as having wholeheartedly adopted facsimile in place of teletype or other methods or "systems" communications.

- Among the large firms, the usage of facsimile ranged from one or two units at the headquarters location, to hundreds of units scattered throughout the organization. The choice as to whether facsimile is used in a particular function, department or subsidiary appears to be at the discretion of each individual manager and not vested in the corporate manager of communications.

- Slow speed, lack of automation and poor or inconsistent quality of copies were all cited as holding back expansion of the use of facsimile.

- Few respondents indicated growth in the use of simple teletype systems for basic communications, although some form of EDP was mentioned periodically as the system of the future, especially for order entry and follow up applications.

- Almost without exception, no comprehensive studies of the total costs of communications have been routinely performed by respondent companies beyond the basic cost of telephone and telegraph.

- Communication via facsimile is at about the same stage of market development as office copying was about 1960. The principle is known, but it has not been applied in quantity in any industry.
- The emergence of sub-one-minute digital facsimile should penetrate higher volume more system oriented applications.

As with digital data transmission systems, facsimile systems have been designed to be compatible with available transmission circuits. Most of the facsimile systems utilize voice grade circuits. For high speed messages and newspaper transmission higher capacity circuits such as Telpack A and above are used. Pertinent parameters on a variety of facsimile services and systems are tabulated in Table 13 (ref. 20).

7.6.1 Data Transmission Parameters

Parameters are presented which define communications channel requirements for the transmission of facsimile data. Shown are the constraints on transmission parameters of

- Type of material to be transmitted
- Size of copy
- Allowable transmission time per page
- Type of modulation

To facilitate comparison of transmission via satellite and competing terrestrial links and to provide for compatibility in a hybrid system, channel bandwidths are usually limited to discrete values corresponding to that available from common carriers,

TABLE 13. FACSIMILE TRANSMISSION PARAMETERS

COPY SIZE	Transmission Time or Rate	Modulating Frequency	Transmission Circuit	Modulation Type	RF or Channel Bandwidth	Req. S/N	APPLICATION
8 1/2 X 11	1.88 in/min.	1200 H_z	VOICE	DSB-AM or VSB-AM	4 KHz	10	Messages, letters and business documents
8 3/8 X Cont.	18 X 11 1 Min.	6600 H_z	15 KHz Broadcast	DSB-AM or VSB-AM	15 KHz	10	Letters and business documents
8 1/2 X 15	8 X 11 45 Sec.	15,600	48 KHz Telpak A	DSB-AM VSB-AM	35 KHz 20 KHz	10	High Speed Message Transmission
18 X 22	0.625, 1.25 in/min,	900/1800 Hz	VOICE	DSB-AM VSB-AM	4 KHz	16db	Weather Maps and Charts
Newspaper Page	21 min/pg.	40,000 Hz	Telpak A Telpak C	VSB-AM FM(D=z)	48 KHz 240 KHz	10	Newspaper Transmission (Pressfax)
Newspaper Page	4.5 min/pg	0.74 MHz		DSB-AM VSB-AM FM-(D-2)	1.5 MHz 1.0 MHz 4.5 MHz	20	Newspaper Transmission (Pressfax)

namely voice, group, supergroup and wideband. Nominal copy sizes are 8-1/2" x 11" for documents, messages, drawings and pictures, and 22" x 15.4" for newspaper transmission.

Scanning is usually either electromechanical using a rotating drum and high intensity light scanning the copy by attachment to a lead screw or electronic using a CRT tube to produce a flying spot scan of a copy moving linearly past the beam. The resolution of the transmitted copy is determined by the scanning lines per inch. In order to determine the communications channel characteristics to satisfy a specific facsimile transmission requirement, it is first necessary to specify signal quality (See Table 14, ref. 20), and the allowable transmission time. The channel response characteristics can be determined from

$$fm = \frac{H\ W\ d^2}{120\ T}$$

where H = height of document in inches

W = width of document in inches

d = scanning density in lines/inch

T = transmission time in minutes

fm = frequency response in Hz/sec.

TABLE 14. FACSIMILE SIGNAL QUALITY REQUIREMENTS

TYPE OF COPY	Lines per inch Resolution, d	Required contrast in db
Alpha-numeric (messages, letters and business documents)	96-130	20
Photographs	100 to 150	35
Weather maps, charts, drawings	96 to 190	20
Newspapers, magazines	300 - 1000	20

The channel requirements are specified for analog and digital facsimile systems.

- Analog Systems (amplitude modulation)

  DSB-AM, double-sideband amplitude modulation, requires a channel bandwidth of 2 fm + guard bands. VSB-AM, vestigial sideband amplitude modulation, requires a channel bandwidth of approximately 1.2 fm + guard bands. The carrier frequency selected must be greater than fm. The signal-to-noise ratio for the channel must be adequate to meet black to white contrast requirements.

- Digital Systems

  In a digital system the scanning is performed in the same manner as an analog facsimile system but the output is sampled and a comparator converts the samples to a two-level signal corresponding to black or white elements. The resulting bit rate is 2 times the modulation frequency. The two-level signal can modulate a channel as either frequency shift keying (FSK) or phase shift keying (PSK). If PSK is used further choices can be made as follows:

binary (non-coherent) PSK

binary or quaternary coherent PSK

binary differentially coherent PSK

quaternary differential coherent PSK

7.6.2 Typical Wideband Facsimile Equipment

Some widely used types of facsimile equipments are representative of facsimile newspaper transmission and high speed document transmission. The characteristics of the "Litcom Pressfax", the "Xerox LDX" and the "Rapifax 100" are given below:

- Litcom Pressfax

  Effective picture size: 22" x 15.4"

  Drum speeds: 300, 400 and 2000 RPM

  Scanning line density: 300, 400 and 600 lines/inch

  Modulation: AM

  Maximum amplitude corresponds to picture black (or white). Black to white ratio greater than 12 dB

  Carrier frequency: 32 KHz and 500 KHz

  Using the highest resolution of 600 lines/inch and 2000 RPM drum speed, a newspaper page can be transmitted in 4.5 minutes requiring a DSB-AM channel of 500 $\pm$ 154 KHz.

- Xerox LDX

Document size: 8-1/2" x 11' nominal (width may vary from 4 to 9 inches; length may vary from 5 inches to virtually any length)

Speed/Resolution: Five speed/resolution combinations are available and are related to the bandwidth of the communications circuit as follows:

Communication Circuit Bandwidth (KHz)	Speed in No. of 8-1/2" x 11" documents/min.	Resolution in Scans per inch
240	8.7	135
240	4.3	190
48	3.3	100
48	1.7	135
48	0.9	190

Video Channel - The video signal is a 2-level, non-synchronous, dc coupled, wideband signal. At the beginning of each sweep of the scanner there is a short burst of "synch" signal followed by the two-level scanning data.

- Rapifax 100

Document Size: Any size up to 8-1/2" x 14"

Speed/Resolution: Average density text 8-1/2" x 11" page

	Vertical Resolution	Horizontal Resolution	Time
High Speed	67 lpi *	200 lpi	35 sec.
Standard	100 lpi	200 lpi	50 sec.
Fine Detail	200 lpi	200 lpi	90 sec.

*lines per inch

High Speed is employed for normal typewritten documents and will produce improved copy quality over existing four-minute units.

Standard produces the copy quality required for financial data and smaller type sizes. This mode corresponds to the six-minute modes employed in existing facsimile units.

Fine Detail produces high quality copy and will faithfully reproduce four-or-six-point type and detailed drawings.

The Rapifax network equipment will operate over standard nonconditional voice grade lines, DDD, FTS and AUTOVON.

7.6.3 High Quality Facsimile Transmission of Newspapers and Magazines

Recent developments have made possible the introduction of a new generation of high-definition facsimile equipment based on pinpoint light sources or electron beams. Rather than 100 lines/inch, resolution of over 2000 lines/inch is now offered. This easily resolves the dots from which a half-tone image, black-and-white or color, is formed.

There is already one well-known commercial application of high definition facsimile equipment in this country. The Wall Street Journal is transmitted to second-tier printing plants from the first-tier plants in which the basic type setting and composing operation is performed.

The first newspaper production plant in the world to be operated through a communications satellite system was dedicated in Orlando, Florida by Dow Jones & Co., publisher of The Wall Street Journal. The Orlando plant, now printing Wall Street Journals for day-of-publication distribution in the Southeast, receives facsimiles of full-size Journal pages via satellite from another Dow Jones production plant in Chicopee, Mass. The satellite capacity is being provided by American Satellite Corporation on WESTAR I.

Two earth stations, each consisting of a 10-meter diameter antenna and related ground equipment, have also been designed and installed - one in Chicopee, the other in Orlando - by American Satellite Corporation.

In Chicopee, where The Journal is set in type, reproduction proofs of each page are placed under a high intensity light scanner. The scanner converts the black and white images into electronic impulses which are beamed to WESTAR I, 22,300 miles over the equator. The satellite relays the impulses to the Orlando plant where they are received on page-size photographic film. The sending and receipt of data for a full page takes 3.5 minutes.

7.7 Computer Telecommunication

In recent years, scores of new industries have been created in this area including software developers, information management services, data base disseminators, word processing and text editing, specialized communications carriers, and computer-communications networks.

At the same time, traditional industries are constantly finding new applications. These range from insurance providers, medical research and library information dissemination, to education, banking, drivers license record-keeping, and stock market quotes.

The world's airline reservation systems, and the check processing and funds transfer system of American banks are prime examples that many industries simply could not cope with the volume of transactions required without the benefit of modern computer-telecommunications. Dr. Paul Polishuk, Acting Deputy of Commerce's Office of Telecommunications, (ref. 21) illustrates this by noting:

- Some 170 airlines world-wide make hundreds of millions of data entries annually for seat reservations, boardings at airports and freight shipping--typically obtaining confirmations within minutes; computer-communications process over 30 billion checks annually in the U.S. alone, and these are expected to grow to 45 billion by 1980. New systems installed in the U. S. will be capable of transferring bank funds up to 40 times faster than current systems.
- A Medical Literature Analysis and Retrieval System (MEDLARS) contains over 2 million bibliographic medical citations, in which entries are growing at 220,000 per year. The system links over 240 institutions, accommodates more than 30,000 searches per month, serving the U. S., Europe, Australia and Latin America.

- Newspapers are finding that computer-telecommunications technology can substantially reduce labor and time requirements not only for traditionally labor-intensive typesetting, but will also help in getting news from the reporter into central storage at the newsroom. Labor-saving for typesetting alone is expected to top 50 percent.

- Electronic movement of information is becoming competitive with conventional paper oriented systems. Computer storage of information is becoming far less expensive than the costs of printing and storage on paper. Some analysts project a decline in the use of paper by 1980, and that its use will be limited to highly specialized purposes by 1990. A decrease in the need for human travel for information exchange is also projected.

During the past few years a number of international pioneering computer-communications systems have come into being. Some others, besides the international airlines system and MEDLARS mentioned above, which offer selected teleprocessing and information management services across national boundaries are:

- SWIFT (Society for World Interbank Financial Telecommunications), an extensive network for international payments and financial data, which serves 239 member banks in 13 European countries, Canada, and the United States.

- General Electric's Information Services, a commercial network linking over 400 cities in North America, Australia, Japan, and Europe. The network allows users to make a local telephone call and connect to the main computing facilities in Cleveland, or Rockville, Ohio. The services range from interactive time sharing to batch processing.

- TYMNET provides time-sharing services to as many as 900 individual users simultaneously. The system serves more than 50 United States cities and has a link to Paris. Customers can access the system's three major computing centers or use the TYMNET as a communications services.

- ARPANET is providing computing services in the United States, Norway, and the United Kingdom for scientific purposes. The system has over 50 computers connected to each other and to over 500 terminals.

It is difficult to assess the net impact of these technologies on the world's economies, but it probably measures in terms of hundreds of billions of dollars annually. Studies of the growth rate of new applications and new hardware and software sales suggest a continual and steeper trend toward dependence on these and related technologies. As an indication, computer and related equipment sales in 19 countries are expected to grow as follows: minicomputers 301 percent; independent peripheral sales 314 percent; data transmission equipment 534 percent; small and medium computers 184 percent; for a total market increase of 252 percent.

8. Teleconferencing

8.1 Introduction

The advent of the energy crisis has generated an increase in the use of teleconferencing as a substitute for travel for attending meetings and conferences. A large number of users in industry and Government have begun participating in meetings and conferences through teleconferences using two-way audio and video communications. Numerous experiments in teleconferencing have been conducted in recent years using both audio and video teleconferencing facilities. Some of the key programs in teleconferencing are described in the following paragraphs to illustrate the potential growth and advantages which can be accrued in the use of teleconferencing, particularly from the standpoint of using telecommunications in lieu of transportation.

8.2 Teleconferencing Using Common Carrier Facilities

The present common carrier facilities have been used for several years in a number of teleconferencing projects in industry and government. The results of some experiments conducted by one government agency were discussed in a November 1974 article (ref. 22) by the Institute for Telecommunications Sciences, Office of Telecommunications, Boulder, Colorado. The following paragraphs discuss these experiments, and some of the findings and observations. Another major teleconferencing project, implemented by the National Aeronautics and Space Administration for the Apollo Project, is described to illustrate the operational experience, and some of the advantages and disadvantages of this market area.

8.2.1 Teleconferencing at the Institute for Telecommunications Sciences

Experiments were conducted by the Office of Telecommunications between Boulder, Colorado, and Washington, D.C., using available common carrier facilities and terminals as well as commercially available audio components interconnected to the telephone set. No visual information was transmitted. One observation made during these audio teleconferences was the complete absence of secondary conversations (which would normally be subdued) among participants in the local conference room. The audio sensitivity was such that local room noises were amplified out of proportion to the voice signals, so that they appeared louder at the other terminal than expected. As a result, the participants apparently felt a subtle group pressure to inhibit their voices more than normally done in such meetings. Many participants observed that such behavioral changes made the audio teleconferences more fatiguing than face-to-face group meetings. Such disadvantages may tend to limit widespread acceptance of audio teleconferencing.

A second set of meetings was conducted in Boulder, Colorado, between two small conference rooms interconnected with the same audio facilities used in the aforementioned experiments. Both conference rooms were located in the same building at the Institute for Telecommunication Sciences (ITS), Office of Telecommunications. The two rooms were equipped with black and white television cameras and commercially available television sets interconnected by coaxial cable.

During these teleconferences with National Television Standards Committee (NTSC) video images from the fixed camera in each room, the speech patterns among participants were found to be more interactive than with only audio transmission. The long pauses after a speaker finished were not nearly as prevalent and appeared to occur more naturally. The limitations of the audio facilities were less noticed. Hence, it was concluded that at least some visual information was helpful to interactive communications among participants in these meetings (technical program management type meetings).

8.2.2 Teleconferencing at NASA

NASA has had extensive experience in teleconferencing using the network established for the Apollo Program (ref. 23). The system included conference rooms at NASA and contractor installations. High speed facsimile machines at all of these conference rooms enabled figures and written material to be distributed prior to a scheduled meeting. Each room had projectors which displayed this material simultaneously during the meeting. Voice-actuated circuits enabled conversation over the network. The voice and data used dedicated (4-wire private line) leased circuits which are connected through a wideband switch at Marshall Space Flight Center (MSFC). The advantage of the dedicated circuits is that conferences can be set without delay, and high quality transmissions can be assured.

The Apollo network cost approximately $500,000 per year, but saved several times this amount in travel costs and permitted fast coordination. The Apollo experience indicated that substantial savings can be effected by teleconferencing. After the advent of teleconferencing in January 1969, the average travel costs per person decreased to 81 percent of tis former level. This reduction saved $300,000 per year at Johnson Space Flight Center (JSC) in travel funds. JSC's share of the Apollo Program-related travel was approximately 35 percent, so the annual saving of travel funds in the Manned Space Flight Organization can be estimated to be $800,000.

During 1975, the network installed for Apollo was expanded to provide teleconference rooms in the major NASA installations. These rooms are connected through the wideband switching center at MSFC. Each room is equipped with voice-actuated circuits, fax machines, and projectors.

An employee at each center is designated to be in charge of the teleconference room and equipment, and to schedule and monitor the activities.

The goal of this project is to demonstrate that net savings in excess of $1 million can be achieved without compromising management effectiveness. If successful, new equipment and techniques involving video transmissions, perhaps via NASA experimental satellites, will be added.

Analyses of the 1975 experience of NASA with its teleconferencing project indicated that over 1200 teleconferences were conducted with a reported savings in travel costs of over $1 million.

8.3 Use of Satellites for Teleconferencing

The potential exists for using satellites for teleconferencing in the future and experiments are planned using the Communications Technology Satellite (CTS) which was launched early this year. This satellite, a joint effort between NASA and Canadian Department of Communications, is expected to advance the state-of-the-art in spacecraft and earth terminal technology and show planners of future systems new ways of using modern communications. Using the 12 GHz frequency band, an experiment entitled "Communications in lieu of Transportation" will be conducted with the CTS by Westinghouse Corporation (ref. 24). Using the 12 GHz frequency band, an experiment entitled "Communications in lieu of Transportation" will be conducted with the CTS by Westinghouse Corporation. The purpose of the experiment will be to determine if a large geographically dispersed industrial organization can substitute video and audio communication for travel. A second experiment in teleconferencing with the CTS to be conducted by NASA is called "Interactive Techniques for Intra-NASA Applications". Brief descriptions of each of these experiments are given in the following paragraphs to exemplify the use of satellite technology for teleconferencing.

8.3.1 Westinghouse Teleconferencing Experiment

The Westinghouse Electric Corporation and other similar organizations are continually seeking new methods to reduce the cost of information and data exchange. Specifically, in an attempt to lessen the need for costly air travel, while still bringing participants face to face, Westinghouse has developed an experiment which will utilize satellite teleconferencing in lieu of transportation.

The Westinghouse earth terminals via the CTS will link the Defense and Electronic Systems Center in Baltimore, Maryland to the Aerospace Electrical Division in Lima, Ohio. Each location is equipped with a small earth terminal to both send and receive conference video/audio signals.

The prime objective of the Westinghouse experiment is to test the hypothesis that a large geographically dispersed industrial organization can economically use a communications satellite coupled with low cost earth terminals to effectively exchange information necessary to conduct business by video, audio and hardcopy media in lieu of transportation.

The Westinghouse/CTS experiment is being conducted in two phases. Phase I (pre-launch) began in mid-1975 and has lasted for six months. During this phase, all support equipment and facilities were configured and utilized to simulate actual satellite teleconferencing. Phase II (post-launch) will continue the experimentation via the CTS using teleconference rooms designed from data acquired in Phase I experimentation.

The ground systems will consist of full-duplex FM analog television transmitting and receiving facilities located in Baltimore, Maryland and Lima, Ohio. The facilities will employ a ten-foot parabolic antenna at Lima and a fifteen foot antenna at Baltimore.

The Westinghouse experiment will evaluate the two general areas of:

1) Effectiveness in terms of potential cost savings (in lieu of transportation) to the Westinghouse organization for information exchange at various managerial/professional levels and various functional groups.

2) Performance/Reliability of Westinghouse developed and integrated low-cost ground equipment for communications satellites.

A methodology will be established to document the tangible cost-savings (transportation, subsistence and lodging) and intangible cost-savings (value of managerial time) which are accumulated versus the effectiveness of video/audio information exchange.

8.3.2 NASA Teleconferencing Experiment

This experiment will link together three NASA Centers through the CTS by two-way video, audio, and facsimile. The three NASA Centers involved include the Ames Research Center in California, the Goddard Space Flight Center in Maryland, and the Lewis Research Center in Ohio. In addition, the close proximity between NASA Headquarters in Washington, D.C. and Goddard will enable Headquarters personnel to enter into a teleconference with Ames or Lewis by making use of the Goddard facilities.

The objective of the experiment on the CTS is to test the hypothesis that NASA can effectively use teleconferencing, in the form of video, audio, and facsimile through a high power communications satellite, as a supplement to and a replacement for travel. This hypothesis will be tested for various types of earth stations and different types of operation (e.g. half-duplex video vs. full-duplex video).

Some of the specific problems that will be addressed throughout this experiment will include:

- The effects of rain at these frequencies, and to what degree the quality of the teleconference will be affected.

- The implementation of low-cost, effective security apparatus on the video, audio, and facsimile circuits.

- The size and sophistication of ground transmitting and receiving stations necessary to provide adequate teleconferencing capability.

During the tests, the minimum requirements for both the transmitting and receiving stations will be addressed. Various types of receiving systems will be used to determine the best combination of antenna and receiving equipment to satisfy the technical requirements of this experiment. The receiving antennas will range from six to sixteen feet in diameter.

Transmit power to the spacecraft will also be varied to determine the minimum power required for acceptable performance. The minimum ground station requirements will be determined for a variety of atmospheric and weather conditions including clear sky, cloudy sky, and light and heavy rainfall.

Security requirements necessary for the conduct of this experiment will also be addressed. A study will be conducted as to the availability of low-cost security equipment to encode and decode both the audio and video signals. Such equipment will be implemented into the system, beginning with the audio and facsimile circuits first, and later introduced into the video path.

The experiment will be evaluated for technical performance and teleconferencing effectiveness. From a technical point of view, the experiment will be evaluated as to the degree to which the ground station hardware satisfies the objectives of the test plan. This will include an analysis of the equipment required to conduct a teleconference through a Geostationary Communications Satellite, the availability and use of equipment to provide secure communications, and the effects of signal attenuation due to precipitation.

9. Commercial Broadcast

9.1 Introduction

The three major television networks, ABC, CBS, and NBC, established their network requirements for a Satellite Television Program Distribution System in April 1971. These requirements provided spacecraft contractors and other interested parties with current information as to the service requirements, performance objectives and operating standards. These requirements contained data for 1975 but were subsequently adjusted for forecasting requirements envisioned for the 1985 to 1995 time period. A major change occurred in the addition of stations for Hawaii and Alaska with Alaska requirements being for four transmit and receive stations plus 100 receive-only stations in Alaska. For network management and switching control, audio channels were specified by the networks.

The following information summarizes some of the key requirements set forth by the networks for the Satellite Television Program Distribution System (ref. 25).

9.2 Service Requirements

The basic requirement is for a network-(studio) to-affiliate (studio) distribution system with the major transmitting center to be located in or near New York City. A capability for transmitting simultaneously to all or part of the distribution system from other specified locations is required. The carrier will be required to service all television stations in the television market areas where there are television stations served by satellite. The capacity of the system will be such that the networks and other users with contract or occasional video transmission requirements can be accommodated. The carrier and/or the networks will make arrangements to provide interconnection with other common carriers or private distribution systems where necessary to perform the basic requirement. Service quality and reliability is to be comparable to present ground-based AT&T service.

In addition to the audio associated with video, there is a requirement for two-way voice for broadcast use, such as occasional audio-only for voice over in a news program or two-way voice programs.

The networks have discussed the possibility of feeding portions of their radio networks by "piggy-backing" the radio audio onto the television satellite channel, and distributing it locally by land-lines either from the television station or from the closest ground station. Since it is possible that the radio sound channel might be interrupted by the switching of a particular television channel, the networks are considering combining a multitude of non-video services on an additional dedicated satellite channel constantly available to all ground stations. This would enable the New York station to distribute radio sound channels, teletype channels, control channels (to remotely start and stop machinery at television stations), voice cue circuits (for program information), and perhaps a universal time base that would permit all elements of the system to be synchronized.

9.3 System Capacity

Initially, each network will require three full-time protected channels. Protection includes continuous service during eclipse and sun transit periods. In addition, and on reasonable notice, the networks will have access to a total of two additional channels at rates reflecting the occasional nature of their use.

In addition to the above, on a scheduled basis between mid-September and mid-January, occasional channels will be needed on weekends in accordance with the following schedule; Saturday, up to 5 channels between 12 Noon and 8 PM; and Sunday, up to 11 channels between 12 Noon and 8 PM.

9.4 Distribution System - Television Stations Served

As indicated earlier, the three networks will distribute programming from New York City to the television stations in conterminous U.S. This list includes 399 receiving channels for 380 stations in 151 television markets. Network stations in Alaska, Hawaii, and Puerto Rico also will be served. A capability will exist for the carrier to include in the distribution system any television station to which a network or networks might need to deliver programming. Each receive-only ground station will be considered as a possible transmitting facility if the proper equipment were added.

9.5 Distribution System - Primary Transmission Points

The major transmission point for most network programming will be New York City. Routine transmissions from each of the other transmission points will be part of the basic service. Initially, this will include 66 uplink transmission channels from 73 stations in 29 markets.

The carrier also will provide for transmission capabilities from locations not now designated as transmission locations, such as currently designated receive-only stations or other designated locations, by using existing ground facilities or transportable earth stations. For sports pickups, the origination will be routed through the nearest television station. For that reason, sports pickups will be routed via the nearest ground station to the satellite. Alternative operational modes involve the use of fully equipped transportable ground stations at the stadium which may be provided by the carrier.

9.6 Ground Station Operation

Each satellite channel receiver in a ground station will be able to switch to, and receive signals from, any of the channels in the satellite, or satellites, that the ground station can "see". This permits each television station linked to the ground station to receive programs or inserts from any of the satellite transponders.

The networks have a requirement for an alternate transmitting point in Los Angeles to take over in the event of catastrophic failure in New York.

9.7 Transmission Performance Objectives

Transmission quality and reliability objectives have been established to govern the acceptability of a circuit from end to end.

There are two performance objectives which the networks consider to be performance requirements:

1) The transmission signal-to-noise objective at the affiliate location is 56 dB. If a circuit falls below this requirement for more than 0.1 percent of the time in any month, it will be considered

unsatisfactory. A circuit with a signal-to-noise ratio below 40 dB will be considered unfit for broadcast, even though for continuity purposes the affiliate continues to use the signal for broadcast.

2) The overall transmission reliability objective of 99.99 percent (less than 53 minutes of allowable outage time per year per channel per station served) is considered to be the reliability requirement.

Thus, the performance of a circuit will be considered unfit for broadcast by the networks if it fails, or the signal-to-noise level at the affiliate studio falls below the 40 dB level, or if the operational reporting limits are exceeded and cannot be corrected within a reasonable time.

10. Intersatellite Data Relay

10.1 Introduction

The concept of using a network of synchronous satellites for the purpose of relaying data from low altitude orbiting spacecraft to the ground was conceived in 1963 at the NASA/Goddard Space Flight Center. The need for such a system was and is being motivated by the limited radio contact presently available between low altitude earth satellites and the ground. Thus, the potential exists for the use of data relay satellites for the relay of data between both manned and unmanned satellites.

Since its conception, there have been a number of studies conducted by NASA regarding a Tracking and Data Relay Satellite Network (TDRSN).

Previous work related to the TDRSN was supported by both NASA and the Department of Defense. Two very comprehensive studies were completed for the Department of Defense in the Spring of 1968. One of these studies was performed by TRW and the other was performed by a team from GE and ITT. Another Department of Defense study, completed by the Mitre Corporation at the end of 1967, was concerned with the national need for a TDRSN, and concluded that the eventual establishment of a TDRSN is inevitable.

Prior to 1970, there were four major studies funded by NASA. Two of these were competitive studies, performed by RCA and Lockheed, which were completed in 1967. A third study performed by Hughes was also completed in 1967. The fourth study was performed in 1969 for the Goddard Space Flight Center by JPL.

In 1972, two major studies of the Tracking and Data Relay Satellite Systems Configuration and Tradeoffs were undertaken. These two very detailed studies, performed by Hughes (ref. 26) and Rockwell International (ref. 27), developed the basic configuration and concepts for the present (TDRSS) system being pursued by NASA.

In February 1975, NASA Goddard Space Flight Center issued a Request for Proposal No. 5-34500476 (Ref. 7) for procurement of a telecommunication service using a Tracking and Data Relay

Satellite System which would be provided by the successful bidder. The TDRSS envisioned would have similar capabilities and essentially the same configuration as that developed in the 1972 studies conducted for NASA.

10.2 The TDRSS Concept

The Tracking and Data Relay Satellite System (TDRSS) will consist of two geosynchronous relay satellites, 130 degrees apart in longitude and a ground terminal located in the continental U.S. The concept is shown in Figure 10. The system will also include two spare satellites, one in orbit and one in configuration for a rapid replacement launch.

The purpose of the TDRSS is to provide telecommunications services which will relay communications signals between low earth-orbiting user spacecraft and the user control and/or data processing facilities. A real-time, bent-pipe concept is utilized in the operation of the TDRSS telecommunications services. The system will be capable of transmitting data to, receiving data from, or tracking user spacecraft over at least 85 percent of the user orbit.

Plans call for the first TDRS to be launched in July 1979 with the TDRSS being fully operational on December 31, 1979. The plans envision a Spaceflight Tracking and Data Network (STDN) consisting of ground based stations at Fairbanks, Alaska; Goldstone, California; Rosman, North Carolina; Orroral, Australia; Madrid, Spain; and the TDRSS. Launch support stations are located at Bermuda and Merritt Island, Florida. It should be noted

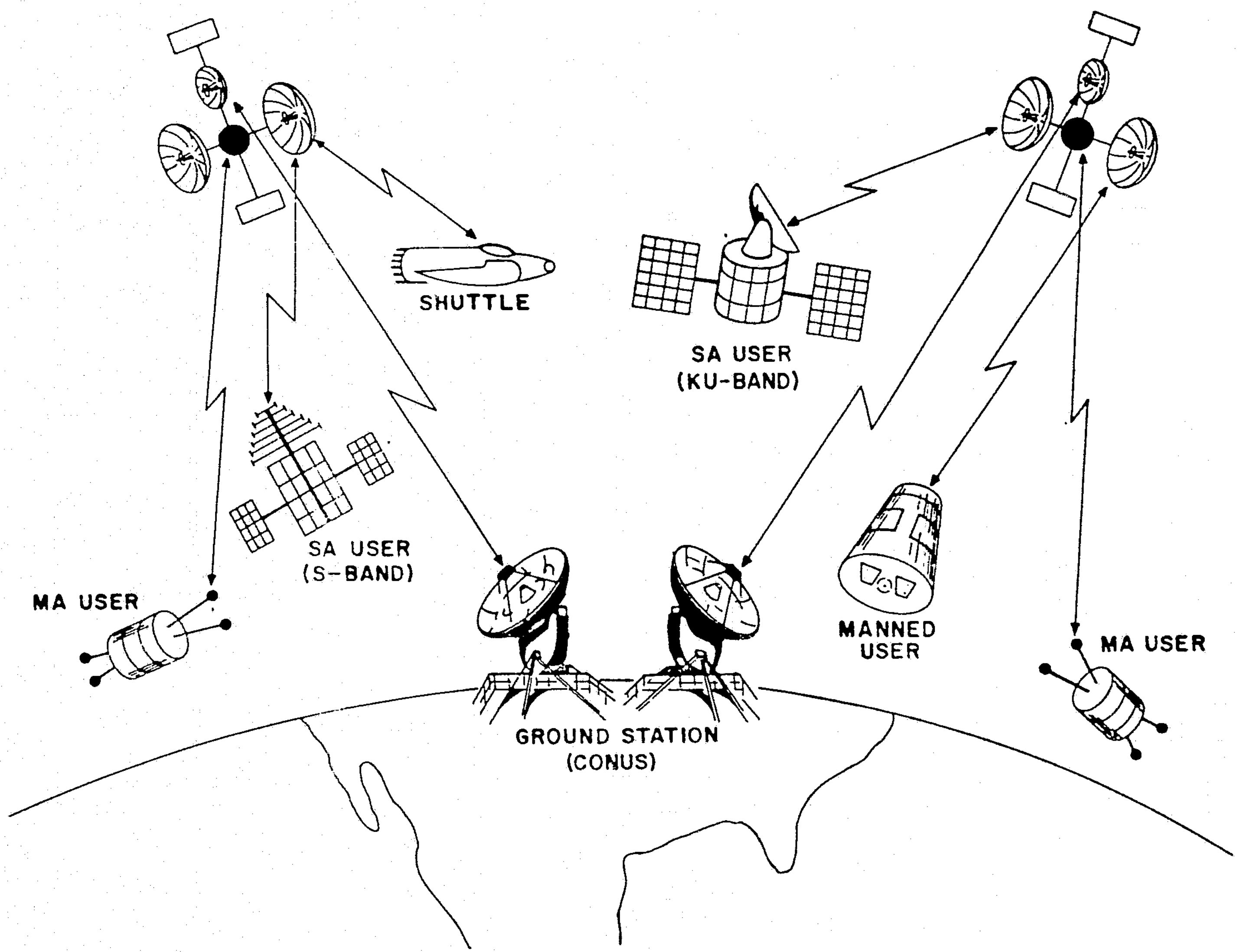


Figure 10. TDRSS concept

that the TDRSS, as a tracking and data acquisition resource of the STDN, will be scheduled and operated as any other station of the STDN.

10.3 TDRSS Services

The services to be provided by the TDRSS include:

- Two-way relay of telecommunications signals between an interface point at the ground terminal(s) and a number of orbiting spacecraft,
- Collection of tracking data from these spacecraft, and
- Provision of a calibration and simulation capability.

For telecommunications, a multiple access service will be provided by the TDRSS. The multiple-access (MA) communication service system is designed to provide simultaneous real-time and dedicated return link service to low earth-orbiting user spacecraft with real-time data rates up to 50 kilobits per second (KBps). Forward and return link support can be provided to all users of this system during the entire portion of their orbit visible to a TDRS, a minimum of 85 percent of the orbital period. Based upon current mission model projections, no scheduling restrictions should be encountered if this system is utilized for return link support. The forward link service provided by this system is time shared with a maximum bit rate of 10 KBps and supports one user at a time. This system will operate at S-band.

The system will also provide a single access communication service. The single-access (SA) communications service system is designed to provide a high data rate return link to users with real-time or playback of science data up to 300 megabits per second (MBps) and for users requiring forward link data rates up to 25 MBps. This system will be utilized on a priority scheduled basis, and will not normally be used for dedicated support to any mission (with the exception of the Space Shuttle). Return link service is provided at S-band (up to 6 MBps) and Ku-band (up to 300 MBps).

The service channel requirements for the forward channel services and return channel services as given in the Request for Proposal (ref. 28) are shown in Table 15. A baseline configuration and an alternate configuration have been established for bidding purposes. Only one of the two concepts will be implemented by the Government.

TABLE 15 SERVICE CHANNEL REQUIREMENTS

Concept I - Baseline Configuration

	MULTIPLE ACCESS	S-BAND SINGLE ACCESS	K-BAND SINGLE ACCESS
Forward Channel Services			
Quantity of Channels per TDRS	1	2	2
Total Channels for the TDRSS	3	6	6
Return Channel Services			
Quantity of Channels per TDRS	20	2	2
Total Channels for the TDRSS	20	6	6

Concept II - Alternate Configuration

	MULTIPLE ACCESS	S-BAND SINGLE ACCESS	K-BAND SINGLE ACCESS
Forward Channel Services			
Quantity of Channels per TDRS	0	3	3
Total Channels for the TDRSS	0	9	9
Return Channel Services			
Quantity of Channels per TDRS	0	3	3
Total Channels for the TDRSS	0	9	9

In addition to the above, cross support communication services will be provided. Any mission which is compatible with the MA system can receive forward or return link support from either the MA or SSA systems. Continuous MA support of a real-time return link and periodic SSA support of a high data rate experiment is a viable support mode for these systems.

Each of the previously discussed service systems can provide range and range rate tracking data for each user supported. This data will be provided by a Pseudo Noise (PN) Range and Range Rate (R&RR) system and will provide tracking accuracies comparable to that currently available from the ground based STDN.

10.4 Intersatellite Experiments

In recognition of the potential usefulness of intersatellite links, the 1971 World Administrative Radio Conference defined the new intersatellite service and has allocated frequencies above 40 GHz for this service. Intelsat is considering use of the 54-58 GHz band.

Both Comsat and Intelsat have been studying, and continue to study various means of increasing capacity and utilization of geosynchronous orbit by means of intersatellite links between geostationary communications satellites. In addition, experiments between ATS-6 and Nimbus-6 using similar techniques have successfully been conducted.

In April, 1975, the NASA ATS-6 geostationary satellite began to relay both tracking and telemetry data from the near-earth geodynamics satellite (GEOS-3). This was followed by the ATS-6 relay of data from the Nimbus 6 weather satellite launched in June 1975.

The experiment on ATS-6, called the Tracking and Data Relay Experiment, demonstrated the control of low orbit satellite equipment through a relay command data transmission and successfully evaluated telemetry relay capability from near-Earth satellites by transmission at various data rates and power levels. In addition, the experiment demonstrated the expansion of real time data coverage available through the synchronous relay satellite.

In the test, an extensive evaluation of telemetry data relay from the Nimbus-6 transponder at GSFC via ATS-6 to the ground station was performed. The principal data type used was the digital evaluation mode (DEM) data generated in the Nimbus-6 T&DRE digital electronics subsystem. The DEM data consisted of a pseudo-random code of 2047 bits at one of four bit rates: 50, 100, 200, and 400 KBps. Transmitting the various combinations of bit rate and power level allowed a bit error curve to be traced. The bit error rate (BER) was measured at the ground station using a code correlator. Typical results of DEM tests, with data transmitted from GSFC and relayed to the ground station were close to predicted levels. The predicted levels were obtained by determining BER's from the calculated received signal levels at the ground station and the practical limit curve for the code correlator performance. Nimbus-6 telemetry data consists of PCM data at 4 KBps and an experiment data channel on an FM subcarrier at approximately 43 KHz center frequency. The 4 KBps data can be transmitted separately or in combination with ranging tones or the FM subcarrier. Tests have shown that the 4 KBps data can be transmitted essentially error free for all regions of ATS-6/Nimbus-6 visibility at any transmitter power level. Transmission of the subcarrier requires the higher power levels and, when combined with PCM data, requires the highest transmitter power level to avoid FM thresholding.

Similar tests were conducted with a GEOS-3 type transponder at GSFC relaying data to the ground station via ATS-6. GEOS-3 generates PCM telemetry data at 1.562 KBps. This data can be used to modulate the T&DRE transmitter separately or in combination with ranging tones. Telemetry data was simulated during the tests by using a test set to generate a pseudorandom code. A similar test set at the ground station was used to make BER measurements on the received data. The results of four separate tests were within 3 dB of nominal expected performance.

These tests have demonstrated command and telemetry relay between two satellites is possible and that the practical application of intersatellite communications is a matter of demand and implementation.

11. Specialized Audio Service

11.1 Introduction

The dissemination of specialized audio information to special audiences or subscribers represents another growing market which is currently using existing communications services. A number of commercial profit making and non-profit organizations are in operation today which are providing information such as news, music, cultural and educational material and talking book programs for specialized audiences or subscribers. Most of the applications are using the Subsidiary Communications Authorization (SCA) channel of FM radio stations as the means of disseminating this information from a central studio.

This specialized audience is exhibiting continued growth on a regional and national basis. One of the major national users of this type of services is the MUZAK Corporation, headquartered in Westbury, New York.

Discussions were held with representatives of this organization during the course of this project to obtain the market potential for this service. It was felt that the MUZAK Corporation represented one of the major users because of their size, the fact they were national in scope and have a large number of subscribers.

11.2 The Existing MUZAK Operation

The MUZAK Corporation provides specialized background music to offices of clients or subscribers throughout the United States. Recording tapes of background music are prepared on a daily basis at the MUZAK Headquarters and distributed by United Parcel Service (UPS) to 200 cities having major studio facilities. These major studios are interconnected to existing FM stations in the area of the studio through the subcarrier. The programmed background music is transmitted on the subcarrier at 67 KHz to special SCA-equipped receiving equipment at the various subscribers in the area of the major studio. The program and background music received by the subscriber is changed on a daily basis and no two tapes of the material are repeated, thus there exists a major distribution problem for the MUZAK Corporation.

11.3 Use of Satellites for MUZAK Distribution

The MUZAK Corporation has conducted technical and cost studies relating to the use of existing domestic satellites for distribution of recorded background music. In 1971, tests were conducted at 4 GHz with RCA using the WESTAR I satellite. Tests were made between the Waldorf-Astoria Hotel in New York and cities located in the four corners of the United States to evaluate coverage outside the main beam of the spacecraft antenna. The cities in the experiment included Miami, Florida; Chicago, Illinois; Seattle, Washington; and San Diego, California.

Receiving terminals at each of these cities used a four-foot antenna.

For these tests, four channels, representing one per time zone were used. The experimentation was designed to test signal-to-noise (S/N) ratios and sun outage problems, particularly in the Seattle area, and general performance and operational characteristics. Signal-to-noise ratios of 51 dB were obtained.

Plans are being made by MUZAK for implementing satellite distribution from New York to approximately 400 receivers at their major studios within 2 years, using four-foot receiving antennas at 4 GHz. Active plans envision direct receptior by between 200,000 to 300,000 MUZAK subscribers nationwide. Cost analyses performed by MUZAK have indicated that the cost of 400 regional receiving terminals is equal to current costs for delivery of background music tapes presently distributed by UPS. Additionally, according to MUZAK representatives, the cost per transponder is less than costs for replacing present studio equipment.

The present studies performed by MUZAK indicate a distinct advantage in using satellite communications technology for high quality audio service on a regional and national basis.

12. Cable Television

12.1 Introduction

Cable television or CATV systems in use today have been primarily limited to one way cable distribution of television programs picked up by a CATV station via microwave or cable links and retransmitted over the cable distribution system. The primary markets for these CATV companies have been subscribers in rural areas and in certain cities. Subscribers in many instances enjoy better television reception, a greater selection of program material and a greater number of channels than offered by a nearby television station.

Cable television has been estimated as growing at a rate of from 20 to 25 percent annually with over 15 million viewers using today's CATV systems. It has also been estimated that 90 percent of all residences will be served by cable TV by the year 1985 (ref. 29).

In addition to the growth in viewers or subscribers, an additional growth is expected to occur in the types of service provided by CATV since the information bandwidth in such systems is sufficient to carry many other services in addition to television programming. Some of the future types of services which may be accommodated using cable systems include:

- Education and Instructional TV
- Library Reference and Access
- Data/Information Services
- Biomedical education, consultation and diagnosis
- Shopping news
- Cultural programs
- Continuous Weather and News Service
- Meetings and Discussions
- Home Access to Time-Share Computers

As implied from the list, some of the services of the future will continue to be one-way, although there exists a growing demand for two-way service or an interactive service capability. Another characteristic of the services of the future lies in the nature of the program material wherein many services represent largely local information dissemination and local communications requirements. With the growth, there will be an increased demand in other program material as systems operations try to satisfy FCC program requirements for local program origination.

This growth potential in services, viewers, and markets was dramatically illustrated in a January 13, 1976 speech before the National Association of Manufacturers by John M. Richardson, Acting Director of the Office of Telecommunications when he stated that next generation cable television enjoys the prospects of a possible six billion dollar annual market by 1985 with dozens of interactive information services brought into the home.

12.2 Use of Satellites for Cable Television

The prospects for the use of satellites such as the present and future domestic systems for interconnecting with cable television systems are real. Through a satellite interconnection system, it will be possible to distribute program material on a nationwide basis.

Although satellite communications systems permit the use of nothing more than a different method of transmission which must prove its value in relation to existing terrestrial systems. microwave relay, and coaxial cables, the one outstanding advantage of the satellite is its capacity to distribute a signal of high quality from one sending location to a great quantity of receiving stations. Further, satellite communications systems are already on the verge of demonstrating their capacity to function in a complementary manner to cable television systems as envisioned in the parts played by both in the field of the subscription television industry and its movement toward networking.

According to a recent issue of "Telecommunications Reports" (ref. 30), the FCC has already received a number of applications for receive-only satellite earth stations from cable television systems. The applicants include: Cablevision Investors, Waco, Texas; River City Cable TV, Louisville, Kentucky; Columbia Television Co., Pasco-Kennewich, Washington; and Store Cable TV, Sarasota, Florida.

Some of the other on-going activities in using satellite systems with cable TV were discussed in the December 1975 "Communications and Engineering Digest" (ref. 31). For example, this magazine reported that Home Box Office (HBO), a subsidiary of TIME, Inc., recently commenced operation of a pay subscription television network, utilizing transmission of television broadcast signals via satellite to UA-Columbia Cablevision's cable television system in the Ft. Pierce-Vero Beach, Florida area, and to the American Television and Communication system at Jackson, Mississippi.

A reduced tariff agreement between HBO and RCA for use of the satellite, and the ability of Scientific-Atlanta, Inc., to provide satellite earth stations to cable television systems at a cost of $65,000 each helped to forge the first domestic subscription cable television network.

Satellite networking through the use of cable systems has proven itself to be technically feasible and initial subscriber response is claimed to be good. At the time of this writing, it is expected that pay penetration in the Ft. Pierce-Vero Beach area will amount to 30-55 percent and it is already 27 percent in Jackson, Mississippi.

Predictions of the future of pay cable in conjunction with satellite communications appear bright. It is expected that 35 to 75 earth stations will assume operational status by 1977 and the number of subscribers to pay cable is expected to increase by 100 percent by then. It is also claimed that live, televised events could be revitalized through the use of satellites. The concurrent operation of earth stations by cable operators and broadcasters, is economically feasible, since an earth station is capable of receiving all channels transmitted from a satellite, including those carrying broadcast signals. All that is required is the addition of approximately $15,000 in receiving equipment added to the existing down converter unit. Further, dual earth station operation takes on added significance in light of the technologically advancing state-of-the-art.

Thus, the future holds the possibility of a broadband interconnected system which would be fully switched. Such a system could create a communications framework, the basis of which could combine satellite and cable transmissions. The industry would then gravitate toward a communications grid which would drape the entire country. Such a grid would permit the recipient unlimited information access.

13. Public Broadcasting Service

13.1 Introduction

In recent years, there has been a growing interest in public broadcasting and the programs and services offered by this national non-commercial system. Leadership and financial support to public television and radio stations transmitting non-commercial programming is provided by the Corporation for Public Broadcasting (CPB).

CPB provides support to local public broadcasting stations for program production and assistance, fosters a national interconnection system for distributing programs to such stations, and supports programs for national distribution. CPB may not, however, own or operate interconnection systems, equipment, or program production facilities relating to public broadcasting.

CPB is funded primarily by annual appropriations from the federal government. For the fiscal years 1970 to 1975, CPB received an aggregate amount in excess of $204,000,000 in basic federal appropriations. CPB has also received smaller amounts of monies in the past in the form of research support and programming contracts, principally from the Department of Health, Education and Welfare and the National Science Foundation. CPB, in turn, awards these programming funds to independent producers for the production of particular programs.

Both stations and independent producers are eligible for CPB grants for program development and production. During 1975, 152 community service television grants were made which ranged from $20,270 to $650,000 and which totalled approximately $25,400,000.

To satisfy its obligation to provide, but not to operate, the network interconnection for public television stations, CPB helped create the Public Broadcasting Service (PBS) in 1969 as another independent, nonprofit tax-exempt corporation.

13.2 Public Broadcasting System

The primary function of PBS is to manage the distribution of national public television programs over the current AT&T long-lines interconnection facilities and to represent and provide services required by the member stations. In addition, PBS is also involved in the gathering, scheduling, and promoting of the programs being distributed.

PBS began distributing programs through the AT&T long-lines interconnection system in 1970. In 1973, CPB, PBS, and the member stations reviewed and revised the arrangements governing their relationship. Under the current format, CPB continues to provide PBS with funds to pay the interconnection services with AT&T.

As of December 22, 1975, there were 155 public television licensees which are PBS member stations. The PBS membership includes almost all public broadcasting licensees. Most member stations produce as well as broadcast programs. Approximately two-thirds of all programs broadcast are for general audience consumption; the other one-third is programming for the classroom.

Licensees are divided into four major sponsor categories. As of December 22, 1975, the composition of the 155 licensees then existing were as follows:

Sponsor	Number of Licensees
State: Authorities and commissions	24
Community: Nonprofit corporations	59
University: Colleges and universities	54
School: School districts, municipal boards of education, and other similar elementary and high school agencies	18

The member stations receive funds from a wide variety of sources. The aggregate funding for all PBS member stations was approximately $202,000,000 in the year ended June 30, 1974. Of this total, state and local governments (including state universities) provided more than 50 percent of such funds.

13.3 National Public Radio

National Public Radio (NPR) is an organization with a structure similar to that of PBS. As of December 12, 1975, it served 162 licensees by providing national radio services. It does so at the present time largely through an inadequate terrestrial distribution system based on 5 KHz bandwidth long lines. These facilities permit the distribution of low quality signals only, and are not suitable for the transmission of high quality monophonic or stereophonic program material.

13.4 Role of Satellite in Public Broadcasting

During the Spring of 1974, PBS approached the Ford Foundation with a draft proposal regarding a possible shift of program broadcasting from a terrestrial interconnection system to a satellite interconnection system. PBS' investigation of this concept had been authorized in January 1974 by its Board of Directors. The authorization and subsequent investigation also had the tacit approval of the Corporation for Public Broadcasting.

In its presentation to the Foundation, PBS recognized that a great deal of work was still needed in analyzing the various possibilities involved in public broadcasting moving to a satellite interconnection system. It also recognized that such a move could not be made without the approval of all of its members, as well as of CPB. Its proposal was that the Foundation participate with it in making an analysis of available and potential satellite interconnection systems with a view toward the possible financing of a significant portion of the capital costs involved in procuring a ground environment that could make use of satellites.

The objectives established by PBS for this service were as follows:

- local autonomy
- reliability and coverage
- flexibility
- costs, and
- timing.

In January 1975, the PBS Board of Governors considered and adopted a staff proposal to establish a CPB, PBS, Ford Foundation Satellite Working Group (SWG) to employ personnel and counsel to develop a plan for the transition from terrestrial to satellite interconnection.

In reviewing alternatives under which public broadcasting would have access to this segment of the satellite interconnection system, the advantages and disadvantages associated with owning or leasing a communications satellite were examined by the SWG. It was decided that project feasibility could be maximized by negotiating for transponder space with commercial entities which already had satellites in orbit or had definite plans to launch satellites capable of relaying high quality television signals. Within those parameters, the choice was narrowed to

Western Union (which currently has two satellites in space) and RCA (which successfully launched its first satellite on December 12, 1975).

The SWG requested detailed proposals from each company as a basis for entering into extensive negotiations. In regard to all the proposals received from Western Union and RCA, the SWG reviewed not only price but also technical quality guarantees, performance risks, and responsiveness to the financial and interconnection development requirements of public broadcasting. On the basis of these criteria, Western Union was targeted as the satellite carrier. On January 14, 1976, the CPB Board of Directors passed a resolution approving the proposed satellite interconnection system project.

13.5 Proposed Satellite Interconnection System

The proposed satellite interconnection system consists of a satellite on which public broadcasting will lease three or four full-time transponders, a master origination terminal that transmits public broadcasting programming to that satellite, approximately 150-165 ground terminals* to receive the programming from that satellite, and regional transmitting capacity which will generally originate from terminals owned by particular groupings of public television stations.

*Ground terminal capacity is being obtained for 165 public television stations.

The space segment of the proposed system consists of a geostationary communications satellite which receives signals from transmitting ground terminals and, in turn, transmits these signals back to receiving ground terminals.

Some of the key provisions of the proposed Western Union WESTAR satellite are summarized in the following paragraphs.

- Either three or four fully-protected transponders will be leased to CPB for a period of seven years. (The choice of whether to select three or four transponders is to be made within six months of the date on which a contract with Western Union is signed; at public television's choice, the fourth transponder will be available either at the end of the project implementation phase or on January 1, 1980.

- One back-up transponder will be kept available for public television on the Western Union satellite being used; if more than one transponder fails, there will be a shift to Western Union's back-up satellite; if both satellites fail, Western Union will transfer public broadcasting to its third satellite, assuming that satellite has been launched and is within the range of usable orbit locations.

- During the contract period, Western Union will maintain at least two operational satellites in space and a spare satellite on the ground or alternatively a third in-orbit satellite; if there is a failure of any in-orbit satellite while only two are in orbit, the third satellite will be launched as quickly as possible; during the initial service term and the two proposed extension terms, Western Union will commit to a continuation of C-band (4-6 GHz) service.

- Western Union will make available its microwave and cable facilities for interconnecting non-collocated ground terminals to public television studios; Western Union will also apply for and construct common carrier microwave facilities, where required, for public television to obtain signals from non-collocated ground terminals.

- The prime Western Union satellite will be east of "Anik"* and at 99° W, if so authorized by the FCC; the back-up Western Union satellite will be at 123.5° W, or some other location within the specified usable orbit for public television and as authorized by the FCC; if the satellite being used is west of Anik, it will be optimized to provide maximum e.i.r.p. to public television.

FCC approval is required for various aspects of public television's proposed arrangement with Western Union. Thus, the FCC may require that Western Union file a tariff regarding the transponder rate provided to public broadcasting in place of a negotiated contract.

The master origination ground terminal will be the central program transmitter for public television's satellite interconnection system and will have the capacity to send out at least four programs simultaneously. This ground terminal will also be capable of receiving programs from satellites in addition to the Western Union satellite on which public broadcasting leases transponder capacity or obtains reception rights. The master origination ground terminal receives television signals in baseband form from the PBS technical operations center, transforms such signals to radio frequency signals and then transmits these radio frequency signals to the satellite.

*Anik I, II and III are the designated names for the three satellites presently in orbit and owned by Telesat of Canada.

It is anticipated that the master origination ground terminal will be located near Washington, D. C. and will be operated and controlled from the PBS national program origination center, presently located in L'Enfant Plaza, Washington, D. C. The master origination terminal will, under normal operating conditions, transmit all programs originating from the PBS technical operations center through the satellite to the Eastern, Central, Rocky Mountain, and Pacific Coast time zones, as well as to Alaska, Hawaii, Puerto Rico and the U. S. Virgin Islands. Special programming to serve PBS stations in all time zones will also be transmitted from the master origination terminal on an as-required basis.

The master origination ground terminal will be fully equipped with back-up (redundant) systems to achieve the highest possible reliability, and is expected to consist of the following communication subsystems:

- Antenna Subsystem - includes two 11 meter antennas both of which will be able to receive as well as transmit;
- Low Noise Amplifier Subsystem (four LNA's) - increases the strength of the signal received from the satellite;
- Transmitter Subsystem (five transmitters) - changes the baseband signals to radio frequency signals and transmits them to the satellite; and
- Receiver Subsystem (five receivers) - changes the received signal from radio frequency back to baseband video and audio signals.

SECTION 3

SURVEY OF SERVICE SUPPLIERS

1. Introduction

In parallel with the survey of the current communications markets described in the preceding section, an extensive survey was performed to acquire data and information on current terrestrial and satellite service suppliers. Several techniques were used in the survey to acquire the data. The survey initiated with the search of publications, literature and symposium records for information on satellite and terrestrial services and Specialized Common Carriers. Filings at the Common Carrier Bureau of the FCC and applications from organizations seeking to establish satellite communications facilities in the U.S. were reviewed and pertinent material was obtained.

Personal contact was made with key management representatives of the major companies such as Western Union, RCA, Comsat, etc. This contact was made to find out what these companies are doing in the domestic arena, their plans for the future, and the markets they are pursuing. Since much of the potential for using the 40 and 80 GHz frequency band for future satellite communications depends on the demand for space borne transponder capacity required for the markets, the growth in the domestic satellite business as to transponder requirements is extremely important. Thus, the survey was directed toward identifying the domestic satellite service suppliers plans and transponder growth. This growth is reflected in Figure 11 for the 1974- 1980 time period.

The domestic systems investigated and discussed in paragraph 2 of this section include the following:

- Comsat/IBM/Aetna
- COMSTAR-AT&T/Comsat
- Satcom-RCA/Globcom
- Telesat-Canadian
- WESTAR-Western Union

The competitive nature of the domestic satellite market made it somewhat difficult to obtain in-depth and detailed data from these sources. However, based on information obtained, the current U.S. market for satellite communications comprises bulk transmission uses by monthly lease or long-term contract. The customers for such services are the existing terrestrial carriers and some of their customers now served by terrestrial facilities. Many of the future markets that satellite transmission could effectively serve are now served by terrestrial facilities of AT&T or Western Union, or in the case of off-shore areas, by satellite facilities of Intelsat. The latent market comprises new special terrestrial carriers, emerging cable television systems, and organizations that use leased-line transmission service; all represent sizable demand aggregations. The leased-line market includes current uses now provided by terrestrial facilities and additional latent uses that are expected to emerge and grow as a result of lower prices made possible by

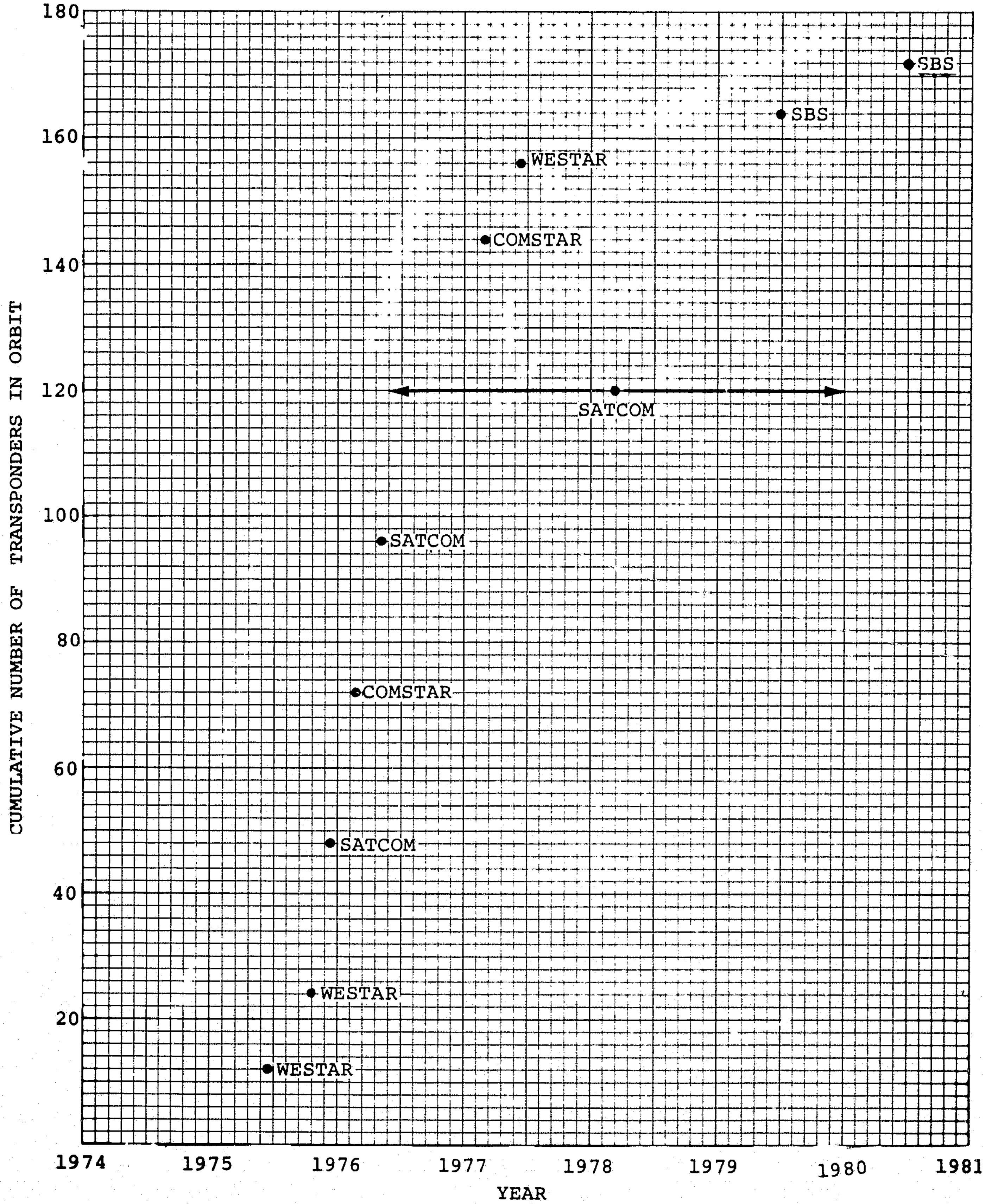


Figure 11. Domestic satellite transponder growth

satellite facilities and vigorous marketing efforts by new competitive satellite carriers.

Additional markets for service under low-risk long-term contracts may emerge during the next few years as groups of users pool their demands in order to reduce their respective individual costs, as current large users of leased-line service -- such as the federal government and the airlines -- procure satellite transmission service, and as latent uses evolve -- such as rapid postal delivery service employing facsimile transmission. These markets may be assembled by marketing efforts of firms aspiring to establish satellite systems, or they may result from users' efforts to reduce transmission costs. As they emerge, these markets may be served by expansion of satellite systems then operating or they may result in establishment of satellite systems by new entrants into the industry.

Some current users of long-distance transmission provided by terrestrial facilities may obtain future service at lower costs from specialized satellite carriers, especially if satellite service is available at the lower price levels indicated by some of the applicants, and if AT&T -- as indicated in its application -- prices its satellite services according to present AT&T tariffs for terrestrial facilities.

On the other hand, the terrestrial communications service suppliers have experienced long-term growth. AT&T is the dominant terrestrial service supplier, providing leased and private-line service along with its sole-monopoly Direct Distance

Dialing (DDD) service. AT&T's long-line services have experienced a compound growth of 14 percent per year since 1966. In recent years, however, competition with AT&T's leased and private-line service has been allowed by the FCC. The growth and markets of these new competitors - called Specialized Common Carriers (SCC) - were of interest and concern in this study. Data obtained could provide an indication of the potential demand for SCC's nation-wide. In addition, there exists the possibility of transferring some of the markets, SCC's and AT&T's leased services over to satellite systems. Accordingly, part of the market survey concentrated on obtaining data on current terrestrial service suppliers with emphasis on the growing Specialized Common Carrier field. Information on the following SCC's was obtained:

- AT&T Dataphone Digital Service
- American Satellite Corporation
- DATRAN Co.
- GRAPHNET Co.
- MCI Telecommunications Co.
- Packet Communications Co.
- Southern Pacific Communications Co.
- Telenet Communications Corporation
- United States Transmission Co.
- Western Telecommunications, Inc.

The services these companies offer and the cities of the United States they service are summarized in paragraph 3 of this section.

2. Domestic Satellite Services

2.1 TELESAT (ANIK)

Telesat Canada, established as a Canadian Corporation by an Act of Parliament, came into being on September 1, 1969, and was authorized to install and operate a multi-purpose system of communications by satellite throughout Canada. This main objective of Telesat was achieved with the commencement of commercial service on January 11, 1973, and during the first year of commercial operations the targeted level of service has been attained.

The system, in its overall configuration, includes spin-stabilized satellites in geostationary orbit; tracking, telemetry and command facilities; a control center and numerous earth stations of several different types. As a multi-purpose telecommunications system providing television, radio, voice, data and facsimile transmission services, it was originally designed to meet the initial requirements of Telesat's customers and to be interlinked with existing terrestrial systems. However, as further requirements have been raised, changes have been made to some of the earth stations and many additional facilities are being implemented.

Telesat's ANIK I and ANIK II launches were successfully carried out on November 9, 1972 and April 20, 1973, respectively. The Delta 1914 launch vehicle provided transfer orbit parameters well within pre-mission predictions and after launch both spacecraft were in 100 percent operational condition.

The launch of Telesat's ANIK III occurred on May 7, 1975. This third launch utilized a Delta 2914 vehicle which replaced the Delta 1914 version previously used and offered some 250 lbs. greater payload capability to synchronous transfer orbit.

Subsequent to the introduction of commercial operations and the second launch in 1973, Telesat implemented a new telemetry and command facility at the Allan Park Station, brought the Supervisory System for monitoring some of the larger unattended stations into service, completed the installation of its Network Control System for television service, and undertook the first commercial application involving time division multiple access (TDMA) technology.

2.1.1 Satellite Description

The Telesat satellites are active spin-stabilized multichannel repeater communications satellites for use in geostationary orbit. The satellites operate at 4 and 6 GHz. Each satellite has twelve high-capacity microwave channels and each channel is capable of relaying one color television program or up to 960 multiplexed voice signals using a single carrier. Multicarrier voice-modulated signals can also be accommodated within a microwave channel with some reduction in total capacity. Each channel has a bandwidth of 36 MHz and provides not less than 33 dBW EIRP throughout Canada.

The communications antenna beam pattern is shaped and aimed to provide optimum coverage of Canada and the coverage area as seen from the satellite at the 114°W longitude position.

The spaceframe consists of a 30-inch diameter thin wall cylinder coaxial with the satellite, and a 73-inch diameter honeycomb sandwich platform. The cylinder surrounds the apogee motor and supports the spin platform, on which is mounted the communications repeater, telemetry and command electronics, and the batteries. The platform supports the cylindrical solar panel at its periphery and the despin motor by a pedestal-type support at its center. The solar panel substrate is a honeycomb sandwich with fiberglass laminates, on the interior of which are mounted three dynamic balance mechanisms 120° apart.

The satellite structure is designed to withstand, without degradation, the simultaneous application of loads, temperature and other accompanying environmental phenomena. The major elements of the structure are the thrust adapter, equipment platform, antenna support, solar panel and reaction control support.

The antennas consist of a 5-foot diameter parabolic reflector with its associated feed and rotary joint, and telemetry bicone and command clover-leaf antennas mounted on the top of the parabolic reflector. The lightweight parabolic reflector is fabricated from a graphite-honeycomb composite with a reflecting surface of metal mesh. The feed assembly consists of a 3-horn feed for the transmit, receive and tracking functions. The rotary joint accommodates three signal paths across the rotating interface, two in the transmit band and one in the receive band.

2.1.2 Earth Stations

The completed communications facilities and earth stations will include 3 manned stations, 7 supervised stations, and 38 remote stations. The corporate head offices and satellite control center are located in Ottawa, Ontario.

Generally, the names which have been given to the station types, as shown below, reflect the character of the service which they provide; however, a few of the stations have provisions for handling more than one type of communications.

Multi-purpose communications facilities ..	Heavy Route (HR)
Main television receive and transmit	Network Television (NTV)
Message and television receive	Northern Telecommunications (NTC)
Television receive	Remote Television (RTV)
Message	Thin Route (TR)

In addition, Telesat is implementing a transportable television transmit station and a transportable message station.

2.2 COMSAT/IBM/AETNA

Subject to FCC approval by Fall 1976 IBM, Comsat General,, and Aetna Life and Casualty plan to begin operations in 1979 with an all-digital domestic satellite communications system, operating in the 12 and 14 GHz bands. The system will use time division multiplexing for switched, wideband transmission of voice, data, and image communications.

To operate the satellite business, IBM and its satellite partners formed a partnership venture called Satellite Business Services (SBS). SBS proposes to offer a private line satellite service to business and government users who can efficiently and economically take advantage of the service and technology which SBS is in the process of developing.

SBS has also asked the FCC to approve an interim system which will operate at 4 and 6 GHz using transponders leased from an existing domestic satellite carrier. The interim system would carry only IBM's internal corporate traffic among a limited number of IBM locations, but the service to IBM would be on a common carrier basis.

2.2.1 Satellite Description

The company will buy three satellites for the system, two for orbit, and one for use as a ground spare. One of the two

C-3

orbiting satellites will carry most of the traffic, while the other will be an orbiting spare to handle traffic overloads.

Each satellite will carry eight transponder channels, each with a power output of 20 watts and a usable bandwidth of 54 MHz. From the proposed locations, the system will provide coverage of the contiguous 48 states.

2.2.2 Earth Stations

SBS is initially proposing two earth stations, one near New York City, at Franklin Lakes, New Jersey, and the other near Los Angeles at Agoura, California. SBS also proposes to install small earth stations on the customers' premises, using antennas 16 to 23 feet in diameter. The applications for these will be filed as customers are identified.

SBS is also applying for earth station facilities at Poughkeepsie, New York, and Los Gatos, California, to be used in conjunction with the preoperational program employing the 4 and 6 GHz bands.

2.3 RCA/GLOBCOM (SATCOM)

The RCA Satcom system will consist of three satellites placed in geostationary orbits to serve the contiguous United States, Hawaii, and Alaska with television, voice channels, and high-speed data transmissions. The satellites will operate at 4 and 6 GHz. In the contiguous states, Satcom will provide private-line voice and data communications for the nation's businesses. It is hoped that Satcom will also provide new opportunities for educational and instructional television as well as other specialized uses such as CATV distribution.

Satcom I, RCA's first domestic satellite, was launched December 12, 1975. It is expected to become operational by the spring of 1976. The second satellite to be launched will be used for service on a preempt basis. A third satellite will be launched before 1980. The launch vehicle for Satcom I was a power-augmented Thor Delta, Model 3914.

The Satcom system first provided domestic satellite service to the U. S. through a new approach to system operation. RCA leased capacity from Telesat Canada on ANIK II until their own satellite becomes operational. They are also leasing nine transponders from WESTAR until Satcom I goes into operation.

2.3.1 Satellite Description

Satcom I, built by RCA's Astro Electronics Division, is the first 24-channel satellite to be placed in orbit. Frequency reuse is achieved through cross polarization. Each channel, or transponder, is capable of carrying one color television signal, 1,000 telephone messages, or 62 million bits of computer information per second.

The permanent system will use a lightweight, three-axis-stabilized spacecraft. The 3-axis attitude control system gives the payload, increased by 29 percent extra weight and power margins. This allows full solar power operation of all 24 transponders throughout the spacecraft's 8-year minimum life.

Single channel per carrier (SCPC) techniques will be employed to establish circuits with low traffic requirements or to establish supplementary circuits for short periods between major earth stations. This technique will be used principally for Alaskan intrastate traffic to provide the most efficient use of transponder capacity for service to widely separated communities with low traffic density.

2.3.2 Earth Stations

Using the ANIK II satellite and earth stations at Valley Forge, Pennsylvania; Point Reyes, California; and near Anchorage and Juneau, Alaska, service began in December 1973. More recently, additional earth stations have been built at Los Angeles, California; and Nome, Bethel, Prudhoe Bay, and Valdez, Alaska. Plans are also underway for earth stations at Houston, Texas; Chicago, Illinois; Vernon Valley, New Jersey; and Washington, D. C.

The earth stations are backed by RCA Central Terminal Offices and Control Centers.

2.4 AT&T/COMSAT (COMSTAR)

Under the domestic program, four satellites, three in orbit and one as an on-the-ground spare, are being built by Hughes Aircraft Company. The first spacecraft is scheduled for launch early in 1976. Comsat General will own and operate these satellites and lease their communications capacity to AT&T under the terms of a seven-year agreement.

2.4.1 Satellite Description

The satellites will reuse frequency bands through a technique known as cross polarization. This doubles the communications capacity of the satellites, making the system capable of handling more than 28,000 simultaneous two-way telephone conversations. The system will be used initially for message telephone services including Wide Area Telephone Service (WATS), and U.S. Government private line communications.

Each satellite will contain 24 transponders and will operate at 4 and 6 GHz. Each transponder will have a bandwidth of approximately 34 MHz. The horizontally-and vertically-polarized transponders will be interleaved frequency-wise; i.e., the channel interval for co-polarized transponders is 40 MHz, and the cross-polarized transponders are offset 20 MHz. Earth-to-space channels lie between 5925 and 6425 MHz; down-links are in the 3700-4200 MHz band. Both bands are shared with terrestrial line-of-sight radio relay systems.

Because each of the 24 transponders is capable of handling either analog or digital signals, a satellite can accommodate various combinations of FDM, TV, and TDM signals at any given time. This flexibility in operating mode, and the ability to reassign facilities as demand changes geographically or with time, make the system particularly useful in meeting the AT&T communications needs.

2.4.2 Earth Stations

Comsat General will also provide earth station facilities at Southbury, Connecticut and Santa Paula, California for satellite control on the east and west coasts, launch services, a system control center and communications performance monitoring of the satellites. The two Comsat General earth stations will include 42-foot and 32-foot antennas to provide the tracking, telemetry, command and communications monitoring of the satellites.

To integrate the satellite links with their terrestrial systems, AT&T will own and operate five communications earth stations. These stations will be located near Hawley, Pennsylvania serving the New York City area; Hanover, Illinois near Chicago; Three Peaks, California near San Francisco; Deluz, California near Los Angeles; and Woodbury, Georgia near Atlanta.

2.5 Western Union Telegraph Company (WESTAR)

The Western Union system consists of three satellites operating at 4 and 6 GHz: WESTAR I, launched April 13, 1974; WESTAR II, launched October 9, 1974; and WESTAR III, whose planned launch date is the second quarter of 1977. The three satellites each have 12 transponders, each with a usable bandwidth of about 35 MHz. One of the satellites will be used as an in-orbit standby. In addition, a ground spare will be available. Two transponders in each of the two "working" satellites will be on standby, leaving twenty working transponders available for service.

Western Union leases three transponders to American Satellite Corporation (ASC), which has been in operation since July 1974. ASC in turn provides common carrier services, voice and voice-band data of some 56 KB data anticipated. They have several hundred orders for circuits for private line traffic. ASC is also carrying radio programming channels for ABC, CBS, and the Mutual Broadcasting System. A second type of service being provided by ASC is a government network. Six ASC earth terminals are used to serve the Air Force Defense Meteorological Satellite Program and the Advanced Research Projects Agency (ARPA). Data rates of 1.5 MB are used.

ASC is constructing two additional dedicated earth stations for Dow Jones for 150 KB digital facsimile data service. ASC is attempting to expand its services into the TELEPAK (AT&T private line for the U. S. Government), the Aeronautical Radio "ARINC", the DOD Autodin Network, and the Postal Service Facsimile Network.

If future business expands to a point where ASC feels it would be more economical to own rather than lease circuits, they will buy their own satellite. They have studied satellites at 12 and 14 GHz for this reason.

Western Union also leases nine transponders to RCA/Globcom by transponder-month. There will be a phase-out of this lease when Satcom becomes operational.

Western Union utilizes WESTAR for their mailgram services, which are described in paragraph 6.4, to exemplify the growth in this market area. In addition, they can now provide data and voice service to users and video service upon request.

Western Union believes that they will be saturated in the 1980's and will go on to an advanced satellite. Total capacity of the present three satellite systems without spares is over 14,000 two-way channels.

2.5.1 Satellite Description

The satellite is a six-foot diameter, spin stabilized cylinder covered with solar cells. It has a 60-inch diameter antenna that is mechanically despun for permanent orientation. The antenna uses multiple feeds to obtain the desired coverage patterns: the contiguous 48 states, Hawaii, Alaska, and Puerto Rico. Position and attitude are maintained by computer controlled ground command jet firings.

2.5.2 Earth Stations

Initially, five earth stations have been constructed: New York (Glenwood, New Jersey), Atlanta (Estill Fork, Alabama), Chicago, Dallas (Yucana, Arkansas), and Los Angeles (Lakeview, California). Each earth station has a 50-foot diameter antenna except the master control station at Glenwood, New Jersey which will initially have two. A second 50-foot antenna will be installed at all earth stations in the near future to give the system additional capability and protection. All stations but the one at Glenwood are unmanned.

Each earth station is equipped with a comprehensive and highly reliable monitor, control, alarm and test system which will restore service automatically from almost any equipment malfunction in less than 100 milliseconds. The stations each have an uninterruptible power subsystem, as well as a terrestrial microwave relay link to the city they serve.

3. Specialized Common Carriers

In 1959, the telecommunications monopoly in the U. S. was broken when the FCC permitted the construction of private telecommunications systems for the use of very large businesses such as pipeline companies, power utilities, and the railroads. The use of these systems spread rapidly and provided a viable alternative to private line services supplied by AT&T, but justifiable only to the largest users of private line services. In some cases, joint use within an industry was authorized, but profit-making was precluded in such private line cooperative ventures.

In 1963 Microwave Communications filed an application with the FCC to offer Common Carrier private line services. Six years later, a license was authorized for the construction of a system between St. Louis and Chicago. However, the real decision was made in June, 1971, when the FCC, addressing Docket 18920, stated that competition was in the public interest, and provided a green light to the Specialized Common Carrier industry. By then the fledgling industry had grown to perhaps a half-dozen empires aspiring to build networks and offer specialized communications services. Most of these companies planned to construct terrestrial microwave networks with analog transmission facilities, duplicating to a great extent the facilities of the established carriers, AT&T and Western Union. One, DATRAN, proposed to construct a nationwide switched digital network.

In December, 1972, the FCC authorized domestic communications satellite systems. Entrants began to appear and to develop systems and to offer specialized communications via satellites.

A third segment of specialized carriers came onto the scene under the category of value added networks (VAN), or value added common carriers, (VACC). These companies lease common carrier transmission facilities and couple them to computers in a communications processor role in order to offer store and forward, translation, and other "value-added" services to data and facsimile users.

The following summaries of the various SCC's obtained during the study project illustrate the status and activities of this communication service.

3.1 American Satellite Corporation (ASC)

ASC became operational July 1974 with satellite service to New York, Dallas and Los Angeles for voice and data communications services, utilizing three leased transponders from WESTAR. Service to Chicago and San Francisco is offered via terrestrial microwave links. Also, dedicated customer earth stations for DCA-Met Sat and DCA-ARPA are in operation at the following five locations: Offutt AFB, Nebraska; Loring AFB, Maine; Fairchild AFB, Washington; Moffett Field, California; and Centerville Beach Naval Facility, California. The dedicated earth station complex is all digital and operates at speeds of 1.344 MBps with a nominal error rate of 10^{-7}, an operating error rate of 10^{-9},[9] and a 99.9 percent reliability.

The ASC network will be expanded in the near future to Washington, D. C., Atlanta, and Seattle. Switched services and direct digital data service plans are now being formulated.

3.2 American Telephone and Telegraph Company (AT&T)

In March 1974, AT&T filed a new tariff with the Federal Communications Commission establishing the rates and regulations governing the provision of DATAPHONE Digital Service between five major cities in the United States.

DATAPHONE Digital Service offers end-to-end digital transmission of data on a synchronous, full duplex basis by utilizing a new digital data network that is functionally discrete but physically integrated with the Bell System's existing telecommunications facility network. DATAPHONE Digital Service is a data-only, private-line service. A variety of speeds will be offered: 2400, 4800, 9600, and 56,000 bits per second. Both point-to-point and multi-station capability will be available.

The service is offered between New York, Chicago, Boston, Philadelphia and the District of Columbia. The network expansion plan called for extension of service from five cities to 24 by the end of 1974, 60 by the end of 1975 and 96 by the end of 1976. Network expansion will be matched by a similar expansion of each of the Digital City Serving Areas as more central offices within each of the metropolitan areas are equipped to provide DATAPHONE Digital Service.

3.3 CPI Microwave, Inc. (CPI)

The CPI common-carrier network currently links the major cities within Texas and has filed plans with the FCC to extend into Louisiana. CPI offers users of the Texas intrastate system access to major national and international cities through interconnection agreements with satellite carriers and other terrestrial specialized common carriers. The CPI network provides two basic types of service:

(1) Leased-line services for business, industry, government and other groups who use or need communication channels between two or more cities. The network can interconnect individual telephones, PBXs, teletypewriters or other devices. A monthly fee is charged with approved tariffs based on the number of circuits, bandwidth required, and the distance spanned.

(2) ABC, CBS and NBC have five-year contracts with CPI to use the system for distribution of all network TV signals to 18 affiliated stations.

The CPI network will provide for a variety of service arrangements for both voice and data, either digital or analog, at speeds to accommodate on-line data processing devices. Network design has been computed to have a reliability factor of 99.99 percent end to end.

3.4 Data Transmission Company (DATRAN)

DATRAN has built and put into operation the first segment of its long-planned digital data communications network which is now serving customers between Dallas, Houston, Oklahoma City, Tulsa, Kansas City, St. Louis and Chicago. Interconnect and further construction will deliver service to the East and West Coasts.

The DATRAN digital circuit switch is one of the characteristics of the DATRAN system. The switch provides the same quality of data transmission that is available from private-line offerings and at speeds up to 19.2 KBps. It permits any computer on the DATRAN network to connect with any other computer in less than one-half a second. DATRAN offers a performance guarantee of 99.95 percent of all one-second intervals of transmission.

3.5 Graphnet Systems, Inc.

In January, 1974 Graphnet received FCC authorization, as a VACC, to establish a nationwide packet-switched store and forward facsimile and data communication network.

The Graphnet System will accept input from a variety of devices, such as teleprinters, facsimile devices, Telex/TWX terminals, CRT's, magnetic tape or direct computer interface, for delivery to facsimile devices. The system also has the ability to accept data destined for busy terminals, and store the information for later delivery when the terminal is available. Network subscribers will have the option of sending information to addressees who do not have receiving facsimile equipment, for priority messenger delivery within 2 1/2 hours, or next day delivery via the U. S. Postal Service. Additionally, the Graphnet System permits a subscriber to store and retrieve forms, message text or address lists for use in message preparation; input a single document and have it transmitted to several addresses regardless of the terminal type; and have certified delivery by return receipt where desired. Computer and terminal tone exchanges provide positive assurance that a document has been properly delivered.

3.6 MCI Telecommunications Corporation (MCI)

MCI is providing high-quality business communications services to an ever-growing community of customers. MCI's system serves more than 30 metropolitan areas with close to 400,000 miles of customer circuits installed and operating at 99.97 percent reliability. Underway is installation of an additional 350,000 circuit miles.

MCI's market penetration has been highest among those users whose communications requirements are the most intense. For instance, the financial community and the airlines are major MCI customers. Orders are being processed through Aeronautical Radio, Inc. (ARINC, the air carrier's communications coordinator) for 17 airlines, with service for six already installed. These orders include FX, CCSA, tandem-dial, private-line, and data -- the full range of leased line services.

Existing orders and projections along the New York to Chicago network segment have led to tripling the capacity along that route. Expansion of MCI's system west from Dallas to

Los Angeles was realized through an agreement by Western Tele-Communications, Inc. Expansion north from New York to Hartford, New Haven and Boston, south to Atlanta, and spurs to additional cities in the midwest will be implemented as soon as arrangements for necessary financing can be completed.

In addition to physical expansion, MCI is undertaking a major thrust toward developing new services for sub-markets of the business and data communications industry. Already, MCI's offerings provide flexibility and cost/effectivenss for private line users. New proposals, such as Data Express, the terminal-to-terminal overnight transmission of bulk data, are designed to utilize available capacity. Ways of optimizing sucscriber network configuration are being developed, as are a number of concepts oriented toward maximizing customer use of communication facilities.

3.7 Packet Communications, Inc.

In November, 1973, the FCC authorized Packet as the first of a new class of communications service companies which have come to be known as Value Added Network or VAN companies. As a VAN, Packet will not construct its own microwave towers or intercity facilities. It will operate a high-quality, packet-switched data communication network service using existing carriers throughout the United States. Thus, Packet Communications is in the service business, not the business of providing raw data channel(s).

Packet Communications' network service has been authorized by the FCC in the following cities: Atlanta, Boston, Cinncinnati, Chicago, Cleveland, Dallas, Detroit, Houston, Indianapolis, Los Angeles, Minneapolis, New York, Philadelphia, Pittsburgh, St. Louis, San Francisco, Seattle, and Washington, D.C.

Packet's network service permits communication between a variety of interactive terminals and the computers on which they are authorized. Packet believes that users of its network will experience greater flexibility, higher performance, more dependability, and lower overall cost than has been obtainable to date with the more conventional data communications facilities available. Service began in 1975 and interactive terminal users can expect such service to cost between $4 and $6 per terminal hour.

Basically, packet-switching is a method of data communications in which messages of arbitrary length are divided into one or more groups of bits called "packets" which are independently routed through the network from sender to receiver via interconnected minicomputer switching nodes. In Packet's network these "packets" are up to 2000 bits in length. At the destination, packets are reassembled into the original message. The use of this store-and-forward packet transmission and distributed switching technology makes it possible for Packet Communications to provide transmission at a lower overall cost. In addition, packet-switching makes it possible to provide a standard set of user-interface protocols, in effect, providing a common language for communication between differing types of equipment and data organizations.

When Packet's network is fully operational, users will have access to a network for data which will support very high data rates, yet is expected to be priced so that users who need wide geographic distribution but have low data volumes will also be able to afford the service. The network will allow users to access any computer on the network to which they are authorized, and eventually, through interconnection agreements, to computers or other networks and in other countries. This interconnection grid of transmission facilities will constitute a marketplace for information and computer services and products.

3.8 Southern Pacific Communications Co.

Southern Pacific Communications Co. has opened service on its own coast-to-coast microwave communications network. The system stretches across 17 states from San Francisco to New York and Boston, and serves 45 major metropolitan areas. SPCC provides point-to-point communication channels for voice, data, facsimile, and various wideband applications to private-line customers in business, industry, government, and education. Services are provided on both a "metered use" and full period basis.

The last stations constructed to complete the transcontinental route were in upper New York state, on the Cleveland-Buffalo link.

3.9 United States Transmission Systems, Inc. (USTS)

USTS was established as a joint venture between ITT and Transcontinental Gas Pipe Line Corporation (TRANSCO). Sensitive to the communications needs of the small and medium sized business users, it will provide quality services currently not supplied by the usual sources. Network designs will enable USTS to provide services specifically to meet customer requirements as revealed by extensive market surveys. Present plans call for initial operations to commence in 1976.

The USTS system will have the capability for pure digital service using both Data Under Voice and Data Above Voice. Initial pure digital applications will probably involve customer requirements for entire 1.544 MB (Tl type) channels. When the source traffic is basic data, then strictly digital radio systems will appear attractive. The compatibility of using both analog and digital radio on the same line of sight path appears to be feasible, but has not yet been field-proven.

3.10 Western Tele-Communications, Inc.

Western Tele-Communications has been providing voice/data service for over two years from San Diego to Yuma and from Los Angeles to San Diego, Phoenix and Tucson for some time. As a result of this initial service experience some interesting customer applications are being discovered. Under the AT&T tariffs, users could not obtain useful service features and needed special applications for the private line. Western

Tele-Communications is being asked for features such as multipoint alternate voice/data with privacy restriction selection, foreign exchanges service plus alternate use point-to-point voice/data on single circuits, facsimile and tie trunks with call restriction, and video teleconferencing. In response to customer needs, Western TCI provided the first common carrier 100 Kbs circuit. These configurations, plus new customer responsive services, are justifying the position of the specialized common carriers in the market.

SECTION 4

DEMAND FORECAST AND DEVELOPMENTAL TIME-FRAME

FOR 40 AND 80 GHz TECHNOLOGY

1. Introduction

To forecast the demand for 40 and 80 GHz satellite communications systems and the time frame for utilization of these frequencies for information transfer required an analysis of the aforementioned markets, the growth projections in these markets, and the plans of the domestic satellite service suppliers. This analysis was accomplished using inputs from the market survey, results of prior economic and market studies of the domestic satellite business potential, and growth projections made subsequent to the applications for domestic satellite services.

In the following paragraphs of this section, the total market for telecommunications is discussed with respect to growth projections for the various services. The satellite's segment of the total market is described along with projected transponder requirements. Various orbit/spectrum considerations investigated during the analyses are compared to the market projections in order to establish a time frame for requiring use of the 40 and 80 GHz frequency range for future services.

2. The Telecommunications Market and Growth Potential

A detailed analysis of the total market and growth potential in telecommunications was beyond the scope of this program. However, in order to project or forecast the need for utilization of 40 and 80 GHz satellite communications in the future it was necessary to investigate the growth expected in various markets and to derive some indication of the service and circuit requirements and the projected transponder requirements.

For the markets identified in Section 2 the type of information to be transmitted will fall into three basic categories: voice, television or video, and data. Accordingly, the service suppliers identified in Section 3, offer or will offer, these three services to their customers through existing terrestrial links or satellite facilities. In analyzing the market and satellite demand, the markets identified fall into the following seven major anticipated areas:

- Leased Voice - Private line leased voice services, for lines tariffed individually and in bulk.
- Leased Data Transmission - Traffic among various combinations of remote terminals, computers, and off-line data handling devices.
- Leased Low Speed Message Services - Private line message and record services, excluding data transmission.

- <u>Cable Television Program Distribution</u> - Transmission of television programming to local cable distributors.

- <u>Electronic Mail Delivery</u> - Facsimile transmission of mail using the Postal Service for local delivery.

- <u>Network Program Distribution and Occasional Use Television</u> - Commercial, public, and educational television network distribution; private line wideband; television audio distribution; and radio distribution.

- <u>Carrier Trunk Lines</u> - Long distance toll trunks for direct distance dial (DDD) network.

Figure 12 presents the relationship between the anticipated use areas and the markets and service suppliers identified during the course of this study and described in Section 2 of this report.

Various studies have been conducted since the advent of domestic satellite services on the current and future telecommunications market. For example, in its filing before the FCC in 1971, MCI Lockheed Satellite Corporation presented results of a study performed by the consulting firm of Booz, Allen, and Hamilton, Inc. which analyzed the telecommunications market. (ref. 32). Another study of the economic viability of the proposed domestic satellites systems was conducted by the Stanford Research Institute for the Office of Telecommunications Policy in October 1971 (ref. 33). These and other studies have looked at the communications requirements of the future and have

Markets and Service Suppliers	ANTICIPATED USES					
	Leased Voice	Leased Data	Leased Message Service and Electronic Special Delivery	Cable TV	Network Program Distribution and Occasional Use TV	Carrier Trunks
Markets						
Health/Medical	X	X		X	X	
Education	X	X		X	X	
Value Transactions		X				
Law Enforcement	X	X				
Electronic Mail			X			
Industry Internal Communications	X	X	X		X	X
Teleconferencing	X	X			X	
Commercial Broadcasting					X	
Intersatellite Service	X	X				
Specialized Audio					X	
Cable TV				X		
Public Broadcasting					X	
Service Suppliers						
AT&T	X	X			X	X
Specialized Common Carriers	X	X			X	
Western Union			X			
DOMSATS	X	X			X	

Figure 12. Relationship between anticipated use areas and markets and service suppliers

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projected market potentials for domestic satellites to the 1985 time-frame.

The studies reviewed during the course of this analysis reveal similar markets to those identified in Section 2 of this report. Similar anticipated uses and circuit requirements were found. Some have suggested higher demands in some specific areas such as cable TV, but the overall total growth is of the same order of magnitude as those figures presented herein.

Reference 32 contained an estimate of the total interstate circuit requirements by a potential market which corresponds to the anticipated uses mentioned above. This estimate, reproduced in Figure 13, covers the 1975-1985 time period and indicates the average annual rate of growth in each of the anticipated uses or markets. The projections are considered to be consistent with the current markets and growth projections obtained during the course of this study. Thus, these projections serve as a point of reference in this analysis and demand forecast. The following paragraphs discuss the basis for the growth projections for the various markets or anticipated uses described above and shown in Figures 12 and 13.

2.1 Leased Voice

Leased voice applications or uses are comprised of two principal segments: leased lines tariffed individually, and TELPAK. In FCC Docket No. 18128, AT&T stated that 59 percent

Market	Simplex Circuit Bandwidth	Estimated "Circuits"(4) 1975	1976	1977	1978	1979	1980	1985	Average Annual Rate of Growth 1975-1980	1980-1985
Leased Voice (1)	4 kHz	181,000	195,000	210,000	228,000	246,000	266,000	391,000	8%	8%
Leased Data Transmission (2)										
Low speed	150 bps	18,000	21,000	25,000	29,000	34,000	41,000	95,000	18	18
Medium speed	4,800 bps	11,000	12,000	14,000	16,000	19,000	22,000	49,000	15	17
High speed	14,400 bps	3,000	3,000	3,000	4,000	5,000	5,000	10,000	11	15
Leased Low Speed Message Services	150 bps	15,000	16,000	16,000	17,000	18,000	19,000	24,000	5	5
Cable Television	Video	4	4	4	5	5	6	8	8	6
Electronic Special Delivery	14,400 bps	8,000	9,000	9,000	10,000	15,000	16,000	32,000	15	15
Television and Radio Program Distribution	Video	24	24	24	24	24	24	27	-	12
Carrier Trunk Lines (3)	4 kHz	220,000	250,000	285,000	325,000	371,000	423,000	814,000	14	14

(1) Includes estimated voice usage from all leased services, after all leased data and facsimile usage has been eliminated.
(2) Includes nonswitched, leased data transmission "circuits" 50 miles or more in length.
(3) Includes total interexchange "circuit" capacity for all switched services (voice, data and record message).
(4) A "circuit" is defined herein as a terminal-to-terminal, end-to-end customer connection.

Figure 13. Estimated total interstate "circuit" requirements by potential market

of total mileage of equivalent voice grade circuits are leased by private users, including airlines, railroads, truckers, and other business users, with the balance leased by the Federal Government. Several of the markets fall into this usage area and it is expected that the following would require the use of leased voice services:

- Health/Medical Telecommunications
- Educational Telecommunications
- Law Enforcement
- Industry Internal Communications
- Teleconferencing

In 1969, 43 million equivalent voice grade circuit miles were leased by these business and government users.

In FCC Application PC 7825, AT&T estimated that about 127,000 private interstate line circuits were in use in 1969, and that approximately 138,000 circuits would be required in 1970 which represented an increase of 8.7 percent over 1969. This rate of growth was significantly less than experienced during the previous five years, and was attributed to a general slow-down in the economy, leveling off of the increase in government usage, and general uncertainty concerning the future of TELPAK tariffs. In the same application, AT&T forecasted a 10.7 percent increase in requirements for 1971 over 1970. Other independent researchers predicted substantially higher growth rates in private line usage. In the MCI Lockheed study, a growth rate of

8.0 percent was used which corresponded to the low end of the AT&T forecast, which has been further discounted because more rapidly growing data traffic has been removed. Nevertheless, it is clear that application of the growth rates experienced in the 1965-1969 period projected to the present time would yield substantially higher circuit requirements than those in Figure 13.

A significant portion of the interstate traffic is over relatively short distances (e.g., New York City to New Jersey or Connecticut) and may not be economically suitable for satellite transmission. Although specific information was not available concerning the distance distribution of leased voice lines it was assumed, for analysis, that the distribution of leased circuits was similar to that for message toll traffic; that is, 20 percent of the interstate traffic is over 1000 miles.

2.2 Leased Data Transmission

Data transmission is defined as the transfer of information between two remote terminals, between a remote terminal and a computer and between two computers. Data transmission is expected to expand dramatically in the next decade as greater reliance is placed on automatic information transfer as shown in Figure 12. The markets which fall into this area include:

- Value Transaction
- Health/Medical Telecommunications
- Law Enforcement
- Educational Telecommunications

- Industry Internal Communications
- Teleconferencing

In Figure 13, the data transmission applications are divided into three speed categories as described below:

- Low Speed - Encompassed all applications operating at 150 bits per second (Bps) or less. Primarily manual input, small message content, inquiry response applications such as on-line credit authorizations, security quotes, and bank teller transactions.

- Medium Speed - Primarily used in the transmission of data between remote tape/disk data collection devices and central processors, this speed range encompasses voice grade equivalent requirements between 150 Bps and 14,400 Bps. Typical applications would include the batch transmission of cash/credit sales and inventory data between a retailing establishment and a data collection center, and production/payroll data from a manufacturing plant to a data processing installation.

- High Speed - 14,400 Bps and above. This speed range may be used for applications requiring periodic bulk transmission of high volumes of data. Typical users would include manufacturers sending bill of material listings and production schedules to plants.

The use of data communications service is constrained by the relatively high cost of data transmission and by the limitations in flexibility and reliability of present service offerings to applications which serve an urgent or specialized need. Such examples include quote services to the securities industry, the airlines' use of centralized, automated reservations systems and order entry procedures used by manufacturers for inventory control and invoicing. In addition, the Federal Government maintains many systems for a wide variety of purposes including two extensive systems: the Advanced Records System (ARS) which provide about 500 low speed, point-to-point trunks in a nationwide service; and AUTODIN, a worldwide defense data communications network, the domestic portion of which constitutes 1,800 circuits (2,400 Bps/circuit).

The future estimates expressed in Figure 13 are presented in terms of "circuits" required to meet the various volumes of data traffic projected for each speed and year. Traffic volume estimates represent the levels of traffic that could be expected if current transmission cost and service constraints were removed.

In estimating satellite requirements for meeting data transmission demands, only those data applications which were long distance (over 50 miles) and for which leased services are applicable were included in Figure 13. Thus, the resulting maximum satellite requirements represent between 40 and 50 percent of total projected data communications needs. However, distances over 1000 miles, where satellite transmission is generally considered to be economically viable, represent only 20 percent of the projected market.

2.3 Leased Low Speed Message Services

These services are defined as point-to-point usage of teletypewriter grade circuits for message services and consequently do not include such switched systems as TWX and TELEX. These circuits generally are used by companies with sufficient volume between certain points to justify private teletype services. Thus, this market includes areas of Industry Internal Communications.

Revenues for leased low speed message services in 1968 were approximately $85 million, divided fairly evenly between the Bell companies and the telegraph companies. Translating the $85 million into 150 baud equivalent "circuits" (approximately the same as 150 Bps) results in an estimate of almost 11,000 "circuits". The rated speed of the "circuits" ranges from less than 50 baud to 180 baud, with the majority of "circuits" in the 60 to 75 baud range. However, 150 baud "circuits" are rapidly displacing lower speeds.

As shown in Figure 13, the growth in message services was expected to be modest in the next decade as a result of diversion of data traffic to other communications media and that the annual growth should not exceed 5 percent. This figure is somewhat less than the historical growth rate.

2.4 Electronic Special Delivery

A potential market exists for the same day or next day delivery of mail. The Postal Service is currently studying facsimile transmission as a method of offering same day or next day delivery of mail and, as indicated earlier in Section 2, is in the process of a definition study of mail delivery via satellites. That portion of the first class and airmail business mail market which does not require physical delivery of enclosures or related materials is a potential satellite market.

As previously mentioned, the Post Office estimates that annual first class and airmail volume is currently about 50 billion pieces, with a projection of 60 billion pieces by 1975. At the present time, 43 percent of this volume does not require cancellation, and is considered to be business mail.

Some small portion of mail volume, assumed to be 2 billion pieces of mail, will be transmitted using Electronic Special Delivery facilities for a nominal surcharge. This represents less than 10 percent of total business mail. This figure approximates other independent estimates.

The Post Office expects this volume could be handled adequately by an 8,000 "circuit" high-speed facsimile network, connecting the 110 Serving Post Offices. Growth of this service is expected to be rapid (doubling every five years) as the network is extended to more post offices and users recognize the usefulness of the service.

The future estimates of ESD mail volumes and facsimile requirements presented in Figure 13 show a 15 percent annual rate of growth in the use of this service (or about four times the growth rate for total mail volume).

2.5 Cable Television

In 1971, over 2,000 cable television systems were in operation with a like number of new franchise applications on file and have had a historical rate of growth of 20 to 25 percent annually. In paragraph 12, of Section 2, the growth projection in CATV suggests a greater application and higher demands for CATV distribution via satellite than many prior studies have predicted. New satellite distributed CATV applications in Florida, the potential of interactive cable TV applications and the number of FCC applications for receive-only terminals indicate a growing market. However, the projected growth for CATV in Figure 13 is from 4 circuits in 1975 to 8 circuits in 1985. The annual growth over the 1976-1980 period is 8 percent while it is 6 percent over the 1980-1985 time period. These figures may be underestimated in view of the previously described activities in CATV.

2.6 Network Program Distribution and Occasional Use Television

For the purpose of evaluating potential satellite markets, network and occasional use television were defined to include the video and audio portions of:

- Commercial network television
- Educational/public network television
- Commercial, occasional use television (e.g., sports programming for over-the-air broadcast and/or real-time cable distribution
- Closed circuit television
- Business video conferences

It also includes network radio, which can be multiplexed on the video carrier.

Currently, commercial network and occasional use television are transmitted on a fully dedicated terrestrial video distribution system comprising about 98,000 channel miles, known as interexchange channels (IXC). This intercity system connects 145 television operating centers (TOC's). These TOC's are, in turn, connected to 400 television stations by about 640 local channels.

As a result of recent rate increases, use of the Bell System's television transmission service is expected to decline. This projected drop in existing system usage reflects conversion of some local channels to lower cost, private or other common carrier microwave facilities or satellites. For example, as indicated in Section 2, PBS is planning to transfer to satellite links and the commercial broadcast stations have distributed their requirements for satellite services to the domestic satellite industry.

Educational television, public television, cable television real time program distribution, closed circuit television and business video conference are expected to provide impetus for future growth in the total television communications market. For example, educational/public television is expected to require at least 3 video channels, the equivalent of regular use requirements for one commercial network. Real time program distribution for cable television would require one transponder at an occasional use level of at least 5 hours per day. Closed circuit television revenues to Bell in 1970 amounted to about $2 million and at existing occasional use rates, this would indicate equivalent usage of one transponder for about 2 to 3 hours per day. The market for business video conference, a potentially large application because of its two-way video transmission needs, is difficult to assess since existing terminal equipment is expensive and difficult to maintain. Usage may be limited to those instances involving group rather than individual travel, and businessmen may prefer travel and personal contact to video conference.

A potential satellite market for the 1975-1985 time period was projected in previous studies for the television and Radio Program Distribution market area. These projections are given below (ref. 32):

Service	Video Channels/Transponders 1975	1980	1985
1) Three commercial TV networks, regular use			
• Broadcasting channels	6	6	6
• Reverse feed channels	3	3	3
2) Peak broadcasting needs for sports	10	10	10
3) Educational/public TV			
• Broadcasting channels	2	2	4
• Reverse feed channels	1	1	2
4) Available for all other occasional broadcast uses, closed circuit television, and business video conference	2	2	2
Total	24	24	27

2.7 Carrier Trunk Lines

This segment is comprised of the long lines interexchange trunks portion of the Direct Distance Dial (DDD) network connecting the toll switching centers. The primary market for this area is in the Industry Internal Communications area described in Section 2. This segment is owned and operated by AT&T Long Lines Department. Only that portion of the carrier trunks used for switched services (voice, data, and message) was included in the results given in Figure 13; all leased line traffic was factored out.

Applications for authority to supplement existing facilities filed by AT&T identify total constructed capacity in necessary services in 1969 as 167,000 interstate toll circuits (AT&T

definition) with 192,000 and 220,000 projected for 1970 and 1971 was 13.7 percent with the 1969-1971 growth rate between 14 and 15 percent. A projection of 14 percent compounded growth is given in the chart of Figure 13. The distance distribution of these calls showed a trend on a percentage basis, of increased traffic over 1000 miles approaching 20 percent of the total market.

3. Orbit/Spectrum Sharing Impact on Frequency Utilization

The projection of the developmental time-frame for 40 and 80 GHz technology requires determining under what circumstances, and when, the available frequency spectrum below 40 GHz will be exhausted considering growth projections such as those previously discussed. This is a difficult problem, however. An analysis was undertaken to indicate the approximate time-frame by comparing market-oriented transponder requirements versus the transponder capacity of the various frequency allocations.

3.1 Market Transponder Requirements

Several prior studies have projected the estimated equivalent transponders required in future satellite communication systems. The results of one analysis (ref. 32) of an equivalent transponder calculation is presented in Figure 14. In this study an equivalent transponder was defined as a 40 MHz bandwidth transponder and the number of transponders was calculated by dividing the number of circuits required by a service by the number of circuits per 40 MHz transponder.

	Satellite Transponders Per "Circuit"(4)	Estimated Equivalent Transponders(5)						
		1975	1976	1977	1978	1979	1980	1985
Leased Voice(1)	1/400	452	487	525	570	615	665	978
Leased Data Transmission(2)								
Low speed	1/4800	5	6	6	6	7	8	20
Medium speed	1/400	28	30	35	40	48	54	123
High speed	1/133	23	23	23	30	38	38	75
Leased low speed message service	1/4800	4	4	4	4	4	4	5
Cable television	1	4	4	4	5	5	6	8
Electronic Special Delivery	1/266	31	34	34	38	57	61	121
Television and Radio Program Distribution	1	24	24	24	24	24	24	27
Carrier Trunk Lines (3)	1/400	550	626	714	814	928	1,058	2,034

(1) Includes estimated voice usage from all leased services, after all leased data and facsimile usage has been eliminated.
(2) Includes nonswitched, leased data transmission "circuits" 50 miles or more in length.
(3) Includes total interexchange "circuit" capacity for all switched services (voice, data and record message).
(4) A factor of 800 average simplex voice "circuits" per transponder was used, based upon earth stations utilizing 32-foot diameter antennas.
(5) Means the total satellite transponder capacity required to transmit the total interstate "circuit" needs as set forth in Exhibits III and IV.

Figure 14. Estimated total equivalent transponder requirements

The numbers given in Figure 14 were for the total market requirements for the 1975-1985 time period for the same anticipated uses described earlier. However, the study indicated that only 20 percent of this market could be available if favorable satellite economies could be achieved and current fixed terrestrial capital equipment investment for over 1000 miles transmissions were not considered. Based on these projections twenty percent of the domestic market would yield a potential requirement of 224 transponders in 1975 and 640 transponders by 1985 if all the projected markets over 1000 miles went by satellite.

Comparing these projections with real life figures at the end of 1975 we found that only 48 transponders were in orbit, and this figure includes back-up and peak-load transponders.

In order to refine the potential communications satellite further, consideration was given to assumptions regarding the growth of terrestrial systems of over 1000 miles. To bound the satellite market the following were assumed: 1) for the maximum market potential, no terrestrial 1000 mile links would be added after 1975; and 2) for a more moderate bound, no terrestrial 1000 mile links would be added after 1995 and satellite systems would continue to grow at their current rate. In addition, for both bounds, terrestrial systems were conservatively estimated to have 30 year life-times. Figure 15 presents graphically the potential satellite market under the first assumption.

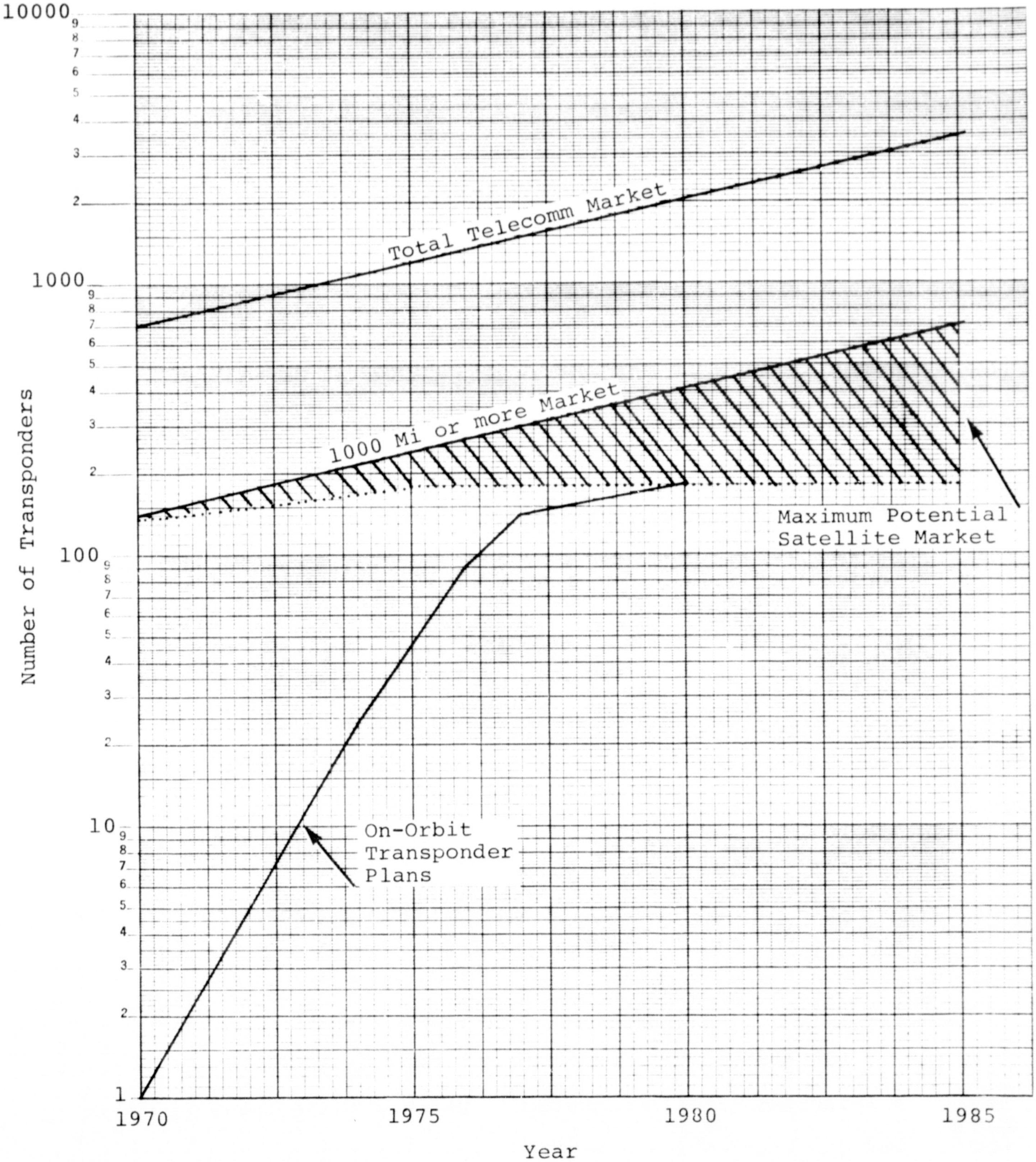

Figure 15. Potential satellite market

The two potential markets described above will form the basis for determining the time-frame for the need of utilizing 40 GHz. It should be kept in mind, however, that these potential markets assume favorable economies for satellite communications systems regardless of frequency utilization.

3.2 Transponder Capacity at Allocated Frequencies Below 40 GHz

3.2.1 Background

In 1963, the International Telecommunication Union (ITU) took official action to acknowledge that satellite communications systems would soon become practical. At the Extraordinary Administrative Radio Conference (EARC) of that year, satellite counterparts for several of the familiar terrestrial services, including the fixed service and the broadcasting service, were defined. Several frequency bands were allocated to the fixed-satellite service.

The ITU in 1971 sponsored a World Administrative Radio Conference for Space Telecommunication (WARC-ST) in order to revise again the international radio regulations to accommodate the needs of satellite systems. The WARC-ST refined the definitions of all the space services, provided frequencies for the first time to the broadcasting-satellite service, and extended the existing allocations of the fixed-satellite service to several new bands.

The WARC-ST defines the broadcasting-satellite service as "A radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. (Note: In the broadcasting-satellite service, the term 'direct reception' shall encompass both individual reception and community reception)."

Individual reception was defined as "the reception of emissions from a space station in the broadcasting-satellite service by simple domestic installations and in particular those possessing small antennae."

Community reception was described as "the reception of emissions from a space station in the broadcasting-satellite service by receiving equipment, which in some cases may be complex and have antennas larger than those used for individual reception, and intended for use: by a group of the general public at one location; or through a distribution system covering a limited area."

The fixed-satellite service was defined as "a radiocommunication service: between earth stations at specified fixed points when one or more satellites are used; in some cases this service includes satellite-to-satellite links, which may also be effected in the inter-satellite service; for connection between one or more earth stations at specified fixed points and satellites used for a service other than the fixed-satellite service (for example, the mobile-satellite service, broadcasting satellite service, etc.)."

Frequency downlink allocations below 40 GHz currently in-force for North America are as follows:

- 2.500 - 2.655 GHz/Broadcast satellite downlink, shared with Fixed and Mobile terrestrial services.

- 3.4 - 4.2 GHz/Fixed satellite downlink, shared with Fixed, Mobile and Radiolocation services.

- 6.625 - 7.125 GHz/Fixed satellite, on a secondary basis with Fixed and Mobile services.

- 7.3 - 7.750 GHz/Fixed satellite shared with Fixed, Mobile and METSAT services (not viable due to military usage).

- 10.95 - 11.2 GHz/Fixed satellite shared with Fixed and Mobile.

- 11.45 - 11.7 GHz/Fixed satellite shared with Fixed and Mobile.

- 11.7 - 12.2 GHz/Fixed and Broadcast satellite, shared with Fixed and Mobile.

- 17.7 - 19.7 GHz/Fixed satellite, shared with Fixed and Mobile.

- 19.7 - 20.2 GHz/Fixed satellite, <u>exclusive</u>.

3.2.2 Orbit and Spectrum Utilization

Efficient orbit-spectrum utilization is an important criterion in determining the capacity saturation point of a particular frequency downlink band. Within the 500 MHz bandwidths at 6 and 4 GHz currently utilized by space communications systems, 24 transponders of 40 MHz bandwidth can be accommodated through cross-polarization and staggered transponder frequencies. In order to further reuse the same 500 MHz bandwidth requires spacially assigning satellite orbit-arc positions and specifying the size of the spacecraft and earth-station antennas. This geometric antenna discrimination approach allows for utilizing many satellites in the same fixed frequency region, yet serving the same terrestrial geographical area.

A 1970 orbit/spectrum sharing study by General Electric (ref. 34) determined that in the 4 GHz region, a 24 channel communication satellite could be spaced as close as 2°-4°, for a certain set of realistic system parameters. To achieve this separation, however, earth stations could not have antennas less the 10 meters (33 feet). Subsequent studies by NASA and the FCC settled on a 5° separation and ground antennas of no less than 33 feet.

In 1974, an orbit/spectrum study by the Rand Corporation (ref. 35) for NASA determined that in the 12 GHz region orbit spacing could theoretically be 0.5° if certain assumptions were allowed. However, at 0.5° orbit sharing the size of the required ground antenna, just to provide geometric discrimination is much larger than 33 feet. Since larger antennas at higher frequencies become quite expensive, it seems reasonable that antennas at higher frequencies will be on the order of 33 feet or less.

AT&T is currently considering 45 and 33 foot dishes at 20 and 30 GHz.

A 33 foot antenna at 4, 12, and 20 GHz produces 3 dB beamwidths of 0.5°, 0.17°, and 0.1° respectively. Since further FCC and NASA studies have refined the 4 GHz spacing requirement to 4°, which represents an 8-fold increase over the ground antennas beamwidth, it seems reasonable to assume that an 8-fold ratio will continue to be required at other frequencies in order to reduce side-beam couplings to tolerable levels. Under such an assumption, at 12 GHz, satellites could be placed 1.33° (8 x 0.17°) apart rather than the minimum theoretical spacing at 0.5. At 20 GHz, the orbit spacing would be 0.8° (8 x 0.1°) rather than a 0.3° minimum theoretical spacing.*

The orbit spacings presented above are for homogeneous satellite systems; that is, only fixed satellite systems and not a mix of broadcast and fixed satellite systems. The utilization of broadcast satellites in the U. S., as defined by the International Telecommunications Union (ITU), is open to question. Recent industry comments to the FCC, documented in Docket No. 20468, and adopted in January, 1976, show that the terrestrial broadcasters oppose direct-to-home type broadcasting systems. They assert that the introduction of such a system would undermine the present terrestrial system of free, local, and independent broadcasting in this country. Western Union

*This spacing was calculated by extrapolating the results of the 1974 Rand study at 12 GHz.

also foresees no requirements for a broadcast satellite service in the U. S., at least not in the 11.7-12.2 GHz band. However, other parties such as HEW assert that there is a need for "community" type reception based on their experience with ATS-6.

There is concern over broadcast satellites because of their inefficient use of the orbit-arc spectrum resource. This inefficiency is brought about by the need for small antennas at earth terminals. Smaller antennas at a given frequency have larger beamwidths, requiring larger satellite orbit spacings to meet present standards relating to interference.

Since it is impossible at this time to resolve the questions surrounding broadcast satellites, the approach taken was to consider all communication satellites covering the 4-20 GHz region to be in the fixed satellite service. If broadcasting satellites require utilization of 12 GHz, after exhaustion of 2.5 GHz, then the number of satellites that can use the orbit arc must be reduced. For a 50 percent broadcast/fixed satellite split-usage of 12 GHz, the number of satellites, and consequently the number of transponders, will be reduced by about 30 percent according to Reference 35. The impact of such a situation will be further discussed in the following section.

The vast majority of the market transponder projections in Figure 14 are for fixed services and shows little market for "broadcast" systems. Even the services analyzed in Section

8 of this report (30 MB data, interactive TV, and three pair quality audio) could all be transmitted by the fixed satellite service, although the audio could possibly be included in a broadcast satellite.

Thus, given the foregoing information, four frequency utilization scenarios were generated for comparison with potential market demand. These four scenarios are:

1) Theoretical maximum utilization - utilize all available fixed satellite frequency allocations to the maximum at the theoretical minimum spacing without regard to ground antenna size.

2) Realistic maximum utilization - utilize all available fixed satellite frequency allocations at spacings accommodated by, at most, 33 foot antennas and utilize all of the available orbit arc (90°) between ground antenna 5° elevation angles for CONUS coverage.

3) Realistic minimum utilization - utilize all the available fixed satellite allocations at spacings accommodated by, at most, 33 foot antennas and utilize only that portion of the orbit arc (24°) that covers all 50 states, at 5° elevation angles.

4) Absolute minimum utilization - utilize only the 3.7-4.2, 11.7-12.2 and 19.7-21.2 GHz allocations, only 24° of the orbit arc; and have spacings of 4°, 2°, and 1° respectively. The 2° and 1° are based on using 24 foot antennas.

Figure 16, taken from Reference 35, presents the orbit arcs for the U.S. and other countries for 5° and 10° ground antenna elevation angles.

3.2.3 Market/Frequency Utilization Comparison

In order to compare the market transponder needs to the number of transponders available at different frequencies, a calculation of the number of transponders under each of the four scenarios presented in the previous paragraphs is required. Table 16 presents the number of 40 MHz transponders at the various frequency allocations under each scenario.

The total transponder capacity of the frequencies below 40 GHz are compared in Figure 17 against the market potential bounds. The frequency bands below 40 GHz are assumed to be utilized first due to an apparent trend of price/frequency relationship for satellite systems which implies that "the higher the frequency, the higher the cost". This implication will be further explored in Section 9 - Development Potential, Costs, and Institutional Considerations.

In Figure 17, the current on-orbit transponder plans are also graphed. Note how the trend line of current and known planned transponders in orbit tracks the upper market trend

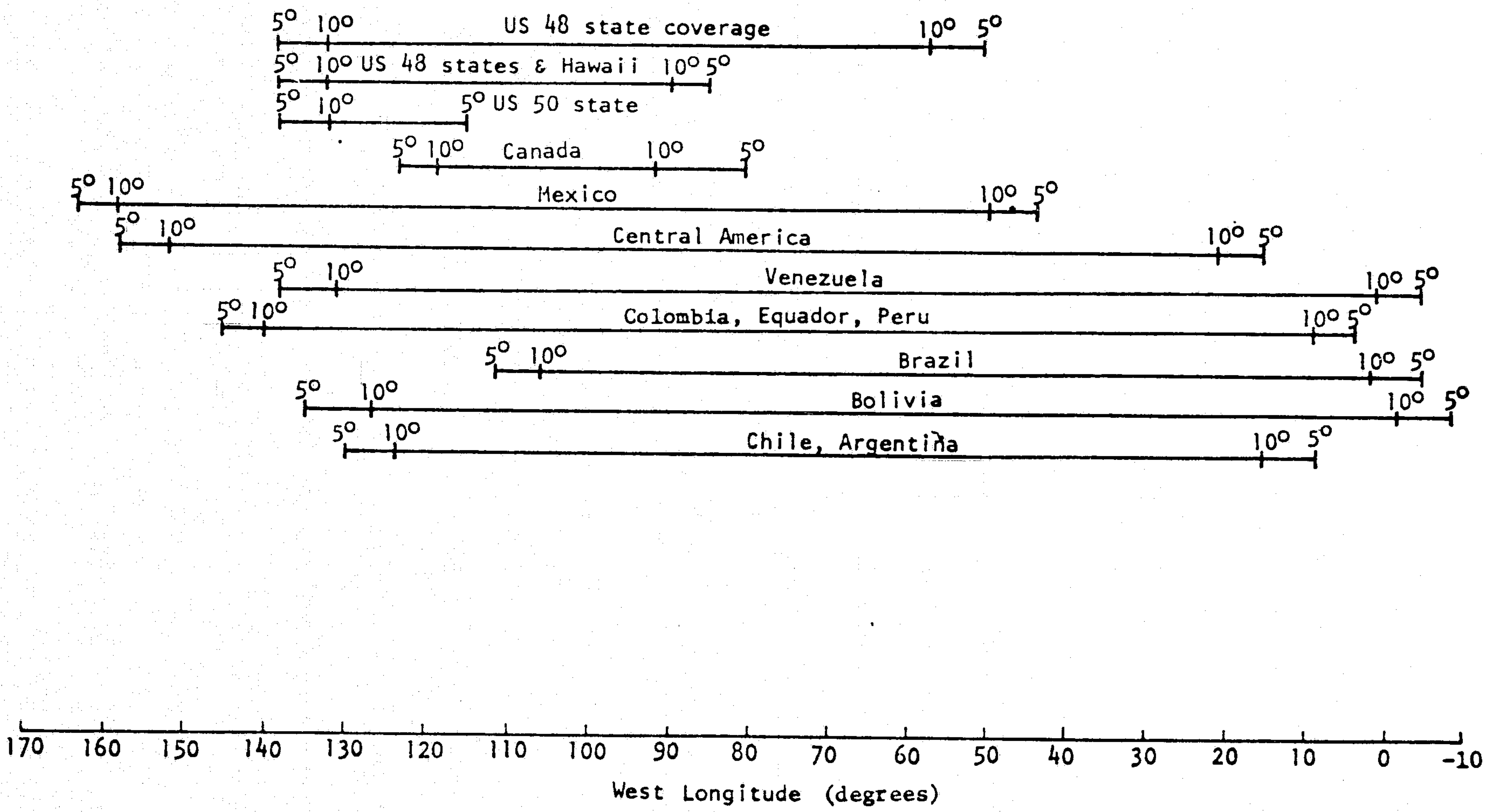

Figure 16. Usable orbital arcs for various countries in ITU Region 2

TABLE 16

TRANSPONDER AVAILABILITY

Scenario	Downlink Allocated Frequency Band	Orbit Spacing	Orbit Arc	Number of 40 MHz Transponders	Total Available
• Theoretical Max.	3.4-3.7 3.7-4.2 6.625-7.125	2°	90°	2,790	7,430
	10.95-11.2 11.45-11.7 11.7-12.2	.5°	90°	8,640	
	17.7-19.7 19.7-20.2	.3°	90°	36,000	
• Realistic Max.	same as above	4° 1.33° 0.8°	90° 90° 90°	1,364 3,264 13,440	18,068
• Realistic Min.	same as above	same as above	24° 24° 24°	372 864 3,600	4,836
• Absolute Min.	3.7-4.2 11.7-12.2 19.7-20.2	4° 2° 1°	24° 24° 24°	144 288 576	1,008

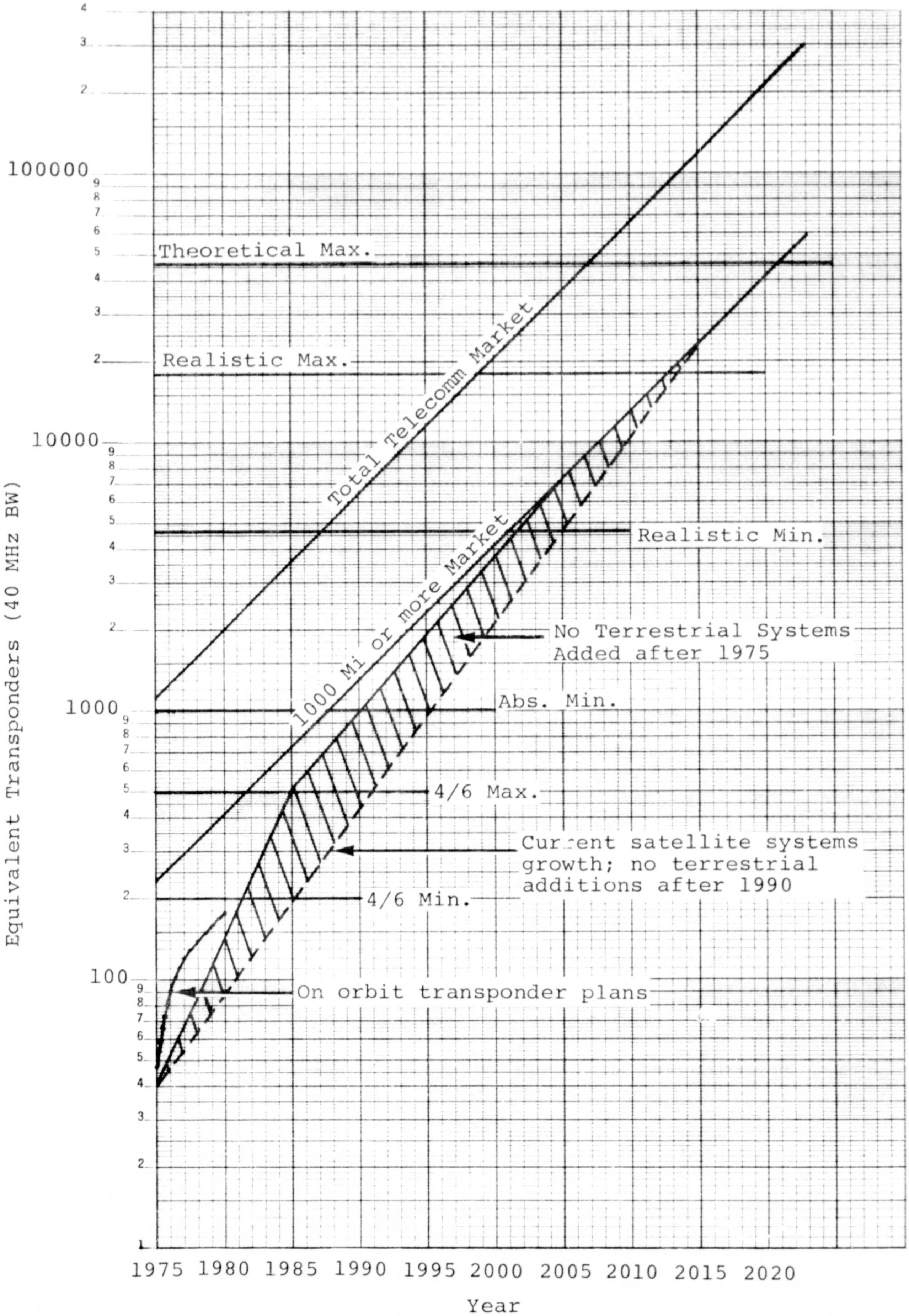

Figure 17. Comparison of total transponder capacity below 40 GHz and market potential

boundary. Actually, the on-orbit transponder trend more likely falls within the potential market boundaries since all of the on-orbit transponders are not meant to be operational; some have spare transponders and others have transponders used for peak-loads and back-up only. Also, not all available transponders have been leased. Thus, it is believed that the market boundaries projected in this study are realistic.

The four scenarios are shown in Figure 17 as horizontal lines. For comparison purposes the current 4 and 6 GHz links maximum/minimum transponder numbers are also presented. The 4 and 6 GHz minimum case corresponds to utilizing only 24° of orbit arc at 4° spacing while the maximum utilizes 90° of orbit arc at 4° spacing. The intersection of the horizontal available transponder line with the market bound lines yields the time-frame for exhaustion of that particular frequency band. In 4 and 6 GHz case, the minimum time of exhaustion would be the early 80's, while the maximum would be in the late 80's. In the case of exhaustion of all frequencies below 40 GHz, the time interval varies from the early 90's at an absolute minimum to as late as 2020 for the theoretical maximum scenario.

If true "broadcast" satellites eventually occupy the 12 and 14 GHz allocation, the four scenario transponder curves would shift slightly down since fewer satellites can be accommodated at the orbit arc if broadcast and fixed satellites jointly share the orbit arc; however, the effect on the time axis would be negligible.

There are other factors that might shift the transponder curves by significant amounts:

- Utilization of more than 90° of orbit arc - If eastern or western areas of the U.S. provide self-sufficient markets, then orbital slots beyond the 90° of orbit-arc could be utilized. It is reasonable to believe that regional markets will develop.

- Multiple beam frequency reuse - Instead of utilizing large area beams, particularly at higher frequencies, the use of spot beams could be used to provide spacial frequency sharing. This approach would only be reasonable if a limited number of ground stations were involved in the various systems at a given frequency.

The above factors will shift the transponder curves upward, thus delaying the need for down-link frequencies above 20 GHz.

However, discussions with industry generated during Tasks I, II, and III indicate an expected need for developed 40 GHz communication satellite technology in a time-frame that corresponds to the period between the realistic maximum and minimun scenarios; that is, between the years 2002 and 2014.

SECTION 5

STATE-OF-THE-ART IN 40 AND 80 GHz TECHNOLOGY

1. Introduction

During the performance of the study a survey was made of the communications industry to determine the state-of-the-art of 40 and 80 GHz technology for both spacecraft and earth station hardware. It was necessary to contact the communications and aerospace industry as well as hardware manufacturers/vendors in order to obtain information on development status, performance characteristics, and related data on systems and components for use in the millimeter wave region. While the survey was concerned primarily with the 40 and 80 GHz regions, frequencies above and below these regions were also of interest as they revealed a development capability. Technologies which were felt to be applicable to the 40 and 80 GHz frequency regions were extracted from the data obtained.

The survey was composed of various types of contacts. Visits were made to aerospace companies, government laboratories, and research organizations. In addition to these visits, other government and industry organizations were contacted by phone or by written requests. At least fifty contacts were made to gather data. The contacts and subjects covered are summarized in Table 17, Technology Survey of the Aerospace Industry, and Table 18, Technology Survey of Hardware Manufacturers/Vendors.

TABLE 17

TECHNOLOGY SURVEY OF THE AEROSPACE INDUSTRY

ORGANIZATION AND CONTACT	SUBJECTS COVERED
Aeronutronics/Ford Dr. H. Goett B. Mendoza D. Davies L. Cuccia W. Scott K. Hashimoto	• European and Japanese gain over U.S. in technology above 40 GHz. Terrestrial guided mm wave systems • Graphite antenna technology - up to 12 ft. diameter • Lens antenna technology - 61 beams beam switching - TEM type - 5 to 6% bandwidth, waveguide type 4% bandwidth - 10 GHz. • Long term R&D needs for the 1980's
Lockheed J. Hockenberry L. Krecji W. Koenig	• Technology requirements for post 1985 communications satellites • Obtained report entitled Information Systems Requirements Study • Discussed Potential for Intersatellite Service Application and Development
Comsat General Robert Briskman	• Discussed Technology Development Proposed by Comsat in Post Office Electronic Mail Proposal Using 30 MB data rates system. • Discussed potential expansion in business data and in broadcast of news and CATV.
Comsat Labs L. Plllack W. Getzsinger P. Bargellini W. Fleming Dr. Hyde D. Fang	• Discussed 40 and 80 GHz need by year 2005 and problems in 40 and 80 GHz test equipment.

TABLE 17 (cont.)

TECHNOLOGY SURVEY OF THE AEROSPACE INDUSTRY

ORGANIZATION AND CONTACT	SUBJECTS COVERED
TRW Systems Group R. Booton J. Honda D. Jarett	• Displayed MM wave hardware - Ka, Ku and V bands - Impatt Oscillators, double balanced mixers, circulators, combiners and filters. Ka band transmitter, 300 mW present, 10 watts goal 10% efficiency by combining Impatt devices. • Discussed potential for flight qualified hardware at 40 and 80 GHz in 2 to 3 years with adequate funding.
Aerospace Corporation V. Wall H. King A. Merrill	• AF SATCOM 45-48 GHz flying command center to satellite, uses VHF to ground. • TWT development 45-48 GHz decision within year, helix or coupled cavity - 5 to 10 watts, 35% efficiency goal; considering dispenser cathodes and high current density. • 94 and 220 GHz radiometer measurements - 15 ft. antenna 3 mil surface, beamwidth .05°, 20 MPH winds 20 arc sec. pointing accuracy. • KITT peak - cooled reciever 500° K, 94 GHz, 36 ft. antenna. • Ka and V band hardware exhibited - adequate test equipment.
Hughes Aircraft Co. (HAC) Space & Communications Group R. Winters C. Zilm M. Triplett L. Stokes R. Roney R. Graves	• Discussed feasibility study for NASA/Lewis - 100 watt travelling wave tube 42.0 GHz, 100 to 200 watt at 85 GHz $\pm$ 2.0 GHz, some circuitry to show feasibility, X-band circuit tests to define parameters. • Discussed potential for scaling present work at 20 and 30 GHz to work at 40 GHz and above.

TABLE 18

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
ANTENNAS AND RELATED DEVICES	
Scientific-Atlanta, Inc.	• Antennas, measurement systems, receivers, recorders and services to above 100 GHz.
Datron Systems, Inc.	• Precision pedestals for antennas, earth service, static accuracy, RSS 0.048 milliradians.
Sigma-Three Systems, Inc.	• Precision pedestals for antennas.
Aeroflex Laboratories, Inc.	• Precision pedestals for antennas, cameras, other optics.
Hitachi Electronics, Ltd.	• Instrumentation from 18 GHz to 170 GHz • 20 dB gain horns (pick-up horns) for instrumentation or for illumination of dish antennas.
TRG Division Alpha Industries, Inc.	• Focus fed, Cassegrain, horn lens type, collimating, spot focus to 300 GHz, cataloged to 200" diameter. Ferrite components to 220 GHz instruments, solid state devices to 220 GHz systems and subsystems.
Transmission Lines, Inc.	• MM wave antennas usable to 300 GHz horns; conical, pyramidal, corrugated, multimode. Paraboloid incl. cassegrain and gregorian to 24" diameter, lens, scanning and monopulse, surface wave antennas.
AIL Cutler Hammer	• Instrumentation to around 300 GHz; mm antennas.
Transco Products, Inc.	• Sophisticated antennas and related hardware to 18 GHz at this time.
Cablewave Systems, Inc.	• Line of sight antennas to 12 GHz.
Prodelin, Inc. Microwave Antennas Line	• Line of sight antennas to 18 GHz.

TABLE 18 (cont.)

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
	RECEIVERS
LNR Communications, Inc. Earth & Space Qualified Hardware	• Non-cryogenic ultra low noise amplifiers for satellite communications earth terminals (parametrics) to approximately 50 GHz and potentially to 80 GHz. Receivers, integrated low noise amplifier and down converter S/N ratio DSB @ 36.5-38.5 GHz 6 dB or ~870 K.
Micro-Tel Corporation	• Microwave surveillance receiver, normally to 18 GHz, to 40 GHz (on special order). Associated products as frequency counter and display set. 3 section YIG tuner, 30 MHz BW nominal.
SpaceKom, Inc.	• 8 GHz to 100 GHz, mixer preamps, frequency converters, microwave receivers, frequency translators, doublers, signal converters. Universal radiometer receiver for radio astronomy. 500 MHz BW NF 2.5 dB max. i.e., 230 K.
Scientific-Atlanta	• Instrumentation receivers, to 100 GHz without plug-ins. Other instruments, recorders, antennas, antenna range and services.
Anaren Microwave, Inc.	• Components to 18 GHz, potentially above.
Scientific Research Corp. of TRAK Microwave Corp.	• IF related, hybrid. IF amps 20 to 150 MHz, 10 MHz BW typical, NF 3 dB IF systems-hybrid.
Plessey, Optoelectronics and Microwave (Great Britain)	• Assemblies and components, local oscillators, microwave devices, gunn diodes, typical TE0-141&142, 26-40 GHz, 50-100 mW, CW Impatt I oscillators 40 to 90 GHz, typical 100 mW, CW gunn oscillator, mechanically tuned and electrically tuned, to 50 GHz typical 20 mW output.

TABLE 18 (cont.)

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
	RECEIVERS (cont)
E&M Laboratories, Inc.	• Microwave Devices/Ferrite, waveguide isolators to 40 GHz, ferrite 3 port circulators to 40 GHz, 4 port circulators to 32 GHz, custom devices to order.
Microwave Associates	• Microwave semiconductors. Coaxial diodes, mixer to 34 GHz, potentially higher. Detector diodes, silicon to 16 GHz. Schottkey barrier mixers and detector diodes to 16 GHz. High power high efficiency varactors (frequency multipliers) to 25 GHz. Avalanche oscillator diodes to 40 GHz.
Norsal Industries, Inc.	• Components, couplers etc. to 18 GHz.
Summit Engineering Corp.	• Balanced mixers, baseband, single/double to 1 GHz.
Aertech Industries	• Tunnel diode detectors to 26 GHz, potentially higher.
Raytheon, Microstate Electronics	• Tunnel diodes - amplifier Gallium Antimonide - to 30 GHz Germanium - to 50 GHz
	• Microwave varactors, multipler to 120 GHz, microwave varactors, multiplier, paramps to 300 GHz.
Varian, Microwave Diodes	• Impatt oscillator to 26 GHz, 200 mW output. Gunn oscillator to 40 GHz, 100 mW output.
	HIGH POWER AMPLIFIERS
Hughes (Electron Dynamics Div.) Local SONCO, Inc.	• Components to 90 GHz. Typically mm wave oscillators to 70 GHz, 1 GHz BW 100 mW min. output. Also passive hardware. Test equipment.

TABLE 18 (cont.)

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
HIGH POWER AMPLIFIERS (cont)	
Hughes (Electron Dynamics Div.) Local SONCO, Inc.	• TWT amplifiers. Typically CW to 96 GHz @ 100 W output. Typically space type/s to 31 GHz, 2.0 W output.
Hughes (Electron Dynamics Div.) Local SONCO, Inc.	• Silicon Impatt diodes.
MODULATORS/DEMODULATORS	
Hughes (Electron Dynamics Div.)	• Extensive mm wave components. Ferrite cavity modulators to 90 GHz. Test equipment. mm wave leveling detectors. Tunable detectors.
Microwave Development Labs., Inc.	• SSB modulators. Extensive wave guide devices, rotary joints, couplers, etc.
K&L Microwave	• IF, Demodulators, etc. Filters to 18 GHz.
Tech. Research & Mfg., Inc.	• IF related to 12 GHz. Power dividers/combiners.
Radiation Systems, Inc.	• Quadraphase PSK Modulators - "Developed hardware" to 1.6 GBps.
Micro Del Electronics	• Wideband amplifier, IF, baseband application, typical 1.0-2.5 GHz, 4 dB NF. Filters. Multicouplers to ~2 GHz.
Electrac, Inc.	• IF related. Polarization diversity. Tracking filters, tracking demods, tracking frequency multiplier, doppler tracking receivers, test sets.
American Electronic Labs., Inc.	• Low frequency IF preamps, typical 60 MHz, 10 MHz BW, 1.9 dB NF.

TABLE 18 (cont.)

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
MODULATORS/DEMODULATORS (cont)	
RHG MIC Microwave Products Division	• High IF related, to 12 GHz. Double balanced mixer with preamp. Typical frequencies 0.5 to 8 GHz, NF ~8 dB
RHG Electronics Laboratory, Inc.	• Lower frequency IF amps.
ANAREN Microwave Inc.	• Extensive lines, IF hardware to 18 GHz. Mixers, modulators, dual channel balanced mixers, typically an IF bandwidth 400 MHz.
ANCOM	• IF related wide baseband. Solid state low noise amps eventually to 18 GHz. Typical 3.7-4.2 GHz, 3 dB NF, MIL qualified, stock.
Microwave Development Labs., Inc.	• Components - single sideboard generators, rotary joints, switches, tees
Baytron, mm wave components	• Extensive waveguide hardware, test equipment, waveguide benches.
C-COR Electronics, Inc.	• Video amplifiers, baseband related typical 1 kHz to 200 MHz, 20 dB gain to 60 dB gain, 50 ohms in and out, NF 6 dB.
COMDEL, Inc.	• Video amplifiers, baseband related typical .5 to 50 MHz gain 9 dB, NF 2.5 dB.
Watkins-Johnson Co.	• Building blocks, video amplifiers, 1-2000 MHz, baseband or IF related, typical gain 16 dB, NF 2.5 dB 1 mW output.
SIGNAL SWITCHING, MULTIPLEXING AND ROUTING	
ASTROLAB, Inc.	• Cable and fittings to 18 GHz, custom assemblies.
PME Machine Tool Co., Inc.	• Precision waveguide flanges.

TABLE 18 (cont.)

TECHNOLOGY SURVEY OF HARDWARE MANUFACTURERS/VENDORS

MANUFACTURER/VENDOR	SUBJECTS COVERED
SIGNAL SWITCHING, MULTIPLEXING AND ROUTING (cont)	
Transmission Lines, Inc.	• Waveguide, fittings, tees, etc. Tunable termination, also mm wave antennas.
TRG Division of Alpha Industries	• Extensive mm waveguide lines, other products through 140 GHz.
Hitachi	• Extensive mm wave lines, waveguide, terminations to 170 GHz, test equipment.
Microwave Development Labs., Inc.	• Extensive products, switches, rotary joints, filters, flanges, windows.
dB Products, Inc.	• Microwave switches to 12 GHz.
K&L Microwave, Inc.	• Filters to 18 GHz
Baytron	• Extensive line waveguide fittings to 140 GHz.
Hitachi	• MM wave lines, broadband power meter to 110 GHz to 3 mW, $\sim$ 2.5% accuracy. Wideband detector 40 to 110 GHz. Broadband frequency meters typically 60 to 90 GHz 0.28% accuracy.
Hughes Electron Dynamics Div.	• MM wave component travelling wave tubes, sweep generator, 32 to 90 GHz and accessories.
Scientific Atlanta	• Components, antenna and microwave instrumentation, pattern recorders for antenna measurements.
Baytron	• MM wave components, waveguide test benches, detectors, mixers, ferrite devices.
Hewlett-Packard	• Components of precision microwave instruments. Spectrum analyzers 10 MHz to 40 GHz, potentially higher in future, conventional oscilloscopes.

As indicated in the tables, millimeter wave technology data obtained from the aerospace organizations was primarily in the frequency ranges of 26-38 GHz, 55-60 GHz, 94 GHz, and 220 GHz, the latter two frequencies being used for radiometric purposes. Some techniques at frequencies below 40 GHz, such as those used for graphite antennas and multi-beam antennas, were of interest since these techniques might also be applied to the frequencies germane to this study. Hardware in the form of oscillators, mixers, filters, combiners, and antennas was displayed for use in the 26-38 GHz, 55-60 GHz, 94 GHz, and 220 GHz frequency bands.

2. System Components Technology

During the course of the survey, it was found that significant developments in terrestrial communication systems have been made in Europe and Japan at frequencies above 40 GHz. This serves as an indication that system components such as amplifiers, oscillators, up and down converters, and filters can be made for operational use in the millimeter frequency range.

The survey showed that, aside from experimental military and short haul terrestrial systems in the 36-38 GHz region, communication system hardware technology development at 40 GHz and above in the United States is lacking because of insufficient incentive and funding. Given adequate funding, the capability does exist to develop system components for use at 40 GHz and above.

It was generally the opinion of the aerospace industry sources that, with sufficient funding, flight hardware could be developed for 40 and 80 GHz use in two to four years. Components such as filters, oscillators, mixers, solid state transmitters, and antennas have already been developed or are in the development process. The majority of the aerospace industry believed that NASA should take a leadership role in the development of these components.

The state-of-the-art for the most critical system components such as antennas, receivers, transmitters, and filters at 40 and 80 GHz is summarized in the following paragraphs.

2.1 Antennas

The technology status of satellite and earth station antennas is shown in Table 19. The table also shows the characteristics of satellite antennas providing conus, time zone, and spot beam coverage.

A number of manufacturers have developed antennas for use above the 36 GHz frequency region. A list of these antennas, their size, application and manufacturers is given in Table 20.

The survey performed for this task revealed that the technology exists for fabricating antennas with diameters as large as 25 meters and with surface tolerance adequate for use at 40 GHz. For a surface tolerance adequate for use at 80 GHz, the technology is available for antennas with at least a 5-meter

TABLE 19

ANTENNA TECHNOLOGY

COVERAGE	SATELLITE BEAMWIDTH DEGREES	GAIN-dB	SIZE-FEET 40	SIZE-FEET 80	TECHNOLOGY STATUS
1. CONUS	3.5 x 7	29	.26	.13	Horn or Parabola - Technology Available
2. Time Zone	2.5	36	.69	.35	Horn or Parabola - Technology Available
3. Spot Beams	1	44	1.74	.87	Depends on number of beams from satellite - may require development if large number required. For example, lens fed by array cluster.

EARTH STATION

1. Size of antenna determined by link requirements.

2. Surface tolerance requirements limits practical size of antenna.

   $\lambda/20$ at 43 GHz = .014 in. - Technology available up to about 25 meters/82 ft.
   Gain = 76 dB, Beamwidth - .02°, E-system/Radiation Systems, Inc.
   For NRAO - 25 meter diameter, 015 in. tolerance

   $\lambda/20$ at 85 GHz - .007 in. - Technology available up to at least 15 ft.

TABLE 20 - ANTENNAS

Type	Frequency (GHz)	Size (Ft.)	Application	Mfg.
Parabola (Cassegrain)	94	15	Aerospace 94-220 GHz Radiometer	ROHR
Parabola (Molded Graphite)	60	12		Aeronutronics/Ford
Parabola	36-40	3	AF Airborne MM Wave Terminal	Raytheon
Parabola	36-40	Spot Beam	LES 8-9 Satellites	Lincoln Lab.
Horn	36-40	Earth Coverage (18°)	LES 8-9 Satellites	Lincoln Lab.
Parabolas and Horns	40-80		General	Scientific Atlanta TRG
Spun Aluminum		4		
Machined Aluminum		2		
Metalized Plastic		4		
Parabola	43	82	Radiometer	E-system/Radiation Systems, Inc.

diameter. Technology exists for automatically pointing large antennas.

Multiple spot beams with up to 61 beams, with 1° beamwidth per beam and bandwidths of 5 to 6 percent are under development at X band. The concepts used in such an antenna might be extrapolated to higher frequencies, but this needs to be proven.

Multiple beam antennas for communications satellites require isolation between beams in the order of 30 dB. Feed designs achieving this order of isolation have been developed up to the Ku band and the techniques used to achieve this degree of isolation are probably useful to 40 GHz, but have not been demonstrated at this frequency range.

Aside from the multiple spot beam antenna development needs, the 40 and 80 GHz technology for satellite and earth station antennas is believed to be at hand.

2.2 Receivers

Uncooled low-noise amplifiers have been built for use in the 36-38 GHz region and this technology is believed to be applicable to the 40 GHz region. Information obtained from hardware manufacturers indicated that no uncooled or cooled low-noise amplifiers in or near the 80 GHz region are available.

Cooled amplifiers are necessary for an earth station receiver and are desirable for the satellite receiver in order to achieve a maximum G/T (gain of the satellite antenna divided by the system noise temperature). Cooled amplifier developments are also needed to achieve minimum system noise temperature.

Satellite receivers need up or down converters, depending on the frequency transmitted to the satellite. During the course of the survey, no up or down converters were found for use in the 40 or 80 GHz region. However, there is quite a bit of technology available on mixers, both cooled and uncooled up to 120 GHz, that is applicable to up and down converters.

The local oscillator chains for these mixers have also been developed. Therefore, the technology for satellite up and down converters, as well as earth station receivers and mixers, is believed to be at hand.

A list of receiver subsystem components for both satellite and earth station, their function, and the present technology status is given in Table 21. Table 22 shows the development of mixers for use above 40 GHz.

2.3 Filters

Filters have been developed at millimeter wave frequencies up to 94 GHz. As filter needs at 40 and 80 GHz are identified, some developments may be necessary to achieve low loss networks. Specific requirements could not be identified at the time of this study.

TABLE 21

RECEIVER TECHNOLOGY

Subsystem	Function	Technology Status
Satellite		
R.F. Amplifiers	Amplifies up-link signal before down conversion amplification overcomes conversion loss while preserving noise figure.	Depends on up-link frequency, uncooled amplifier technology appears available from 40 GHz To 64 GHz. Technology above 64 GHz appears to be experimental.
Down Converter	Converts up-link frequency to an intermediate frequency for amplification.	Technology available from 40 GHz to 120 GHz. Single ended, balanced, and integrated I.F. mixers technology available.
Up Converter	Converts I.F. frequency to 40 GHz or 80 GHz for driving power amplifier.	No U.S. technology found, may exist in foreign guided wave systems.
Earth Station		
R.F. Amplifiers	Amplifies down-link signal before down conversion. Amplification overcomes conversion loss while preserving noise figure.	Uncooled amplifier appears available from 40 GHz to 64 GHz. Technology above 64 GHz appears to be experimental. No cooled amplifiers found (40-80 GHz).
Down Converters	Converts down-link frequency to an intermediate frequency for amplification.	Technology available from 40 GHz to 120 GHz. Single ended, balanced, and integrated I.F. mixers technology available.

TABLE 22

MIXERS

FREQUENCY (GHz)	CONVERSION LOSS (dB)	NOISE FIGURE (dB)	R.F. BANDWIDTH	IF BANDWIDTH	MANUFACTURER	COMMENT
40-60	6.0	*	10%	*	Hitachi	
40-60	7.5-11.0	*	7.0 GHz	*	TRG	SINGLE ENDED SCHOTTKY BARRIER
40-60	7.5-10.0	*	3.0-7.0 GHz	*	TRG	BALANCED MIXER WITH INTEGRATED PREAMPLIFIER
40-60	*	7.5	*	10-500 MHz	SpaceKom	MIXER/PREAMPLIFIER
40-60	5.5-6.0	*	*	DC - 2 GHz	SpaceKom	BALANCED MIXER-FREQUENCY CONVERTER
40-60	7.0	*	2 GHz	*	HAC	TUNABLE (6 GHz)
40-80	5.0-7.0 dB	*	*	1.7 GHz	NEC, Mitsubishi	NTT MILLIMETER-WAVE SYSTEM
50-60	*	7.0	*	10-110 MHz	HAC	SCHOTTKY BARRIER MIXER/ PREAMPLIFIER
50-75	18.0-24.0	*	5 GHz	100-150 MHz	HAC	SCHOTTKY BARRIER HARMONIC MIXER
55	7.0	*	*	2 GHz	Sperry	
60-90	7.5	*	5%	*	Hitachi	
60-90	8.5-12.0	*	8 GHz	*	TRG	SINGLE ENDED SCHOTTKY BARRIER
60-90	8.5-11.0	*	5-8 GHz	*	TRG	BALANCED SCHOTTKY BARRIER
70	*	10.0	*	60 MHz	Aerojet	
75-110	*	10.0	2 GHz	10-1000 MHz	HAC	SCHOTTKY BARRIER MIXER/ PREAMPLIFIER
80-120	5.5	4.35/500°	*	1.4 GHz	National Radio	SCHOTTKY BARRIER - UNCOOLED
92-96	*	9.5	*	60-500 MHz	SpaceKom	MIXER/PREAMPLIFIER
92-96	9.0	*	*	DC - 2 GHz	SpaceKom	SCHOTTKY BARRIER BALANCED MIXER
92-96	*	9.0	1 GHz	100-600 MHz	TRG	BALANCED MIXER/PREAMPLIFIER
95	5.0	*	*	2-4 GHz	Westinghouse	RADIOMETER RECEIVER

* NO DATA AVAILABLE

2.4 Transmitters

Travelling wave tube (TWT) amplifiers for 40 and 80 GHz with powers of 100 and 200 watts are under study by NASA. The Lewis Research Center is presently contracting with the Hughes Aircraft Company for the design of a 43 and 85 GHz, 100 and 200 watt travelling wave tubes which can be used on satellites of the future. Additional efforts related to the development of high power TWT's and the technology state-of-the-art includes the development of a coupled cavity TWT developed by Siemens Corporation which operates in the upper Ka band. This tube has over a kilowatt output power and a basic efficiency in excess of 25 percent. Recent information indicates this tube could be scaled to 4.8 kW.

The work done on the 12 GHz transmitter employed in the Communications Technology Satellite and on the Japanese Broadcast Satellite also provides a technology basis for developing 40 and 80 GHz transmitters. These 12 GHz transmitters have nominal output power of 200 and 100 watts respectively with bandwidths of 85 and 150 MHz.

Solid state amplifiers using IMPATT devices are under development in the 26-36 GHz region with goals of 10 watts output and 10 percent efficiency. To date, 300 milliwatts have been achieved with these devices, and industry is optimistic about achieving a 10 watt level. The technology, specifically of travelling wave tubes, indicates power levels of up to 200 watts at 40 and 80 GHz are feasible.

Coupled cavity TWT power amplifiers for earth station application in the 36-38 GHz region have been built. These amplifiers have a 1 kW output and efficiencies in the order of 25 percent. Such technology appears to be usable at 40 GHz and perhaps as high as 80 GHz. The present development of power amplifiers for satellite and earth station application is given in Table 23.

TABLE 23 - POWER AMPLIFIERS

FREQUENCY (GHz)	POWER (WATTS)	GAIN (dB)	EFFICIENCY	MANUFACTURER	COMMENTS
43	100	*	*	HAC	NASA Feasibility Study
45-48	5-10	*	35% Goal	-	Flying Command Center to Satellite, Development
49.5-58	150	25	*	HAC	Under Development
85	100 & 200	*	*	HAC	NASA Feasibility Study
91-96	100	25	*	HAC	Under Development
36-38	1 K	43	25-30%	Raytheon	U.S. Air Force Airborne Terminal For Satellite Communications
36-38	1 K	*	28%	Siemens	Experimental Submarine Communication System
54.5-55.5	1K - 5K	20	*	HAC	Under Development

* No Data Available

SECTION 6

ATMOSPHERIC ATTENUATION IN THE 40 AND 80 GHz BAND

1. Introduction

Since atmospheric attenuation is a major factor affecting the performance of earth satellite communications links, particularly in the millimeter wave region, an analysis of the effects was undertaken during Task IV of the project. As part of this effort, a study was made of the factors contributing to the attenuation, and reviews of propagation measurements and experiments in or near the frequencies of interest were made.

The three major contributors to atmospheric attenuation, oxygen and water vapor, clouds and precipitation, are listed in the order of increasing importance in Table 24. Although there is precipitation in some clouds, the indicated division between clouds and precipitation was arbitrarily made to permit separate consideration of stratified Rayleigh absorbers and cellular Mie absorption and scattering. The three models in Table 24 are stratified, and the effect of elevation angle E may be included by multiplying zenith attenuation by cosecant E when E is above 5°. For rain cells, an additional reduction factor must be applied to the attenuation.

In the discussion which follows, actual measurements of attenuation near the frequencies of interest have been summarized. Measurements at other frequencies have been extrapolated to support estimates for the attenuation at 40 and 80 GHz. Sky

TABLE 24. COMPONENTS OF ATMOSPHERIC ATTENUATION

COMPONENT	CONSTITUENTS	PROCESS	MODEL	CLIMATIC DATA
Clear Atmosphere	Oxygen Water Vapor	Resonant Absorption	1. Standard Atmosphere	Humidity
Clouds	Small water drops	Rayleigh Absorption	2. Strata	Cloud Cover
Precipitation	Liquid and solid water	Mie Absorption and Scattering	3a Low Strata b High Cells	Precipitation Radar Tops

temperatures are derived as a function of attenuation. The effects of diversity at 40 and 80 GHz are also discussed in the following pages. These estimates were based on available diversity measurements identified during the study.

2. Clear Atmosphere

Oxygen and water vapor are the only significant attenuating gases in the clear atmosphere. They absorb electromagnetic energy because oxygen has a magnetic dipole and water vapor has an electric dipole. While the theory is complex, there is sufficient supporting experimental data to give reasonable confidence in estimates of attenuation. Figure 18 (ref. 36) shows that there is a water vapor resonance at 22.235 GHz and a water vapor contribution from the submillimeter region. Water vapor attenuation is a function of temperature and pressure and is especially sensitive to water content. The 7.5g/m^3 used in Figure 18 corresponds to a partial pressure one-tenth of standard atmospheric pressure, or 43 percent relative humidity at 20°C. Oxygen attenuation rises above that of water between 42 and 77 GHz in one large peak at sea-level that breaks up into many sharp lines at high altitude as shown in Figure 19 (ref. 37).

To determine the effect of the whole atmosphere, profiles of temperature, pressure and water vapor density must be assumed as in the standard atmosphere of Figure 20 (ref. 38). Integration along different elevation angles through the spherical stratified atmosphere then gives the total attenuations shown in Figure 21. This figure shows that the attenuation rapidly rises below 20° elevation, especially at 80 GHz.

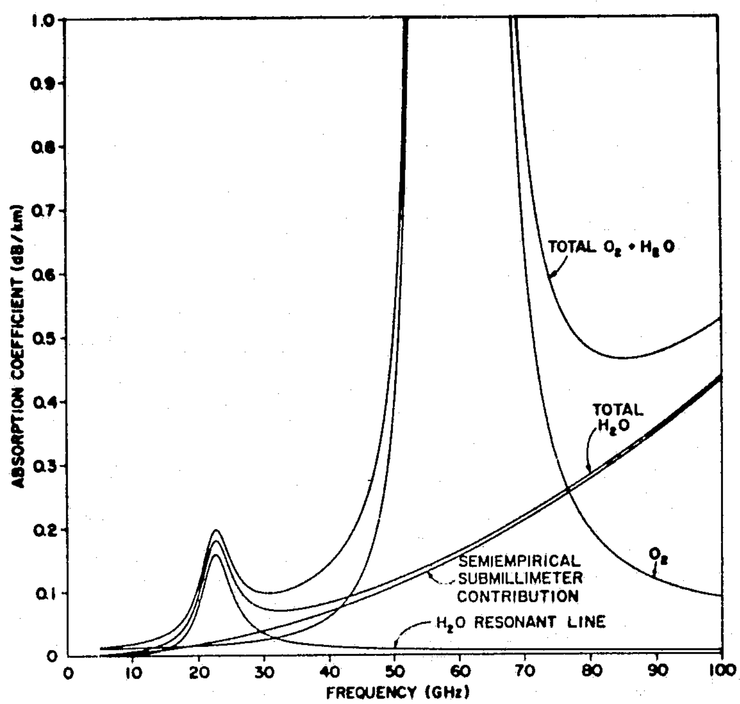

Figure 18. Water vapor and oxygen absorption coefficients vs frequency (T = 15°C = 60°F, P = 760 mm Hg, ρ_o = 7.5 g/m^3)

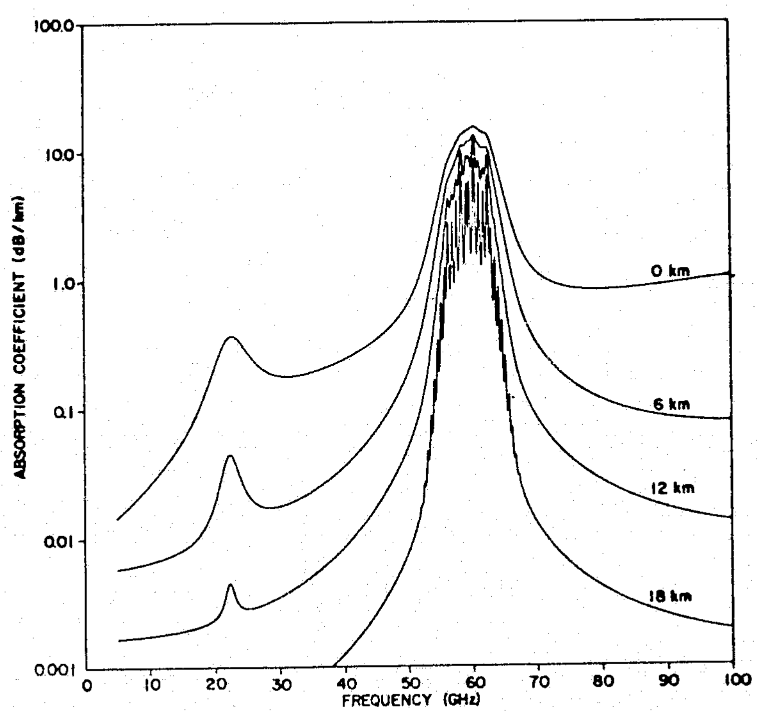

Figure 19. Absorption profiles for various altitudes for ρ_o = 15.0 g/m^3 (60% RH at 80°F)

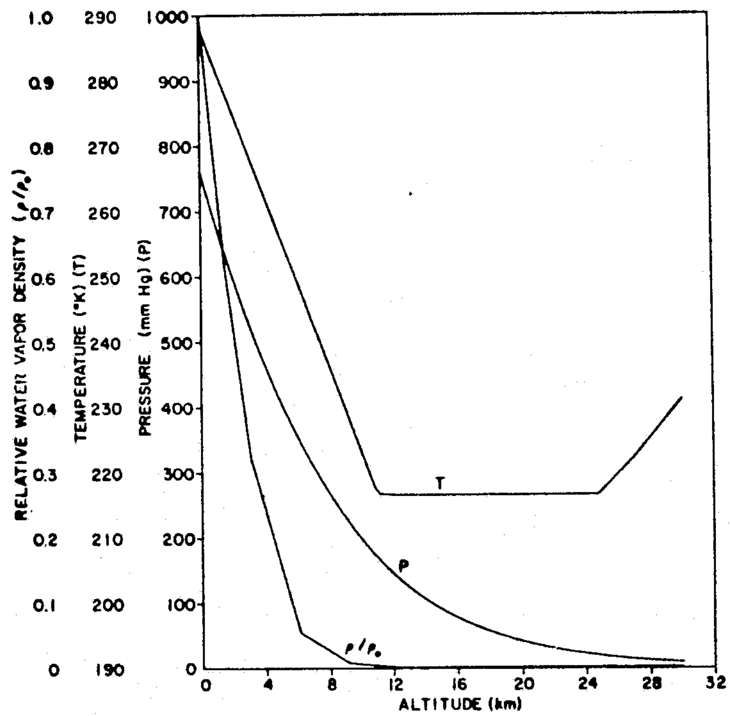

Figure 20. Temperature and pressure profiles of the 1959 ARDC model atmosphere, and average water vapor distribution

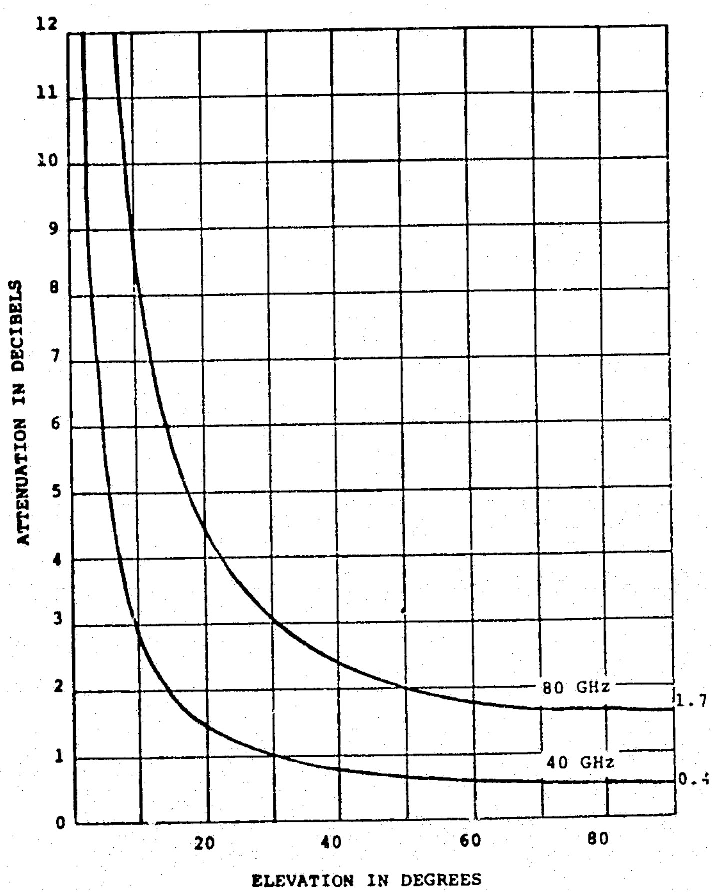

Figure 21. Attenuation of clear atmosphere at surface, $\rho_o = 7.5$ g/m^3

Lefande (ref. 39) gives the following expressions for water vapor zenith attenuation, A_o in dB, based on soundings in the Washington, D. C. area:

For f = 40 GHz

$$A_o = .025M + .370 \quad (1)$$

For f = 80 GHz

$$A_o = .087M + 1.056 \quad (2)$$

where M = water vapor density in grams/meter^3. M may be found from Figure 22a and 22b (ref. 40) as 16 g/m^3 for 50 percent of time for August in Washington or 20 g/m^2 for 1 percent of the time.

From the above equations, with an M=16 g/m^3 the zenith attenuation given by the 50 percent figure is .8 dB at 40 GHz and 2.4 dB at 80 Ghz. After multiplying by the cosecant of the elevation the attenuation is 1.6 dB at 40 GHz and 4.8 dB at 80 GHz at an elevation angle of 30°.

3. Clouds

There are many types of clouds, differing greatly in composition, shape, height and occurrence. They are identified in Table 25. The high clouds may be ignored because they consist of ice and ice attenuates significantly less than water. The cumulus clouds are not large in horizontal extent like the stratus clouds. However, as the variations in M & L are not large, gaps between the cumulus clouds may be treated the same as days without clouds in estimating statistics of cloud coverage and slant-path attenuation. Cumulonimbus and nimbostratus will

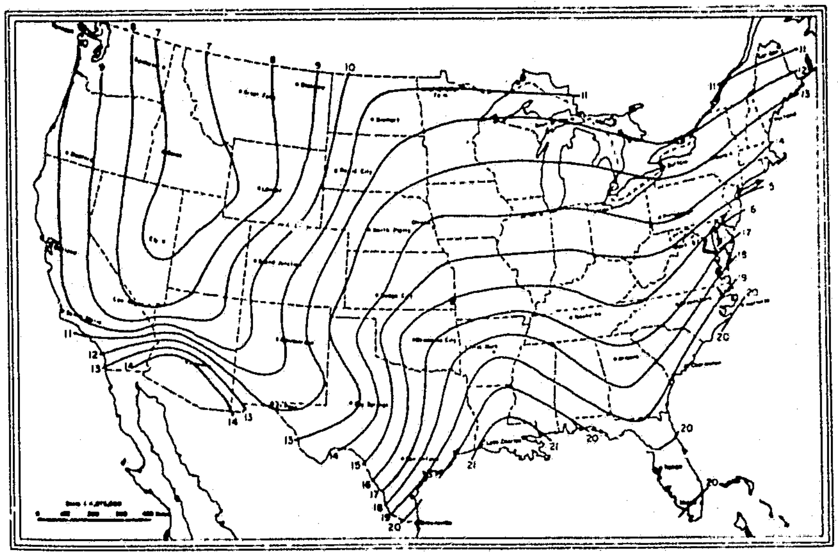

Figure 22a. Estimate of the value of absolute humidity expected 50 percent of the time for August

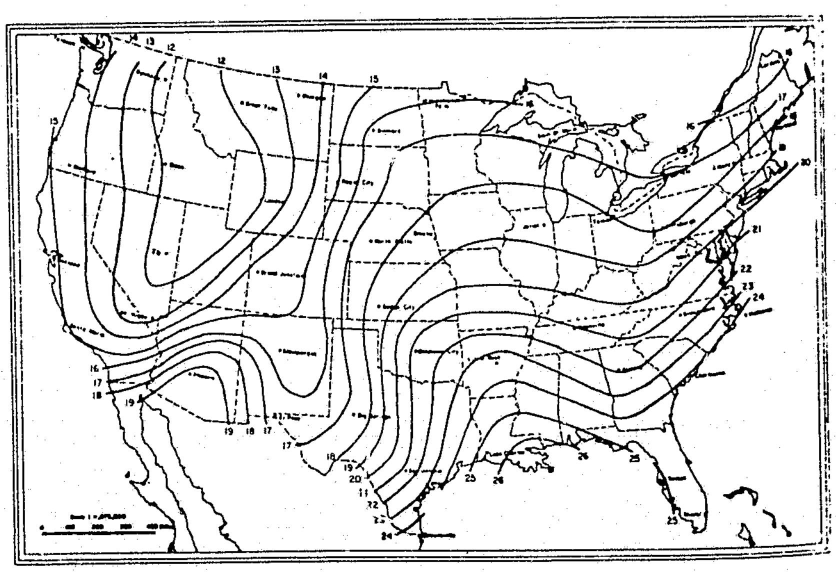

Figure 22b. Values of absolute humidity expected to be exceeded 1 percent of the time for August

TABLE 25. CLOUD CHARACTERISTICS

Ht. above Surface	Name	Symbol	Characteristics	M	L	ML	Note
High 6-13 km	Cirrus	Ci	Ice, no shadows	Negligible			
	Cirrostratus	Cs	Ice, no shadows	Negligible			
	Cirrocumulus	Cc	Ice, no shadows	Negligible			
Medium 2.5-6 km	Altostratus	As	Followed by ppn	.15	2	.3	3
	Altocumulus	Ac	Some shadows	.15	2	.3	3
Low 0-2.5 km	Stratocumulus	Sc	Some shadows	.3	1	.3	
	Stratus	St	Fog	.3	.5	.2	3
	Nimbostratus	Ns	Steady rain	See precipitation			
Vertical 1-20 km	Cumulus	Cu	Low, fair weather	1	1	1	4
	Cumulonimbus	Cb	Thunderstorm	See precipitation			

Notes:
1. M is average water content in grams/meter^3
2. L is thickness in kilometers
3. M and L from Gaut and Reifenstein (ref. 41)
4. M and L from Weickmann and aufm Kampe (ref. 42)

not be considered as clouds because the accompanying precipitation which must be treated separately, is far greater than the water vapor attenuation. Typical occurrence statistics for Cu and Cb, and Cb alone are shown in Table 26 (ref. 43).

The attenuation, A in decibels, due to water vapor may be found from a simplified expression of Gaut and Reifenstein (ref. 41).

$$A = .0005\ MLF^2\ \csc E\ \exp\ (0.02806\ (291-T)) \tag{3}$$

where

M = water vapor density in grams/meter^3

L = cloud thickness in kilometers

F = frequency in GHz

E = elevation angle

T = cloud temperature in Kelvins (see Figure 20)

This expression is plotted in Figure 23, normalized to M=L=1 and e = 90° so that the attenuation for any value of ML may be found by multiplying the value read from the curve by ML and adjusting for elevation angle. Thus, for ML = 1.0 and e = 90° at 80 GHz and 293K (20°C), A = 3.1 dB. Table 25 shows that this value of ML applied only to cumulus clouds. This worst cloud case, with the surface $\rho_o = 1\ g/m^3$ and the equations on page 258 are used in Figure 24, showing attenuation of clear air and clouds as a function of elevation angle.

TABLE 26. - PERCENT FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS CLOUDS

Station 1500 LST	Winter cu cb	Spring cu cb	Summer cu cb	Autumn cu cb	Jan cu + cb	Apr cu + cb	July cu + cb	Oct cu + cb
1. Bedford, Mass.	6 - 0	21 - .6	56 - 1.7	22 - 0	5	19	59	14
2. Hempstead, N. Y.	11 - 0	20 - .7	40 - 1.5	19 - .3	6	20	42	12
3. Washington, D. C.	9 - 0	30 - .9	65 - 2.8	24 - .2	7	29	73	24
4. Savannah, Ga.	16 - 0	45 - 3.3	86 - 15.1	38 - 1.9	17	43	90	41
5. Palm Beach, Fla.	61 - .5	83 - 11	95 - 41	83 - 17	54	79	94	81
6. Biloxi, Miss.	14 - .6	41 - 2.8	97 - 27.8	45 - 5.1	16	38	100	43
7. Houston, Texas	18 - .3	45 - 2.8	93 - 11.9	46 - 4.5	23	36	95	49
8. Fort Worth, Texas	5 - .2	25 - 1.5	75 - 5.7	31 - 1.9	5	24	85	29
9. El Paso, Texas	7 - .2	30 - 3.3	89 - 26.8	38 - 3.5	7	25	100	35
10. Oklahoma City, Okla.	4 - 0	26 - 2.7	75 - 6.4	24 - 1.4	1	23	83	19
11. Phoenix, Arizona	17 - 0	30 - 2.6	67 - 30.5	30 - 2.8	20	35	88	22
12. Riverside, Calif.	15 - .2	26 - .2	32 - 4.7	19 - 2.0	16	24	38	11
13. Merced, Calif.	16 - .3	42 - 1.8	36 - 6.5	17 - 1.4	16	47	37	13
14. San Rafael, Calif.	14 - .8	23 - .9	17 - 1.5	9 - .4	15	23	12	8
15. Great Falls, Mont.	7 - .2	37 - 2.8	72 - 11.8	19 - 1.5	6	31	75	19
16. Salina, Kansas	3 - 0	19 - 1.1	38 - 5.0	9 - 1.1	3	15	45	8
17. Minneapolis, Minn.	2 - 0	24 - 1.4	56 - 4.2	14 - .7	2	21	54	13
18. Ogden, Utah	7 - .5	39 - 2.6	68 - 13.8	19 - 1.1	3	37	76	16
19. Park Ridge, Ill.	2 - 0	20 - 2.0	46 - 3.3	14 - .2	1	23	50	12
20. Columbus, Ohio	3 - 0	25 - 1.1	66 - 5.1	23 - 1.0	1	24	69	18
21. Geneva, N. Y.	7 - 0	16 - .3	44 - 1.8	18 - 0	5	17	48	17
22. Middletown, Pa.	5 - 0	24 - .3	59 - 1.7	19 - 0	4	20	65	15
23. Limestone, Me.	3 - 0	16 - .1	54 - 2.2	15 - 0	1	13	60	10
24. Hampton, Va.	10 - 0	23 - .6	49 - 2.6	22 - .4	9	22	56	26
25. Tacoma, Wash.	13 - .2	37 - 1.8	40 - 1.2	17 - .6	10	36	37	19
MEANS	11 - .2	31 - 2.0	61 - 9.5	25 - 2.0	10	29	65	23

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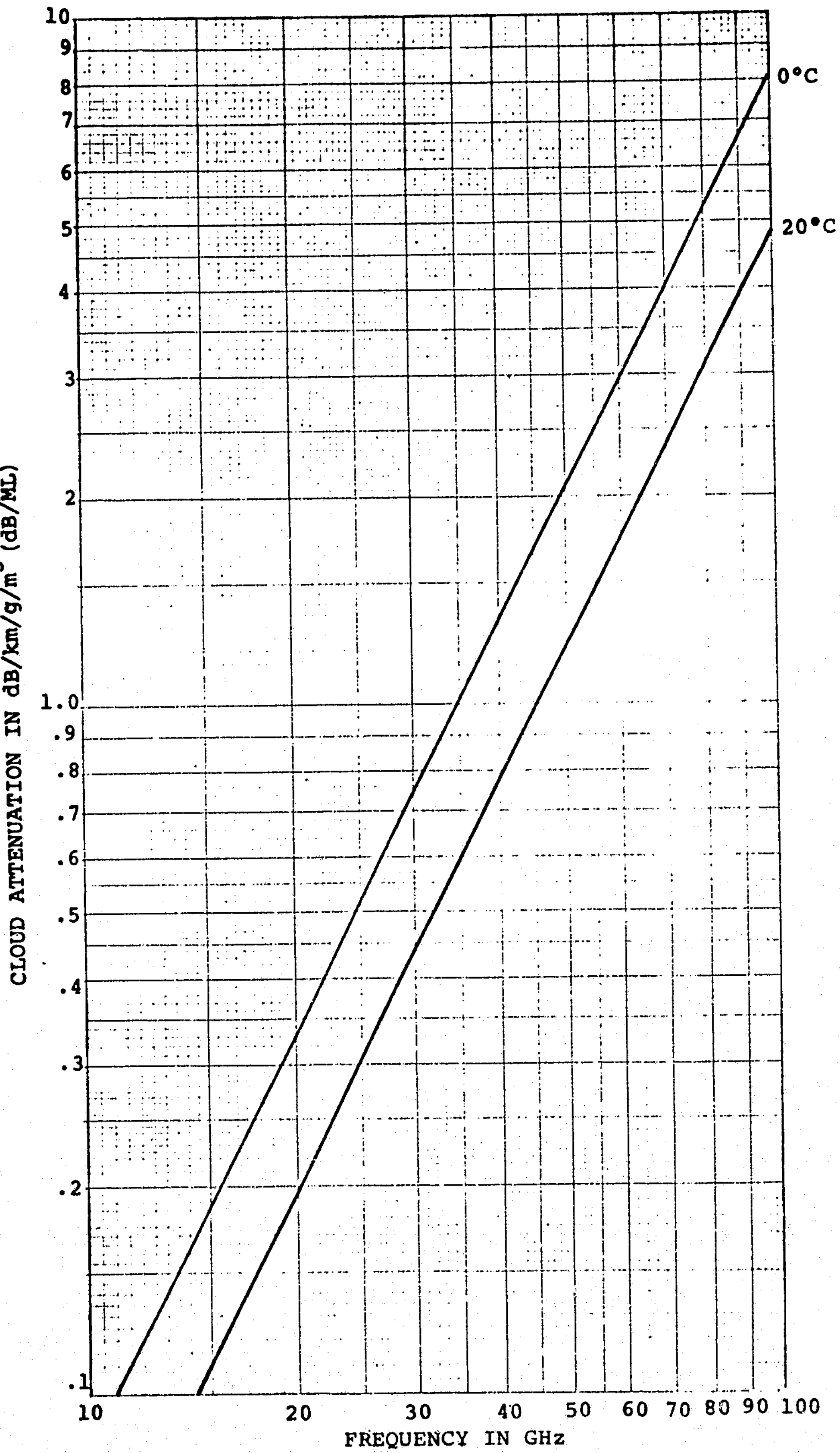

Figure 23. Normalized cloud attenuation vs frequency

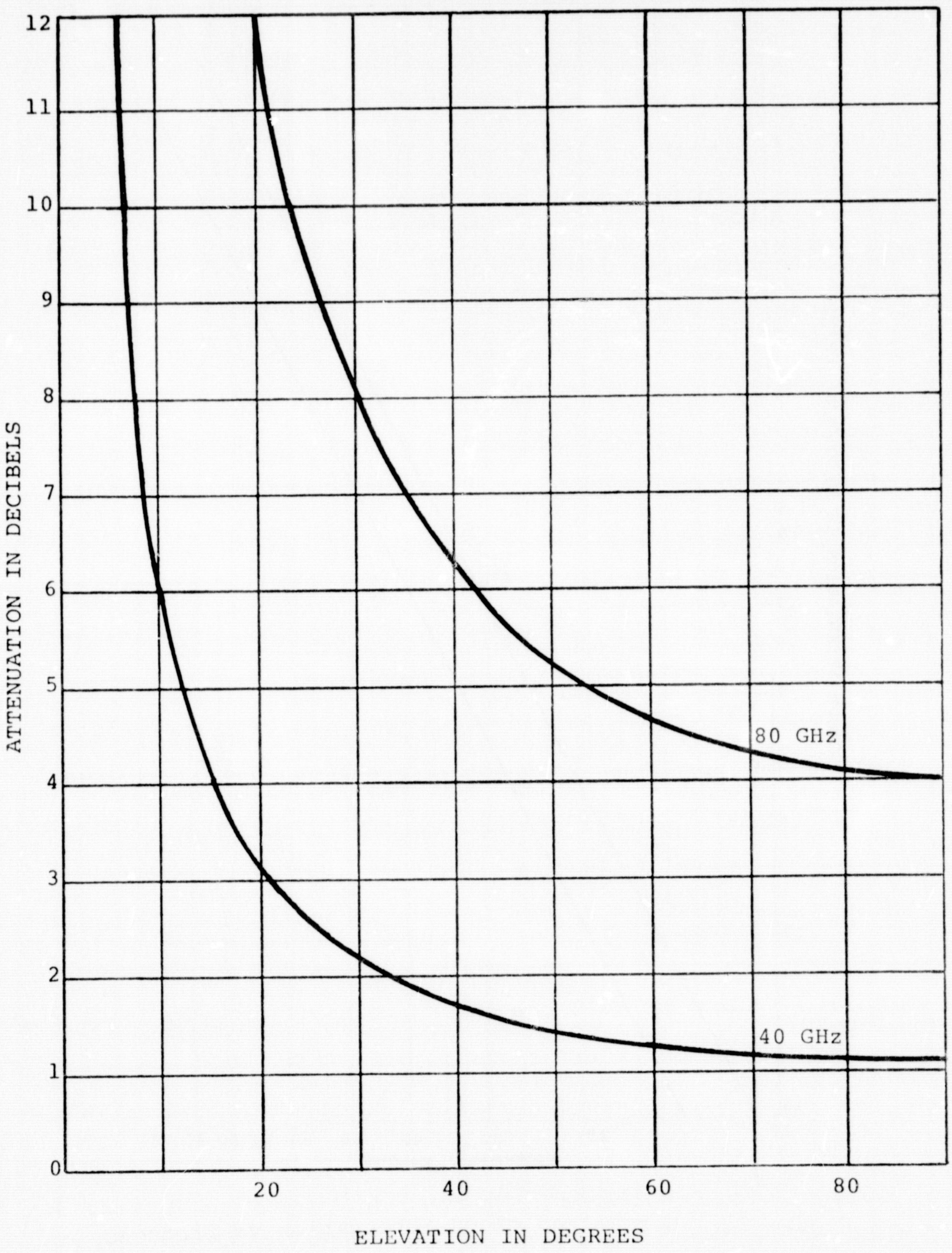

Figure 24. Attenuation of clear air and clouds (ρ_o = 7.5 g/m^3, M=18/m^3, L = 1 km, T = 293 K)

4. Precipitation

4.1 General

There are almost no satisfactory measurements of space-path attenuation at 40 GHz or higher. Even at lower frequencies those available are usually deficient in one or more of the following respects:

- Inadequate length of sample
- Inapplicable climate (England, Hawaii, etc.)
- Inclusion of all elevation angles down to the horizon
- Omission of hours of darkness
- Operation during only rainy, or only clear periods
- Poor resolution display
- Inadequate dynamic range

Satisfactory predictions of attenuation due to precipitation are difficult to make for a number of reasons:

- Unknown, rapidly changing precipitation distributions in space and time
- High attenuations from the melting layer
- Variations in loss when dry hail, or wet hail is present
- Unknown drop-size distributions
- Variations due to unknown temperatures.

These problems are partly overcome by various types of averaging in space and time. The requirement addressed here is to extrapolate lower frequency attenuation distributions to the frequencies of interest. The starting point for the method is in Hogg and Chu (ref. 44), and this extensive reference is recommended for a great deal of general material not included below.

4.2 Theoretical Curves

The attenuation of rain in dB/km is given by

$$A = .434\int_0^\infty n(r)Q_t(r,\lambda)\,dr \qquad (4)$$

where
λ = wavelength in cm
r = raindrop radius in cm
$n(r)dr$ = number of drops per m^3 in interval dr
$Q_t(r,\lambda)$ = extinction cross-section in cm^2.

Q_t includes effects of both absorption and scattering. Attenuations calculated by Setzer (ref. 45) for 20°C and the Laws and Parson drop-size distribution are shown in solid lines versus frequency in Figure 25 and can be used in interpolation at the frequencies of interest. To indicate the effects of small changes, several dotted curves are also shown:

- Medhurst (ref. 46), under conditions that are the same, gives results negligibly different
- Crane (ref. 47) at a temperature of 0°C, shows departure at the high end which is significant because the ordinate is logarithmic in decibels;

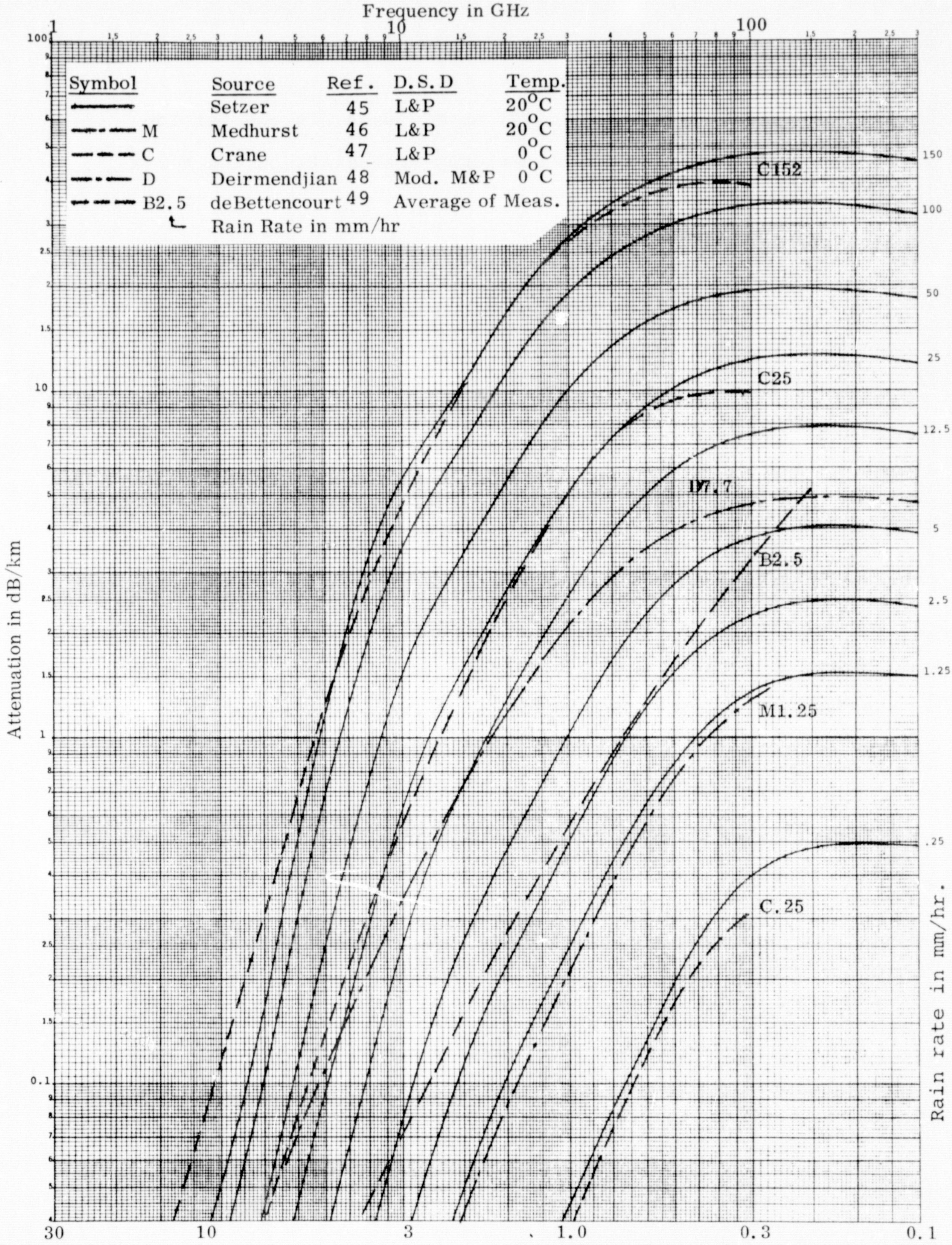

Figure 25. Attenuation vs. frequency for specific rain rates

- Deirmendjian (ref. 48) at 0°C uses his own version of the Marshall-Palmer drop-size distribution for a "medium" rain;

- deBettencourt (ref. 49) has fitted curves to measured distributions (mostly terrestrial). The good fit at lower frequencies is lost at the extrapolated high end because the theoretical curves were not considered.

For extrapolation purposes, curves at several frequencies not considered by Setzer are required, preferably attenuation versus rain rate, as shown in Figure 26. Several of Crane's curves for 0°C are added to indicate the effect of temperature versus rain rate, at a given frequency. For example, the 0°C curve for 94 GHz is below that of Setzer for 20°C and 60 GHz at rainfall rates of 12.5 mm/hr or higher. The effects of temperature dependence are diminished by using the same temperature set for any exercise. Two kinds of approximations are also shown in Figure 26. Hogg and Chu (ref. 40) show in their Figure 3 straight lines of attenuation in decibels versus rain rate, both on linear scales. These are useful at the higher rain rates of significance. Atlas and Ulbrich (ref. 50) provide surprisingly good fits, with straight lines on the log-log representation of Figure 26. Although these are based on the Marshall-Palmer drop-size distribution, the authors state that this is not important, and this seems reasonable in view

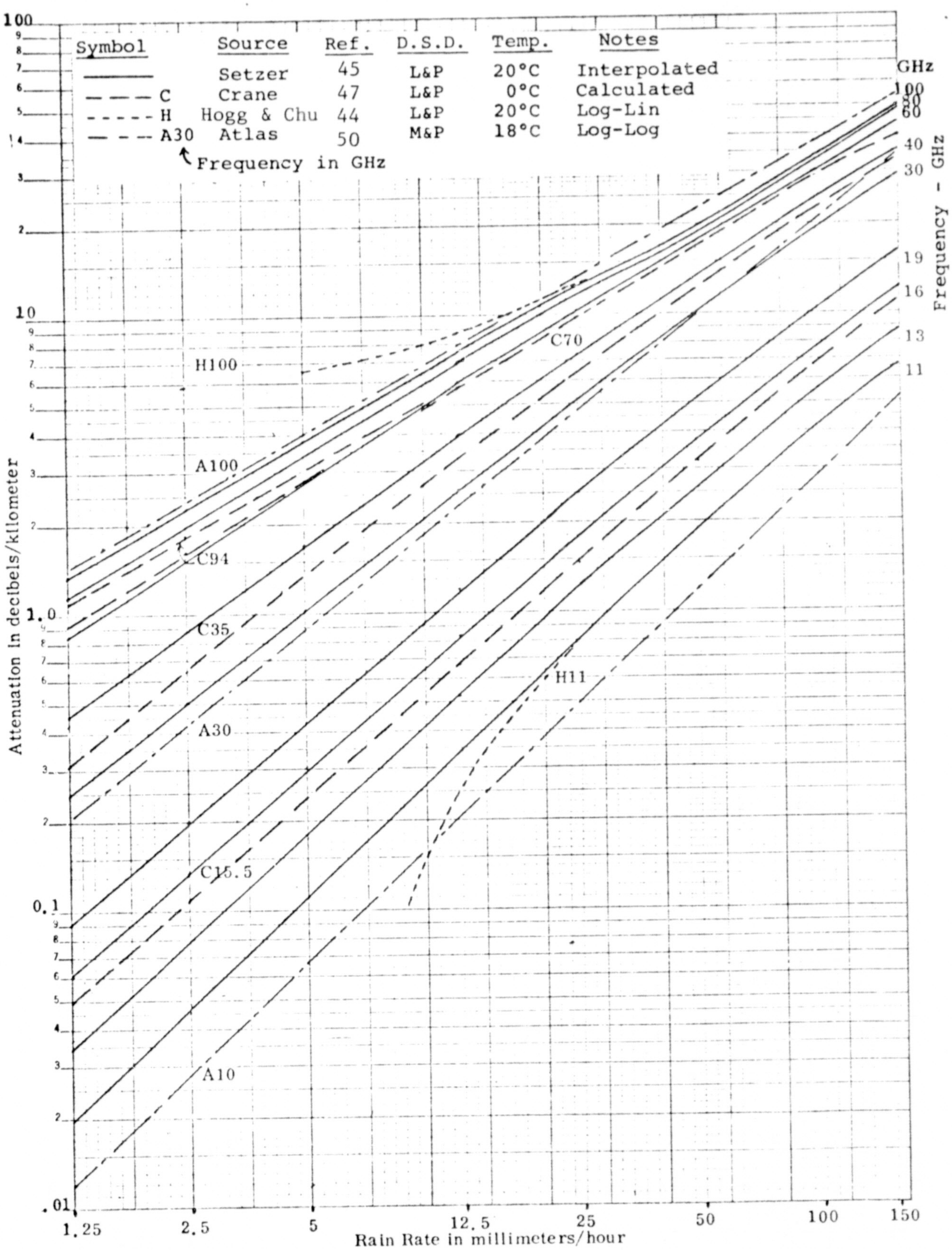

Figure 26. Attenuation vs. rain rate for specific frequencies

of the temperature problem noted above. There are several advantages to a log-log display, namely, linearity, capability of analytic expression, and good fit at low as well as high rainfalls. Furthermore, the log-log paper lends itself to certain graphical steps suggested below.

According to Lin (ref. 51) there are theoretical reasons and practical proof that the logarithm of attenuation is normally distributed during the rainy time. Goldhirsh and Robison (ref. 52) note on page 225 that their curves "...may be shown with good approximation to be log-normally distributed". Altshuler et al (ref. 53) use a log-normal display in their Figure 3. Furthermore, Turner (ref. 54) plots logarithm of attenuation in decibels versus logarithm of percent time, which is closer to a log-normal distribution than Hogg and Chu's linear plot in decibels. All this supports the general use of log (attenuation) plots like Figure 26, which have the useful property that ratios between curves for different frequencies are simple linear distances, easily measured from the curves.

4.3 Attenuation Measurements

4.3.1 Radiometer Measurements

Radiometers are of two major types, active and passive. The passive type measures the noise power from the sky, usually the zenith. It does not require mechanical tracking equipment, operates day and night at constant elevation, but it has a dynamic range limited to about 10 dB. The active type usually tracks the sun during daylight hours with varying elevation angle, but with a dynamic range of up to 30 dB. Both types are used in two versions. The simple form requires high-quality low-noise design to attain modest dynamic range. The mechanically or electrically switched form looks alternately at the target and the adjacent sky reference so that synchronous detection can provide high dynamic range.

The measured noise power, P, may be used to determine temperature, T_b, by using $P=kT_bB$ where k is Boltzmann's constant and B is the bandwidth. With an attenuating atmosphere at absolute temperature T_a, the effective brightness temperature T_b is

$$T_b = T_a (1 - 10^{-A/10}). \tag{5}$$

T_a must be found from other attenuation or upper-air measurements, or is estimated from surface temperatures and the attenuation A in decibels is

$$A = -10 \log_{10} (1 - T_b/T_a). \tag{6}$$

Table 27a lists the available radiometer measurements of most interest. The first three are in non-stormy climates. The next displays percent time on a linear 0-100 scale so that percentages of interest cannot be read accurately. Altshuler's measurement is at a single frequency so it cannot be used for extrapolation. The next two, from the Bell Laboratories, are used by Hogg and Chu and will be used below for extrapolation even though all sun angles above 20° are included.

TABLE 27. ATTENUATION MEASUREMENTS AND ESTIMATES

		Frequency-GHz					
Reference	Ref.	Data	Estimate	Period	Location	Elev.	Remarks
a (Radiometer)							
Turner	54	12,17		3-12/70	E. England	5,20°	Passive, log-log display
Davies	55	19,37		9/71-9/72	S. England	5-62	Pass. & Act., worst month shown
Wulfsberg & A.	56	15,35		Rainy	Hawaii	45	Pass. & Active
Wulfsberg	56	15,35		1-7/66	E. Mass.	4-40	Passive, log dB display
Altshuler & W.	53	35		11/72-7/73	E. Mass.	90	Passive, worst season shown, normal %
Wilson	58	16,30		12/67-11/68	New Jersey	2-74	Active, high elevation in Lin 73
Henry	59	11,19,30		8/72-8/73	New Jersey	25	Active
Wrixon	60	90		12/2-16/69	New Jersey	21-27	Active
b (Radar)							
Austin	61	3	10	61,62	E. Mass.	20	Used 4 rain gauges H = 4,5,6 miles
Rogers	62	9	5-24	5-9/63	Montreal	20	Elliptical model. H = 5 miles
Rogers	63	3	10	5-8/70	Montreal	20	ADA, constant H/D model
Inkster & Rogers	64	3	10	Summ. 72	" & Alberta	3-20	ADA, constant H model. H = 4 miles
Goldhirsh & R.	52	3	13,18	6-8/73	Va. Coast	45	Culled, extrapolated, diversity
Goldhirsh	65	3	13-100	6-8/73	Va. Coast	45	Culled, extrapolated, diversity, elevation
c (Satellite)							
Craft	66	15		7/70-7/71	Maryland	35	Worst month shown. Some radiometer
Ippolito	67	15		70,71	N. Carolina	42	Extrapolated using radiometer & gauges
Ippolito	68	20,30		7/74	N. Carolina	42	Extrapolated using rain gauges

The Wrixon data provide useful high frequency checks.

4.3.2 Radar Measurements

Weather radars can be conically scanned at different elevations to obtain a detailed three-dimensional knowledge of the reflectivity of the hydrometeors within about 100 km of the radar. If wet snow in the bright band and wet hail in some thunderstorms can be ignored, it is possible to use the reflectivity data base to predict attenuation. This has been done as noted in Table 27b. Austin (ref. 61) used 5x5 mile elements and rain gauges at four points for the earliest estimate. She used models for storms of three different intensities with tops, H, as shown. Rogers of the McGill Stormy Weather Group produced a series of estimates, the first of which agreed well with Austin, although it was largely analytical. In 1972 an Azimuth Display of Attenuation computer, ADA, was used to store and display, in real time, the attenuation at 10 GHz along each radius vector of a PPI screen. From the stored data, models were created which gave analytical results close to those measured. Unfortunately, the latest work in 1974 shows a much more rapid fall-off of attenuation with elevation than earlier and other studies (BTL), and this effect is unclear. Points at an elevation of 20° from these early references are plotted on Figure 27 without using the time correction discussed in section 4.4 because it is unknown.

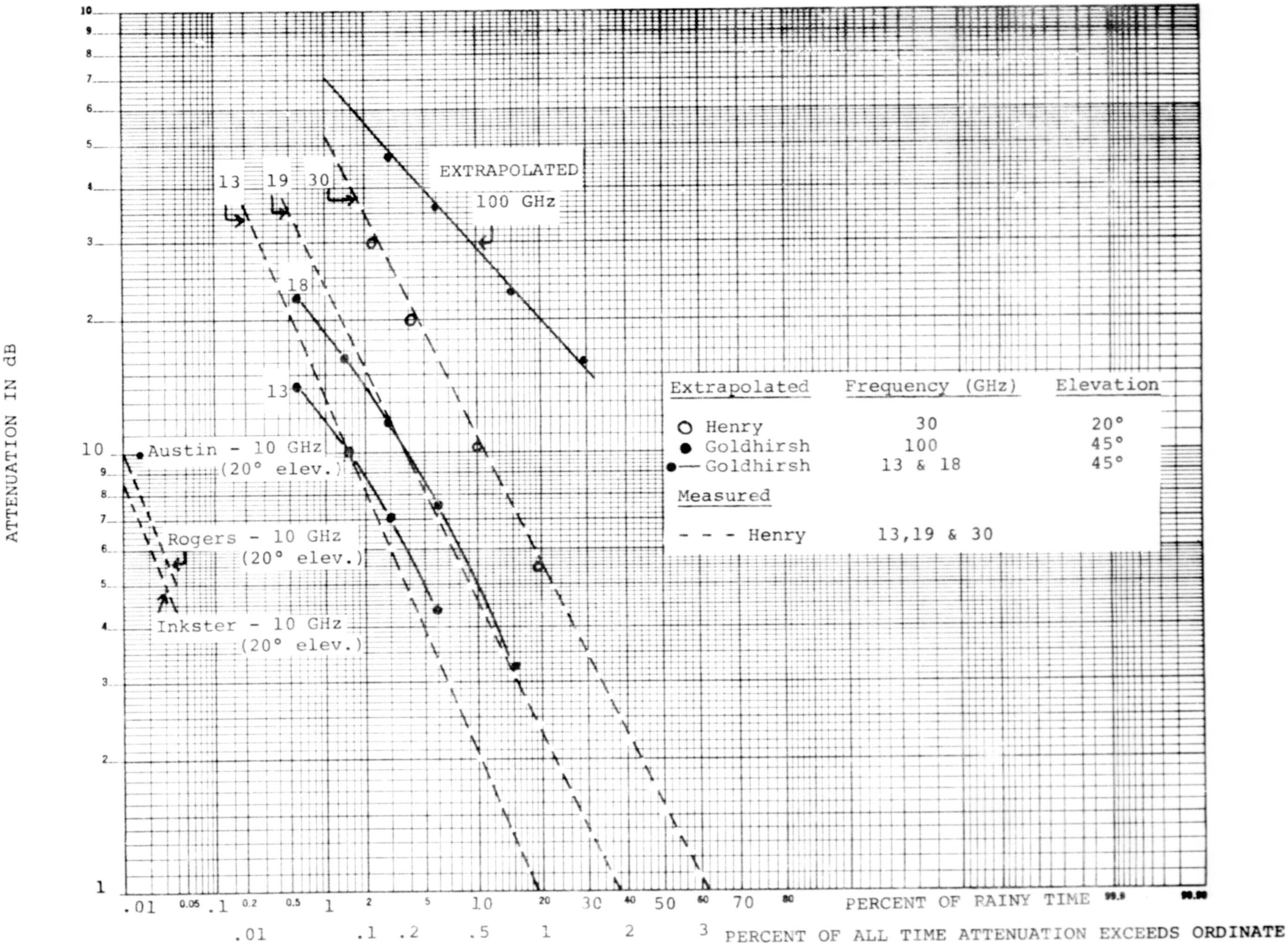

Figure 27. Attenuation distributions

Goldhirsh and Robison (ref. 52) used a high-power, high-precision S-Band radar to produce high resolution, three-dimensional digital records of reflectivity. Using the reflectivity data the attenuations along many evenly-space slant paths through the atmosphere were calculated for frequencies of 13 and 30 GHz. Goldhirsh (ref. 65) applied the same approach to other elevation angles and frequencies up to 100 GHz. The results are directly useful for diversity gain, but incomplete data were taken only during rainy periods, in arbitrary sextants and then culled even more arbitrarily, so that it is difficult to estimate attenuation on an annual or worst month basis.

4.3.3 Satellite Measurements

Satellite measurements are listed for reference in Table 27c, but the data is not used here because radiometers and radar provided more continuity.

4.4 Data Smoothing

Lin (ref. 51) showed that the distribution of rain attenuation in decibels during rainy time is approximately log-normal. For example, Figure 28 reproduces his plots of Wilson's 1969 data at 16 and 30 GHz in dashed lines. The low elevation data, presumably below 20 or 25 degrees, have been eliminated in accordance with unpublished work (Wilson-ref. 69).

Since Lin supports the lognormal plots with both theory and a mass of data, it seems reasonable to use them to refine experimental plots, culling from one end the effects of cloud

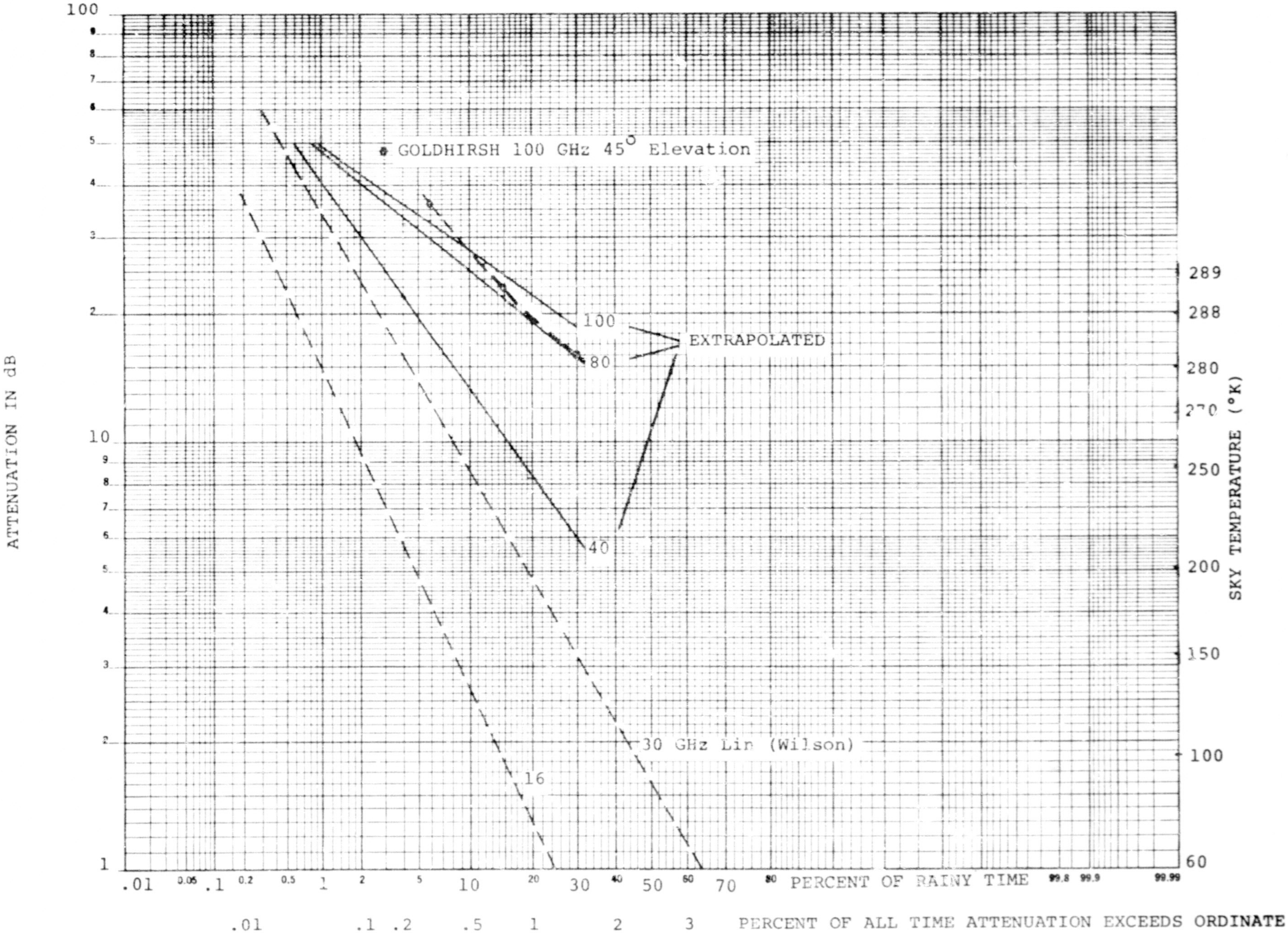

Figure 28. Attenuation distributions from Wilson

and clear air attenuation, and from the other the effects of dynamic range limitations of the measuring equipment, as well as the usual vagaries due to measurement techniques and climatic non-uniformity. This linearization will be seen to gain support below in the critical area of evaluating diversity results.

The parameters defining one of these distributions in Figure 28 are the attenuation median and variance in decibels and P_o, the ratio of rainy to total time and is used to shift the time scale.

For Henry's 1973 data a measured P_o is not available. Lin gives values of P_o of .0523, .059 and .0415 for 1968, 1969, and 1970 respectively at Crawford Hill, N. J. A value of P_o = .05 seems reasonable and can only produce second order errors in any case, since it drops out when returning to percentage real time. With a P_o = .05, Henry's data is replotted as shown in Figure 27.

To aid in plotting these distributions or in finding parameters from a plot a few facts are useful. P_o has already been discussed. It determines the ratio between the percent time scale used and that of the original data but is not otherwise involved in the plot. Each line is defined by a median, A50, and a standard deviation, s. However, when plotted, the intersection with the fifty percent abscissa may be off the page as for all of the lower frequency plots of Figure 27.

C.4

It is then useful to find the ordinates at some of the other points shown in Table 28. The values for s and A50 for Wilson are found in Lin (ref. 51). The other values of A_p are found from:

$$A_p = 10^{ks}A50 \tag{7}$$

where the k values for each p are given in the second column. For Henry's data, s and A50 are found from the values of A.2 and A20, read in Figure 27, using the equations:

$$s = (1/2.04) \log (A.2/A20) \tag{8}$$

$$A50 = A20/10^{.84s} \tag{9}$$

4.5 Extrapolation in Frequency

Semplak (ref. 70) showed that the Laws and Parson drop-size distribution was consistent with the ratios of instantaneous attenuations and their distributions that he found over a 2.6 km terrestrial path at 18.5 and 30.9 GHz. This drop-size distribution was used by Setzer, whose calculations discussed in Section 4.2 are used below. Hogg (ref. 71) has suggested that the ratio of attenuations measured at two frequencies be used to determine an effective rain rate over the path. Henry (ref. 59) confirmed this approach with measured data at 13, 19, and 30 GHz by extrapolating from the two lower frequencies and getting a good check with the higher as shown in Figure 27.

Evans (ref. 72) and Henry (ref. 59) both seem to use similar methods to Hogg and Chu (ref. 44) but the latter's procedure is the most explicit and will be used below with

TABLE 28. LOGNORMAL DISTRIBUTION PARAMETERS

		WILSON			HENRY				
		F = 16GHz s= .71	30GHz s=.57	Ratio	13 GHz s= .69	19 GHz s=.68	30GHz s=.66	Ratio	
P, Rainy Percent	k	A_p	A_p	30/16	A_p	A_p	A_p	19/13	30/19
50	0	.33	1.60	4.85	.265	.60	1.53	2.26	2.55
20	.84	1.30	4.82	3.70	1.01	2.24	5.48	2.22	2.45
10	1.28	2.68	8.59	3.21	2.03	4.45	10.70	2.19	2.40
4	1.75	5.77	15.9	2.76	4.27	9.29	21.9	2.18	2.36
2	2.05	9.42	23.6	2.50	6.88	14.9	34.5	2.17	2.32
1	2.33	14.9	34.1	2.29	10.74	23.0	52.8	2.14	2.30
.4	2.65	25.1	51.8	2.06	17.9	38.0	85.8	2.12	2.26
.2	2.88	36.6	70.1	1.92	25.7	54.5	121.8	2.12	2.23

improvements. First, the attenuation ratios of interest are found and plotted. Hogg's and Chu's Figure 36 plots attenuation ratio (30GHz/16GHz) versus attenuation in dB at 16 GHz, on linear scales. He also plots the attenuation ratio for a corresponding rain rate where the rain rate is on a logarithmic scale. That these two plots are linear and coincident seems fortuitous, perhaps a special case, and certainly not general. An equivalent but more generally useful approach is followed here, based on log-log paper for several reasons. First, Atlas and Ulbrich (ref. 50) and others have used log-log presentation of straight lines of attenuation of polydisperse rain at various frequencies versus rain rate (Figure 26.) The ratios of these lines are, of course, also straight log-log lines. Second, as noted in Table 27, some experimenters have used log displays of attenuation in decibels versus percent time. Lin and Altshuler have used the almost equivalent lognormal percent scale. Finally, logarithmic scales are convenient for graphic work as ratios can be measured and transferred with dividers. Also, if desired, scales can be stretched, shifted, and even warped as required for matching by a simple graphical reflection process, as will be shown.

To demonstrate the method of extrapolation in frequency, Henry's 13 and 19 GHz distributions will be extrapolated to 30 GHz to find the same sort of check he did. Then his 13 and 19 GHz distributions will be extrapolated to 100 GHz in order to compare with radar data from Goldhirsh. The ratio between the measured 19 and 13 GHz curves of Figure 27 is shown as curve M19/13 of Figure 29, using the bottom and

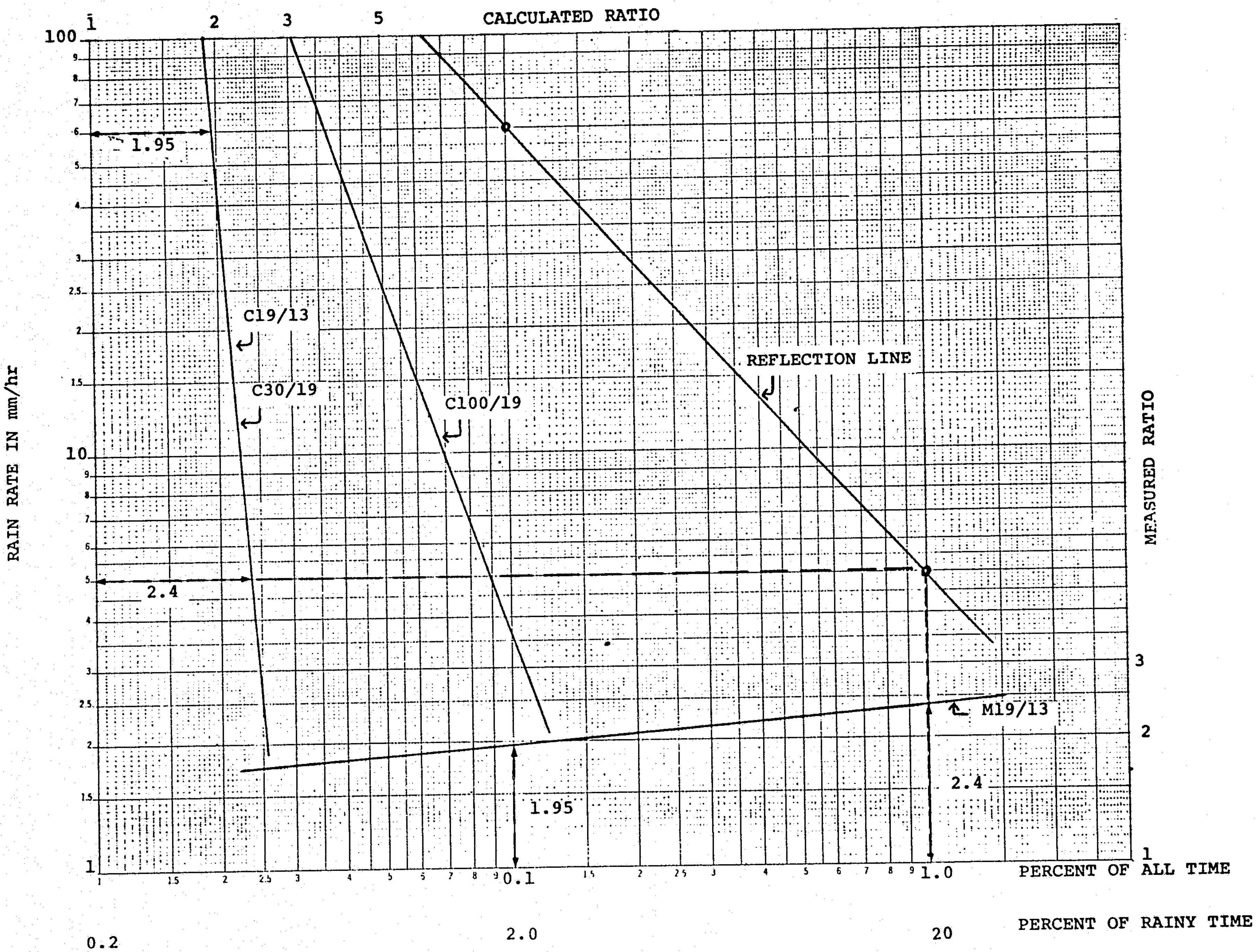

Figure 29. Extrapolation worksheet (Henry)

right-hand scales. The ratio between the Setzer 19 and 13 GHz calculated curves of Figure 26 is shown as curve C19/13 of Figure 29, using the top and left-hand scales. For 20 percent of rainy time the attenuation ratio M19/13 = 2.4. This is seen to correspond to a rain rate of 5mm/hr at which C19/13 also equals 2.4. Similarly at 2 percent, M19/13 = 1.95, and the corresponding rain rate is 60mm/hr. These two correspondences are marked by circles. Then a reflection line is drawn through the circles, straight because it is on a log-log plot. At any point on this reflection line the measured and calculated ratios are equal, and the percent time corresponding to any rain rate may be read easily. Hogg and Chu's Figure 36 show the 16 GHz attenuation and rain rate scales at bottom and top, aligned by some method not explicitly detailed. Here, the necessary shifting and expansion or compression is achieved with the reflection line on a log-log plot. Now calculated ratio lines for new frequencies of interest such as 30 and 100 GHz may be measured on Figure 26 and plotted at the left of Figure 29. By coincidence, lines C30/19 and C19/13 are the same. The calculated ratio is 1.95 on scale at top left for the new frequency of interest (30 GHz) at 60mm/hr which reflects to 2 percent of rainy time. This ratio can be multiplied by the attenuation at 19 GHz and 2 percent of rainy time, 15.3 dB from Figure 27, to find the attenuation at 30 GHz (15.3 x 1.95 = 30 dB). In effect this is the way the circles for 30 GHz on Figure 27 were found, but the use of dividers simplified the process. These extrapolated points fit Henry's measured curve about as well as in his paper, recognizing, as he does, that the low percentage measured points are unreliable. Similarly, the extrapolated line for 100 GHz is found from the calculated ratio C100/19 on Figure 29.

It will be found that this extrapolation is about 10 dB lower than that of Hogg and Chu except where the latter's curve is limited by dynamic range at high attenuation. The difference is due to elimination by Lin of the low angle data which came from longer paths through stratiform rain, which is not common throughout the year.

In Figure 28, the dashed line with circles is a plot derived by Goldhirsh (ref. 65) and is discussed above in Section 4.3.2. His estimates apply at a 45° elevation at Wallops Island, Virginia in 1974. The value of P_o is not known so .033 was assumed to provide very close alignment with Henry's data at 19 GHz and the extrapolation from Henry's data at 100 GHz.

A similar exercise has been performed with Wilson's data, taken from Lin (ref. 51). The basic distributions are the two lower plots of Figure 28. The worksheet, Figure 30, has been used to extrapolate 40 and 80 GHz, the frequencies of interest in this study. For comparison to Goldhirsh the extrapolation to 100 GHz is also shown in Figure 28. The line M30/16 is curved because precise ratios were found from the lognormal distributions defined by Lin as in Table 27.

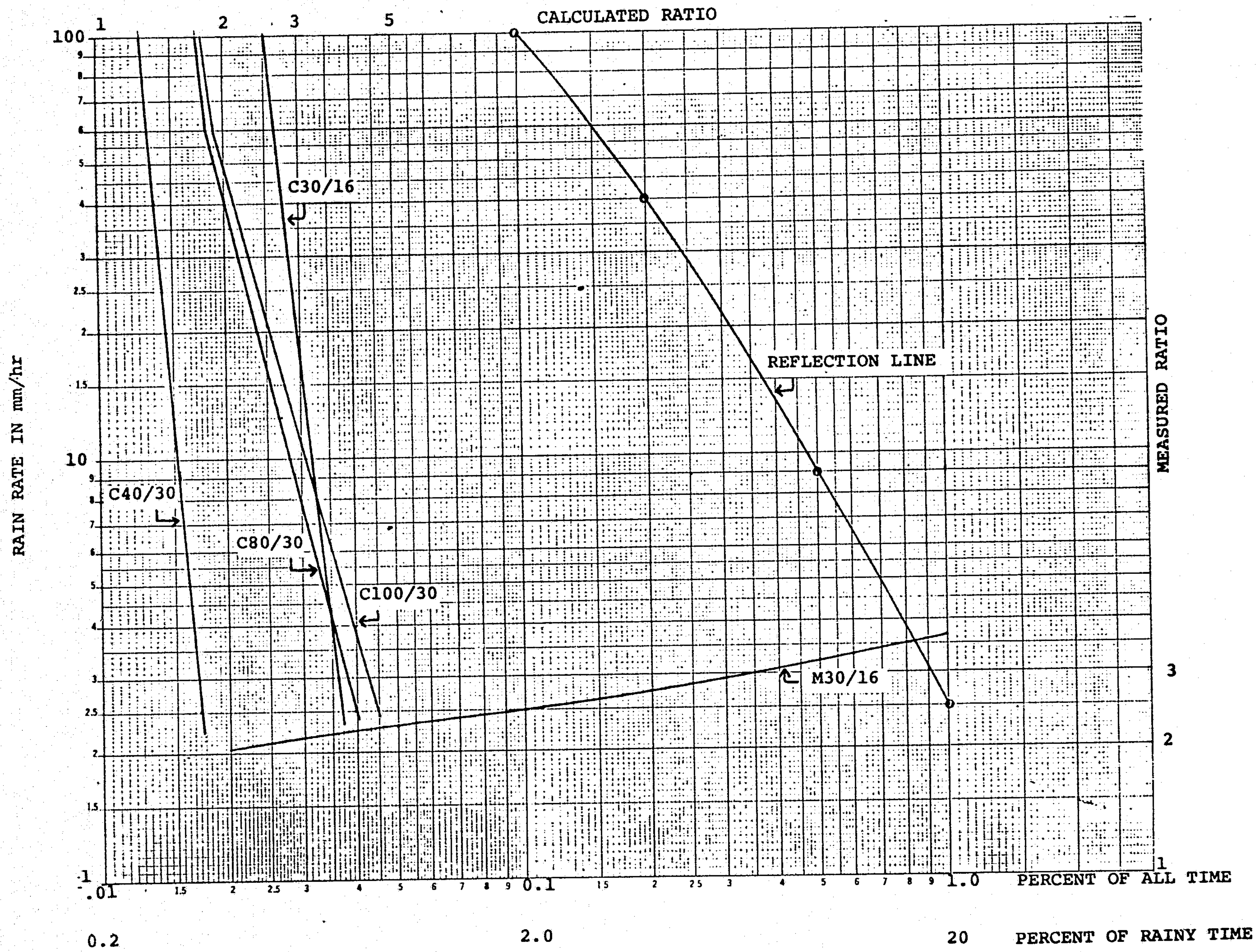

Figure 30. Extrapolation worksheet (Wilson)

Similarly, the calculated ratio lines, C80/30 and C100/30 are bilinear because of the sag at the high ends of the 100 and 80 GHz rainfall characteristics of Figure 26. The resulting curved reflection line demonstrates the capability of this method to include non-linearities in either measured or calculated ratio plots. This provides enhanced generality and precision. The points from Goldhirsh fall in the right area along a line of different slope from that extrapolated from Wilson's measurements. This may be due to geographic and climatic differences.

4.6 Noise Temperatures

Just as the radiometer temperature readings were converted into attenuation (Section 4.3.1), any attenuation can be converted to noise temperature of the atmosphere by using the left and right-hand scales of Figure 28.

4.7 Diversity

4.7.1 Evaluation of Diversity

Diversity reception via the least attenuating of two alternate paths can overcome some of the rain attenuation discussed above. This is because the more intense precipitation arises from smaller cells, of the order of 5 km across. The amount of improvement to be expected from diversity and the measurement of the amount actually obtained is not clear in the literature. Bell Laboratories and the British use "diversity advantage", the time ratio for the same fade level, even though this sometimes involves unreliably small percentages which depend on a single storm. Hodge (ref. 73) and others use "diversity gain" introduced by Altman and Sichak (ref. 74), the improvement in fade level at a given time percentage. This gives no indication of performance at deeper fades. Hodge (ref. 73) introduced the concept of an unattainable "ideal" characteristic corresponding to elimination of all fading, but Hodge (ref. 75) suggests an optimum diversity characteristic which is the square (time-wise) of the single-terminal distribution. Goldhirsh and Robison (ref. 52) find this optimum useful because, like Lin, they are working only with rainy times. Just as in troposcatter, when the fading follows the Raleigh law during periods of true scatter (not ducting, etc), and squaring is permissible in estimating worst-hour performance, so the postulated rain mechanism leading to the attenuation must be operative during all the hours included in the distribution to be squared. This was automatically true in Goldhirsh and Robison's data processing, but not in Hodge's. Similarly, it is assumed to be true in Lin's distributions of rainy hours, which produce straight lines on lognormal plots and whose squares are again closely linear.

With this true optimum distribution available, the performance of a diversity system can be evaluated in either of two ways. First, the parameter of most theoretical interest is the correlation caused by both beams passing through the same attenuating cell. The correlation can be estimated from the resulting distribution by reference to Figure 31, derived

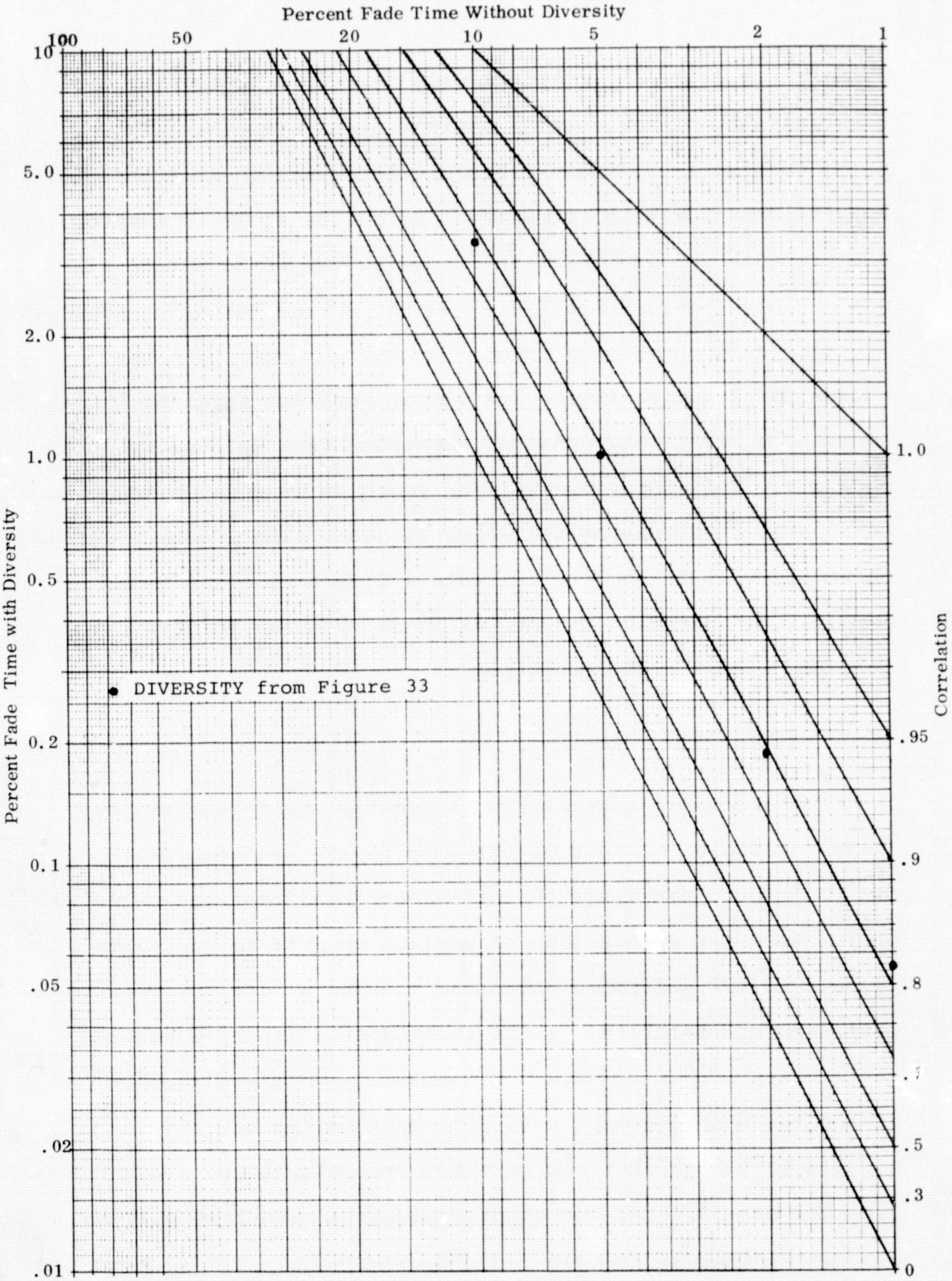

Figure 31. Correlated diversity distributions

from Staras (ref. 76. This family of curves looks like the usual display of attenuation against time, with the line for unity correlation being the basic single-station distribution, and the line for zero correlation being its square. However, the presentation is normalized by using the percent fade time without diversity as abscissa, and the curves for other degrees of correlation have been added. It may be noted that the curves for low correlation are almost parallel straight lines, implying a relatively constant departure from optimum in decibels. This departure will be found in most experiments to be about 1 dB at one of the spacings used. Therefore, a second parameter will be used to evaluate a diversity experiment, namely the separation between stations required to give performance within 1 dB of optimum.

4.7.2 Experiment Results

The available diversity measurements and estimates are listed in Table 29. Most of the entries are self-explanatory. The dB @ Km column lists the distances in kilometers where performance was within 1 dB of optimum in most cases. The Effects column indicates phenomena present during the measurements and are described in the references. In a few cases the results are inconsistent. Funakawa and Otsu distributions at the two stations were very different in the day time. Hodge's 1971 distributions were too irregular to be evaluated like the others. The method of evaluation used here will be demonstrated by an example.

TABLE 29. DIVERSITY MEASUREMENTS AND ESTIMATES

Source	Ref.	F-GHz	Period	Location	Elev.	Time	Equipment	dB @ Km		Remarks	Effects
	a (Radiometers)										
Wilson	42	77	4-7/69	New Jersey	32°	All	3 Rdmtrs	1	11	T = 273	
Wilson & M.	43	78	1-12/70	New Jersey	32	All	3 Rdmtrs	1	30		Hurricane
Hogg & C.	9	44	11/70-11/71	New Jersey	30	All	3 Rdmtrs	1	19	T = 270	Orthogonality
Wulfsberg	44	79	11/70-11/71	Mass.	15	Day	2 Suntkrs	2	11		Season
Funakawa & O.	45	80	2-7/73	Tokyo	15	Day	2 Suntkrs	-			Diurnal
					45	Night	2 Rdmtrs	1	15		
Hall & A.	46	81	6/73-8/74	London	30	All	6 Rdmtrs	1	7	T = 275,7 Km min.	Diurnal
	b (Radar)										
Strickland	82	15	5-12/73	Ottawa	5	Rain	3 G. radar cal. by ATS-5 Rx.			Cell size & Sep.	
Goldhirsh & R.	52	13,18	6-8/73	Va. Coast	45	Rain	3 G. radar	1	16		Opt. Sep.
Goldhirsh	65	13-100	6-8/73	Va. Coast	45	Rain	3 G. radar				Elev.
	c (Satellite)										
Hodge	73,75	15	70	Ohio	38	TSTS	2 ATS-5 Rx	.5	4		
			71	Ohio	38	TSTS	2 ATS-5 Rx	?	8		Orientation
King & H.	83	13,18	7-11/74	Boston		All	4 ATS-6 Rx	1	20		
Ippolito	68	20	7/74-3/75	Wash. D.C.	41	All	4 ATS-6 Rx	1	30		

Wilson's 1969 data are shown on Figure 32, taken from his paper of 1970 (ref. 77). The three single-station attenuation distributions, labeled 1, 2, and 3, are somewhat intertwined so they are fitted by one straight-line lognormal plot shown by the triangles. The lognormal straight line is shown on Figure 33, for which a P_o of 0.06 from Lin was used. The square of this line, the optimum diversity distribution, is also shown. It is derived by using the 10 and 1 percent ordinates at 1 and .01 percent respectively. These points are marked with circles on the figure. This optimum diversity characteristic just derived is plotted on Figure 32 after multiplying percentages of time by $0.06 = P_o$. It may be seen to be about 1 dB left of curve 4 for 11 km (seven miles) spacing. Curve 5 for 3 km (two mile) spacing exhibits correlated fading, so points derived from the percentages of time at the triangles and from Curve 5 at the same abscissae are plotted as the dots on Figure 31. It can be seen that the correlation is approximately 0.8. To summarize the experimental measurements used in Table 29, it appears in general that performance within 1 dB will, on the average, be obtained with a separation of about 16km or 10 miles. Goldhirsh (ref. 65) shows that this estimate is independent of frequency.

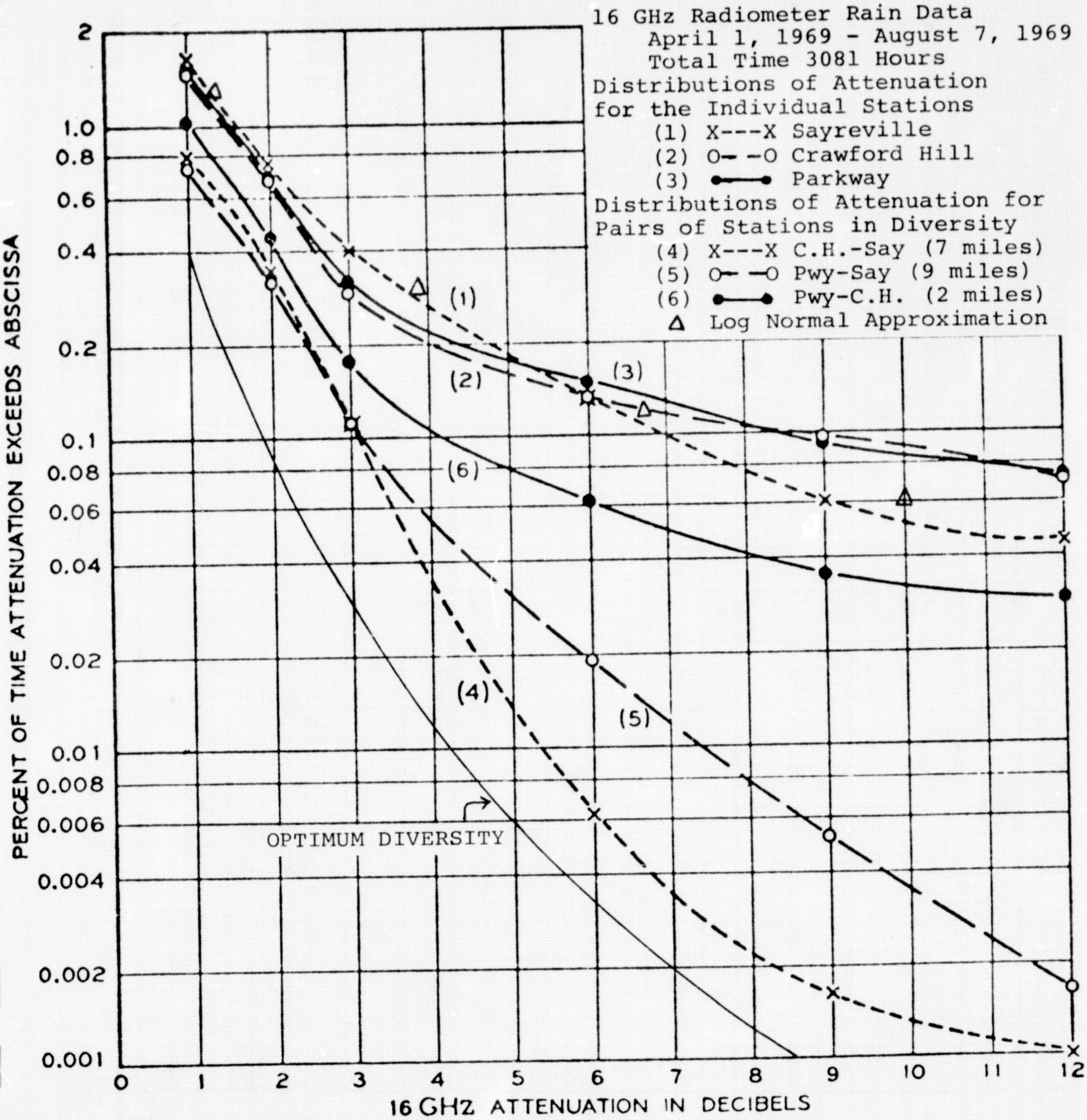

Figure 32. Diversity distributions (ref. 77)

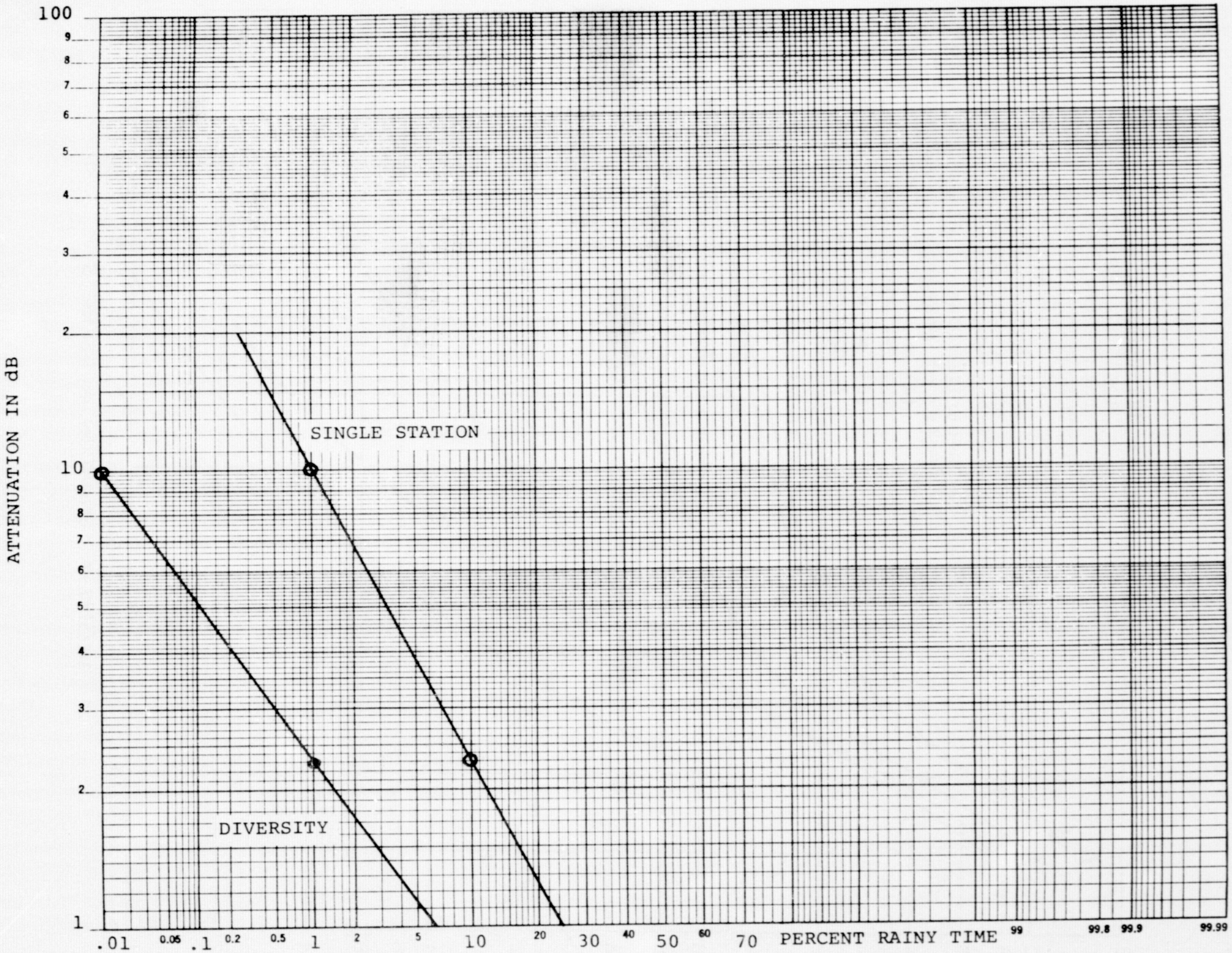

Figure 33. Diversity worksheet

5. Conclusions

Using the attenuation distributions for 40 and 80 GHz of Figure 28, expected diversity distributions can be derived by taking the square root of the rainy time abscissae of interest, reading the attenuations, and degrading by 1 dB, with the following results:

		Attenuation - dB	
	Time%	40 GHz	80 GHz
Single Station	.1	31	41
	1	9.3	20
Diversity	.01	21	33
	.1	11.5	23
	1.0	5.0	13.7

These with and without diversity results are plotted in Figure 34.

As these estimates are based on sun-tracker data taken above about 20° elevation angle at a latitude of about 40°, they may be considered to apply at an effective elevation angle of about 30°. To determine the attitude at any other elevation angle divide the attitude in dB by the csc of 30° and multiply by the csc of the new elevation angle.

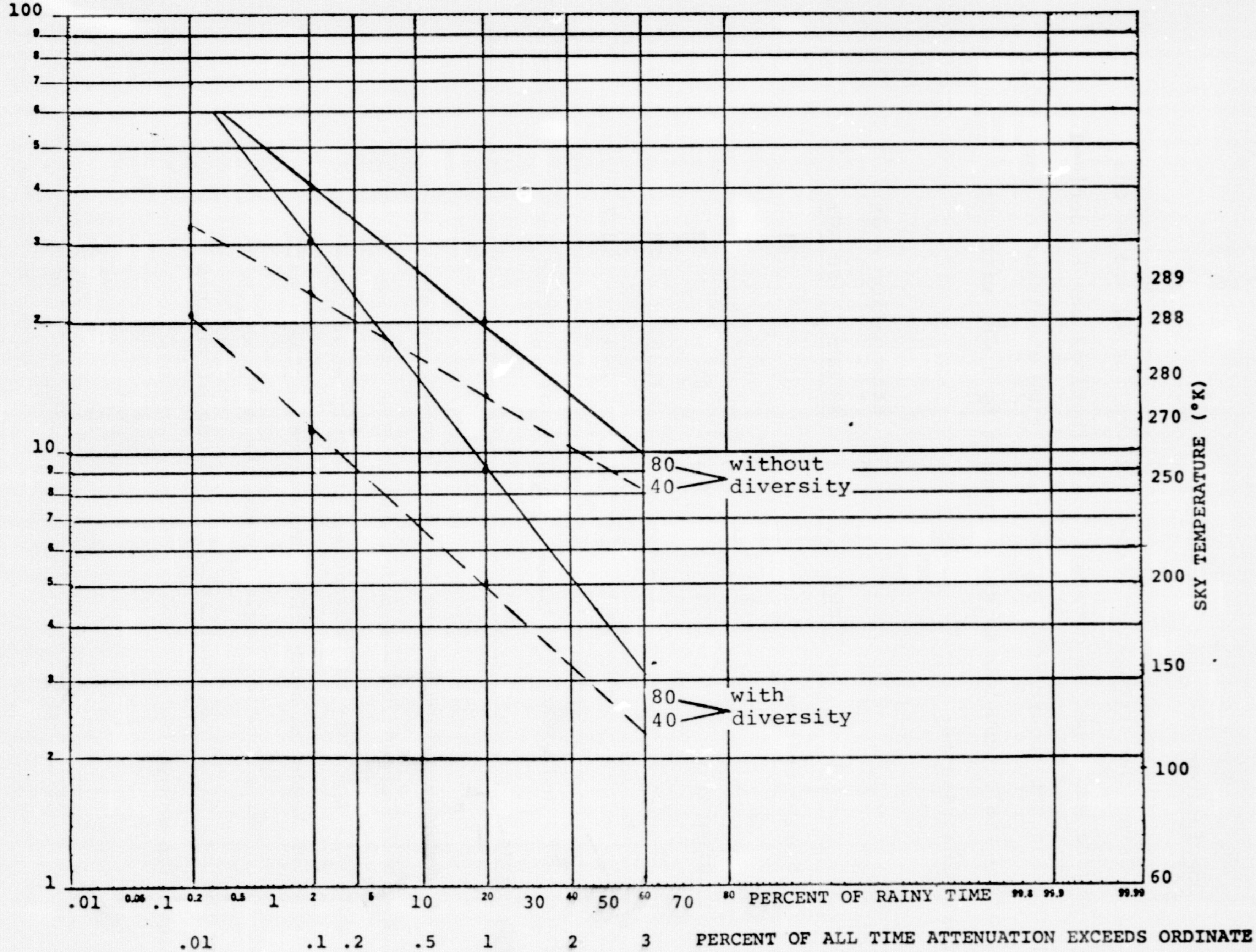

Figure 34. Rain attenuation with and without diversity

SECTION 7

TECHNOLOGY REQUIREMENTS FOR SUPPORT OF CURRENT AND PROJECTED SERVICES

1. Introduction

For this study, a parametric analysis was made to define the system parameters for the down and up links of satellite communication systems operating in the 40 and 80 GHz regions. The analysis encompassed the range of characteristics of those services identified in the Task I Market Survey, and utilized the technology data gathered under Task II of the study.

In performing these parametric analyses, it was necessary to estimate what system parameters, such as satellite and earth station system noise temperatures, antenna gains, and transmitter powers might be technologically feasible for systems in the 1980-2000 year time frame. To make such estimates, information on existing and planned Domestic satellite systems operating in the 6 and 4 GHz region and 14 and 12 GHz region and the technology data described in Section 5 were used.

As might be expected, the rain attenuation statistics, estimated in Task IV and described in the preceding section, played a dominant role in defining system characteristics and limitations. The link analysis using these statistical analyses indicated that, for those services requiring outage times of 0.1 percent or less, earth stations will require high G/T, automatic antenna pointing, automatically variable transmitter powers and diversity sites. Satellite antennas with spot beams also will be required. Examples of such services which might require these system characteristics are standard broadcast television, heavy traffic FDFM telephony, and high digital bit rate ($>$10MBps) service.

Because of the rain attenuation, systems at 40 GHz appear more feasible than at 80 GHz. This suggests that technology developments at 40 GHz might be more advantageous for communication satellites than at 80 GHz.

2. The Down Link

The basic satellite-to-earth (downlink) link equation is:

a) $$(G_s + P_s) + (G_e - T_e) + k - L_{fs} - B - P_l - P_p - L_r - C/N = 0 \qquad (10)$$

where

1) (G_s+P_s) = satellite effective intrinsic radiated power (EIRP)

G_s = satellite antenna gain (dB) - The following earth coverages were used to define the satellite antenna characteristics as shown in Table 30.

P_s = satellite transmitter power (dB) at the antenna

TABLE 30 - SATELLITE ANTENNA CHARACTERISTICS

COVERAGE	BEAMWIDTH (DEGREES)	GAIN (dB)	DIAMETER (METERS) 43 GHz	DIAMETER (METERS) 85 GHz
CONUS	3.5 x 7.0	30	≈.08	≈.04
TIME ZONE	2.5 x 2.5	36	.21	.10
SPOT BEAM	1.0 x 1.0	44	.55	.27
SPOT BEAM	.5 x .5	50	.95	.47

2) $(G_e - T_e)$ = earth station G/T (dB/°K)

G_e = gain of earth station antenna (dB)

T_e = System noise temperature (Kelvin)

T_e is the sum of the sky noise temperature, which at 40 GHz and 80 GHz approaches 290°K as shown in Section 6. The lower limit on T_e is therefore in the order of 300° K (25 dB) even when cooled low noise amplifiers are used. Such a system temperature requires development of cooled low noise amplifiers at 43 GHz and 80 GHz since none exist at present. Present state-of-the-art indicates uncooled amplifiers with a noise temperature of about 400°K at 36-38 GHz can be built. Cooled mixers with a noise temperature of 300°K at 80 GHz have been built.

3) k = Boltzman's constant = -228.6 dB

4) L_{fs} = free space loss between isotropic antennas (dB)

L_{fs} = 92.45 + 20 Log f + 20 log d

f = frequency in GHz

d = distance from earth to sync. satellite

= 36,000 Km

L_{fs} = 217 dB @ 43 GHz

L_{fs} = 223 dB @ 85 GHz

5) B = receiver noise bandwidth (dB Hz)

Noise bandwidths of 2, 10, 44 and 250 MHz are used since they represent the range for the services encountered

6) P_l = polarization loss (dB) due to polarization rotation between the satellite antenna and the earth station antenna. One dB is believed to be a practical, achievable value in most cases.

7) P_p = pointing losses (dB) due to satellite position and earth station pointing. Two dB is believed to be a practical, achievable value when steerable earth station antennas are employed. Where fixed antennas with beamwidths less than 1° are used and/or satellite antenna beam widths of less than 1° are used, pointing losses may be computed from the equation:

$$\Delta G_{dB} = 12 \left(\frac{\Delta\Theta}{\Theta}\right)^2 \qquad (11)$$

where: Θ = antenna 3 dB beamwidth
$\Delta\Theta$ = antenna pointing error off boresite

This equation is plotted in Figure 35 as $\frac{\Delta\Theta}{\Theta}$ vs. gain loss.

8) L_r = loss due to rain (dB). The following rain losses, taken from Section 6 are used in Table 31.

TABLE 31 - RAIN LOSSES

	OUTAGE TIME	ATTENUATION-dB 40 GHz	80 GHz
SINGLE STATION	.1	31	41
	1.0	9.3	20
DIVERSITY	.01	21	33
	.1	11.5	23
	1.0	5	13.7

9) C/N - carrier-to-noise ratio (dB) - a discriminator threshold level of 12 dB is used for the 2, 10 and 44 MHz bandwidth cases and a C/N = 15 dB for the 250 MHz bandwidth (ref. 16).

Equation 10 is plotted in Figures 36 through 43 as satellite EIRP vs. earth station G/T for various noise bandwidths and outage times. Specific service requirements are indicated in each figure where appropriate.

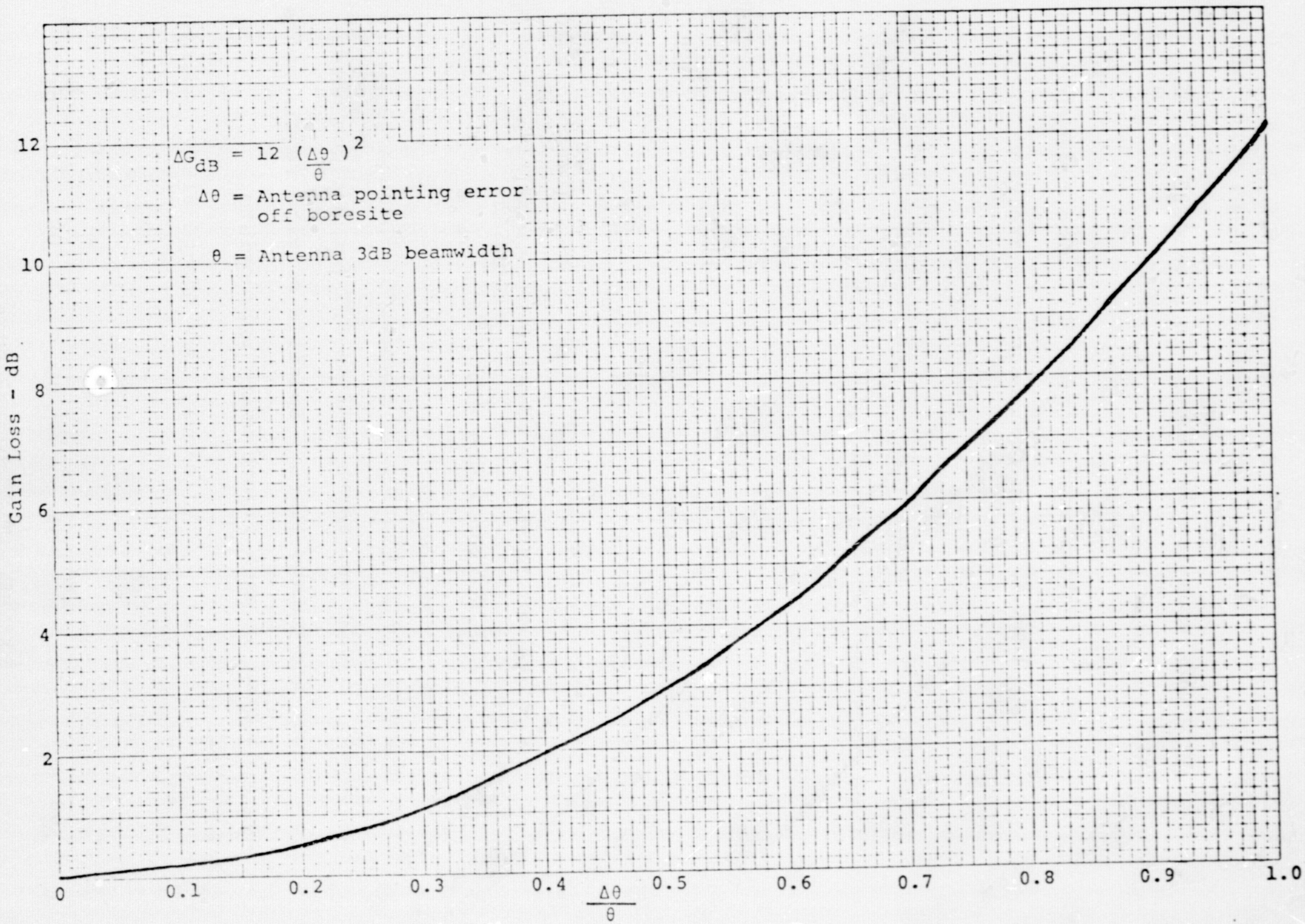

Figure 35. Gain Loss Due to Antenna Pointing Error

3. <u>The Up-Link</u>

1) The uplink system characteristics were determined by first calculating the input noise power, P_i, to the satellite transponder:

$$P_i = k + T + B \text{ (dBW)} \qquad (12)$$

where: k = Boltzman's constant, -228.6 dB

T = satellite system noise temperature assumed to be 1260°K (31 dB) as representative of the state-of-the-art in present satellites.

B = transponder bandwidth (MHz)

P_i = is shown in Figure 44 as the C/N = 0 curve

2) The carrier power, C_i, required at the satellite transponder input for various carrier-to-noise ratios (C_i/N) was determined from the equation:

$$C_i = P_i + C/N \text{ (dBW)} \qquad (13)$$

This equation is plotted in Figure 44 as transponder bandwidth vs. C_i for several C_i/N ratios.

3) The minimum station EIRP (G_e+P_e) was determined from the equation:

$$(G_e+P_e) = C_i - G_s - L_{fs} \text{ (dBW)} \qquad (14)$$

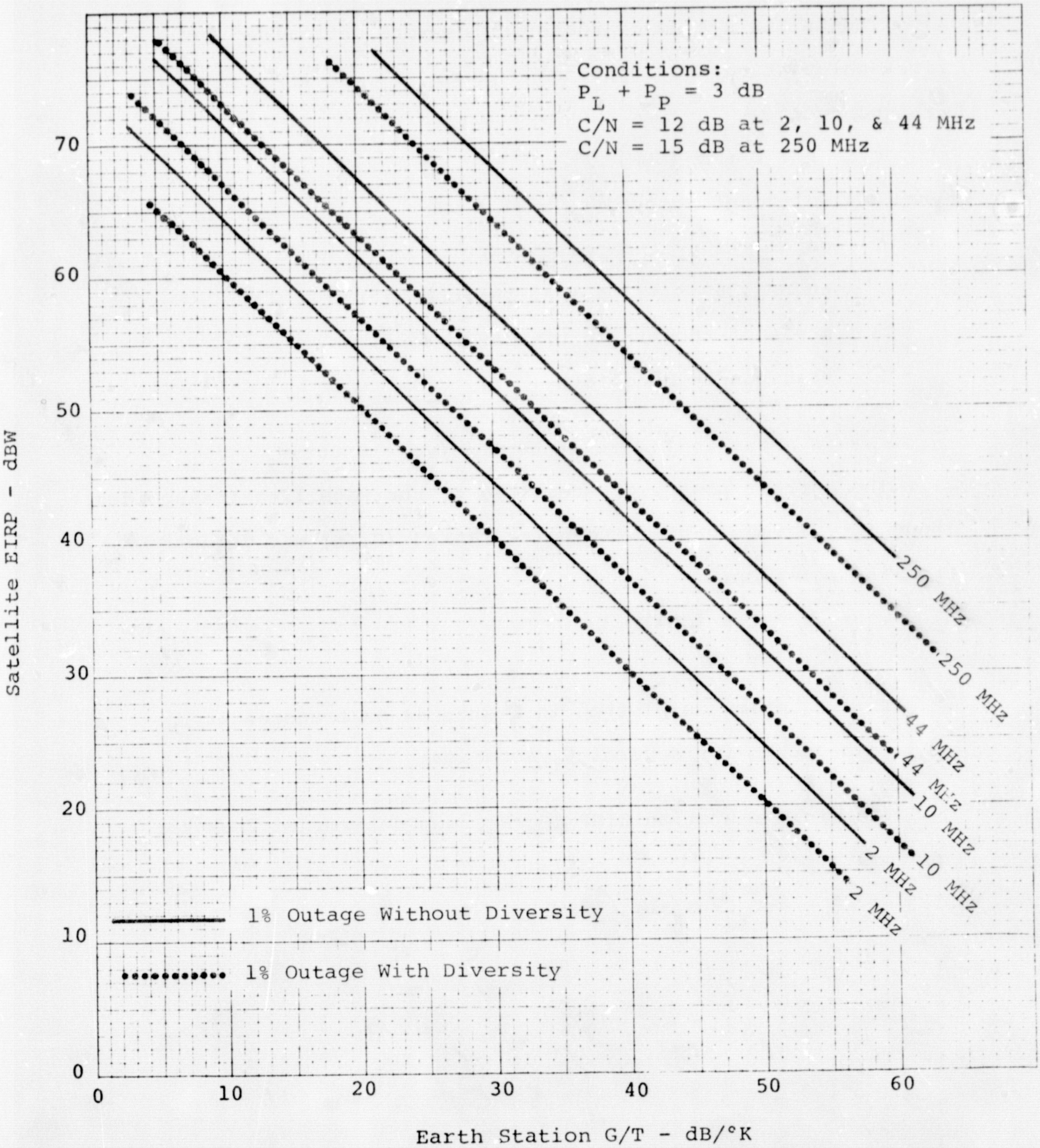

Figure 36. Down Link System Characteristics - 40 GHz
1% Outage

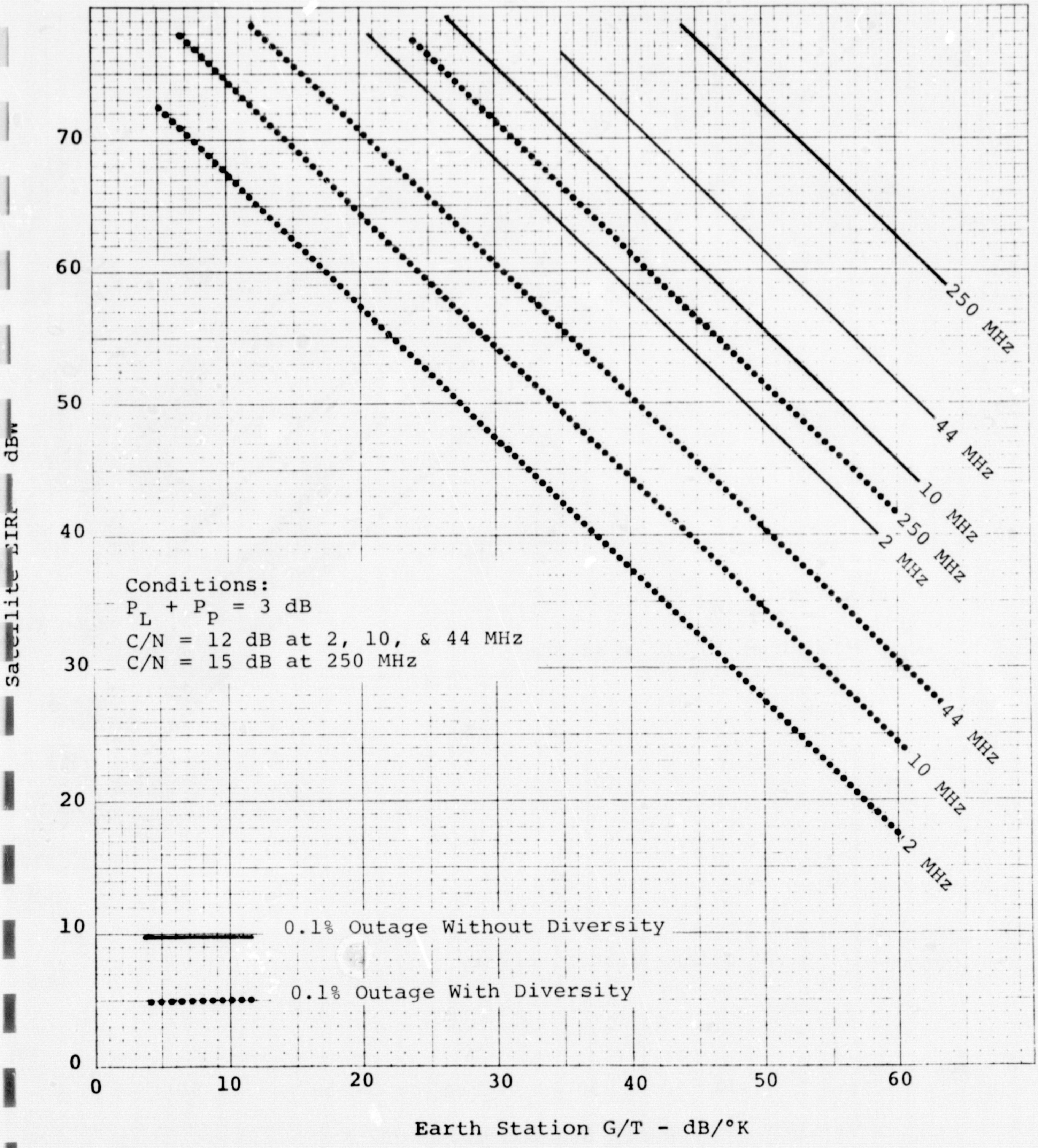

Figure 37. Down Link System Characteristics - 40 GHz
0.1% Outage

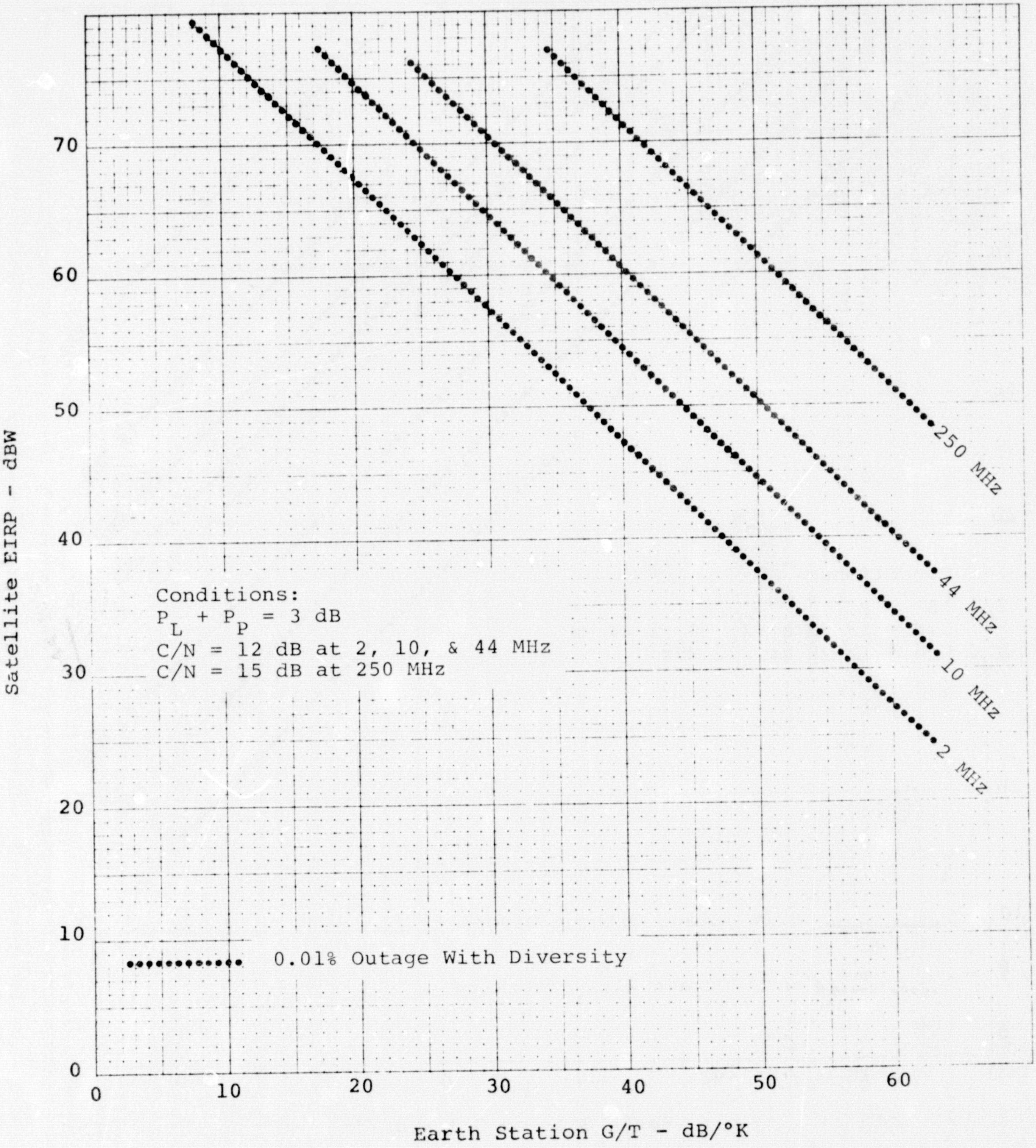

Figure 38. Down Link System Characteristics - 40 GHz 0.01% Outage

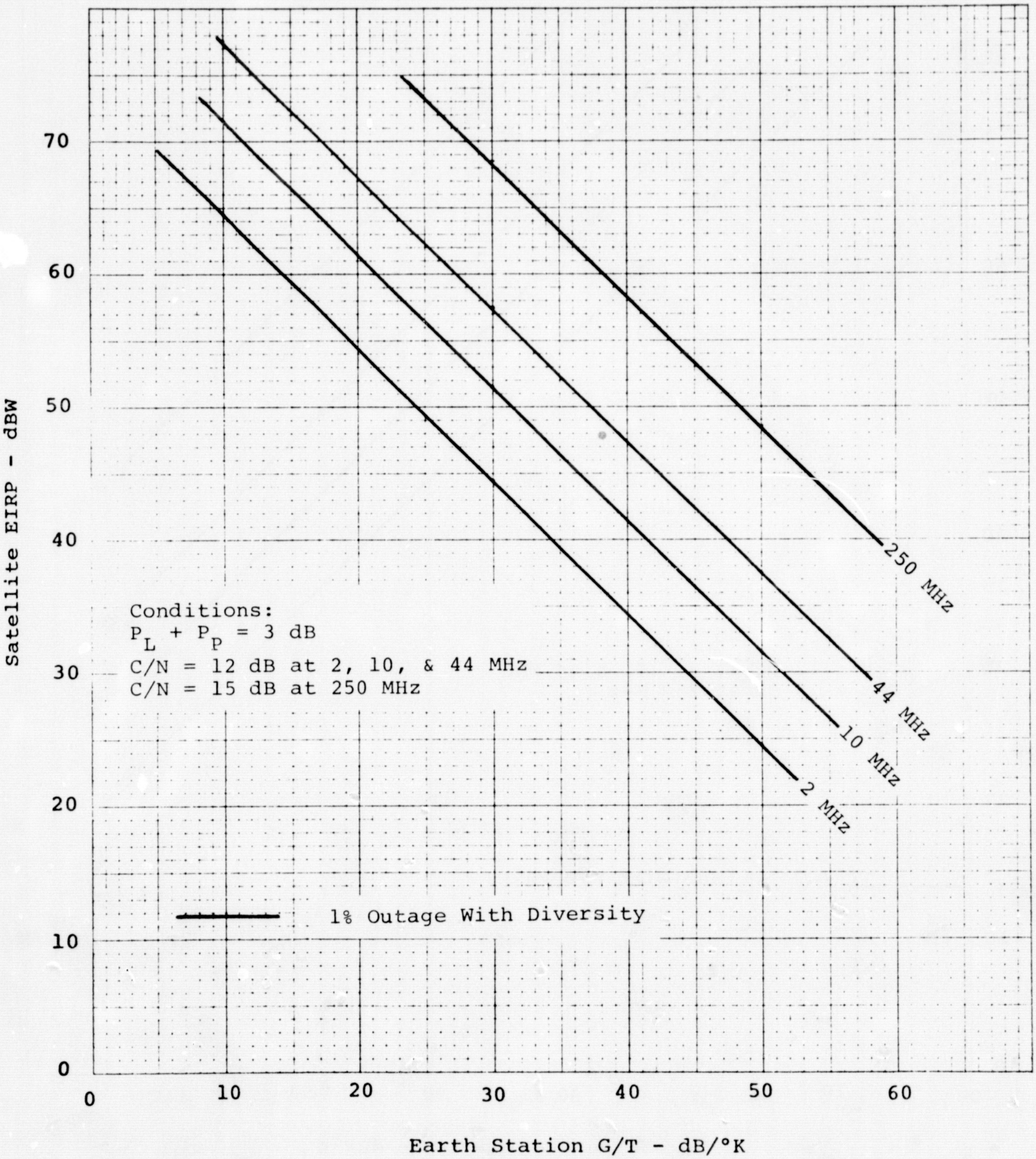

Figure 39. Down Link System Characteristics - 80 GHz
1% Outage with Diversity

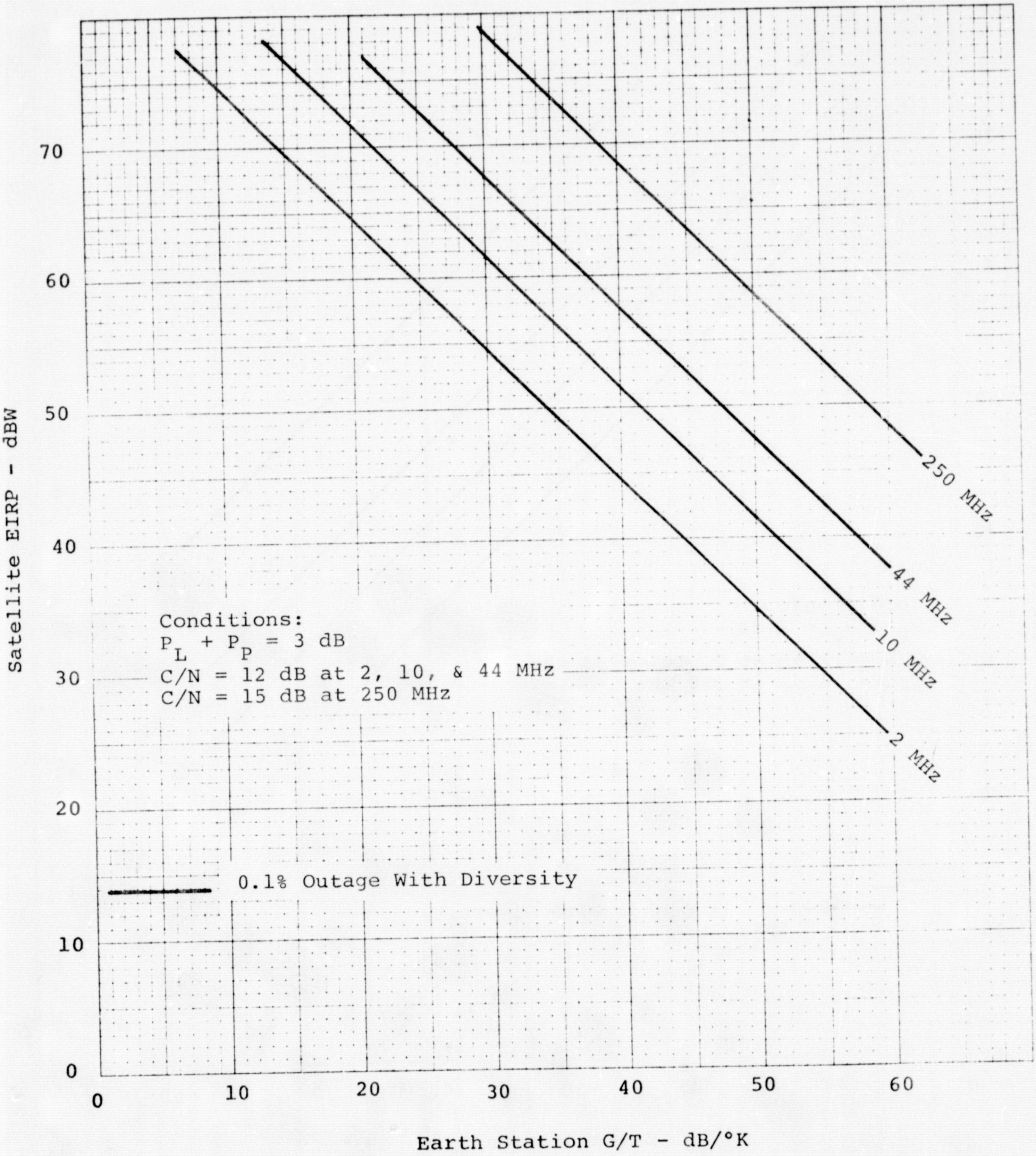

Figure 40. Down Link System Characteristics - 80 GHz
0.1% Outage with Diversity

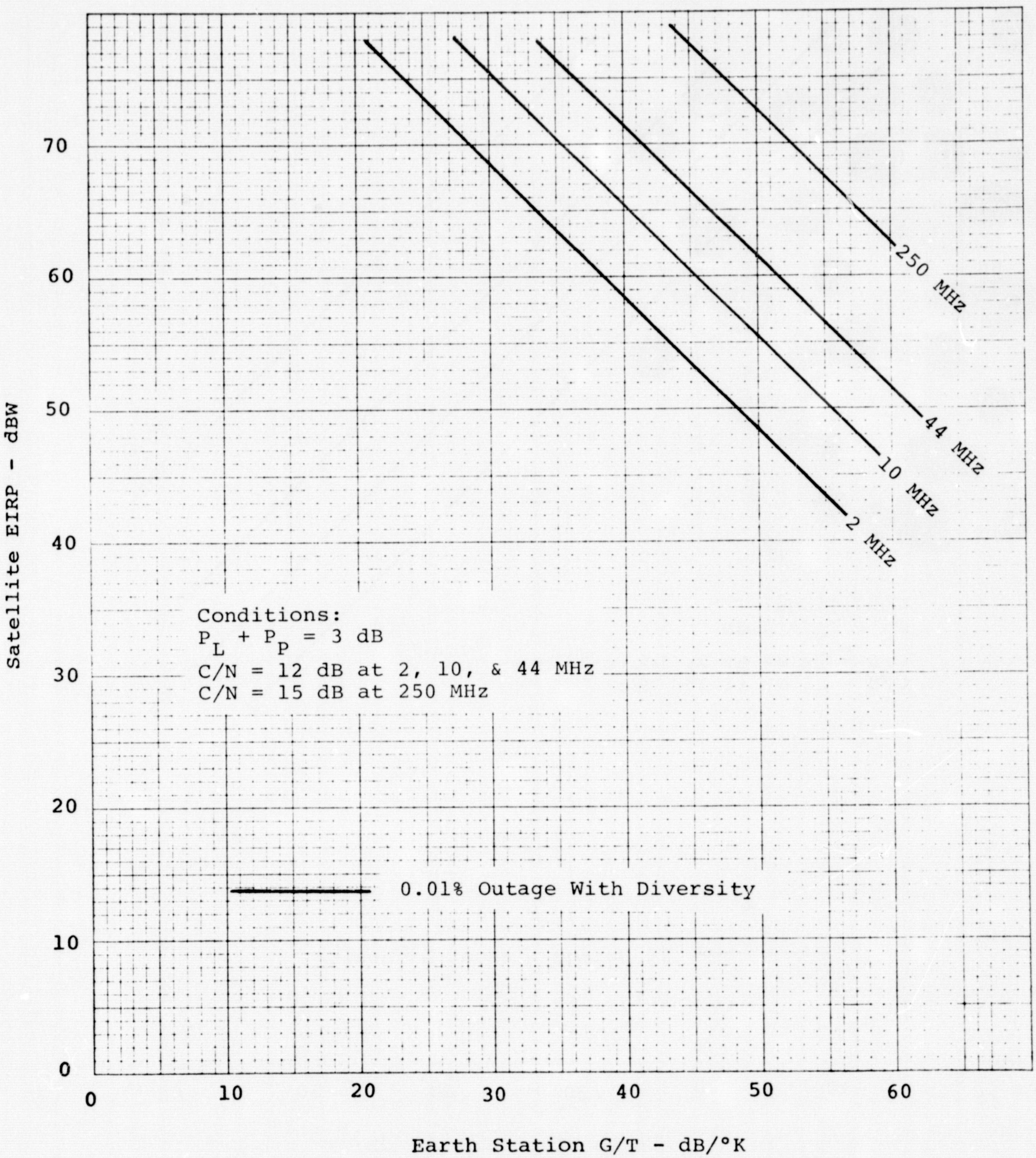

Figure 41. Down Link System Characteristics - 80 GHz
0.01% Outage With Diversity

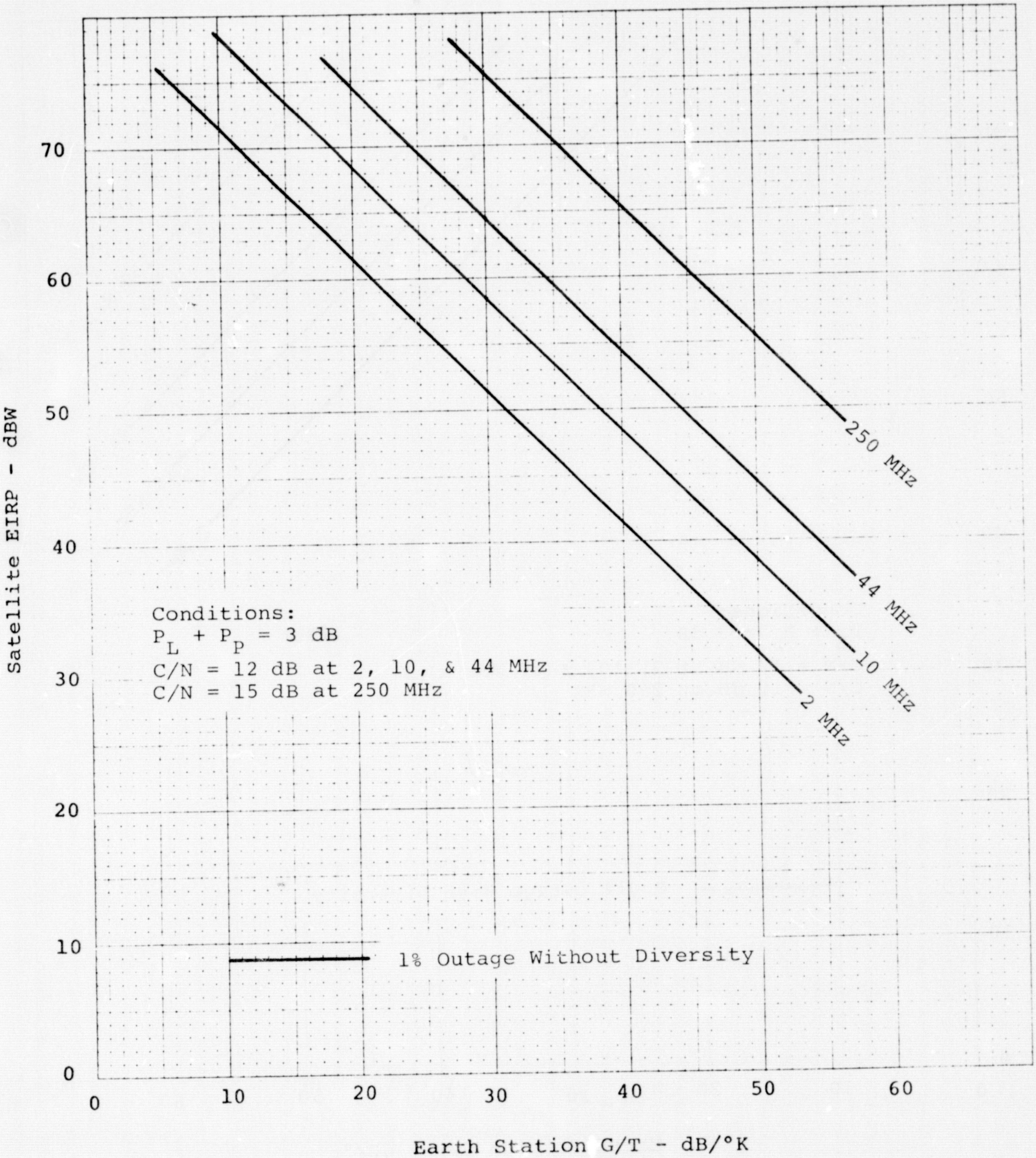

Figure 42. Down Link System Characteristics - 80 GHz
1% Outage Without Diversity

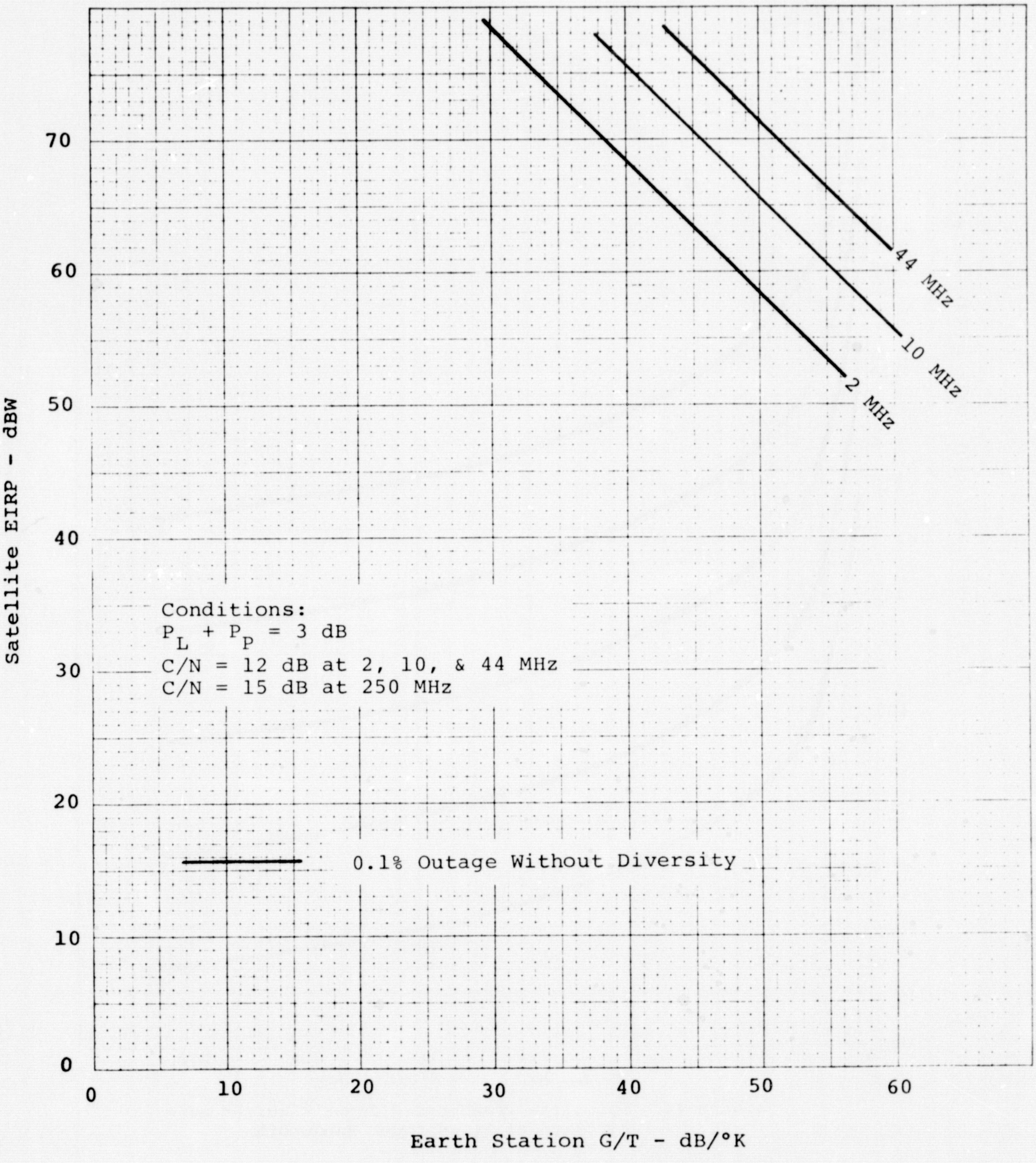

Figure 43. Down Link System Characteristics - 80 GHz
0.1% Outage Without Diversity

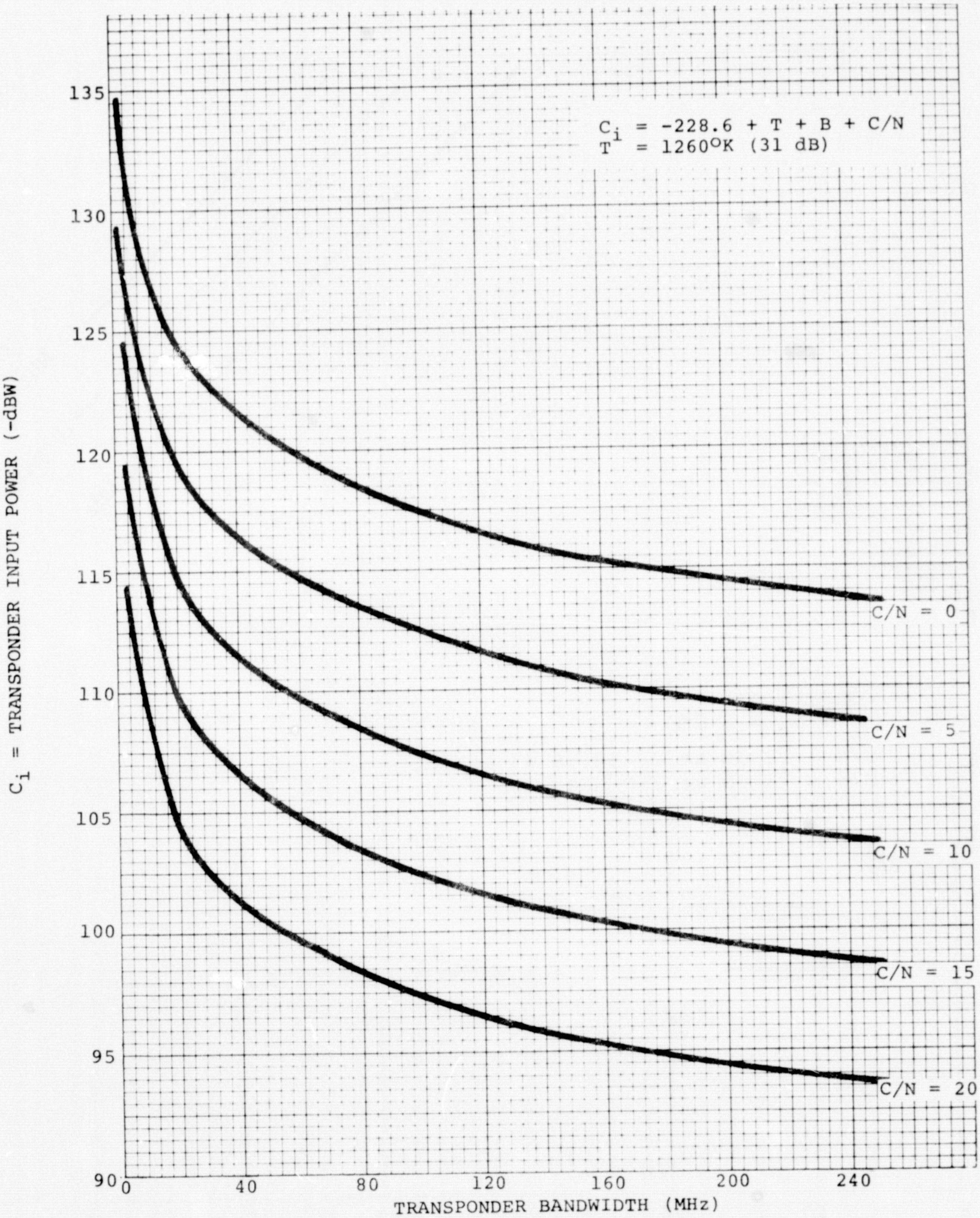

Figure 44. Satellite Transponder Input Required as a Function of Transponder Bandwidth

where (G_e+P_e) = earth station EIRP (dBW)

G_e = antenna gain (dB)

P_e = transmitter power at the antenna (dBW)

L_{fs} = free space loss between isotropic antennas

L_{fs} = -217 dB @ 43 GHz

L_{fs} = -223 dB @ 85 GHz

Equation 14 is plotted in Figures 45 and 46 for satellite antennas with coverage and gains as those used for the downlink.

The range of EIRP's shown in Figures 45 and 46 are unburdened. There are no pointing, polarization or rain losses included. Neither is there a multi-carrier TWT power back-off included.

4) Polarization and pointing losses of the magnitude $(P_1 + P_p)$ = 3 dB , as indicated in the down link, can be expected. Rain losses will occur with the magnitude and percent outage time indicated in Table 31.

5) As in the down link, diversity operation improves the situation. Transmitter power, particularly when multiple stations are illuminating the satellite, will be required to be varied in accordance with the rain attenuation, to prevent one carrier from saturating the others or saturating the satellite transponder. A transmitter power variation of 10 dB has been suggested by Hogg and Chu (ref. 44) and others as being a variation consistant with the down link fading exceeding the fade margin.

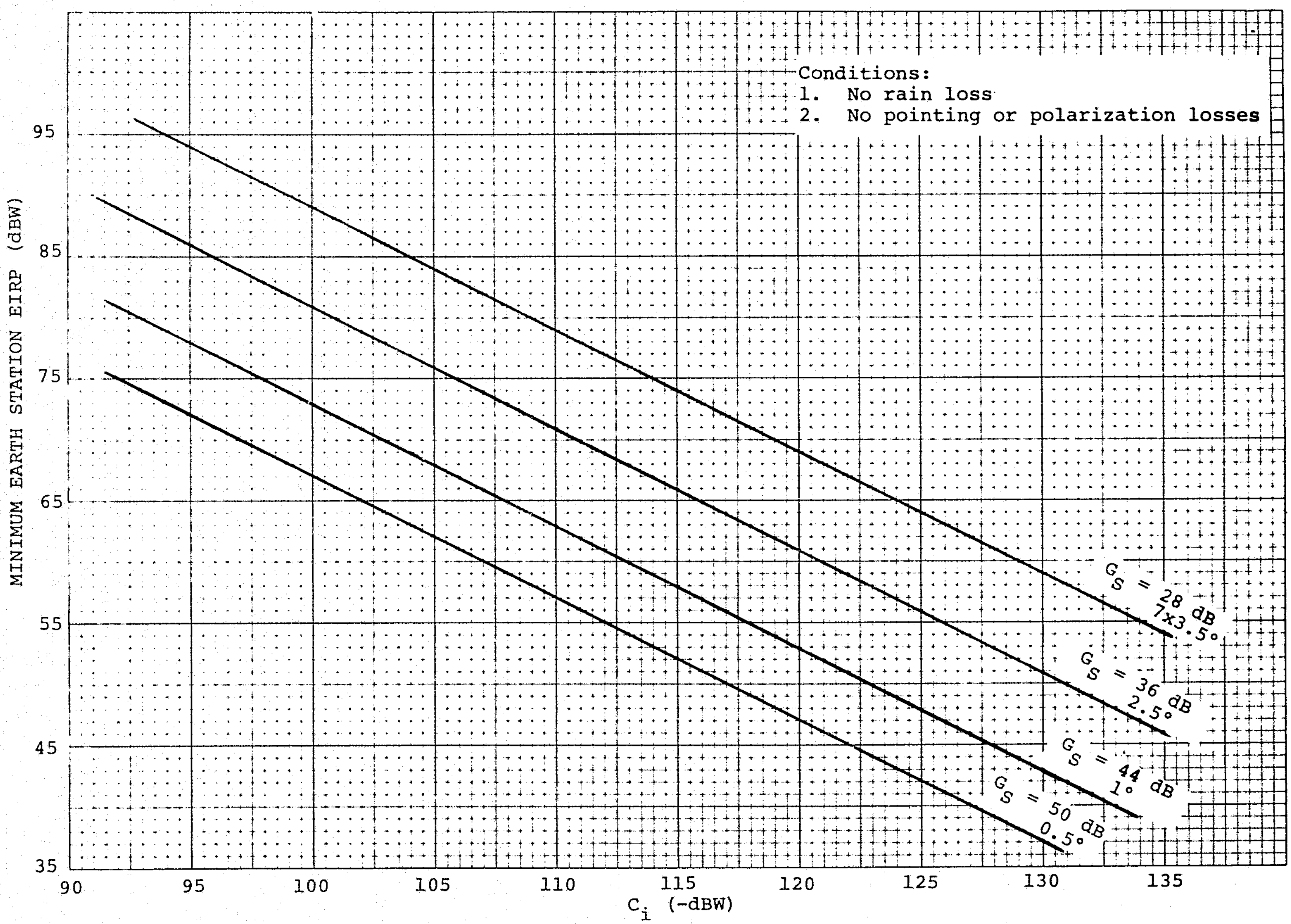

Figure 45. Minimum Earth Station EIRP as a Function of Satellite Transponder Input - 40 GHz

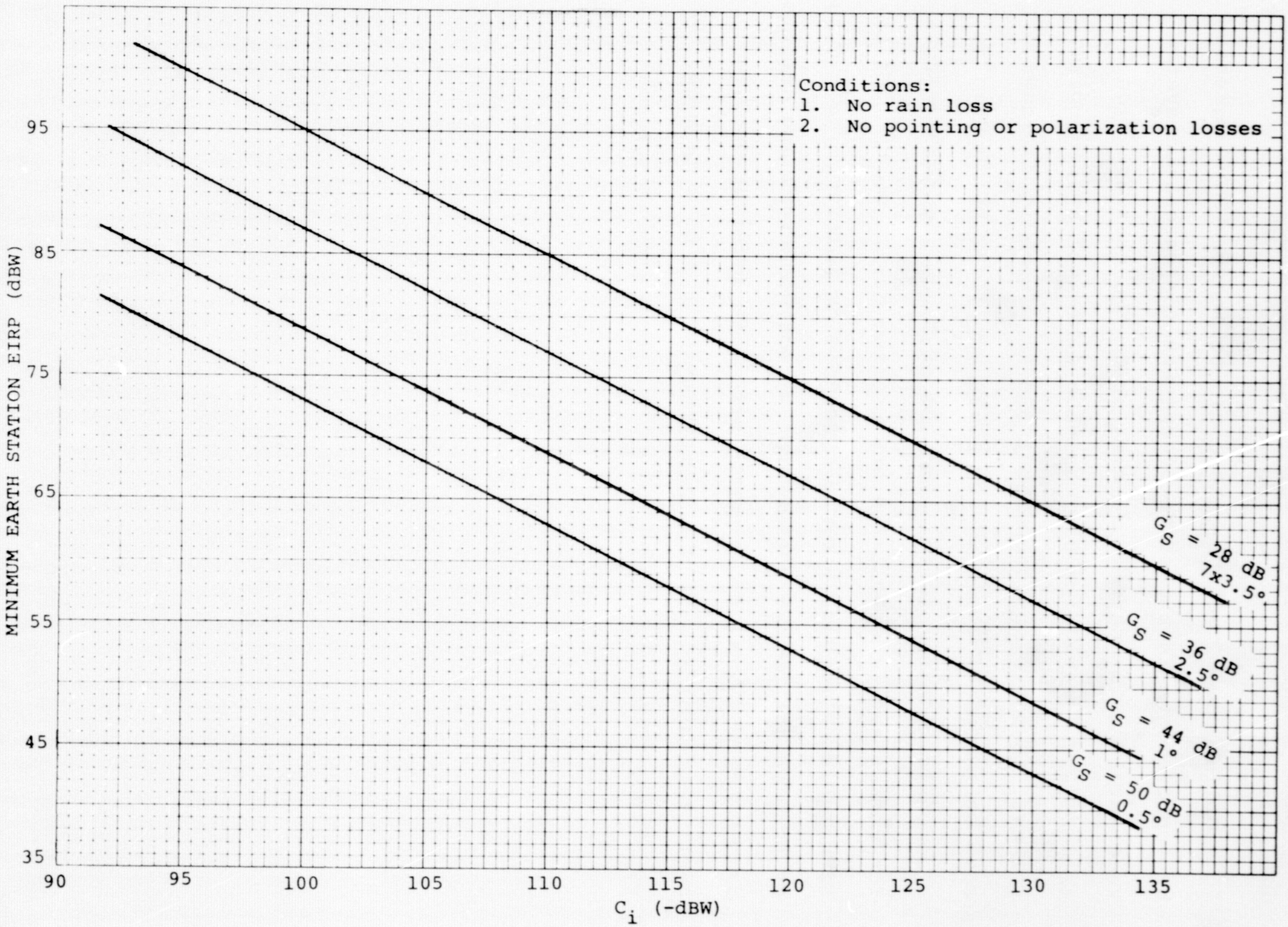

Figure 46. Minimum Earth Station **EIRP as a** Function of Satellite Transponder **Input** - 80 GHz

Uplink power requirements could be measureably decreased by improvements in the state-of-the-art for satellite system temperature. The satellite, similar to the earth station sees a "warm" earth (290°K) so that a minimal system noise temperature would approach about 300°K. There is no known case on record of a cooled low noise amplifier being used in a communication satellite. Because of long life requirements for communication satellites any cooling device must be of the passive radiator or closed cycle cyrogenic or peltier type. A number of passive and active coolers for sensor detectors are described in reference 84, which suggests satellite receiver cooling might be feasible. If so, improvements of 3 to 4 dB might be expected.

SECTION 8

POTENTIAL NEW SERVICES

1. Introduction

The market survey has identified many markets and services that might use satellite communications. Many of these markets and services are either: 1) using satellites at the present time, 2) are in the process of transferring to satellites, or 3) considering the use of satellites for future services. Satellite communications, as with other forms of communications, is evolving. The rate and degree to which it evolves will be dependent upon such factors as cost advantages, availability to certain geographical areas, competition from terrestrial systems, and spectrum/orbit considerations.

The propagation characteristics of 40 and 80 GHz frequencies and their influence on systems at these frequencies has been determined. As a result, possible use of 40 GHz for satellite systems appears to be more feasible than at 80 GHz.

Three potential new services which might be feasible at 40 GHz were identified to be interactive television, high quality audio, and 30 MBS data rate service.

2. Link Calculations for Potential New Services

A link analysis was accomplished for the three potential new services. The following paragraphs describe the objectives for each of these services.

The objectives of the interactive television service are to provide high quality video to four time zones within the CONUS. Two satellite transponders per time zone will permit simultaneous interactive television between two points or more than two points if time sharing is employed. A system link reliability of 99 percent permits reasonably sized satellite and earth station transmitter power as well as an earth station antenna of modest dimensions.

The objectives of the high quality audio service are to provide three stereo pair (6 channels) with a per channel bandwidth of 15 KHz to four time zones within CONUS. The high signal-to-noise required, together with a link reliability requirement of 99.9 percent, can be met on the down link with small fixed earth terminals used in diversity pairs. This, in turn, requires terrestrial communications between the two sites or a terrestrial broadcast transmitter at each site. For transmitting program material to the satellite, four earth station transmitters, one in each time zone, are postulated. To minimize the size of the earth station antenna and to overcome rain losses in the uplink, 0.5° spot beams on the satellite are postulated. The earth station transmitting antenna requires automatic pointing.

The objective of the 30 MBS digital data service is to provide a medium data rate capability to several points. Information to be transmitted could be in the form of electronic mail or financial transaction data such as that required for credit card transactions, Federal Reserve Board transactions, or large amounts of business or administrative data such as is used by industry or government. Such data links should have high reliability and low bit error rates. Link calculation tradeoffs indicate diversity earth stations are required together with satellite spot beams to satisfy the reliability and error rate requirements. The earth station antennas are relatively large but within the state-of-the-antenna-art and require automatic pointing.

It has been postulated that an improved power capability of up to 400 watts could be achieved on a Delta-launched satellite. Consequently, 9 to 20 transponders could be carried on the satellite depending upon whether the link reliability is 99.99 percent or 99.9 percent.

The requirements and down link and up link calculations for each of the three services are given in the following pages.

2.1 Interactive Television Service

2.1.1 Requirements

Video Signal-to-noise ratio (S/N) = 50 dB

Outage time of 1% (99% link reliability)

Time zone coverage

Two transponders per time zone

Frequency - 43 GHz

The carrier-to-noise ratio (C/N) at the earth station is related to the S/N by the equation:

$$C/N = S/N - 20.5 - 20 \log \frac{\Delta f}{f} - 10 \log \frac{BW}{f}$$

where:

Δf = 9.5 MHz deviation

f = 4.2 MHz video base band

BW = 34 MHz receiver bandwidth

therefore,

$$C/N = S/N - 36.7 = 13.3 \text{ dB}$$

2.1.2 Down Link Calculations

The carrier, Ci, required at the earth station receiver with an assumed system noise temperature of 450°K (sky noise and cooled amp) to achieve a C/N of 13 dB is:

$$Ci = -228.6 + T + B + C/N = -228.6 + 26.5 + 75.3 + C/N = -113.5\text{dBW}$$

The total propagation path losses are:

$L_t = L_{fs} + P_L + P_p + L_r$ where

L_{fs} = free space loss: 217dB

$P_L + P_p$ = polarization and point losses = 3dB

L_r = loss due to rain for 1% outage = 9.3dB

Therefore:

L_t = 229.3dB

Assuming a satellite transmitter power of 50W (17dBW), the gain of the earth station antenna is:

$G_e = 229.3 + Ci - G_s - P_s$ where

G_s = satellite antenna gain = 36dB for time zone coverage

P_s = satellite transmitter power = 17dBW

Therefore:

G_e = 62.8dB or a 13.5 ft. diameter antenna.

Since the beamwidth is in the order of 0.1°, automatic pointing will be required.

2.1.3 Up Link Calculations

The input noise power, Pi, of the satellite transponder, assuming a system noise temperature of 1260° K, is:

$P_i = -228.6 + T = B = -228.6 + 31 = 75.3 = -122.3$ dBW

To minimize the noise contribution of the up link, a C/N ten time (10dB) that of the down link is required and the up-link carrier at the satellite transponder is therefore:

$C_i = P_i + C/N_D + 10$

$C_i = -122.3 + 23.3 = -99$ dBW

With the above C_i and a satellite time zone coverage antenna with a gain G_s of 36 dB, the earth station EIRP is:

$$EIRP = L_{fs} + P_L + P_p - G_s + C_i = 217 + 3 - 36 - 99 = 85 \text{ dBW}$$

$$L_{fs} = 217 \text{ dB}$$

$$P_L + P_p = 3 \text{ dB}$$

The transmitter power is:

$$P_e = EIRP - G_e$$

$$P_e = 85 - G_e = 85 - 63.6 = 21.4 \text{ dB} = 138 \text{ watts}$$

To provide power margin for rain loss,

$$P_e = 21.4 + L_r$$

$$P_e = 214 + 9.3 = 30.7 \text{ dBW} = 1175 \text{ watts}$$

2.2 3 Stereo Pair, 15 KHz Base Band

2.2.1 Requirements

3 stereo pair

15 KHz bandwidth - 30 KHz/pair

S/N = 50 dB

0.1% outage

non-steering small earth station antenna

Bandwidth required/channel

$$B.W. = 2B\ (M+1) = 2 \times 15 \times 10^3\ (8.3 + 1) = 280 \text{ KHz}$$

$$B.W. (\text{in dB}) = 10 \log B.W. = 54.5 \text{ dB}$$

$$M = \frac{125 \text{ KHz}}{15 \text{ KHz}} = 8.3 \text{ (standard broadcast)}$$

$$C/N \text{ required/channel} = S/N - I_{fm} - I_{premph} - W$$

$$I_{fm} = 3M^2\ (M+1) = 3(8.3)^2 (8.3+1) = 1922 \text{ or } 32.\ 8 \text{ dB}$$

$I_{premph} = 4$ dB

W = Psophometric weighting factor = 2 dB

C/N = 50 - 32.8 - 4 - 2 = 11.2 dB/channel

B.W./channel = 336 KHz = 672 KHz/stereo pair

2.2.2 Down Link Calculations

Earth Station Receiver Bandwidth = 336 KHz/channel (55.3 dBHz)

Receiver input noise power (NP) = -228.6 + T + B + C/N

T = 150°K + 270° (Sky noise) = 420°K = 26.2 dB

NP = -228.6 + 26.2 + 55.3 + 11.2 = -135.9 dBW/channel

Assuming a diversity earth terminal antenna 2.6 meters in diameter the gain would be 57.4 dB @ 43 GHz with a beamwidth of 0.22°. No antenna steering is required and losses due to satellite motion will be tolerated.

Satellite EIRP/channel = NP - G_e + L_{fs} = -135.9 - 57.4 + 217
= 23.7 dBW/channel

		23.7
6 channels	+	7.8
		31.5 dBW
Sat. TWT backoff from saturation	+	7.0 dB
		38.5 dBW
With a time zone coverage antenna	-	36.0
		2.5 dBW
Pointing and polarization losses	+	6.0 dB
		8.5 dBW
For 0.1% rain loss (diversity)	+	11.5 db
Transmitter power required.		20.0 dBW (100W)

2.2.3 Up Link Calculations

The input noise power, P_i, of the satellite transponder, assuming a system noise temperature of 1260°K, is:

$$P_i = -\ 228.6 + T + B$$

B = 336 KHz/channel (55.3dBHz) or 63.1dBHz for 6 channels

so,

$$P_i = -\ 228.6 + 31 + 55.3 = -142.3 \text{ dBW/channel}$$

Allowing a C/N in the up link ten times that of the down link

$$C_i = P_i + C/N_D + 10$$

$$C_i = -142.3 + 26.2 = -116.1 \text{ dBW}$$

where C_i is the carrier input/channel to the satellite.

For 6 channels, C_i becomes

$$C_i = -116.1 + 7.8 = -108.3 \text{ dBW}$$

The unburdened* earth station transmitter power at the antenna is:

$$P_e = L_{fs} - G_e - G_s + C_i$$

Let G_e be 15 ft. antenna = 63.6dB

L_{fs} = 217 dB

G_s = 50 dB for 0.5° beam width

C_i = -108.3 dBW for 6 channels

*No polarization, pointing, or rain losses.

Accounting for rain loss (L_r) and polarization (P_L) and pointing (P_p) losses, the power required is as follows:

$P_e \quad = -4.9$ dBW

$L_r \quad = 31.0$

$P_L + P_p = \underline{\ 3.0}$

29.1 dBW = 813W

2.3 30 Megabit Data Rate

2.3.1 Requirements

30 Megabit/channel data rate

Bit error rate (BER) of $>10^{-7}$

Outage time 0.1% or less

25' Antenna

2.3.2 Down Link Calculations

The Earth Station Receiver input noise power, P_i, assuming a system noise temperature of 450°K (26.5 dB), is:

$P_i = -228.6 + T + B$

Bandwidth = 30 MBS x 1.2 = 36 MHz = 75.6 dB

$P_i = -228.6 + 26.5 + 75.6 = -126.5$ dBW

For C/N = 20 dB

$C_i = P_i + C/N$

$C_i = -126.5 + 20 = -106.5$ dBW

$L_T = P_L + P_p + L_{fs} + L_r$

$P_L + P_p = 3$ dB

$L_{fs} = 217$ dB

Let L_r = 21 dB for .01% outage
11.5 dB for .10% outage } with diversity

$$L_{T_{.01}} = 3 + 217 + 21 = 241 \text{ dB}$$

$$L_{T_{.1}} = 3 + 217 + 11.5 = 231.5 \text{ dB}$$

For a satellite down link with a .01% outage the satellite and earth station parameters are:

- Down Link

$$\text{SAT EIRP}_{.01} = L_T - G_e + C_i = 241 - 68 - 106.5 = 66.5 \text{ dBW}$$

With a satellite spot beam of 0.5° the satellite antenna gain, G_s, is 50 dB and satellite power is

$$P_s = \text{EIRP} - G_s = 66.5 - 50 = 16.5 \text{ dBW or 45 watts}$$

- Up Link

Satellite Transponder input noise power (NP) = 228.6 + T + B = -228.6 + 31 + 75.6 = - 122 dBW. For a C/N 10 times the down link, the signal input to the transponder is $C/N_D + 10 = 20 + 10 = 30$ dB and the required signal input to the transponder is

$$S_i = NP + 30 = -122 + 30 = -92 \text{ dBW}$$

The earth station EIRP is

$$\text{EIRP}_{.01} = L_{T_{.01}} - G_e + S_i - G_s = 241 - 68 - 92 - 50$$
$$= 31 \text{ dBW or 1260 watts}$$

For a satellite down link with a 0.1% outage the satellite and earth station parameters are:

- Down Link

  Satellite EIRP = $L_{T.1} - G_e + C_i = 231.5 - 68 - 106.5 = 57$ dBW

With a satellite spot beam of 1° the satellite antenna gain is 44 dB and the satellite power is

$P_s = EIRP - G_s = 57 - 44 = 13$ dBW or 20 watts.

- Up Link

  $EIRP = L_{T.1} - G_e + S_i - G_s = 231.5 - 68 - 92 - 44$

  $= 27.5$ dBW or 560 watts.

3. Summary of System Characteristics

Table 32 summarizes the system characteristics of the three potential new services. In addition, the table indicates potential markets, which were discussed previously that fall into the potential new service categories. While the system characteristics are not optimized for any of the markets, each could use the satellite through variations in the earth station design. The driving factors in determining the earth station requirements are the quality (signal-to-noise ratio) and the link outage time requirements. For commercial markets, high signal-to-noise ratios in the order of 50 to 55 dB with link outage times of 0.1 percent or better are provided by present day satellite and terrestrial systems. Whether such markets as health/medical telecommunications and educational telecommunications require such high standards is not clear. In any event, these high standards

TABLE 32

POTENTIAL NEW SERVICES, POTENTIAL MARKETS AND SYSTEM CHARACTERISTICS

Potential New Services	Potential Markets	Type of Service	System Characteristics
Interactive Television Service	• Health/Medical Telecommunications • Educational Telecommunications	Video, Voice, Data	Video S/N = 50 dB 1% outage time Time Zone Coverage Two transponders per time zone Satellite: Transmitter power 17 dBW/time zone Antenna gain 36 dB/time zone Earth Station: 15 ft. antenna Transmitter 1200 watts System noise temp. 450°K
High Quality Audio Service	• Specialized Audio Services • National Public Radio • Teleconferencing	Voice Music	3 Stereo Pair per time zone 15 kHz bandwidth/channel S/N = 50 dB 0.1% outage with diversity earth stations Satellite: Transmitter power 20 dBW/time zone Satellite antenna gain transmit. 36 dB/time zone Satellite antenna gain rec. 50 dB Earth Station: Rec. antenna 2.6 meters fixed Transmit antenna 15' steerable Receiver noise temperature 420°K Transmit power 800W
30 MBs Data Service	• Value Transactions • Industry/Government Internal Communications • Law Enforcement • Electronic Mail	Data	30 megabit data rate per channel BER 10^{-7} Outage time 0.1% or less with diversity earth station 0.5° spot beam 9 to 20 transponders depending on outage time of .01% or 0.1% Satellite power 45 dBW or 20 dBW depending on outage time Satellite antenna beamwidth 0.5° or 1.0° Earth station antenna 25' Earth station noise temp. 450°K Earth station transmit power 31 dBW or 27.5 dBW depending on outage time.

are, at least, desirable. Such standards can be provided at 40 GHz by careful attention to overall system design. Whether these standards would be cost effective is yet to be determined.

On the basis of the foregoing service/market potentials, it is possible to postulate three types of satellite systems and the markets they might serve. These satellite systems could be either point-to-point or broadcasting satellites. These satellite services are given below:

1) Social Services Satellite
   - Health/Medical Telecommunications
   - Public Broadcasting
   - Educational Telecommunications

2) Government Services Satellite
   - Value Transactions
   - Law Enforcement
   - Electronic Mail
   - Government Internal Communications

3) Domestic Satellites
   - Industry Internal Communications
   - Specialized Audio Services
   - Cable Television
   - Commercial Broadcast
   - Public Broadcasting (current)

Before embarking on any of the three satellite service systems for operation at 40 GHz or 80 GHz, further knowledge should be gained through additional study and/or experimentation in the following areas:

- Propagation
- Diversity improvement
- User signal quality and link reliability requirements.

With a thorough knowledge of the above areas, firmer system designs and cost estimates could be made which would provide the framework for system optimization trade-off analyses.

SECTION 9

DEVELOPMENT POTENTIAL, COSTS AND

INSTITUTIONAL CONSIDERATIONS

1. Introduction

In the previous sections, the market, developmental time-frame, and technological feasibility of utilizing 40 and 80 GHz technology were explored. However, an analysis of future millimeter wave space communications systems would be incomplete if competitive risks and institutional factors relating to their development were not discussed.

This section discusses the development potential for 40 and 80 GHz, particularly in light of competition from terrestrial systems since the space telecommunications market growth forecast and, consequently, the developmental time-frame, is dependent on an eventual no-growth situation for over 1000-mile terrestrial systems.

Costs are another important aspect of the developmental potential of 40 and 80 GHz. Costs are presented for 4, 12 and 40 GHz systems and a comparison with current and future terrestrial systems is presented.

Many times, a limiting obstacle in developing new markets and services is the institutional impediments of existing institutions or the lack of an institutional mechanism for implementing the proposed service. Thus, some examples are presented on institutional considerations.

2. 40 and 80 GHz Development Potential

2.1 Space Systems Development Potential

Determining the technology development potential in the 40 and 80 GHz frequency domains required utilization of information developed in previous tasks. Visits were made during Task II to aerospace companies in order to seek their advice and judgements on the state of millimeter wave technology and the feasibility of building flight hardware. This information gathered in Task II was then combined with the systems analysis of Task V.

It should be pointed out that in the approach to the analysis of the technology development potential, the main area of focus was systems and not devices. As a result, the technology developments discussed are those which would be required to develop a technologically viable satellite system and not the technological improvement of those devices necessary to make a system component.

Guided millimeter wave systems at frequencies above 40 GHz are being studied for terrestrial applications and are being pursued more vigorously in Europe and Japan than in the United States, with the notable exception of AT&T's effort. In addition, Japan has an experimental satellite underway which will operate in the 30 and 35 GHz region and is planning a communication satellite system for Japan in the 18 and 30 GHz and 6 and 4 GHz region. As a result, the foreign sector has a larger technological base. Aside from experimental satellite systems developed by the military and operating in the 36-38 GHz region, and short-haul terrestrial experiment in the same frequency region, little hardware development in the 40 and 80 GHz region has been made due to lack of pressing requirements and adequate funding.

During the link analysis conducted in Task V, it was apparent that technical advances in certain areas are required to improve the link margin and diminish the effects of attenuation due to rain. These requirements call for the improvement of satellite and earth station performance.

To provide more satellite EIRP, the development of multibeam antennas at millimeter frequencies with beamwidths in the order of 0.5° to 2.5° is considered to be of paramount importance. With satellite spot beams in the order of 0.5°, satellite motion, particularly in the north-south, or east-west, station keeping could reduce the effective gain of the antenna. For example, if the satellite were permitted to drift ±0.2° in a north-south direction, the satellite antenna gain with a 0.5° beamwidth would decrease 2 dB at the extremes of the drift. This suggests that for such small beamwidths, antenna steering would be desirable if the maximum gain of the antenna is to be realized at all times. In most instances, satellite transmitter powers of up to 200 watts and spot beams are required to achieve 0.1 percent or better link outage (due to rain) even with diversity earth stations.

Development of satellite receivers at 40 and 80 GHz with noise figures the same or less than those (6.5 to 8.0 dB) currently employed in 6 and 14 GHz satellite receivers will permit reduction in earth station transmitter power. This will help overcome the disadvantages of rain attenuation in the uplink.

Another way of increasing satellite EIRP is to increase the satellite transmitter power. However, present and projected state-of-the-art appears to limit current developments to 200 watts at 40 and 80 GHz. For this reason, no greater RF carrier powers have been assumed in the earlier analyses.

Along with achieving more satellite EIRP, more D.C. power must be made available to achieve the maximum channel (bandwidth) capability on the satellite and this will require utilization of more efficient and larger solar arrays.

It does not appear practical to overcome the rain attenuation through satellite improvements alone. Therefore, additional link margins must be provided in the earth stations. Maximum earth station G/T values are required. The sky temperature at 40 and 80 GHz limits the achievable system noise temperature to about 300°K during rain. This fact, coupled with what appears to be maximum achievable antenna gains on the order of 75 dB, suggests that the maximum G/T achievable is about 50 dB/°K.

To achieve outage times of 0.1 percent or better, the use of diversity earth stations appears mandatory, in most cases, for both the up and down links. A diversity earth station requires duplicate antennas with transmitters and receivers as well as a terrestrial link tying the sites together to transfer the traffic in accordance with the rain attenuation prevailing at the sites. It also will be necessary to monitor the rain attenuation and process the information in order to control traffic flow.

It probably will be necessary to program the earth station transmitter power in accordance with the rain attenuation. A transmitter power variation of 10 dB, as suggested previously, coupled with worst-case up-link carrier-to-noise requirements indicates transmitter powers up to at least 2 kW at 40 GHz and higher at 80 GHz will be required. Additional transmitter power back-off may also be required to reduce intermodulation when employing multiple carriers such as in single carrier per channel or high capacity telephony operation. Present back-off levels are in the order of 5 dB to 7dB for TWT transmitters. This would increase transmitter power requirements at 40 GHz and 80 GHz to the order of 6 to 10 kW.

2.2 Terrestrial Systems Development Potential

Development of 40 and 80 GHz technology for commercial satellite systems may be preceded by guided millimeter wave terrestrial applications. If terrestrial systems continue to be built, then the market analysis and, consequently, the time-frame for the need for space utilization of frequencies over 20 GHz, must be reevaluated. According to AT&T, millimeter waveguide affords 230,000 to 460,000 simultaneous voice circuits per link. This is equivalent to 12 to 24 satellites, each with 24 transponders capable of 800 simplex circuits per transponder. AT&T currently has an experimental millimeter waveguide installation in New Jersey carrying simulated traffic over a 8.7-mile route. It seems reasonable to expect continued development of terrestrial links as long as costs per circuit mile continue to drop. AT&T believes that new opportunities still exist for lower unit cost and are particularly investigating guided millimeter wave and optical technologies. In the January 1975 edition of Telecommunications (ref. 85), AT&T states,

> "If the trend in long distance calling continues, our industry will have to double the capacity of its interstate network by the mid '80's. Before that occurs we expect traffic volumes on some major routes that will justify installation of transmission facilities of the capacity that millimeter waveguide affords..." and "Later use of fiber optics in long-haul circuits is distinctly possible where their broadband capacity would make them especially suitable for Picturephone service."

In the market analysis, the major market, Common Trunks, are controlled by AT&T's Long Line Division, as is a significant part of the other markets. Consequently, if terrestrial application of millimeter waves, and later optical systems, realize AT&T's expected cost per circuit mile reduction, then the time-frame for requiring all space links above 12 and 14 GHz could be further downstream.

Projected costs per circuit mile made by AT&T for new terrestrial systems such as the L-5 cable, guided wave and optical fiber systems indicate possible cost advantages over satellite systems, particularly those in the millimeter wave regions. Such projections may be optimistic, but even if they are not there is still a role for satellites, even for under 1000-mile routes such as in Alaska and sparsely populated rural areas or in applications where timeliness and other factors dominate economic considerations.

It is also probable the costs of millimeter wave systems will decline with expanded usage and be competitive with the lower frequency satellite and terrestrial systems. In any event, the effect of new terrestrial systems can only delay the chronology of millimeter wave satellite systems.

An example of other considerations dominating economic considerations in the development process concerns AT&T's COMSTAR system which is being developed for balancing the long haul switching network; for diversity and redundancy to terrestrial systems; and to keep AT&T's "foot-in-the-door" for possible future exploitation of satellite communications. However, unless cost reductions are achieved in satellite systems, AT&T's COMSTAR program will remain at its current projected size.

3. Cost Analysis

System costs associated with a particular service at various frequency allocations were analyzed as part of Task V of the Project. Because it was expected that costs at 40 GHz would have to be inferred from costs at lower frequencies, a service that could be utilized at all allocations was chosen to facilitate a projection to 40 GHz. The chosen common denominator was based on the current DOMSAT services; that is, voice, data and TV using 40 MHz transponders. As it turned out, however, there was no need to develop an extrapolation methodology per se, since industry estimates were secured for frequencies near 40 GHz.

The estimates presented in the following analysis were obtained from material made available by PBS, SBS, AT&T, TRW, GE, RCA, Aeronutronics-Ford, and some government sources. In the interest of confidentiality, the cost estimates have been aggregated and consequently not attributable to any one source. Also, it should be noted that the higher frequency costs are for small quantity development and production.

Table 33 presents the major cost items at various frequency allocations as determined from our analysis. As is apparent from Table 33, the cost for receive/transmit ground stations, and the cost per transponder launched, increase with increasing downlink frequency. This situation supports the assumptions

TABLE 33

MAJOR SYSTEM COST COMPONENTS AT VARIOUS FREQUENCIES

Cost Item		Cost ($M)	
	4/6 GHz (Present Systems)	12/14 GHz (Three Satellites)	40 GHz (Three Satellites)
Launch Vehicle (Delta 3914)	15	15	15
Satellite Bus	10	12	16
Transponders	5.28	5.36	20-24
- RF Power-watts	120	160	400
- No. of Trans.	24	8	8
- Cost per/ transponder	.22	.68	2.5-3.0
Total Cost for One Satellite	30.28	32.36	51-55
Cost Per Trans. Launched	1.26	4.04	6.38-6.88
Ground Station Receive/Trans.	.270*	.475	1.77**
Antenna Size	33 ft.	24 ft.	15 ft.

*Plus $80K for microwave ground link if co-location is not possible.
**Cost would be approximately twice this amount for diversity operation.

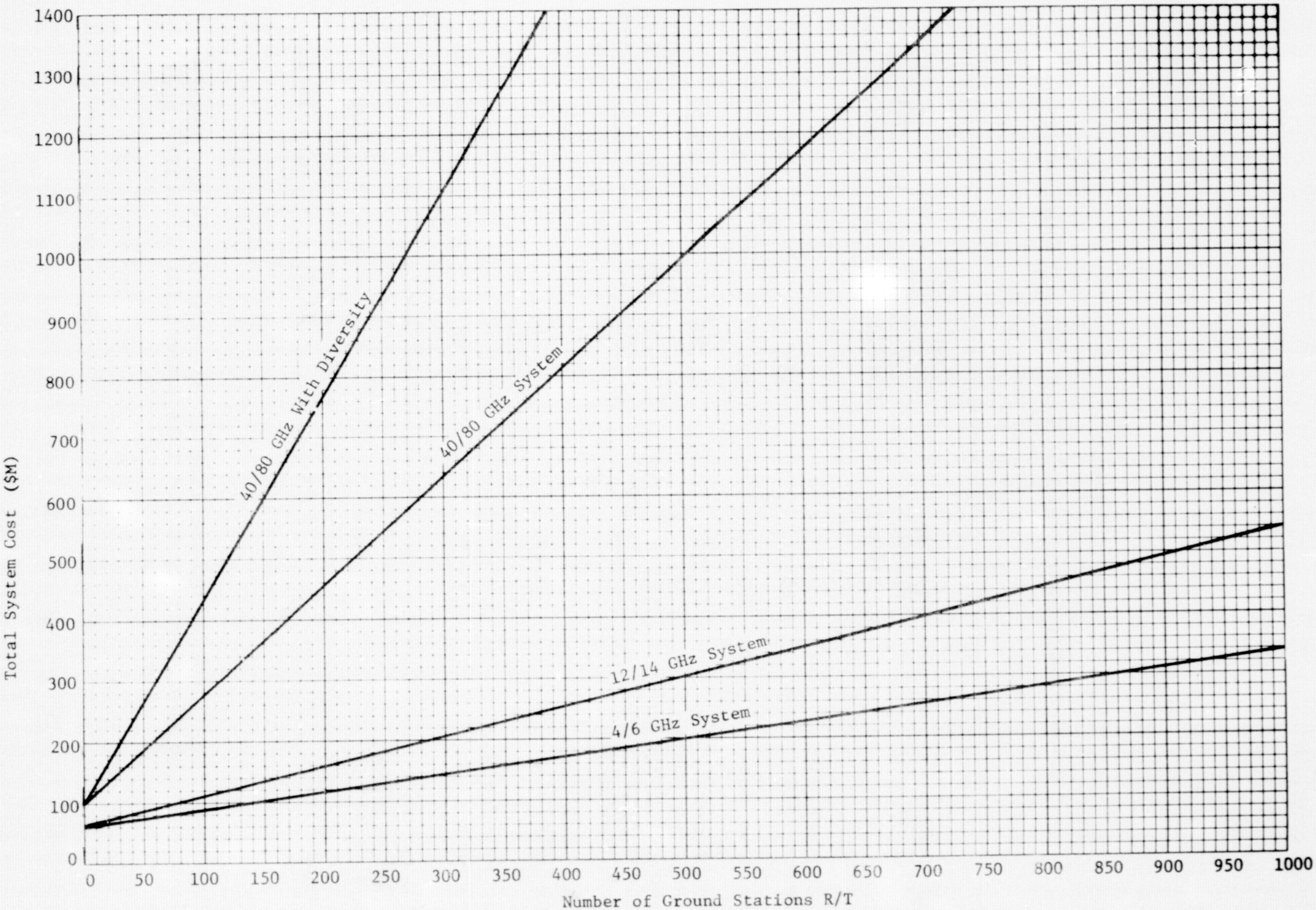

Figure 47. Total system cost vs. number of ground stations

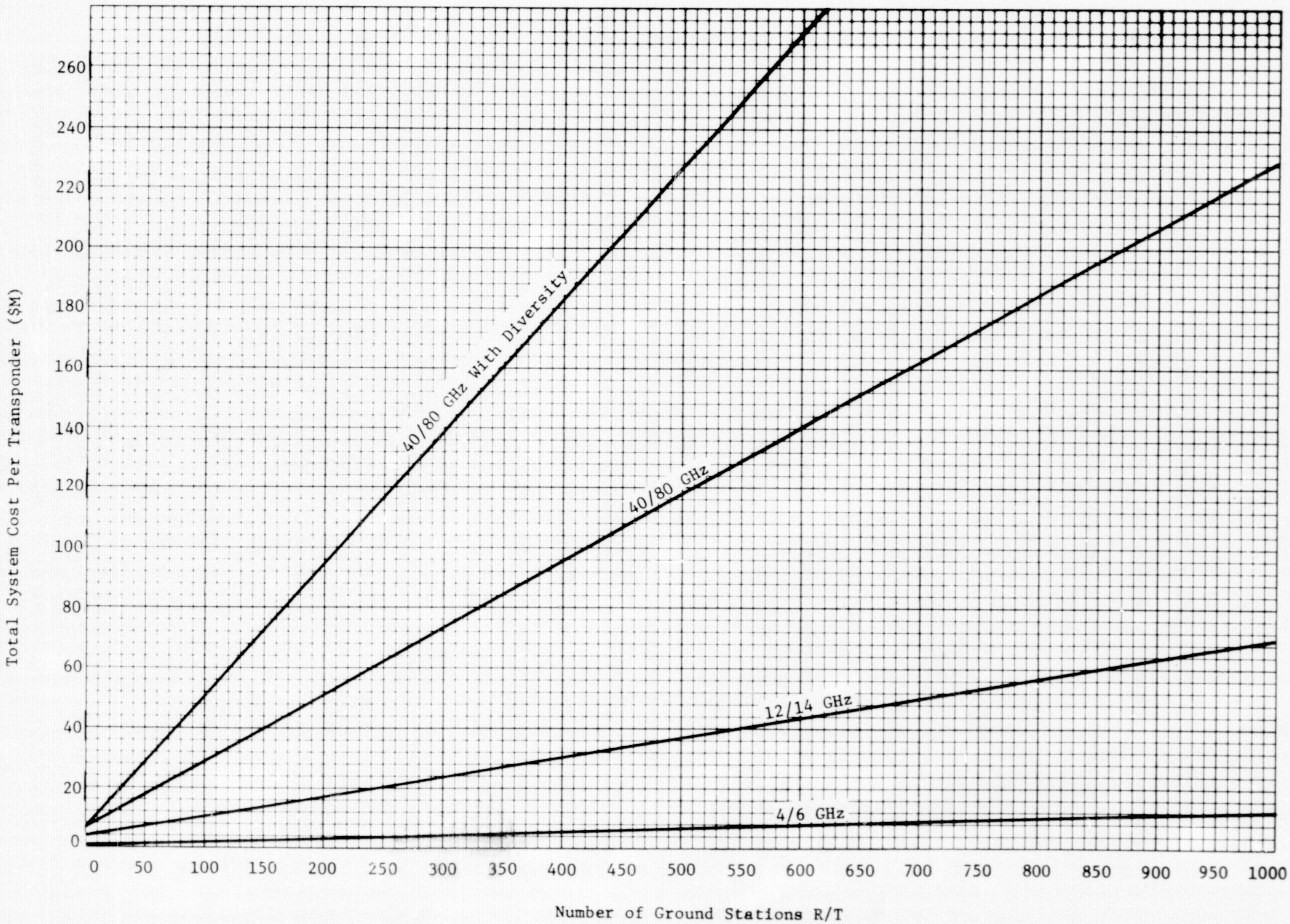

Figure 48. Total system cost per transponder vs. number of ground stations

made in the discussion on orbit/spectrum utilization that lower frequencies would be utilized before the higher frequencies for economic, if not technical, reasons.

In order to put into further perspective the cost relationships between various frequencies, Figures 47 and 48 were developed to show the divergent nature of total system costs (Figure 47) and total system cost per transponder launched (Figure 48) as the number of receive/transmit stations increase. These graphs utilize the cost estimates of Table 33 and assume two satellites are in orbit - one operational and one for back-up/peak loadings.

The divergence of these cost curves does not diminish the viability of higher frequencies, but only points out the desirability of the lower frequencies. This supports the thesis that a service must be forced into higher frequencies due to overcrowding at the lower frequencies.

4. Institutional Considerations in Market Development

The most limiting obstacle in developing new markets and services is frequently the institutional impediments of existing institutions or the lack of an institutional mechanism for implementing a proposed service. It is not the purpose of this discussion to indicate whether the various market projections of previous sections will or will not occur; but rather to point out some aspects of implementation that must be considered when determining when the need for new technology will occur. The following paragraphs discuss examples of some typical institutional situations and considerations.

4.1 The Public Service Satellite Consortium

The Public Service Satellite Consortium (PSSC) is an example of users coming together and forming an institution, where none previously existed, to provide a vehicle to assist in integrating and implementing the communications needs of a diverse community of users.

The Public Service Satellite Consortium was incorporated in March of 1973 and consists of educators, health care specialists and communications experts excited by the results of an array of health and education experiments on NASA's ATS-6 satellite. The goal of the Consortium is to utilize the technology demonstrated by the ATS-6 experiments as the basis for a permanent, operational system. The Consortium is attempting to identify and aggregate potential users, to arrange communications services on a cost sharing basis, to assist in coordinating telecommunications planning by public and private institutions, and to develop practices encouraging the use of new telecommunications services.

The members of the Public Service Satellite Consortium come from a wide spectrum of health, education, and public broadcasting interests. Some, like the State of Alaska and the Federation of Rocky Mountain States were experimenters on ATS-6. Others, like the Indiana Higher Education Telecommunications System, have extensive experience in operating terrestrial systems. Some are, themselves, consortia: the Joint Council on Educational Telecommunications, the Southern Educational Communications Association and the Western Interstate Commission on Higher Education. The Corporation for Public Broadcasting and National Public Radio are also members.

PSSC's prime task is the identification and development of the potential user community. This requires assisting in the identification of those user needs which improved communications might help alleviate, plus the educational process of assisting eventual users to relate the opportunities for satellite communications to their needs.

However, one of the problems facing this new institution is that many of the groups, professions, and institutions which might benefit from satellite communication systems are, as yet, unaware of the Public Service Satellite Consortium, as well as the whole field of communications via satellites.

4.2 The Public Broadcasting Service

The Public Broadcasting Service (PBS) is an example of an existing institution which will soon be utilizing satellite communication links for connecting to their member stations.

At present, PBS member television stations and NPR radio stations are tied together by the terrestrial facilities of AT&T. Tariff arrangements currently in force will end soon and the public broadcasting community, through the Satellite Working Group, has studied satellite communications systems in order to provide a more flexible and cost-effective means of interconnecting public radio and television stations. This is distinct from the PSSC's more general concerns with the broad spectrum of potential benefits for health care, education, and public service which might be opened by satellite communications and might, indeed, use an expanded PBS system to accomplish its goals.

Some institutional problems facing PBS involve the trade-offs necessary in achieving their stated goals in local autonomy, reliability (99.99 percent), and coverage (all 50 states), flexibility, and timing.

- Local autonomy may worsen timing problems because the more reception and transmission facilities that must be built to satisfy local autonomy requirements, the more federal approvals that will be required, the more financing problems that will have to be overcome, and the more production and installation problems that will have to be solved.

- Reliability impacts upon transmission and reception frequency choices in that there is less reliability for a given transmission as one goes up in frequency. Frequency/orbit assignments by the FCC, even when allocations are dedicated to the satellite service, can be lengthy due to certain desirable orbit slots being in great demand and the overall orbit/spectrum utilization coordination problem. The choice of frequencies is also conducted by the joint intergovernmental agreements of the ITU.

- Time lags may decrease the interest of the owners of present satellite systems in working out special joint ventures and/or special rate arrangements with public broadcasting.

- Timing will be affected by the decision either to own a satellite or lease transponders. If the decision is made for ownership, the timing issue relates to the problems involved in obtaining Federal Communications Commission (FCC) approval and this, in turn, involves the twin issues of whether it appears to the FCC that the spectre of "public ownership" of interconnection facilities is involved and whether the satellite's frequencies and use raise the other spectre of "direct broadcasting". On a leasing basis, it seems clear that less time problems are involved in using the current group of satellites as compared to new higher frequency satellites even considering the 4 and 6 GHz siting problem.

- Timing is also related to whether the satellite must serve Hawaii and Alaska; it may be difficult to secure orbital locations from the FCC meeting this requirement.

- Finally, timing is related to the proposed public broadcasting long-term financing legislation.

As the foregoing institutionally generated considerations show, there are many interconnecting impacts that could seriously affect the overall system's viability. If nothing else, delays are the most likely impact. Delays may be longer than experienced by most new services due to these institution impediments, particularly the regulation aspect. PBS, however, is still actively pursuing a switch from terrestrial to space systems and hoping for minimum delays.

4.3 Other Institutional Considerations

There are other institutional considerations that will effect every market and submarket for telecommunications. In the electronics funds transfer and electronic mail system, security of data and questions involving personal privacy will be of extreme importance. Privacy will also be important in teleconference applications.

In the education area, one of the biggest impediments will be accreditation. A virtual revolution is required in the educational field to overcome accreditation problems - employers and acedemians have "discriminated" against individuals with degrees from "open universities", "university without walls" and other "new" forms of educational institutions. Although accreditation is the most important problem, there are many organizational and administration problems. Even though the experiments on ATS-6 were limited in scope, and involved only some 100 terminals rather than the tens of thousands that would be involved in a large-scale operational system, the amount of organizational activity was extensive and complex. The various groups requiring coordination included several federal agencies, state and local governments, universities, private and public organizations, and several commercial manufacturers of technical equipment. Contractual agreements and letters of understanding had to be developed and agreed among all of the some 127 organizations involved to assure that each carry out their assigned functions.

Venture capital will be another constraint on the rapid growth of satellite telecommunications market not because of any "bias" against this market, but due to the competition for funds by all markets and the generally low rate of capital formation in recent years.

For AT&T, the largest service supplier, the FCC rate regulation will be a dominating institutional effect. If the FCC requires AT&T to use average system costing, rather than marginal costing of services, then it will be impossible for AT&T to compete, at least in the near term, with satellite supplied private leased line communications. AT&T could then lose 25 percent of its long haul market (the private-line market). Such a loss of revenue would drive up the Direct Dialing System costs significantly, as well as create excess long lines capacity - possibly negating AT&T's ability to install the cheaper L-5 and guided wave systems and then possibly dooming AT&T's ability to recapture any of the lost market until most of the terrestrial systems were outmoded and replaced. Marginal costing, on the other hand, would allow AT&T to be competitive in the long haul private line market; yet AT&T is not completely convinced about the economic viability of satellite systems. AT&T's COMSTAR system is primarily meant to provide flexibility for the Direct Dial Network and to "keep a foot in the door" for leased private line service. It is not known at this time what the FCC's rate ruling will be. However, the FCC has banned AT&T from offering private leased-line service via satellite for a period of 3 years after the COMSTAR system comes on line.

Another possible constraint is the ability of the aerospace community to build, in virtually assembly line production, the number of satellites required for full penetration of the potential satellite market. A corrollary to this problem is the ability of the U.S. to launch such numerous satellites to synchronous orbit. The breakdown given below shows the average yearly launch requirements for 24 transponder satellites over each five year period from 1980 to 2020 if the lower bound on the satellite market growth were achieved.

Number of launches per year

1980-85	85-95	95-2000	2000-2005	2005-2010	2010-2015	2015-2020
1	2	6	23	46	92	184

The number of launches includes replacements and assumes satellite life-times of seven years. This doubling of the yearly launch requirement every five years does not seem to pose a problem before the year 2000, but afterwards it is not clear that such doubling could be maintained. The launching of communications satellites might be the best justification for a reusable tug to ferry loads from the shuttle to synchronous orbit.

In conclusion, then, there are both positive and negative institutional signs. It must be realized, and appreciated, that although a market may be here today, exploiting that market usually takes time, particularly when revolutionary change in institutional relationships is required.

SECTION 10

CONCLUSIONS

The objective of this study was to conduct an assessment of the market potential, the technology development state-of-the-art, and atmospheric attenuation effects, and to project new services using 40 and 80 GHz for satellite communications. In the analysis, the use of 40 GHz appeared more feasible than 80 GHz based on atmospheric attenuation effects. Consequently, 40 GHz was analyzed in more detail than 80 GHz.

The 40 GHz region is particularly advantageous over 4 and 6 and 12 and 14 GHz regions in that the available bandwidths are larger by a factor of four. It was found that although there are great potentials in the telecommunications market and that 40 GHz technology could be developed with no major impediments expected, the satellite, ground stations and overall system costs are expected to increase at the millimeter wave frequencies. This is particularly true of commercial services which require outage times of 0.1 percent or better, and therefore, satellite systems with high satellite EIRP and diversity earth terminals.

The three services that were judged to be feasible utilizing a satellite system at 40 GHz were: 30 MB data, interactive TV and high quality 3-stereo pair audio. Because of market demand, two of the three services (interactive TV and 3-stereo pair) may be initially serviced at 4 and 6 and 12 and 14 GHz due to the near-term availability of satellite systems operating at these frequencies. There is a trend in telecommunication systems toward digital transmission with bit rates of several hundred megabits and they may eventually reach gigabits. Millimeter wave satellite systems with gigahertz bandwidths are a likely candidate for such service if they prove to be cost competitive.

However, it would appear that services may find it necessary to eventually utilize the 40 GHz region through market pressures, timeliness requirements and orbit/spectrum depletion.

Based on an analysis of maximum potential market growth, various orbit/spectrum usages and with the assumption that terrestrial systems would cease growing in 1975 or 1995, it was found that the time-frame for requiring satellites at 40 GHz could vary between the early 1990's and 2020, with the most probable time-frame between 2000 and 2015.

The key variables determining the chronology for a 40 GHz satellite system were determined to be the market driven growth of primarily long haul telecommunications, orbit/spectrum utilization and competition from new high capacity, terrestrial systems such as AT&T's L-5 cable system, guided millimeter wave and, in the distant future, optical systems.

Current Domestic Satellite Systems are growing primarily because they offer cost and institutional advantages over terrestrial systems. This is evidenced by the entry of PBS, MUZAK, and SBS high data rate services into the Domestic Satellite field. As this report indicates, there is a large potential market for satellite communications which could provide impetus for future growth. Not among the least of these is the Social Services market which includes health, medical, and educational communications. Whether the cost and institutional factors will permit dedicated satellites for such purposes is uncertain. Nevertheless, satellites are being considered and offer some advantages over terrestrial systems for these markets.

The large network of Government communications is another potential satellite market which may evolve if institutional and cost advantages occur.

On the basis of this study, it is believed that, in the long run, satellites will service a variety of markets, even those under 1000 miles (such as Alaska and sparsely populated service areas) and those markets with high timeliness requirements regardless of capacity. Terrestrial systems will undoubtedly continue to play a significant role in long-haul communications. Whether future terrestrial systems, such as guided waves and optical fibers, will challenge the advantages of satellite systems is, at present, uncertain.

Because of the market potential for satellite communication systems, we believe, that there are benefits in vigorously pursuing a balanced communications satellite R&D effort which includes continued research in the 40 and 80 GHz region. Particularly, we feel that a prudent near-term program in the 40 GHz area should include:

- Continued development of technologically critical components such as high powered TWT's.
- Studies of outage requirements of users.
- Further analysis of growth projections for 4 and 6 and 12 and 14 GHz.
- Further investigation of diversity concepts and techniques.
- Propagation experiments at 40 and 80 GHz.
- System definition studies at 40 GHz.

Such a research program will provide balance and flexibility until such a time when the need for above 40 GHz frequency links becomes more pressing.

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