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FSI REPORT NO. 242

AN ADVANCED DOMESTIC SATELLITE COMMUNICATIONS SYSTEM

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March 1980

Prepared for

NASA HEADQUARTERS
Washington, D.C.

Prepared by

Future Systems Incorporated

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SECTION 1
EXECUTIVE SUMMARY

This report was prepared by Future Systems Incorporated (FSI) for NASA Headquarters under Contract Number NASW-3300. It defines an advanced domestic satellite communications system (ADS) and identifies the technology developments which are required for its implementation. The report draws extensively on earlier work that had been sponsored by NASA Headquarters, NASA-Lewis Research Center, and Marshall Space Flight Center.

1.1 Traffic Projections

The utility of a satellite communications system can only be measured against a traffic model. Taking into account earlier work performed by Western Union and ITT for NASA-Lewis Research Center, FSI prepared an updated traffic projection for U.S. domestic satellite communications service covering a period of 15 years; mid-1980 to mid-1995. This model takes into account expected technology advances and reductions in transmission costs, legislative and regulatory changes permitting increased competition, and rising energy costs which will encourage more extensive substitution of telecommunications for travel.

Satellite transmission requirements have been expressed in units of transmission capacity equivalent to a typical domestic transponder with 36 MHz bandwidth. Such a transponder is capable of transmitting approximately 1,000 one-way voice channels or 64 Mbps of one-way data.* A summary of the total requirements is shown in Table 1-1 and in Figure 1-1. Since there is still some uncertainty concerning the development of video conferencing systems, we have performed the subsequent analysis for a "high traffic" model which includes video conferencing and for a "low traffic" model which contains voice and data requirements only.

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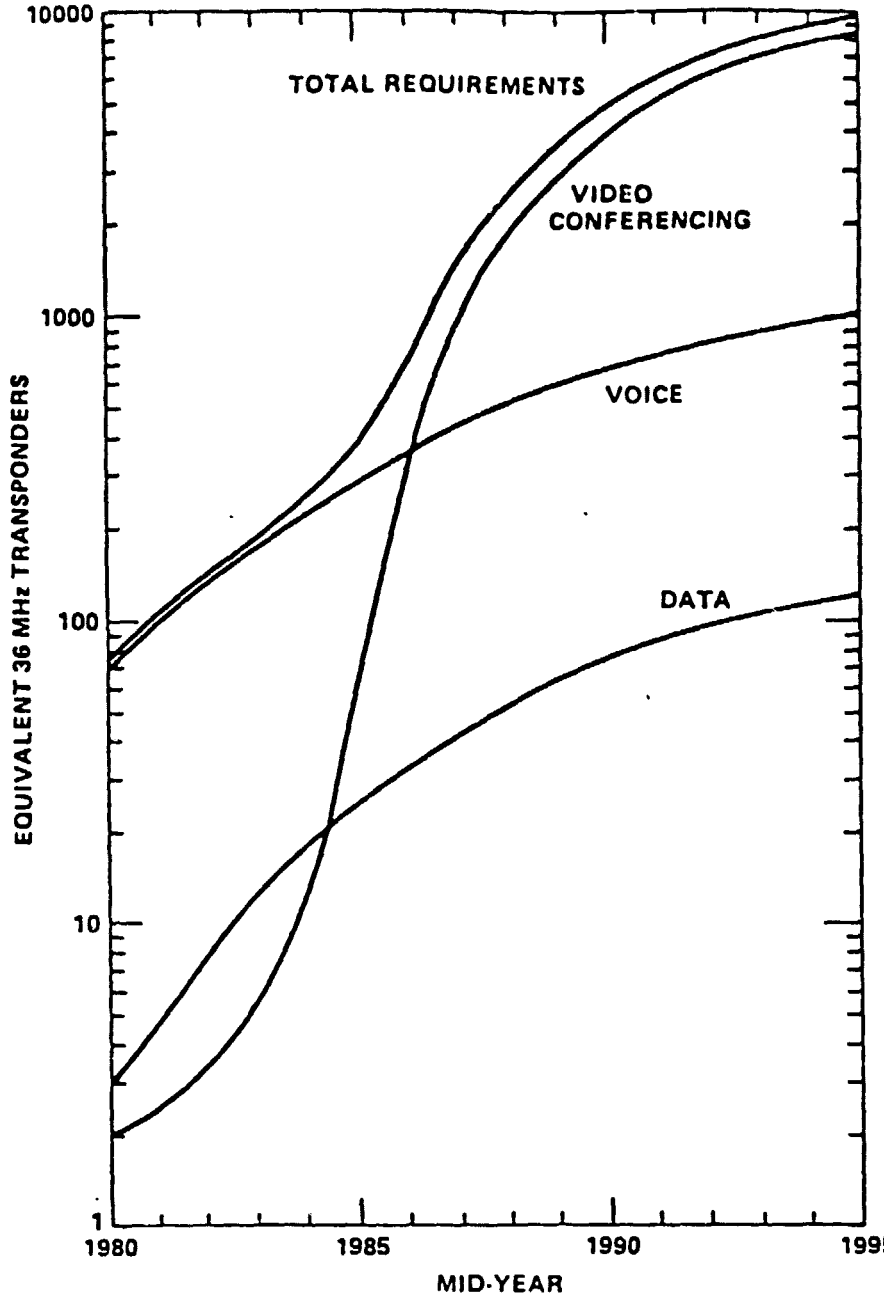
* The term "transponder" is used as a reference to express traffic levels. The transponder capacity is assumed to remain constant over the study period.



(Log Ordinate)

The reference transponder capacity is assumed 'o remain constant with time.

Figure 1-1

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

(excluding TV distribution)

Table 1-1

Total Satellite Service Demand

(Number of Transponders)

Year	Video Conferencing	Data	Voice	Total
1980	2	3	70	75
1985	60	24	289	373
1990	3,980	74	660	4,714
1995	8,280	120	1,008	9,408

Another important traffic element is T.V. distribution for network and CATV application. Projected requirements are shown in Table 1-2.

Table 1-2

T.V. Transmission Requirements

(1980 - 1995)

Year	Video Channel Requirements
1980	50
1985	100
1990	200
1995	350

TV distribution requires different payload configurations than point-to-point traffic. In subsequent sections the development of spacecraft configurations considers only point-to-point traffic.

1.2 System Evolution

The history and projected evolution of the U.S. domestic satellite systems using an extension of conventional satellites is shown in Figure 1-2. The resulting total in-orbit capacity is shown in Figure 1-3.

Follow-on satellites are expected to have higher EIRP at C-band and Ku-band to permit high capacity with smaller, lower cost earth stations and with cross strapping between the two frequency bands.

1.3 Orbit Utilization

The last few orbital slots available for use by U.S. domestic satellites are already being contested by several domestic carriers. In the future, increasing total systems demand can only be satisfied by increasing the capacity of each satellite. Figure 1-4 shows the average capacity that is required to meet the service demand as a function of time. Because of a number of factors, the actual utilization of in-orbit capacity will be lower than 100 percent. This implies that the design maximum capacity of the spacecraft in these slots will need to be higher than indicated. Some of the reasons for this inefficiency are:

> The use of some slots for T.V. distribution. This function is not compatible with the frequency reuse and switching provided for point to point communications.
>
> The operation of satellite systems by different entities. This results in the situation where Carrier 1 may be filled up while (for some reason) Carrier 2 may not be able to fill his available transponders. All systems do not saturate at the same time.
>
> The uneven distribution of traffic. This causes areas of high traffic (such as New York City) to saturate well before areas of low traffic density (such as the West). While some allowance can be made in spacecraft construction for this tendency, it is not possible to forecast the future traffic patterns with sufficient accuracy to eliminate it entirely.

The conclusion from this analysis is that orbital congestion dictates the development of high capacity satellites. A capacity in excess of what can be achieved with conventional satellites will be needed between 1987 and 1996.

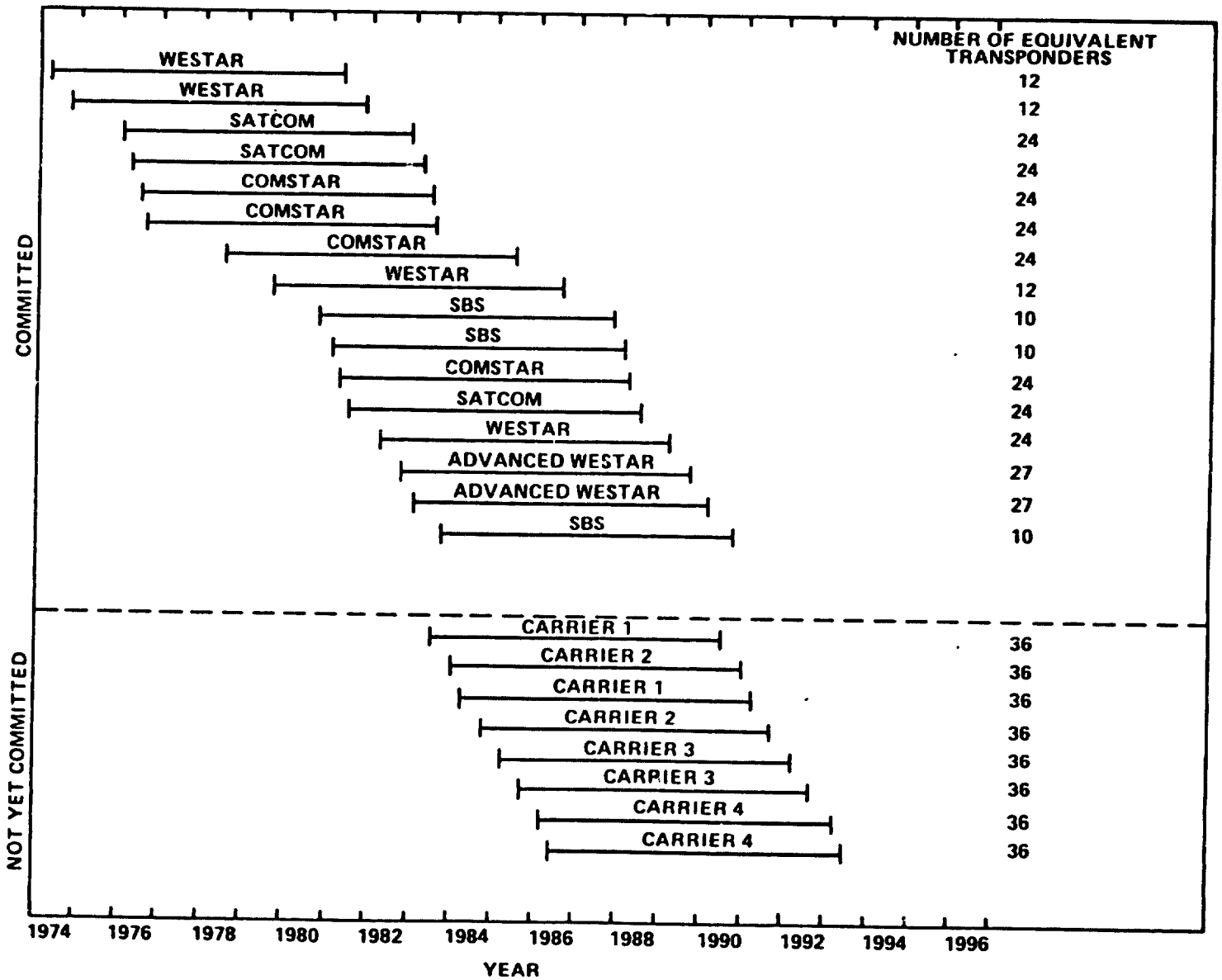


Figure 1-2

PRESENT, PLANNED AND PROJECTED SATELLITES IN-ORBIT

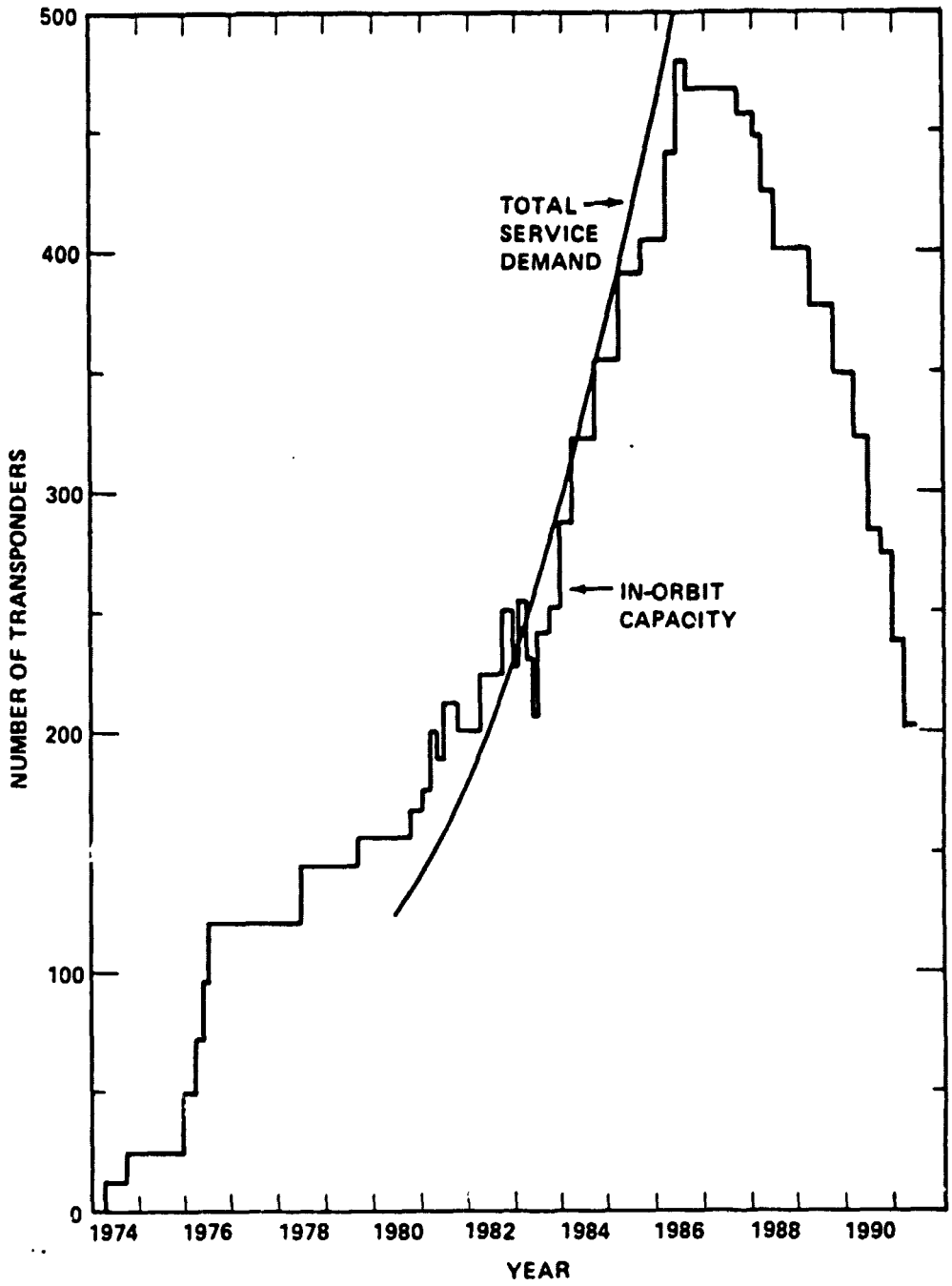


Figure 1-3

IN-ORBIT CAPACITY AND DEMAND FOR
OPERATING, PLANNED AND PROJECTED SATELLITES

(excluding TV distribution)

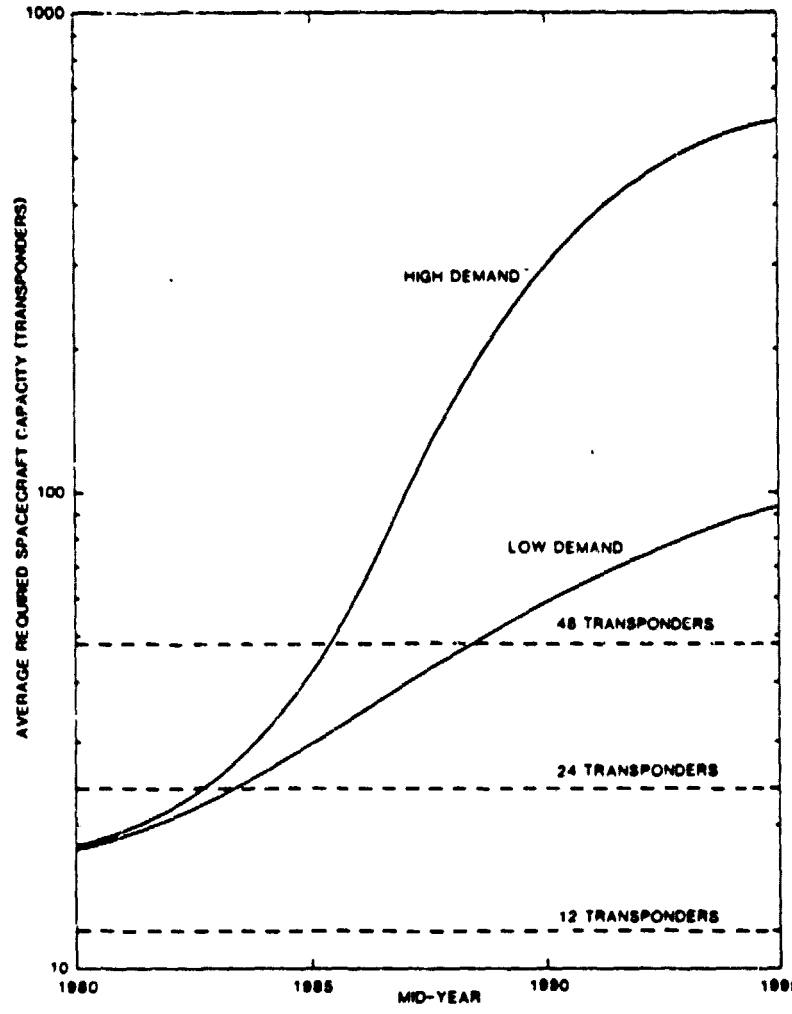


Figure 1-4
REQUIRED AVERAGE SPACECRAFT CAPACITY
TO MEET SERVICE DEMAND
(1980-1995)

(Including TV distribution)

1.4 Spacecraft Configuration

The constraint of using a single Space Shuttle launch with an improved upper stage for the advanced domestic satellite leads to a configuration such as that shown in Table 1-3, with an antenna coverage as shown in Figure 1-5.

Table 1-3
Major Features of ADS Spacecraft

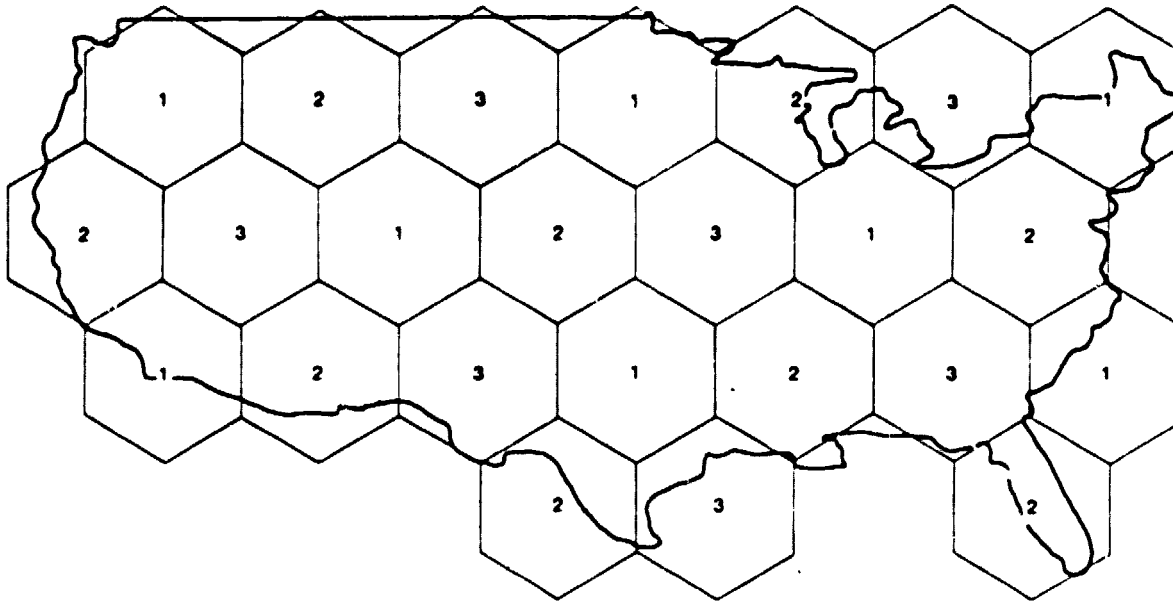
	All-CONUS** System	Offloaded*** System	
		Primary	East Coast
Capacity at Saturation (36 MHz transponder)	387	578	195
Spacecraft BOL Mass (kg)	4,440	4,800	4,000
Launch Vehicle	STS	STS	STS
Transfer Vehicle	Centaur	Centaur	Centaur
Spacecraft EOL Power (kw)	11	16	5.5
Number of Antenna Beams*			
at C-band	25	25	7
at Ku-band	11	14	5
At Ka-band	4	6	4
Antenna Beamwidth			
at C- and Ku-band	1.3°	1.3°	1.3°
at Ka-band	0.6°	0.6°	0.6°

* does not count dual polarization as 2 beams

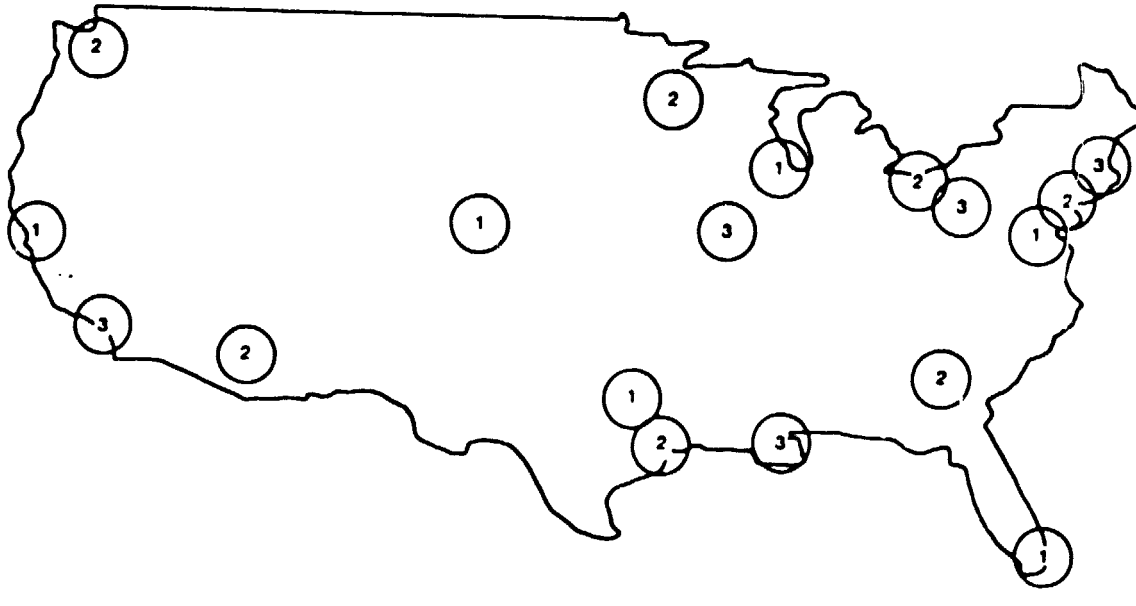
** contiguous United States

*** Part of the traffic is offloaded onto satellites over the Atlantic Ocean, which do not have full CONUS visibility. Connectivity is established by means of intersatellite links.

Figure 1-5



C-BAND AND Ku-BAND
SPOT BEAM ANTENNA COVERAGE OF CONUS
(Numbers 1, 2, 3 indicate freguency assignment)



KA-BAND COVERAGE AND FREQUENCY ASSIGNMENT

It should be noted that a major factor in increasing the satellite capacity has been the allocation of additional frequency bands at the 1979 WARC. While the exact time at which these bands would become available has not yet been determined, we have assumed that as a result of WARC decisions, an additional 300 MHz would be available at C-band and an additional 500 MHz would be available at Ku-band in the late 1980's when ADS would become operational.

With the advent of inter-satellite links some further increase in systems capacity will be available by placing satellites to the east and west of the U.S. service arc. Such satellites will achieve coverage of only part of CONUS, but full systems connectivity is available through inter-satellite link connection.

Area coverage by means of multiple spot beams has the further advantage that each country or region may use the total service arc. International agreement must be reached, however, on size and positions of spot beams, and the beam patterns of satellites serving different countries or regions must be meshed.

The interconnection of multiple spot beams places a major requirement on the on-board switch. Because of weight limitations we have avoided baseband processing and have instead provided satellite switched TDMA for the hearier routes and IF switched links at 6.3 Mbps for the lighter routes. The latter is useful for video conferencing and for low rate TDMA.

1.5 Earth Station Configurations

As the spot beam and switching capability of the spacecraft increases, the earth stations become simpler and cheaper. Higher satellite antenna gain translates into lower earth station antenna gain and transmit power requirements. More on-board switching leads to simpler baseband arrangements at earth stations.

Since video conferencing will take place largely at Ka-band where adequate transmission capacity is available, a special operating mode has been provided which is rain outage tolerant. When the rain attenuation exceeds the available margin, the transmission bit rate (and the corresponding bandwidth) is reduced from 6.3 Mbps to 64 kbps. This permits an additional 20 db of margin and

conferencing can proceed with audio and graphics support. Satisfactory availabilities result in all cases.

1.6 System Costs

Space segment costs are reduced substantially from today's values. Annual transponder costs will be about $100,000 (1980 dollars). Coupled with low earth station costs, the ADS system will be cost competitive for distances of more than 50 km. for most typical applications. For video conferencing, satellite transmission will be cheaper for any distance over which direct wiring is not practical.

1.7 Technology Identification

To implement the advanced domestic satellite, technology development is needed in the following areas:

- Multiple-beam, frequency-reuse antennas
- High-capacity RF and IF switch hardware and architecture
- 10-year reliability and redundancy configuration for multi- beam satellites
- Lightweight, moderate power (30 - 40 watts) solid state amplifiers at GHz frequencies
- Integrated microwave subsystems
- Intersatellite link technology
- Packaging and deployment schemes to fit the Shuttle orbiter cargo bay

SECTION 2
INTRODUCTION

This report was prepared by Future Systems Incorporated (FSI) for NASA Headquarters under Contract Number NASW-3300. It addresses the likely development of U.S. domestic satellite communications systems and desirable technology development to meet systems capability requirements. The report draws extensively on information prepared under other prior or concurrent NASA contracts, as listed below:

Reference	Subject	Author
1	Large Platforms	FSI
2	18/30 GHz Systems	Ford Aerospace
3	18/30 GHz Demand	Western Union
4	18/30 GHz Systems	Hughes
5	18/30 GHz Demand	ITT
6	18/30 GHz Architecture	TRW
7	On-Board Processing	Mitre Corp.
8	Platform Payloads	COMSAT
9	Platform Feasibility	Aerospace Corp.
10	Platform Concepts	General Dynamics
11	25 Year Forecast	FSI
12	FCC Filing for Orbital Slots	Hughes
13	Comments in Opposition to #12	SP Communications
14	On-Board Switching	MIT Labs

In Report No. 221, FSI compared communications systems using large platforms with systems using conventional satellites. As an extension of that work, the present FSI report describes an advanced, high capacity communications satellite system with the constraint that satellites are configured for the full capacity of a single space shuttle launch. The designation for this system is Advanced Domestic Satellite System (ADS).

In order to be able to measure the utility of a satellite communications system it is necessary to define a traffic model. FSI has developed a traffic model for U.S. domestic satellite traffic 1980 to 1995, covering data, voice, and video requirements. This model takes into account work performed by Western Union and ITT for NASA Lewis Research Center last year, as well as FSI's own forecasting data base. The FSI traffic model also considers the fact that the U.S. is now at the threshold of a telecommunications revolution. This revolution is triggered by new technology which reduces switching and transmission costs and increasing energy costs which encourage the use of telecommunications. Satellite transmission is one key technology which permits rapid and economical expansion of transmission capacity. Thus, the FSI traffic model is contingent on the availability of high capacity advanced satellites of the type described in this report. Section 3 describes the FSI traffic projections; the complete analysis underlying these projections is presented in Annex A.

In recommending a technology development program for NASA, we believe it is important to identify how the new technology will be used in an operating system, and how it could be introduced. The transition from the present system to new systems is especially important, considering existing investments in space and ground segments. Transition should be accomplished not only with minimum obsolescence of equipment, but also without service disruption. The shortage of orbital satellite locations on the geostationary arc is a further complication. In order to provide a good understanding of transition requirements, we have presented the current U.S. domestic space segment and its likely evolution during the next few years. This information is shown in Section 4.

An analysis of the congestion of the geostationary arc (Reference 11) was performed in 1977. It projected that all slots available for satellites serving North and South America would be occupied rapidly, and that sufficient systems capacity could be provided only by increasing the capacity of individual spacecraft. In fact, we have already reached a situation where two U.S. communications carriers are competing for the last two orbital satellite positions which are needed

for services they plan to offer (References 12 and 13). This competition underlines the requirement for higher capacity satellites and we project that future applications for satellite systems will be compared by the FCC on the basis of systems capacity. The satellite capacity which is required for a given orbital location can be determined from the total systems capacity requirement and from the number of orbital slots available for a given service area. An analysis of minimum satellite capacity needed to satisfy total systems capacity requirements for U.S. domestic systems is presented in Section 5.

In Section 6 we have selected a conceptual spacecraft configuration which can be launched on a single space shuttle flight with the use of a suitable upper stage. Weight and power budgets are extrapolated from work which has already been performed for NASA by others (References 2, 4, 6, and 10). The overall space segment needed to satisfy the total U.S. domestic traffic demand is also presented in this section, along with estimates of space segment systems costs and costs per channel.

Section 7 addresses the ground segment which is required to provide service in conjunction with the space segment described in Section 6. Trunking and direct-to-the-user service is provided and the requirement for terrestrial extensions is examined. Estimates of ground segment costs and costs per channel are made. Total systems costs for the space and ground segment are shown in Section 8. These costs are compared with terrestrial microwave transmission and fiber optics transmission costs. Finally, Section 9 identifies the required technology development and major conclusions are presented in Section 10.

SECTION 3
U.S. DOMESTIC SATELLITE TRAFFIC PROJECTIONS

3.1 Background

In a precursor study (Reference 1) FSI performed a comparison of large communications platform systems with systems configured with conventional satellites. In support of this study, FSI prepared traffic projections for U.S. domestic communications satellite service. In parallel NASA Lewis Research Center had commissioned two studies, one with Western Union and the other with ITT U.S. Domestic Transmission Systems, for the preparation of satellite communications service demand models (References 3 and 5). Taking into account this earlier work and other information that has become available, FSI has prepared an updated projection for U.S. domestic satellite communications service. This projection is presented in this section.

The traffic projection covers a period of 15 years, mid-1980 to mid-1995. The following information and factors have been considered in the preparation of this projection:

1. Technology Advances

   Rapid advances in communications technology are taking place and these advances would have a significant impact on the future development of communications facilities. These advances would be in the area of low-cost space segment facilities, low-cost earth stations, new microwave data distribution facilities of the type proposed by Xerox XTEN, new data concentrating and switching equipment, and finally development of practical fiber optics communication systems.

2. Legislative and Regulatory Changes

   Three bills addressing regulation and competition in the field of telecommunications are currently before the U.S. Congress, and the FCC is conducting its MTS/WATS inquiry. We expect the the future communications environment will include increased competition, and this competition will stimulate the introduction of advanced technology and will insure that cost advantages gained from this technology are passed through to the end-users.

3. Energy Costs

Rising energy costs will lead to the substitution of communications for some travel. This will take the form of increased use of facsimile and electronic mail, narrowband teleconferencing, and full video conferencing.

This Section provides summary information on the traffic model. Traffic is generally expressed in terms of number of equivalent 36 MHz C-band transponders. Such transponders are capable of transmitting a digital rate of 60 to 64 Mbps or of approximately 1,000 one-way telephony channels. The use of reference transponders is not intended to imply that actual satellite facilities will always be offered in terms of transponders with 36 MHz bandwidth. Annex A to this report provides detailed backgound data that were used in the derivation of the traffic estimate.

3.2 Data Traffic

Data communications traffic consists of message traffic, computer traffic, and narrowband teleconferencing traffic. While the total rate of information transfer will increase greatly during the next 15 years, increased transmission efficiencies will reduce the overall rate of increase of data traffic. The satellite portion of the data service demand, however, grows rapidly because of the inherent economies of satellite service. Satellite data transmission requirements are shown in Table 3-1.

Table 3-1
Data Transmission Requirements

Year	Transmission Bit Rate Mbps	Number of Equivalent 36 MHz Transponders
1980	80	3
1985	963	24
1990	3,485	74
1995	6,216	120

Our estimate of data communications traffic refers to that traffic which is clearly identifiable as data traffic. This type of service will progressively be transferred to packet type transmission systems with increasing transmission efficiencies. In addition, there will remain some data transmission requirements which are satisfied via conventional dial-up or leased telephony lines using relatively inefficient transmission arrangements. Often such service is provided as alternate voice/data service, where a transmission line is used for voice transmission during part of the day, normally working hours, and for data transmission at off-peak voice hours, normally evenings, perhaps for transmission of batch computing information. In our model this type of traffic has been included in the voice channel requirements section. The remaining data requirements will therefore all be handled with relatively good efficiencies, and therefore, the number of transponders required for this more efficient data transmission is relatively smaller than other estimates.

For the purpose of this study, the segregation of voice and data is not important, since we expect that generally the same earth stations will be used to handle both voice and data communications and the satellite transmission facilities are completely interchangeable. In our model all transmissions are digital, and therefore, a 64 kbps data channel is equivalent to a one-way voice channel.

3.3 Telephony Service

Telephony service includes MTS, WATS, and private line service. The satellite service demand is summarized in Table 3-2.

Table 3-2
Telephony Service Demand

Year	Two-Way Circuits in 1000's	Number of Equivalent 36 MHz Transponders
1980	28	70
1985	130	289
1990	330	660
1995	504	1,008

3.4 Video Conferencing

We expect that extensive video conferencing will be required and can best be provided by means of satellite communications. The costs of transmission and conference room facilities will be low, as shown below:

Space segment transmission costs per hour	$10
Incremental earth station and conference room facilities costs per hour	$10
Communications carrier's administrative expenses and profit per hour of use	$10
Total hourly charge	$30

Rising costs and inconvenience of business travel will become a strong incentive to substitute telecommunications for some travel. Video conferencing will replace some air travel and some local travel and will be used as a more efficient means of conducting business. Large and medium size corporations will have their own conference rooms in lieu of public facilities. Once established, the video conferencing system will lead to further decentralization of business, permitting people to live where they wish and to work near their homes. Table 3-3 is the estimate of video conferencing requirements.

Table 3-3
Video Conferencing Requirements

Year	Two-Way Video Circuits	Number of Equivalent 36 MHz Transponders
1980	9	2
1985	293	60
1990	19,900	3,980
1995	41,400	8,280

We at FSI are firmly convinced that video conferencing will become an important service offering; however, in recognition of the fact that public opinion is divided concerning the value of video conferencing, we have treated the video conferencing requirement as one of two alternatives. In the first system implementation scenario, we assume that there will be little or no video conferencing and the total point-to-point telecommunications requirements will consist only of data and voice. In the second implementation scenario, we have assumed that video conferencing will develop, and in this case video conferencing requirements are included in the total.

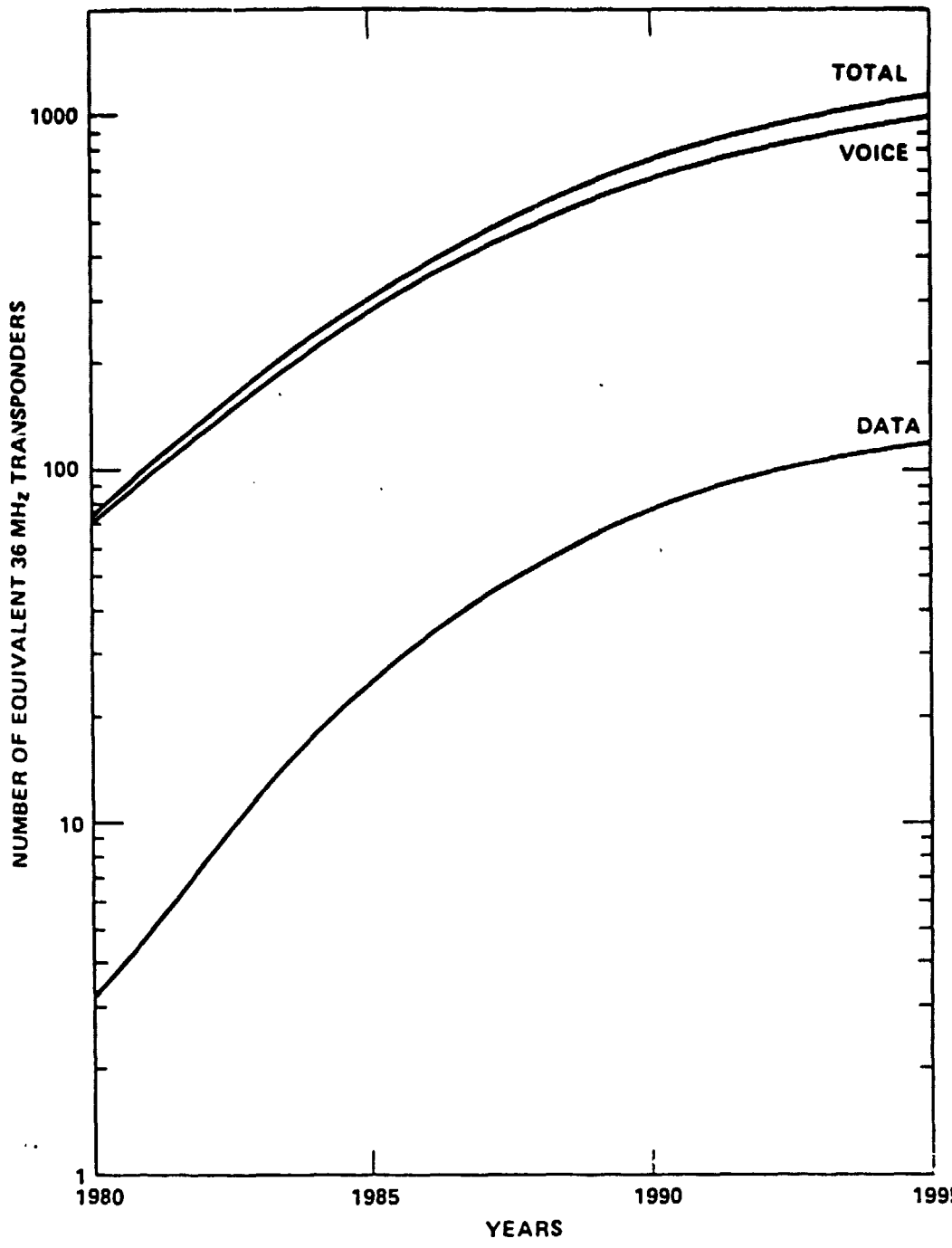
3.5 Total Point-to-Point Traffic

3.5.1 Data and Voice Only

Total satellite service demand expressed in equivalent 36 MHz transponders is shown in Table 3-4 and Figures 3-1 and 3-2. Voice requirements are always much larger than data transmission requirements and are therefore controlling the service.

Table 3-4
Total Satellite Service Demand
(Number of Transponders)

Year	Data	Voice	Total
1980	3	70	73
1985	24	289	313
1990	74	660	734
1995	120	1,008	1,128



(Log Ordinate)

Figure 3-1

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

(excluding TV distribution)

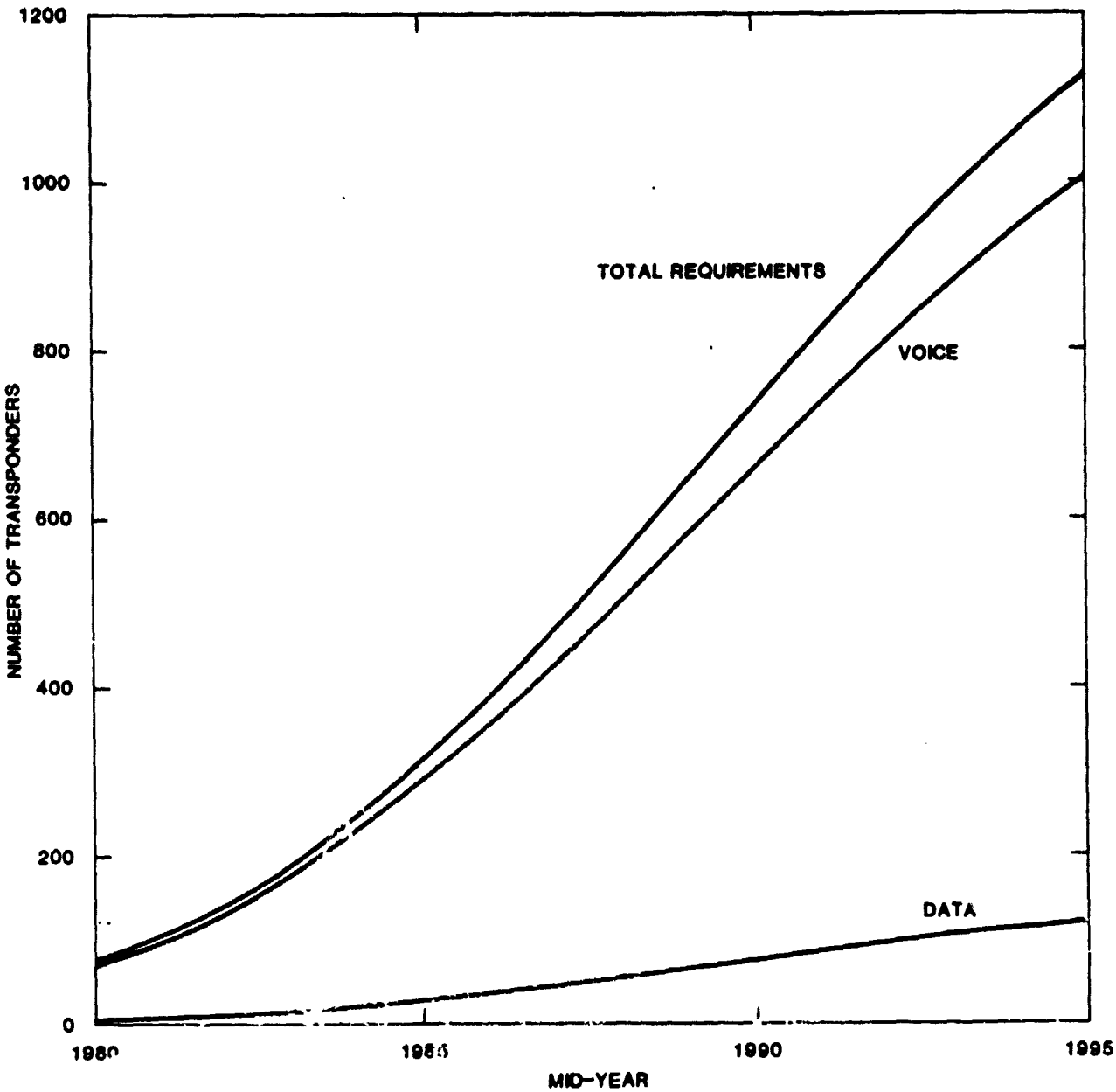


Figure 3-2

SATELLITE TRANSPONDER REQUIREMENTS

(1980-1995)

(Linear Ordinate)

(excluding TV distribution)

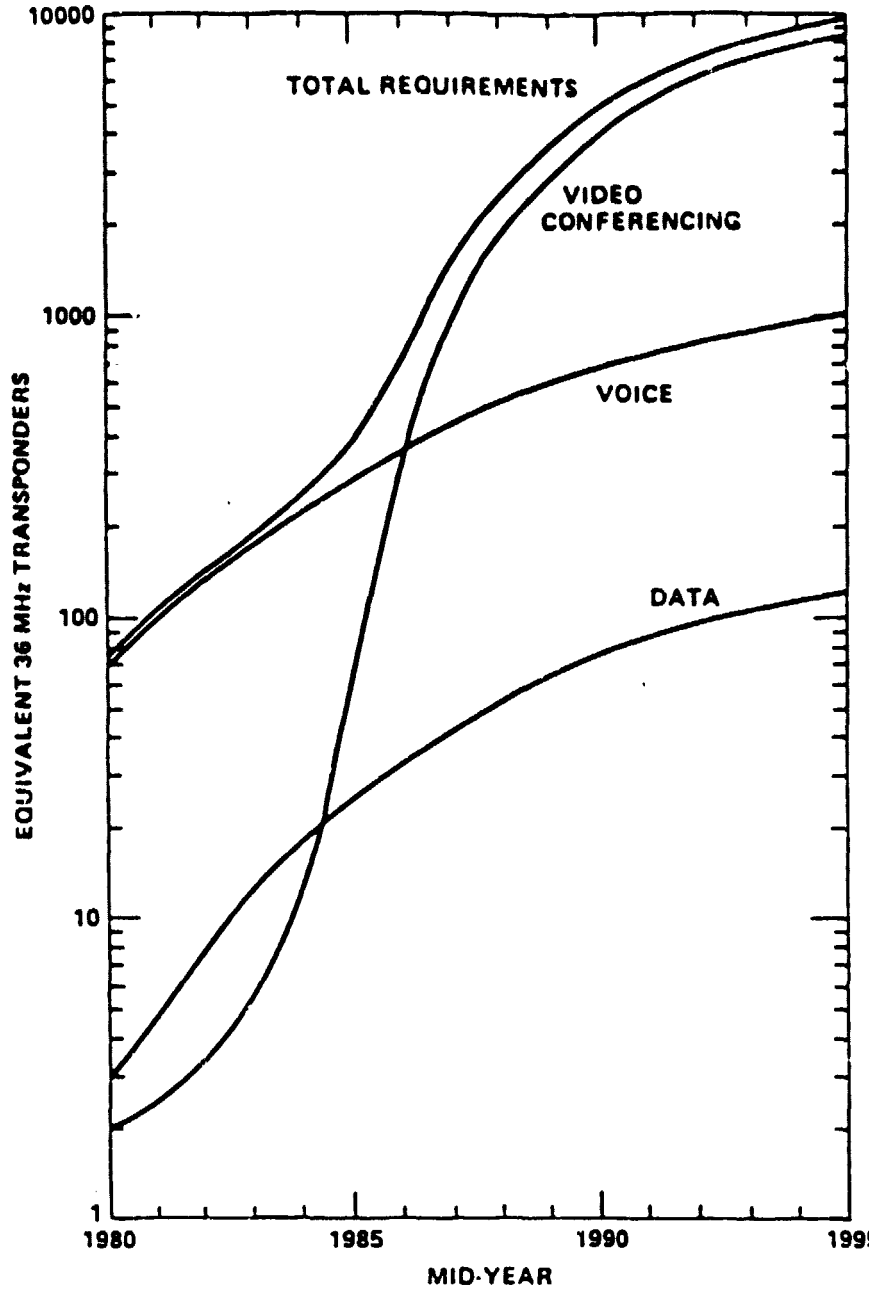
3.5.2 Data, Voice, and Video Conferencing

Total satellite service demand is again expressed in equivalent 36 MHz transponders and is shown in Table 3-5 and Figures 3-3 and 3-4. Voice requirements are always much larger than data transmission requirements and video conferencing becomes the controlling service as soon as adequate transmission facilities become available.

Table 3-5
Total Satellite Service Demand
(Number of Transponders)

Year	Video Conferencing	Data	Voice	Total
1980	2	3	70	75
1985	60	24	289	373
1990	3,980	74	660	4,714
1995	8,280	120	1,008	9,408

For video conferencing we have assumed that high quality transmission will be used on the average in order to make this service acceptable. High quality video conferencing transmission requires a transmission rate of 6.3 Mbps per one-way video conferencing channel. It is assumed that interframe processing is provided; that means the information on one video frame is stored and compared with the information on the next video frame and a technique is employed whereby the primary information transmitted consists of changes between frames. In this manner a 6.3 Mbps transmission for video conferencing applications provides full resolution and signal-to-noise quality in concurrence with TV network standards; however, this system would not be suitable for transmission of sports or other events with rapidly changing background. It is fully suitable for conferencing applications, where background information is relatively static.

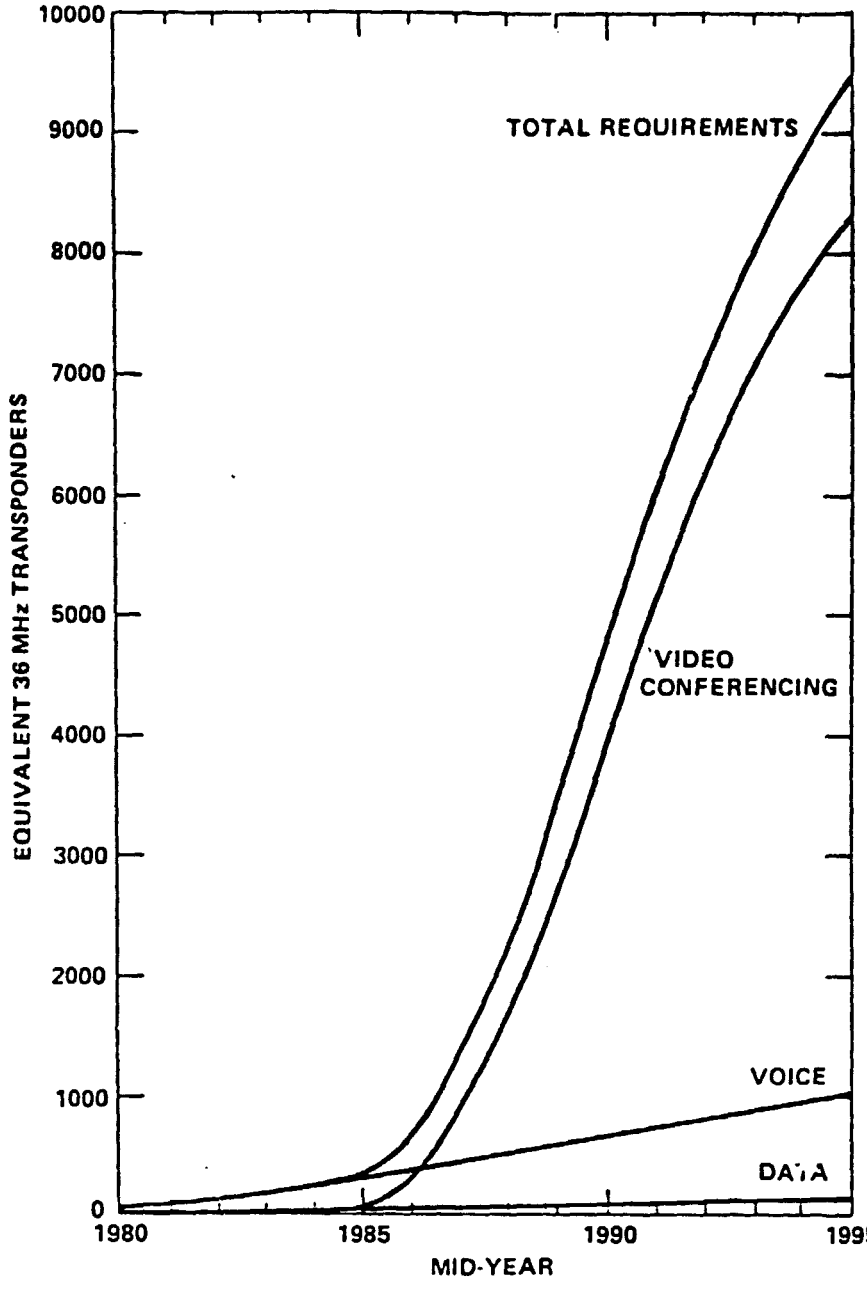


(Log Ordinate)

(excluding TV distribution)

Figure 3-3

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)



(Linear Ordinate)

(excluding TV distribution)

Figure 3-4

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

3.6 TV Distribution Requirements

This section summarizes point-to-multipoint TV distribution requirements. This type of traffic has been treated separate from point-to-point video transmission, since it requires different facilities. We have included in this section all requirements for network TV, occasional TV and CATV transmission. Other applications, such as educational video, telemedicine, disaster relief and law enforcement, are considered to be within the video conferencing category since they do not have the characteristic of requiring widespread distribution, as is the case with entertainment video.

3.6.1 Transmission Facilities and Channel Requirements

Point-to-point transmissions can be provided via future high capacity satellites with great efficiency of spectrum and orbital arc utilization through multiple frequency reuse via narrow spot beams. Satellite capacity can be increased by reducing the beam size and increasing the number of beams per satellite. On the other hand, the characteristics of the point-to-multipoint transmissions require wide area coverage by the same transmission signal; thus satellite capacity cannot be increased through multiple frequency reuse. For this reason we expect that the TV distribution satellites of the future will be quite different from the high capacity communications satellites that will be employed for point-to-point transmissions.

Future video transmission satellites will provide wide area coverage beams, perhaps matched to the U.S. time zones. Each beam will provide coverage at all available frequency bands, and dual polarization will be used at the lower frequencies. The bandwidth of the transponders will be more closely matched to the TV transmission requirements than is the case today.

It should also be noted that the uplink inhomogeneity between multibeam and area coverage satellites will require wide orbital spacings between the two types of satellites. TV distribution satellites can be used to occupy the intermediate spaces, provided that their uplinks are furnished by narrow beams. As long as program originations remain within a few locations, this can easily be accomplished.

A further contributing factor will be the rising energy costs, which will provide an incentive to increase the amount of entertainment that is available at home. Table 3-6 shows estimates of TV transmission requirements for 1980, 1985, 1990, and the year 1995. Figure 3-5 is the FSI estimate for equivalent quality TV transmission requirements, taking into account the above mentioned considerations.

Table 3-6
TV Transmission Requirements
1980-1995

Year	Video Channel Requirements
1980	50
1985	100
1990	200
1995	350

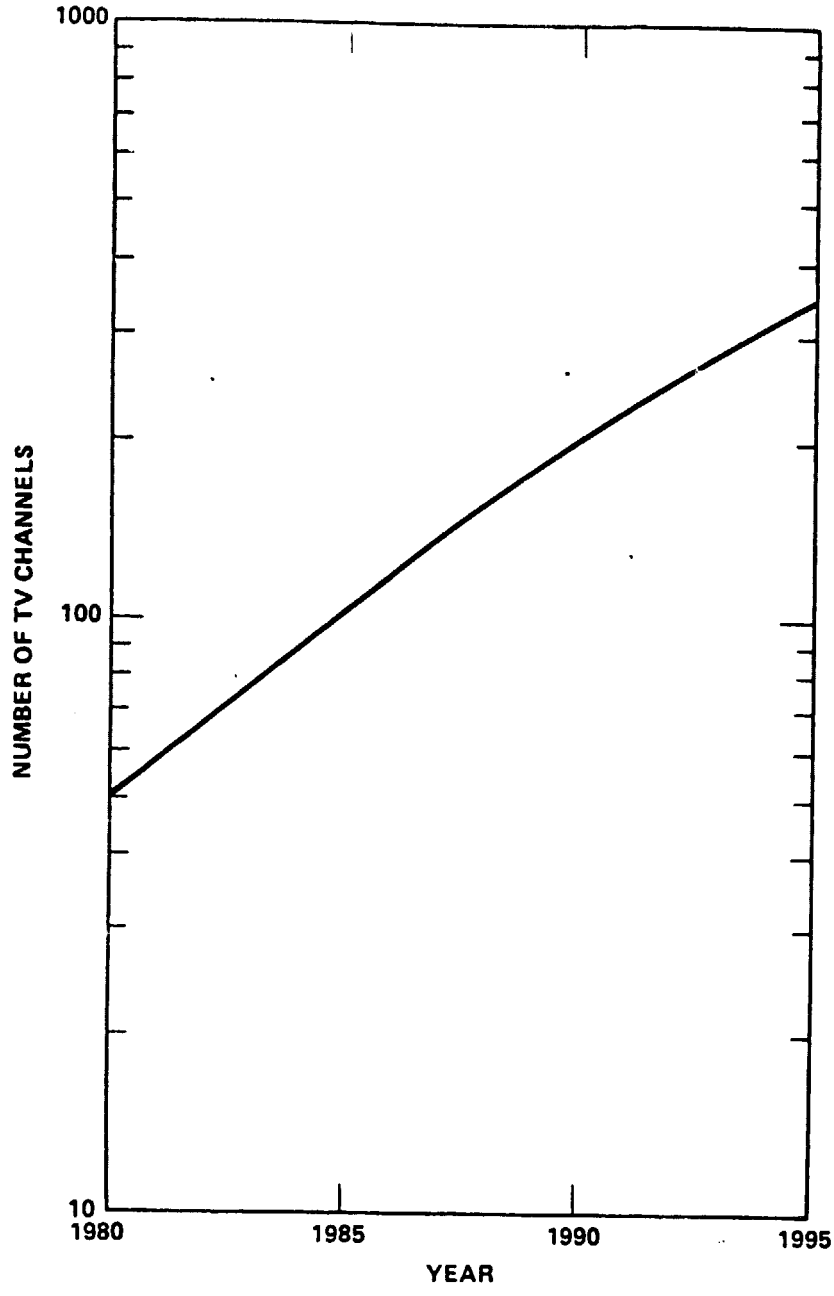


Figure 3-5

TV DISTRIBUTION ESTIMATE

(Log Ordinate)

SECTION 4
SATELLITE SYSTEMS EVOLUTION

This Section describes the current status of the U.S. domestic satellite communications system and projects and their likely development during the next few years. This projection is important to permit planning for transition from conventional systems to the advanced satellite system described in this report.

4.1 Historical Development and Current Status

The first commercial communications service on a U.S. domestic communications satellite was provided by Western Union's Westar I satellite in 1974. Since that time, seven additional U.S. domestic satellites have been successfully launched. These satellites are part of AT&T's Comstar system, Western Union's Westar system, and RCA Americom's Satcom system. The eighth satellite, RCA Satcom F-3, was lost in orbit, presumably upon apogee motor malfunction. An additional seven satellites have been procured and will be launched during the early 1980's. Among these additional satellites are Western Union's follow-on to Westar, Advanced Westar, and a new entry into the U.S. domestic satellite market, Satellite Business Systems. RCA's F-3 will be replaced by F-4, already under construction.

In addition, others may soon join in the satellite communications business. Included in these are Xerox, with its proposed Xerox Telecommunications Network (XTEN) to be used for high speed data and voice both inter- and intracity, the newly proposed partnership of Fairchild Industries, Continental Telephone Corporation, and the Western Union Telephony Company. The latter entrant proposes joint ownership of Western Union's Westar and Advanced Westar systems. Thus, the formalization of this partnership, which still requires approval by the FCC, will have substantial impact on the satellite communications market. For example, American Satellite Corporation, a wholly-owned subsidiary of Fairchild Industries, will have assured space segment at a competitive price relative to its present situation where it leases space segment from a competitor. Telenet has

announced its intention to construct an earth station network to supplement its leased terrestrial facilities for the packet data network and SP Communications has advised the FCC of its intention to operate a satellite network.

Table 4-1 shows the capacity launch dates for 17 operating and planned U.S. domestic satellites including a fourth Westar, a fourth Comstar, and a third SBS. Of those satellites shown, four have not yet received permission for launch (Westar 4, Satcom 4, Comstar D4, and SBS C). However, except for Westar 4, these satellites are either under construction or already constructed. Figure 4-1 shows the projected in-orbit service of these presently operating and planned satellites based on an expected mean life of 7 years. The projected in-orbit capacity for these satellites along with total service demand is shown versus time in Figure 4-2.

The comparison of currently existing and committed in-orbit capacity with projected demand shown in Figure 4-2 shows that any slip in the projected launch dates of the satellites not yet in-orbit will cause a shortage of capacity to occur, perhaps as early as 1982. The launch of Satcom F4, for example, is contingent on receipt of FCC approval relatively soon. In addition, the approaching ends-of-life for some of the earlier satellites will affect the number of operating transponders, and hence the number of in-orbit transponders will be somewhat lower than that shown. At best, without new commitments, the shortage will occur around 1983 when the first satellites begin to reach 7 years in-orbit.

4.2 Projected New Satellite Programs

The projected shortage of in-orbit capacity provides an opportunity for communications carriers to procure new satellite systems. Any new procurement is subject to FCC approval, and the timespan required for approval introduces an additional uncertainty into the projections. The allocation of orbital slots is another problem. Table 4-2 shows possible launch dates for 4 second generation satellite systems, which could conceivably be launched beginning around mid 1983. This projected launch date allows some time for FCC approval to occur during 1980 and a 30 month procurement schedule. The transponder capacity for each satellite of 48 transponders should be easily achievable through the use of both C-band and Ku-band and frequency reuse. Figure 4-3 shows the projected in-orbit lifetimes

for these second generation satellites along with the projected in-orbit lifetimes of the presently planned and operating satellites as previously shown. Figure 4-4 shows a comparison of available and required in-orbit capacity including the second generation satellites. New spacecraft programs may come too late to eliminate the in-orbit capacity shortage of 1981 and 1982, but adequate capacity can be provided from 1983 on.

Table 4-1
Capacity and Launch Dates of
Operating and Planned U.S. Domestic Satellites

Number of Transponders	Satellite	Launch Date
12	Westar 1	4/74
12	Westar 2	10/74
12	Westar 3	8/79
24	Westar 4	3/82
27	Advanced Westar	9/82
27	Advanced Westar	1/83
24	Satcom F1	12/75
24	Satcom F2	3/76
24	Satcom F4	6/81
24	Comstar D1	5/76
24	Comstar D2	7/76
24	Comstar D3	6/78
24	Comstar D4	3/81
10	SBS A	10/80
10	SBS B	1/81
10	SBS C	9/83

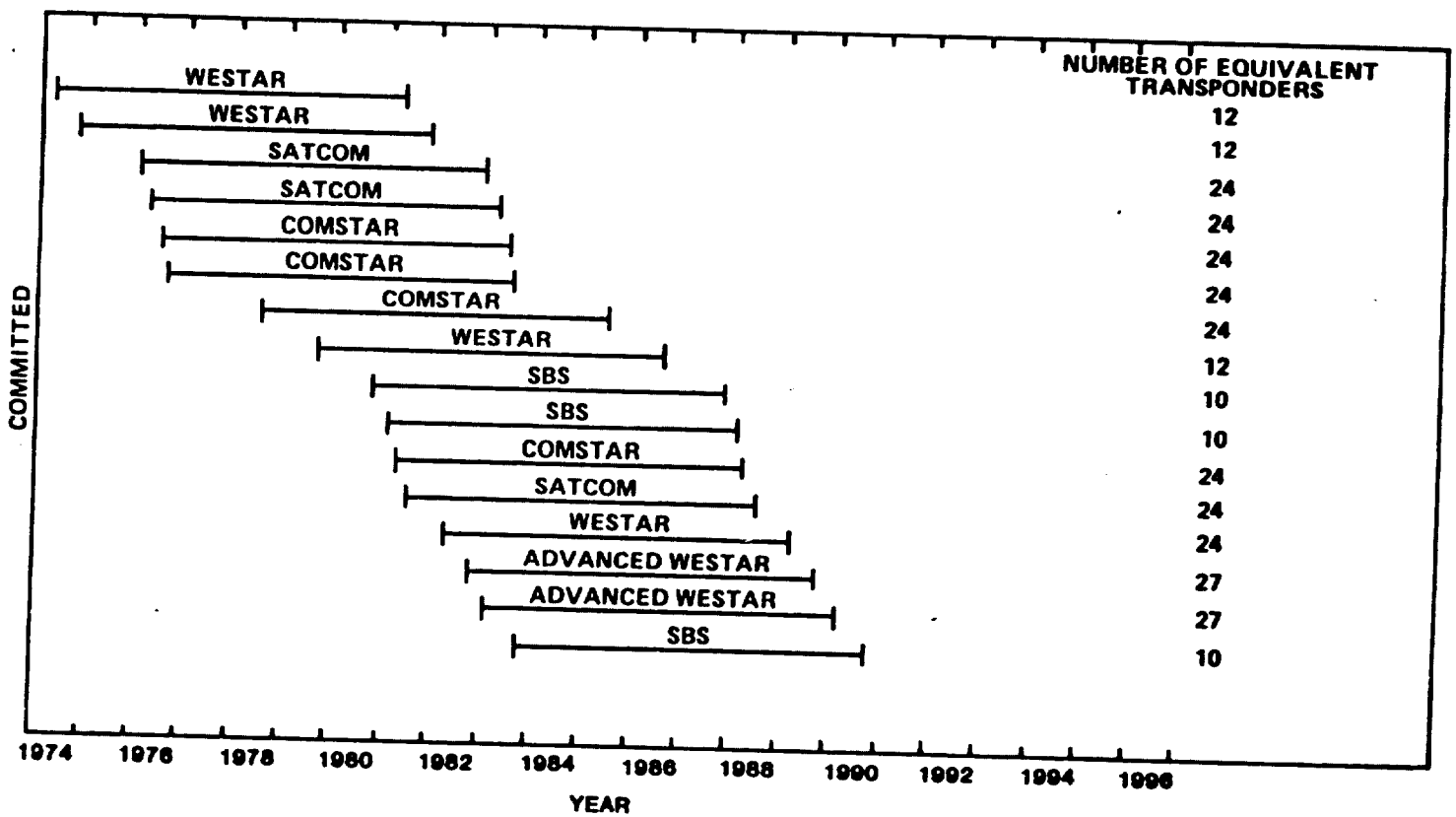


Figure 4-1

PRESENT AND PLANNED SATELLITES IN-ORBIT

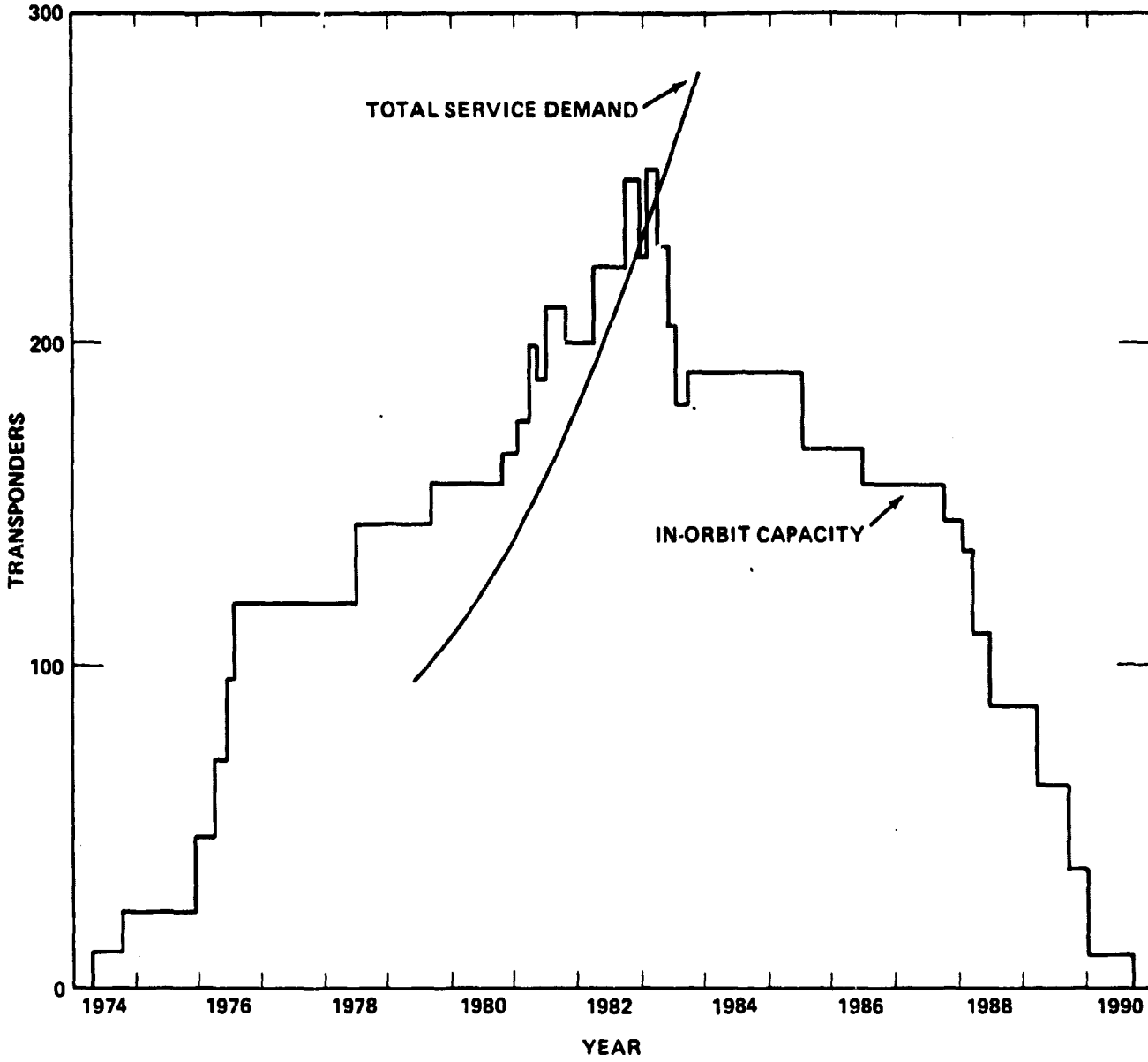


Figure 4-2
IN-ORBIT CAPACITY OF
PLANNED OR EXISTING SPACECRAFT

(excluding TV distribution)

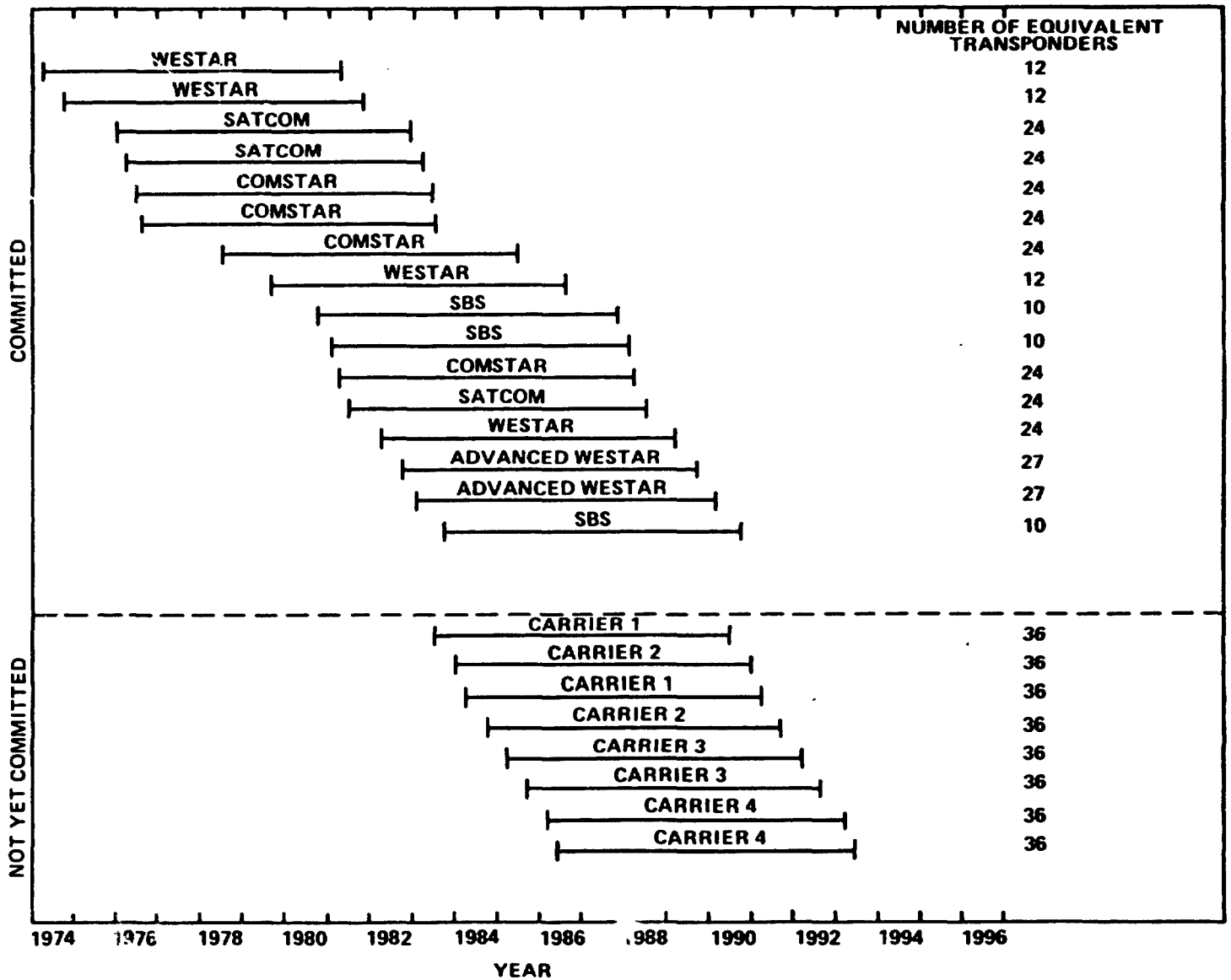


Figure 4-3

PRESENT, PLANNED AND PROJECTED SATELLITES IN-ORBIT

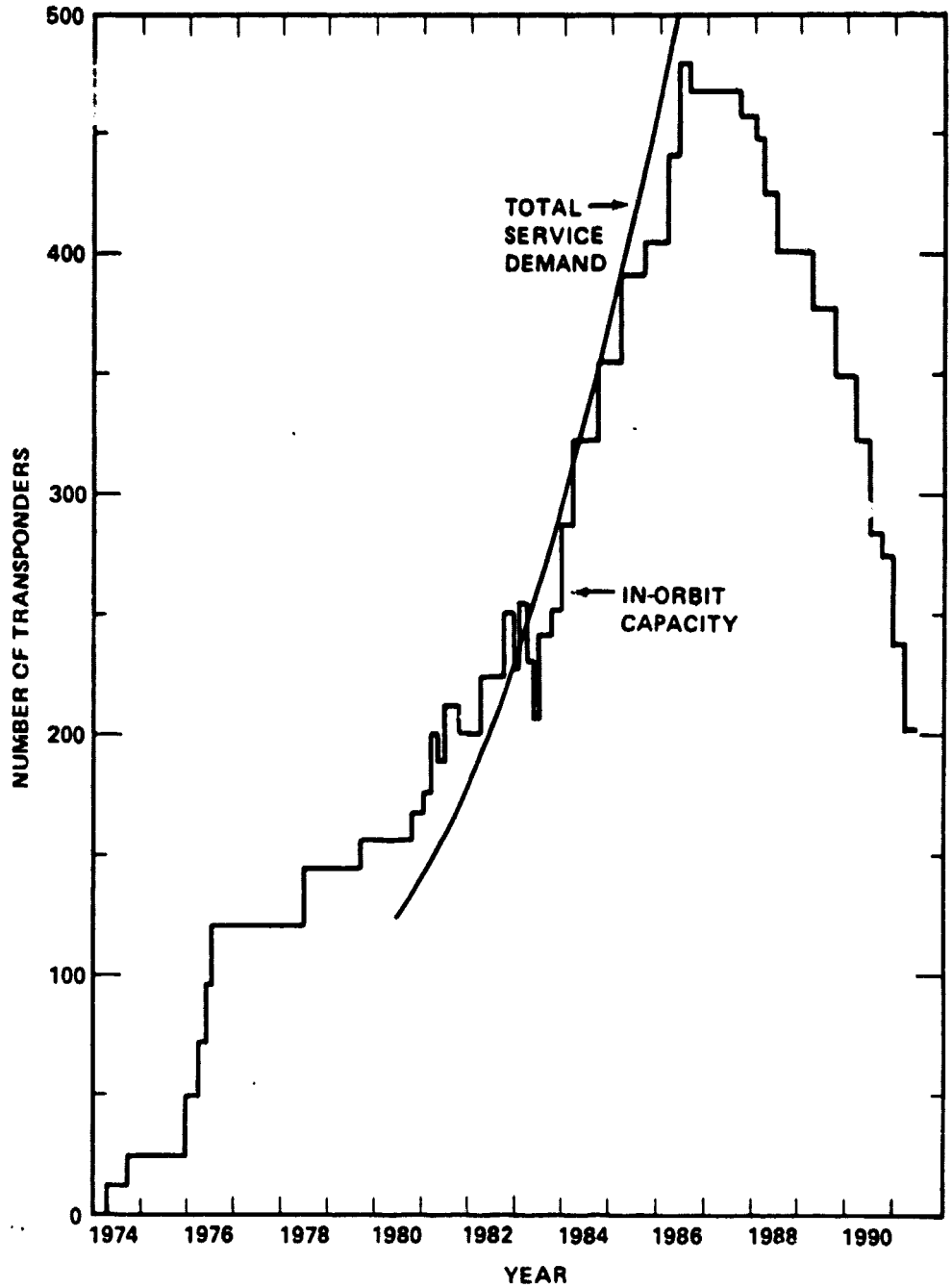


Figure 4-4

IN-ORBIT CAPACITY AND DEMAND FOR
OPERATING, PLANNED AND PROJECTED SATELLITES

(excluding TV distribution)

Table 4-2

Projected Capacity and Launch Dates

For Second Generation U.S. Domestic Satellites

Number of Transponders	Satellite	Launch Date
36	Carrier 1	6/83
36	Carrier 1	9/83
36	Carrier 2	7/83
36	Carrier 2	10/83
36	Carrier 3	12/83
36	Carrier 3	1/84
36	Carrier 4	3/84
36	Carrier 4	6/84

The second generation satellites will most likely be a combination of follow-on satellites to existing satellite systems, such as a follow-on RCA Satcom and a follow-on Comstar, and new entrants into the U.S. domestic satellite market, such as the recently proposed Hughes Communications system or the SPC system.

During the period of in-orbit shortage, special techniques will be employed to increase satellite capacity. These techniques consist of companded FM transmission, TDMA transmission with DSI,* and compressed video transmission.

At this time, the following communications carriers are working towards new satellite programs; however, no firm commitments have been made ajd the FCC has not yet approved any of these systems:

Western Union Telegraph Company

Two satellites with 24 transponders each to offset the delay of the Advanced Westar launches.

* Digital Speech Interpolation

Hughes Communications

Two satellites with 24 transponders each for lease to other carriers and for corporate networks.

SP Communications

Filed with the FCC its intent to implement a satellite system.

AT&T Long Lines

Planning for a follow-on system to Comstar.

RCA American Communications

Planning for a follow-on system to Satcom

4.3 Characteristics of Follow-On Systems

At this time, most carriers are planning their follow-on spacecraft only for the capacities and characteristics needed for their own requirements, without adequate consideration of total U.S. domestic systems capacity requirements and orbital arc efficiency. This approach, however, is bound to fail because of conflicting claims for orbital satellite slots. We project that as a result of the saturation of certain parts of the orbital arc, the FCC will be required to institute more comprehensive planning for the totality of U.S. domestic system requirements. This will lead to satellites with higher capacity, multiple frequency bands, and better connectivity. New frequency bands made available at the 1979 WARC will be allocated at an accelerated schedule. Typical characteristics of follow-on satellites are summarized below.

Characteristics of New, Improved Satellites

By providing a new generation of domestic satellites, the opportunity exists to improve on the characteristics of these satellites. Optimum characteristics of a new generation of domestic satellites provide the following features:

Increased EIRP at C-band and Ku-band

This increase will permit achievement of higher capacity with small diameter earth stations--for example, 4.5-meter diameter at C-band—and would therefore lead to lower systems costs.

Interconnection of C-band and Ku-band

In this manner, currently existing C-band systems can expand by adding new C-band or Ku-band stations for optimum network design.

New C-band stations will be constructed in all cases where co-location of stations with the central offices is practical. In other cases, Ku-band stations would be implemented on a co-located basis. The new satellites provide trunking service and direct-to-the-user service both at C-band and Ku-band in a fully interconnected mode.

Advantages of Shared Space Segment

Several new users of communications satellites will be able to share a common set of satellites and derive a number of advantages from shared use:

Availability of Geostationary Arc

The congestion of the geostationary arc limits the number of slots available for U.S. domestic communications satellites. For this reason additional satellites will have to have higher capacity and will have to be shared by several users as shown in Figure 4-5.

Larger Capacity Satellites

Larger capacity satellites result in lower unit transmission cost (cost per transponder) due to economies of scale.

Higher Transponder EIRP

With larger satellites, it is more practical to provide higher EIRP per transponder, leading to higher transponder capacity with small earth stations.

The result of these advantages are lower system transmission costs. Earth stations will be located closer to the end user, thereby eliminating a significant portion of terrestrial extension costs.

Problem Areas

The introduction of a new generation of spacecraft requires the solution of several problems:

1. The availability of orbital slots is limited. A two-stage coordination program is required.

   a. Approval must be obtained from the FCC for a new satellite program and proposed orbital locations.

b. Once agreed by the FCC, application must be made by the FCC with the International Frequency Registration Board to obtain protection on a global basis. Particular attention must be paid to the requirements of orbital locations for joint use at C-band and Ku-band.

2. Because of certain program changes in the Space Transportation System Program (Space Shuttle), the availability of launches during the early 1980's may be limited. For this reason, it will be desirable to make an early reservation with NASA for intended launch services. In the absence of assured Shuttle launches, the carriers will plan on the use of the Delta launch vehicle, thereby limiting the achievable capacity.

3. Coordination with respect to interference from and into adjacent satellite systems has to be carried out. Increased EIRP on the proposed new satellites requires planning to demonstrate that interference into adjacent systems is not excessive.

The above mentioned problems can be solved by careful planning and early consideration of technical and regulatory aspects affecting system implementation.

SECTION 5
ORBIT UTILIZATION

5.1 Orbital Arc Occupancy

This section provides information on the present and planned use of the orbital arc. Table 5-1 shows the service arc-that is, the range of possible satellite locations which provide adequate visibility for various countries. Table 5-2 shows the existing and planned satellite locations for systems for North and South America.

Table 5-1
Service Arc

World Region	Reference Number	Coverage Range	Visibility Arc Minimum Elevation Angle or 10 Degrees (Degrees in West Longitude)
North America	1	Canada, Including Yukon and NW Territories	114 - 116
	2	Canada, Vancouver to Halifax	61 - 128
	3	USA, Including Hawaii and Alaska	133 - 134
	4	USA, CONUS only	61 - 134
	5	USA, CONUS and Hawaii	92 - 134
Latin America	6	Brazil	0 - 139
	7	Colombia	10 - 143
	8	Chile/Argentia	10 - 130
	9	Total Regional Coverage	10 - 109
	10	Mexico/Caribbean	46 - 143

Table 5-2
Satellite Locations

Satellite	Location*	Satellite	Location*
Satcom F1	135	Westar 1	99
Satcom F3	132	Advanced Westar	99
Comstar D1	128	Comstar D2	95
Westar 2	123.5	Westar 3	91
SBS A	122	Comstar D3	87
Satcom F2	119	U.S. Domestic	81.7
Anik A3	114		
Anik A2	109	Brasilsat	75
Anik B1	109	Colombia	75
SBS B	106	Brasilsat	70
Anik A1	104	Brasilsat	65
Advanced Westar	103	Brasilsat	60

*Degrees west longitude

Shown are actual or planned locations of communications satellites from 60 to 134 degrees west longitude. A 4-degree spacing is assumed as a minimum to provide protection against intersatellite interference; thus within any 4-degrees there can generally be only one satellite per coverage area per frequency band.

Most of the satellites shown are C-band, and thus each slot can also handle a Ku-band satellite, but the congestion is evident. To some extent it will be possible to retain already coordinated positions, but as more and more demand is made on the arc, the situation will naturally become more critical.

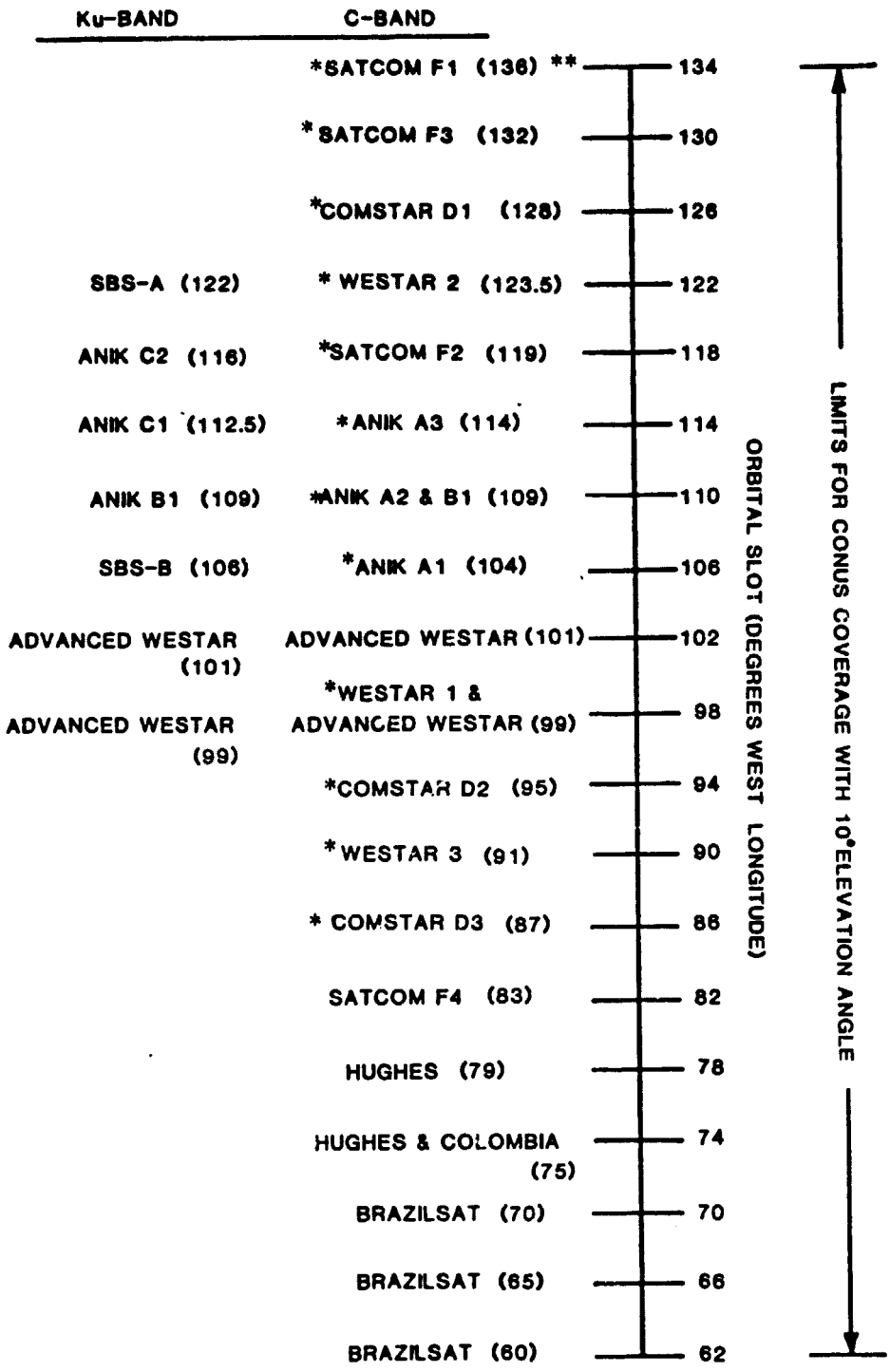
Figure 5-1 shows the orbital slots in graphical format. In the future it will be possible to share slots for use by North and South America by means of antenna discrimination.

The visibility arc for CONUS extends from about 61 to 134 degrees west longitude. The present and planned occupancy for this portion of the arc is shown schematically for C-band and Ku-band using 4-degree orbital slots. At present there is only one operating Ku-band satellite, Anik B. There are eight unoccupied slots at C-band, six of which have been coordinated, thus leaving only two which have not been coordinated. The positions coordinated for Latin American countries are likely to be available to U.S. domestic carriers provided that there is sufficient isolation between antenna beams for the systems which will operate in different hemishperes. Taking these factors into account, there are six slots available at this time for U.S. domestic satellite systems providing C-band coverage of CONUS. Ku-band slots are more available at this time with only 5 out of 19 slots presently coordinated. WARC decisions on the use of broadcast satellites will have an important impact on the availability of Ku-band slots.

5.2 Spacecraft Capacity Requirements

The service arc for coverage of CONUS with a minimum elevation angle of 10 degrees is about 74 degrees wide. With a four-degree spacing this permits 19 satellites in orbit. Part of the same service arc is also required for coverage of Canada and Latin America. At present the available antenna beam isolation for spacecraft antennas is adequate to permit sharing of the same orbital slot by North and South American countries, especially if satellite positions are interleaved. However, different slots must be used for satellites serving adjacent countries, such as the U.S. and Canada. At present there are probably 12 slots available for service to the U.S. with three slots used by Canada and four requested by South American countries.

At a time when advanced spacecraft with multi-beam antennas of the type described in Section 6 are used by all countries which share the service arc with the U.S., each country will have available the total number of slots.



*Satellite currently in orbit
**Numbers in parentheses are actual locations

Figure 5-1

ORBITAL ARC OCCUPANCY

Thus, at that time the number of slots available to the U.S. could be 19. It is understood that this would require agreement on the technical characteristics of the spacecraft, especially the antenna beam and frequency assignment plan. To be conservative, however, we have assumed that only 16 slots would be available. Based on the number of slots and on the service demand, the average required spacecraft capacity versus time can be determined. This information is shown in Table 5-3 and Figure 5-2.

Because of a number of factors, the actual utilization of in-orbit capacity will be lower than 100 percent. This implies that the design maximum capacity of the spacecraft in these slots will need to be higher than indicated. Some of the reasons for this inefficiency are:

> The use of some slots for TV distribution. This function is not compatible with the frequency reuse and switching provided for point to point communications.
>
> The operation of satellite systems by different entities. This results in the situation where Carrier 1 may be filled up, while (for some reason) Carrier 2 may not be able to fill his available transponders. All systems do not saturate at the same time.
>
> The uneven distribution of traffic. This causes areas of high traffic (such as New York City) to saturate well before areas of low traffic density (such as the West). While some allowance can be made in spacecraft construction for this tendency, it is not possible to forecast the future traffic patterns with sufficient accuracy to eliminate it entirely.

In an evolving system the spacecraft capacities vary. For example, at present there are both 12 transponder and 24 transponder spacecraft in orbit. The usable capacity is generally lower than the available capacity, because of the nature of the traffic distribution. The usable capacity of future TV distribution satellites will be lower than the usable capacity of point-to-point service satellites, which permit more frequency reuses.

A good general design guideline for new spacecraft would be to select a capacity that is at least as large as the required average capacity required at the end of the projected lifetime. In a more precise evaluation one would take into

Table 5-3

Required Average Spacecraft Capacity to Meet Service Demand

Mid-Year	Number of Slots Allocated	Total Service Demand In No. of Transponders		Average Spacecraft Capacity In No. of Transponders	
		Low Demand	High Demand	Low Demand	High Deman
1980	7	123	125	18	18
1981	7	156	159	23	23
1982	9	197	200	22	22
1983	12	259	264	22	22
1984	16	325	338	20	21
1985	16	413	473	26	30
1986	16	508	774	32	48
1987	16	615	1,584	38	99
1988	16	727	2,401	45	150
1989	16	840	3,620	53	226
1990	16	934	4,914	58	307
1992	16	1,144	7,304	72	457
1993	16	1,252	8,172	78	511
1994	16	1,361	9,081	85	568
1995	16	1,468	9,748	92	609

Note: Low demand includes voice and data traffic only.
High demand includes the above plus video conferencing.

Both include TV distribution.

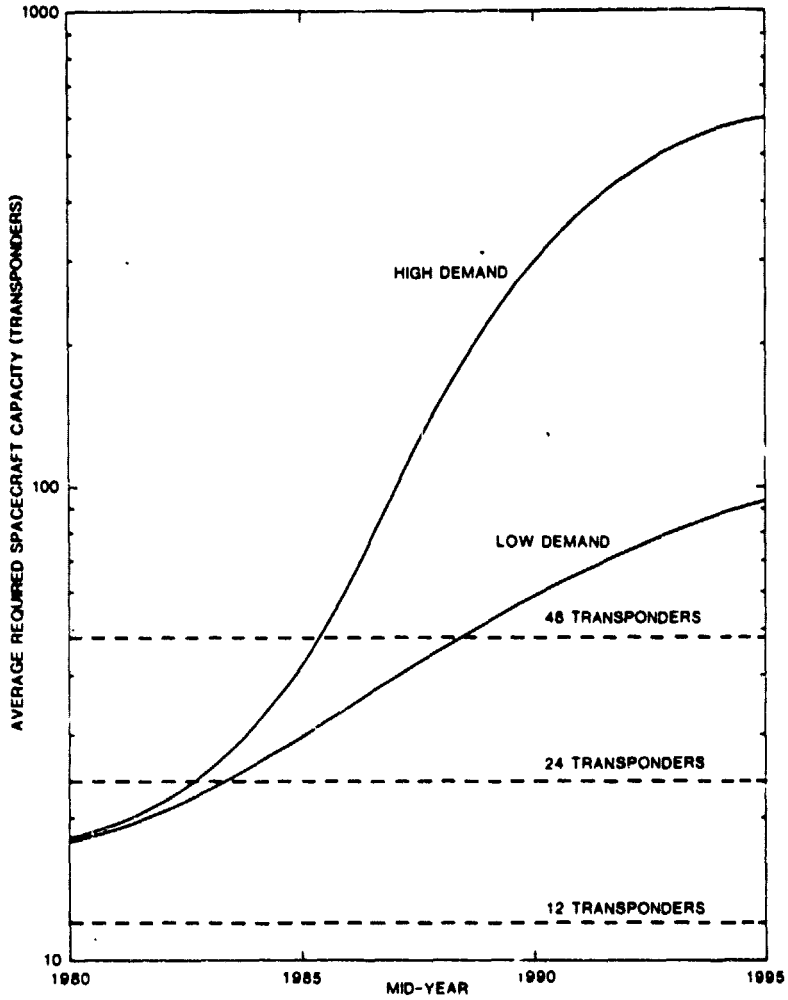


Figure 5-2
REQUIRED AVERAGE SPACECRAFT CAPACITY
TO MEET SERVICE DEMAND
(1980-1995)
(including TV distribution)

account the projected capacities and lifetimes of all satellites already in orbit or committed, and then calculate the incremental capacity required for new or replacement satellites.

Satellites operating in different frequency bands may be assigned to the same orbital locations. In this manner a systems capacity, for example, of 48 transponders at one location may be achieved by means of two separate satellites: one with 24 transponders at C-band and the other with 24 transponders at Ku-band. Alternatively, both frequency bands may be combined on the same satellite, leading to lower costs because of economies of scale and to better connectivity if the two frequency bands are cross-strapped.

Based on this analysis, new satellites to be introduced in the early 1980's should have capacities of about 48 transponders. Satellites introduced around 1985 should have at least 72 transponders. Capacities of much more than 72 transponders will not be easily achievable with conventional approaches. Therefore, in the high demand case the advanced satellite described in Section 6 should be operationally available around 1987. In the low demand case the advanced satellite would not be needed from an orbit use point of view until the early 1990's although systems economics will make its introduction desirable much earlier.

Generally, the sooner the advanced satellite is introduced, the sooner the system will benefit from the resulting economies. The efficient orbit utilization for point-to-point services will provide more orbital arc for TV distribution services.

5.3 Connectivity

The following approaches may be taken to achieve network connectivity when multiple satellites are used to provide coverage of a given area:

1. Multiple Earth Station Antennas

High capacity trunking earth stations can be equipped with several antennas, one for each satellite that is accessed directly. Since these earth stations carry high capacities, the cost per channel will be acceptable. However, this concept is not practical for low capacity stations and for urban environments with space limitations.

2. Multi-beam Torus Antennas

A single torus antenna equipped with multiple feeds may access several satellites. This concept works best when the satellite separation is small. The torus area and antenna expense increase for larger satellite separations. Each feed must be equipped with its own receive and transmit RC circuitry.

3. Segregation of Communities of Interest

It will be attempted to segregate communities of interest on separate satellites. This is possible for private corporate and government networks and for the public networks offered by specialized common carriers.

4. Intersatellite Links

Intersatellite links will be used to provide the required connectivity for residual traffic which was not satisfied by one of the above approaches. Intersatellite links lead to increased transmission delay as shown in Figure 5-3. For the maximum beam separation of 72 degrees for the U.S. service arc, this delay is still considerably less than for double hop transmission and will probably be acceptable for many applications. An attempt will be made, however, to allocate traffic so as to lessen the intersatellite link spacings.

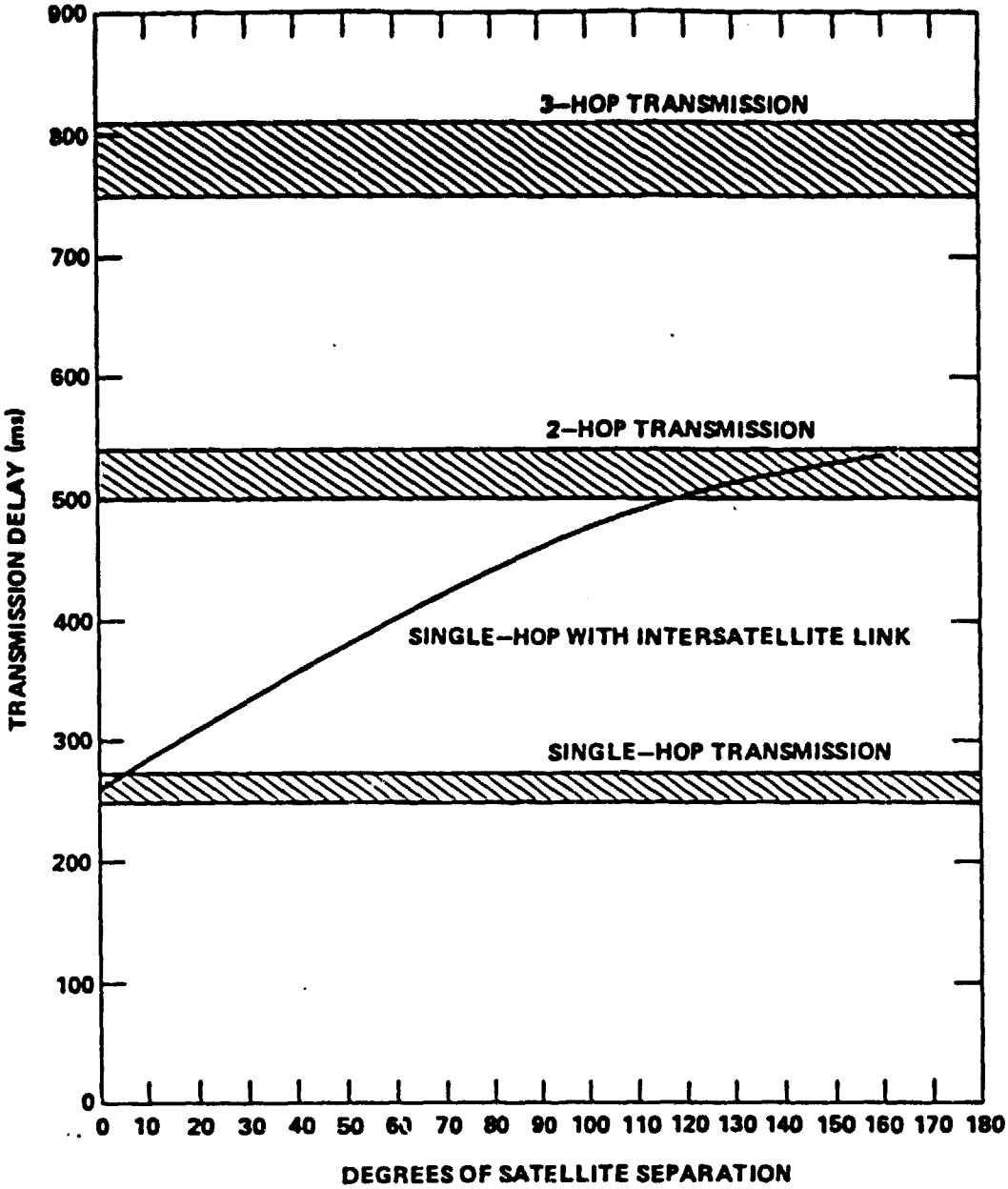


Figure 5-3

MULTI-HOP INTERSATELLITE LINK TRANSMISSION DELAY

SECTION 6
SPACECRAFT CONFIGURATION FOR SINGLE SHUTTLE LAUNCH

6.1 Background

NASA has already sponsored several studies aimed at defining spacecraft or platform configurations. Among those studies listed in Section 2 of this report, the following recent work has had the greatest impact on the selection of a configuration for an advanced satellite for use in U.S. domestic systems:

(a) General Dynamics "Geostationary Platform Systems Concepts Definition Study", Reference 10

(b) Mitre "Application of Advance On-Board Processing Concepts to Future Satellite Communications Systems", Reference 7

(c) Ford "Concepts for 18/30 GHz Satellite Communication System Study", Reference 2

(d) Hughes "18 and 30 GHz Fixed Service Communication Satellite System Study", Reference 4

(e) TRW "30/20 GHz Mixed Use Architecture Development Study", Reference 6

(f) FSI "Large Communications Platforms Versus Smaller Satellites", Reference 1

Major results of these studies have been used as a basis for the definition of spacecraft configurations for the advanced operational system.

The FSI study (Reference 1) developed an operational platform configuration based on LEO platform assembly from three Shuttle launches. This capability has been scaled back to a single Shuttle launch. The General Dynamics study (Reference 10) is still underway. Results from the second interim report covering weight and power budgets for single Shuttle launch have been used as an input to the operation configuration. The Mitre study (Reference 7) has made important contributions to the understanding of communications spacecraft switch design, which is a major technology problem. Ford, Hughes, and TRW (References

2, 4, and 6) have studied 30/20 GHz satellite communications systems concepts for trunking, direct-to-the-user, and for mixed applications. Results from these studies have been used as references for the development of weight and power budgets, estimates of communications capability, and for technology evaluation.

Figure 6-1 is the block diagram of the communications subsystem that had been developed by FSI in its earlier study (Reference 1). It was largely intended to show the general switch architecture that might be used on a large platform for an arbitrary mix of communications requirements. Meanwhile, SS/TDMA and baseband switching have been analyzed by Ford, Hughes, TRW, and MITRE (References 2, 4, 6, and 7), and some of the results are summarized below.

Mitre concluded that a digital processor capable of performing high speed switching of multiple T1 and T2 channels may be feasible in the 1990 to 2000 time frame and that extensive technology development is needed in various areas. For a 100 x 100 RF switch, Mitre proposes a design goal equal to 4 percent of the Bell System 4-ESS, or about 10,000 lbs. (4,500 kg) and 20 kW. Compared with this, the earlier FSI allocation for the switch and transponder electronics was 2,500 kg and less than 10 kW.

TRW describes an SS/TDMA system with 18 fixed beams and a scanning beam system. An SS/TDMA switch matrix is provided, and in addition, the scanning beam is associated with baseband processing with 3 GBps throughput. TRW's power allocation for the switch and digital processor is 475 watts, and the total communications weight is 638 kg.

Thr Ford direct-to-the-user system includes a 25 x 25 baseband switch with 3.75 GBps throughput. The power allocation for the switch and other communications subsystems excluding the power amplifiers is 509 watts and the total communications subsystem weight is 435 kg.

Hughes estimates that a 32 x 32 RF switch matrix would weigh 64 lbs., and a 64 x 64 matrix would weigh 512 lbs. For a 25 beam direct-to-the-user satellite, Hughes estimates a repeater weight of 667 kg and a power of 9,620 watts. The weight and power for the switch is only a small portion of the above allocation.

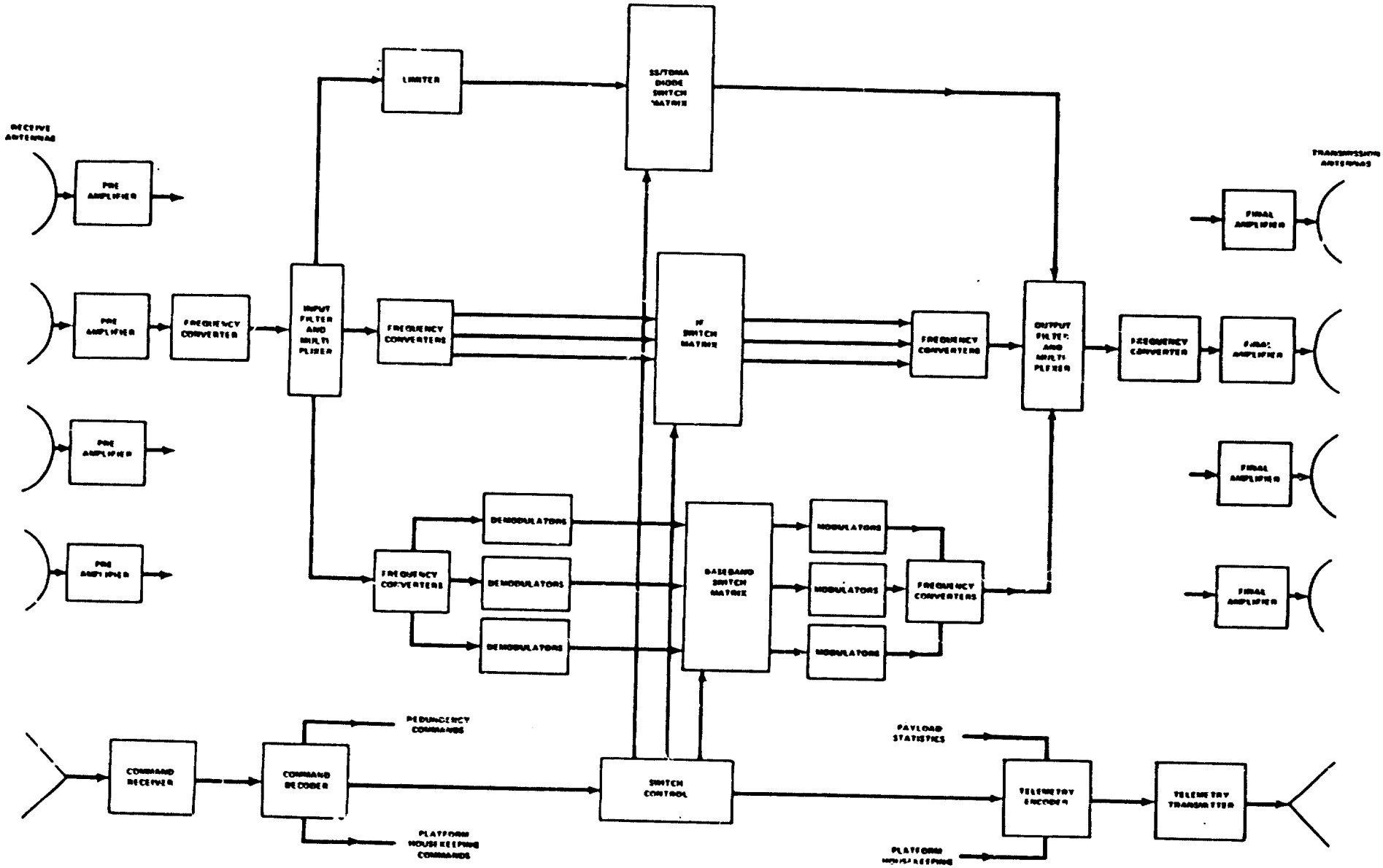


Figure 6-1
GENERAL COMMUNICATIONS SUBSYSTEM BLOCK DIAGRAM
FOR LARGE PLATFORMS

6.2 System Architecture

FSI's selection of systems architecture for the Advanced Domestic Satellite (ADS) was based on the following considerations:

1. Weight, Volume, and Power Constraints

   The requirement for single Shuttle launch leads to reduced weight, volume, and power allocations relative to FSI's platform configuration (Reference 1).

2. Implementation Time Frame

   Based on orbital arc constraints, an operational system should be available by around 1987. This dictates more modest technology objectives than would be possible with later implementation.

3. Traffic Distribution

   Traffic distribution is an important input for the selection of systems architecture. Transmission bandwidth requirements for data, voice, and video conferencing will be in the ratio of 1 to 10 to 100. Video conferencing will develop in the most heavily populated areas first, and therefore, a "cream skimming" approach is practical.

4. Availability Requirements

   Severe propagation attenuation at the 30/20 GHz frequencies leads to transmission diversity requirements for voice and data services. Space diversity is expensive for low and medium capacity earth stations, and frequency diversity (Reference 1) would place a too demanding requirement on a first generation spacecraft switch for single Shuttle launch application. Voice and data services will therefore be provided primarily at C-band and Ku-band. Ku-band will be used primarily for video conferencing with an operating arrangement as described in Section 6.3.

5. TV Distribution Services

   The ADS emphasizes high capacity by means of multiple spot beams and frequency reuse. Flexible interconnectivity is obtained by on-board switching. A TV distribution system has different requirements in terms of area or time zone coverage with fixed uplinks and remote uplinks. The same spacecraft bus can undoubtedly be used for these requirements, but the communications subsystem will be different. In this study we have concentrated on the more complex point-to-point transmission requirements, and TV distribution has not been covered in the systems design

The resulting spacecraft systems architecture is based on a reduced number of beams for area coverage at C-band and Ku-band, and selective spot beam coverage at Ka-band. For simplicity and reliability baseband switching is not used on the first generation ADS, but it is expected that baseband switching will be introduced on later spacecraft generations. An SS/TDMA transmission system is used for high density trunk traffic, and IF switching at T-2 transmission rates provides connectivity for T-2 trunks, low rate TDMA systems, and video conferencing. The communications subsystem block diagram is shown in Figure 6-2.

Each spot beam is associated with its own receive and transmit feed, low noise amplifier, output amplifier, and frequency converters. The frequency band is divided as appropriate into two subbands: one for SS/TDMA operation, and the other for multiple T-2 operation (6.3 MBps). The system contains one frequency converter for each T-2 stream, and IF switching is greatly simplified through the use of frequency synthesizers which transpose the T-2 signal to the required relative frequency within the transponder band. This arrangement is similar to the well-known INTELSAT SPADE system or the domestic demand assigned SCPC systems.

Figure 6-3 shows the Conus beam coverage as seen from the satellite. In our previous design for a communications platform with three Shuttle launches, we provided the same area coverage for Ka-band. This was demanding on primary power because of the large transmission bandwidth and precipitation attenuation margin required. To reduce weight and power requirements we have reduced the Ka-band coverage to spot beams for major city coverage. The Ka-band coverage is shown in Figure 6-4.

6.3 East Coast Satellites

Prior FSI studies (Reference 1) showed that spacecraft saturation tends to occur in the antenna beams covering the triangle formed by Boston, Chicago, and Washington. When it becomes necessary to increase the systems capacity in the slots available within the CONUS service arc, we propose to allocate satellites further east (which requires coordination with INTELSAT), to offload some of the

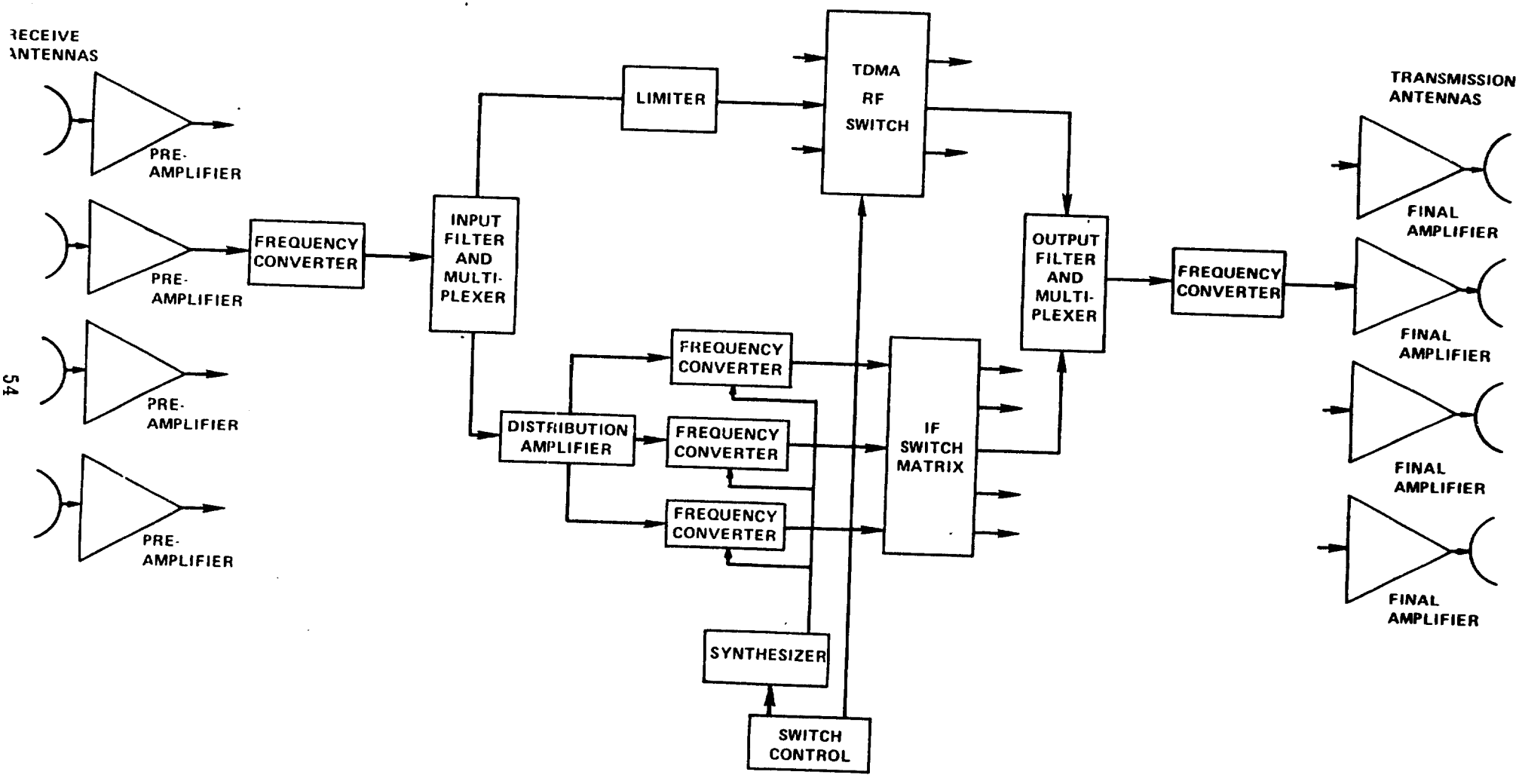


Figure 6-2
COMMUNICATIONS SUBSYSTEM BLOCK DIAGRAM FOR SINGLE SHUTTLE LAUNCH

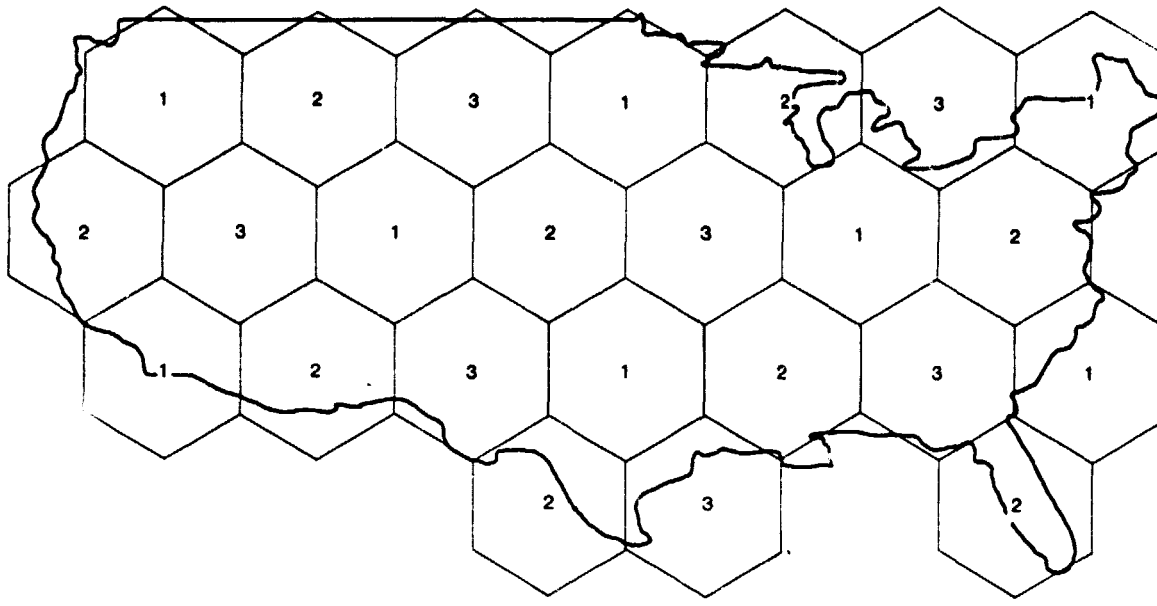


Figure 6-3
SPOT BEAM ANTENNA COVERAGE OF CONUS
(Numbers 1, 2, 3 indicate freguency assignment)

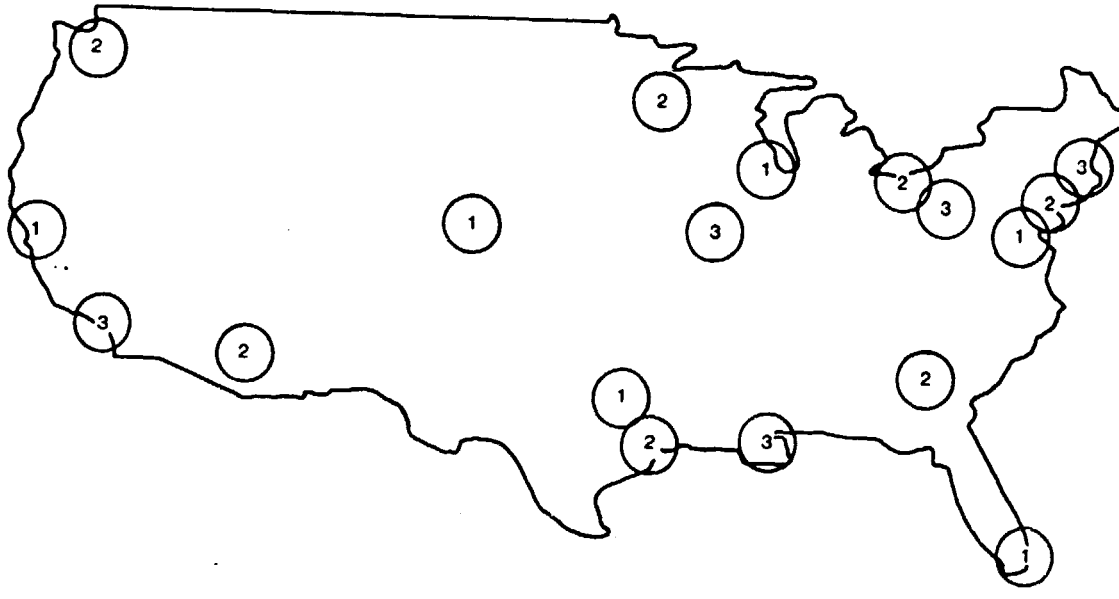


Figure 6-4
KA-BAND COVERAGE AND FREQUENCY ASSIGNMENT

dense East Coast traffic. These satellites will achieve full CONUS coverage only via intersatellite links, but at any rate a large traffic percentage will remain within the East Coast area. The same principle may be used to offload the Los Angeles - San Francisco area, when this becomes necessary.

East Coast satellites may be identical to the full CONUS satellites but with squinted antenna beam pointing, or they may be of a special design to provide coverage only for the high traffic areas, as shown in Figure 6-5.

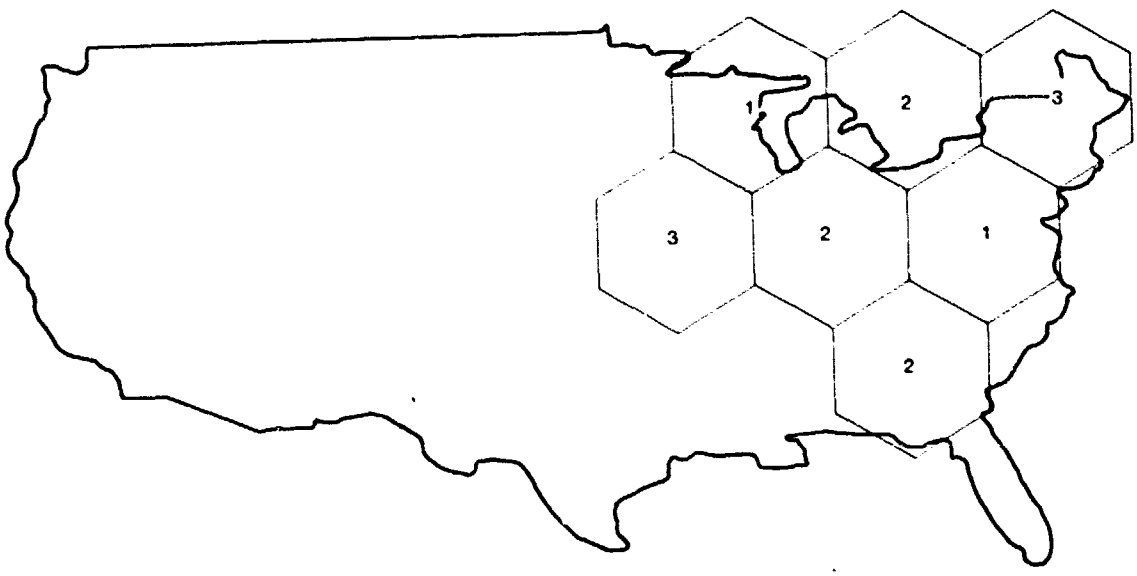


Figure 6-5

HIGH-TRAFFIC AREA COVERAGE OF
EAST COAST SATELLITE
(Numbers 1, 2, 3 indicate frequency assignment)

6.4 Frequency Bands Used

Based on the frequency band assignments made at the 1979 WARC, we have assumed that the frequency bands shown in Table 6-1 will be used in the ADS System. The available allocations and WARC 1979 results are shown in Figure 6-6.

Table 6-1
Frequency Band Assignments

Uplink Band MHz	Downlink Band MHz	Available Bandwidth MHz	Equivalent Number of Transponders
5,925-6,725	3,400-4,200	800*	20
{12,750-13,250 14,000-14,500}	11,200-12,200	1,000*	24
27,500-30,000	17,700-20,200	2,500	60
TOTAL		4,300	104

*Dual polarization is used in some beams at these frequencies, thus doubling the available bandwidths and number of equivalent transponders.

WARC 1979 set the allocation for the frequency band covering 10.7 GHz to 11.7 GHz as international use only. We have assumed that one-half of this, or 500 MHz, will become available for domestic use. At best, all 1000 MHz would be available, and there is a possibility that none will be allocated. We have chosen a middle course.

6.5 Traffic Assignment and System Capacity

Figures 6-7 and 6-8 show the traffic assignment to the different beams and frequencies in the all-CONUS system. In a similar manner, Figures 6-9 through 6-12 show the traffic assignments for the system with offloading to an East Coast satellite. Table 6-2 summarizes the capacities and loading of the two systems. The traffic divisions were all based on the population density and the telephone density in major cities.

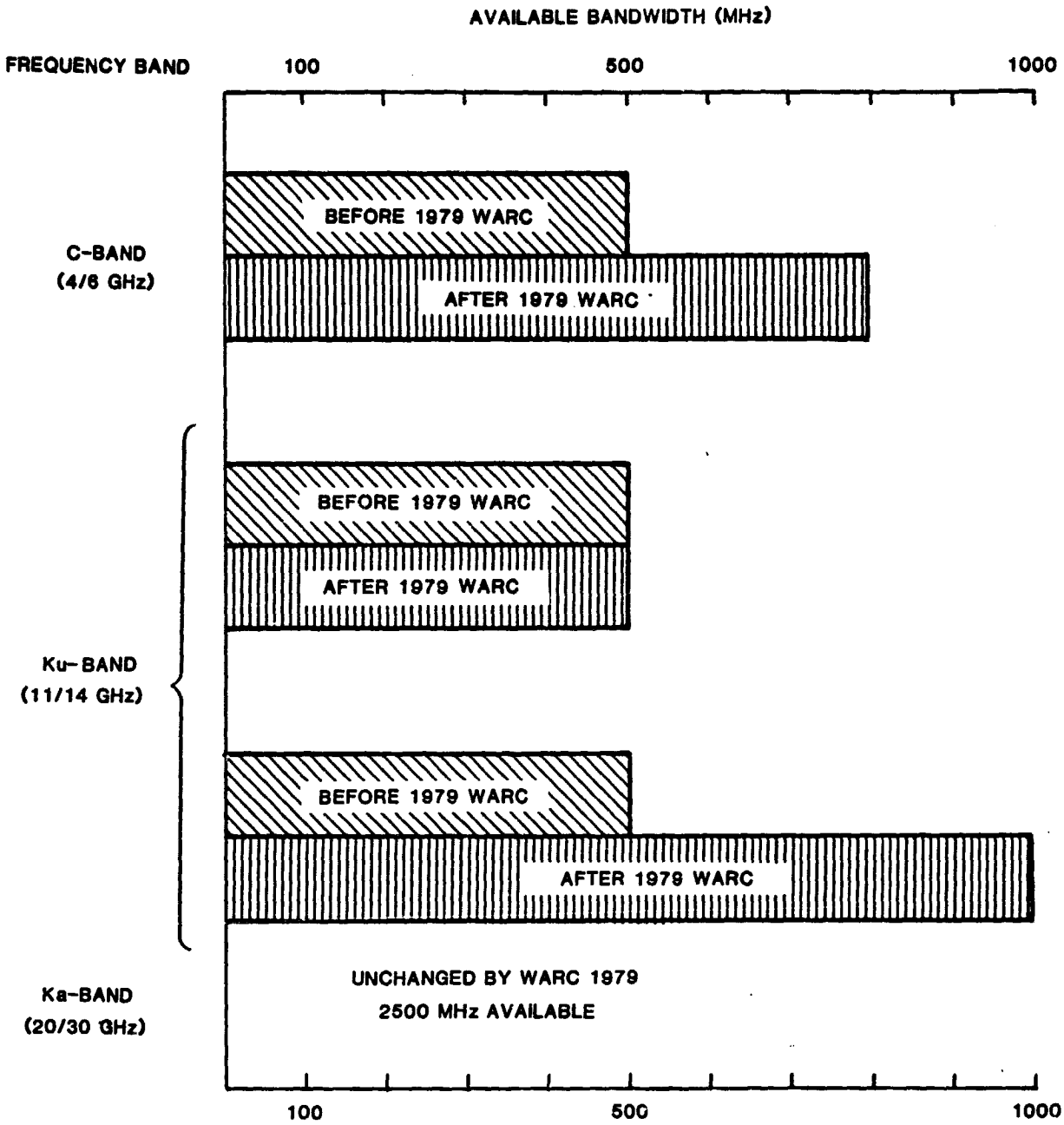


Figure 6-6

EFFECTS OF 1977 WARC ON FIXED SATELLITE ALLOCATIONS

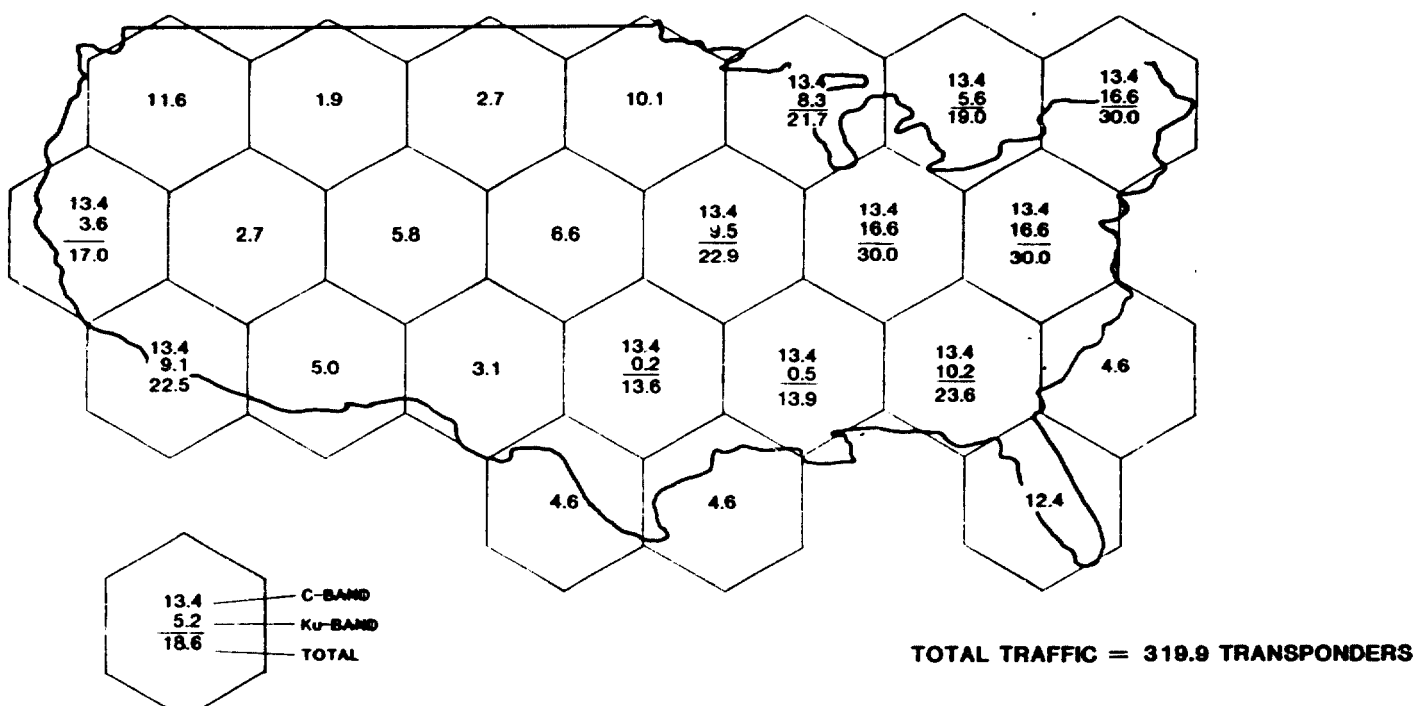
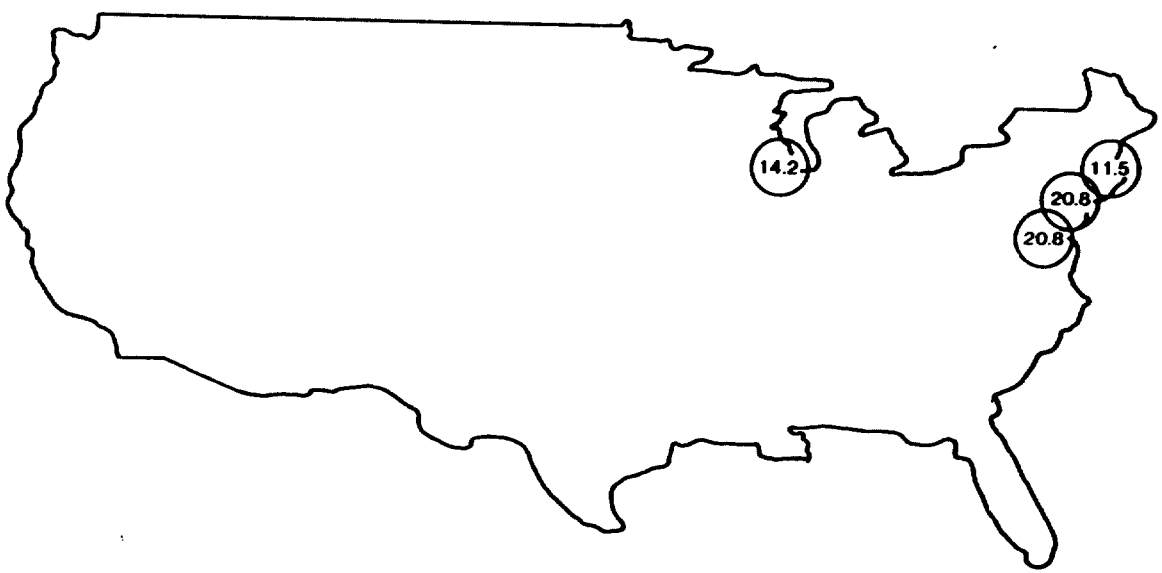


Figure 6-7

TRAFFIC AT C-BAND AND Ku-BAND ONLY ALL-CONUS SYSTEM

(36 MHz Transponders)



TOTAL TRAFFIC = 67.3 TRANSPONDERS

Figure 6-8
TRAFFIC AT Ka-BAND ONLY
(36 MHz Transponders)
ALL-CONUS SYSTEM

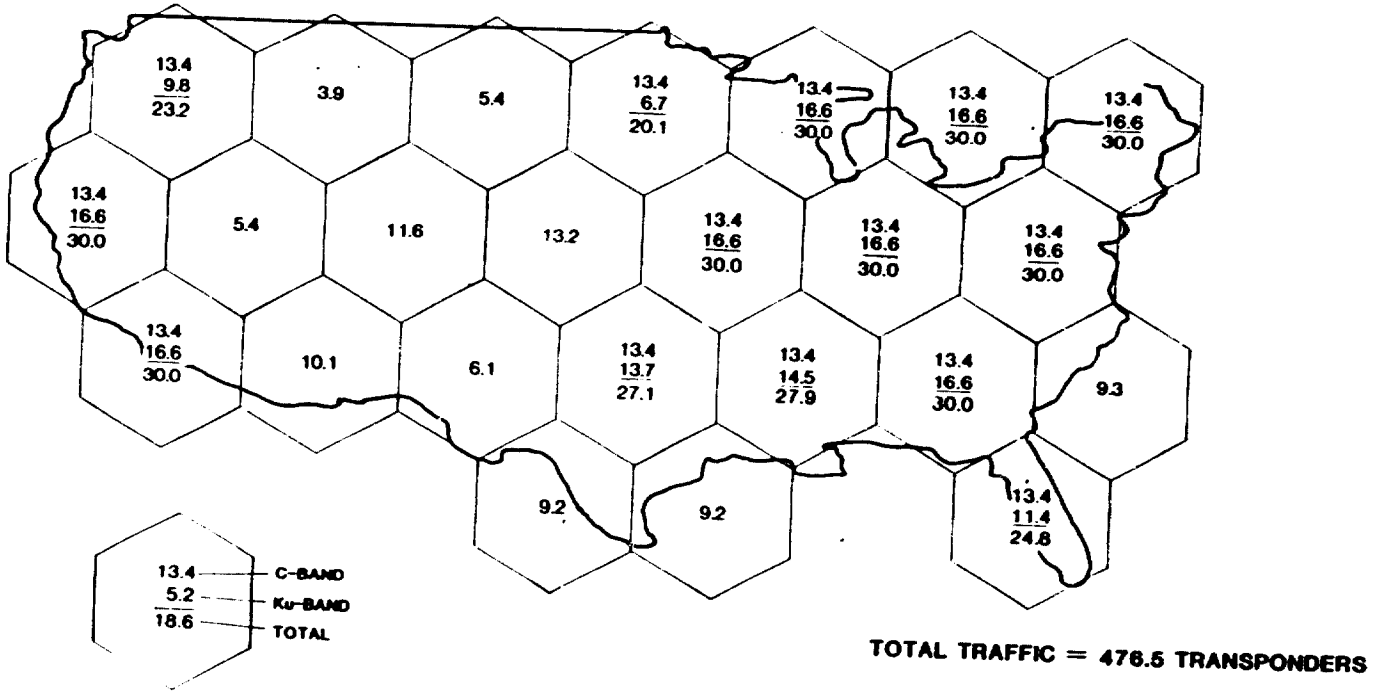
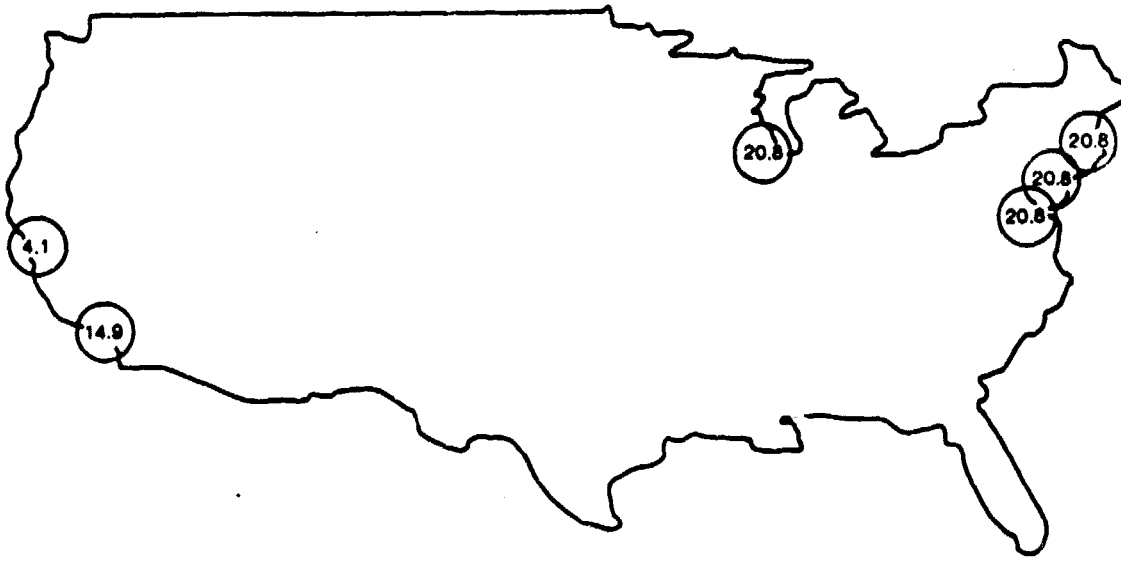


Figure 6-9

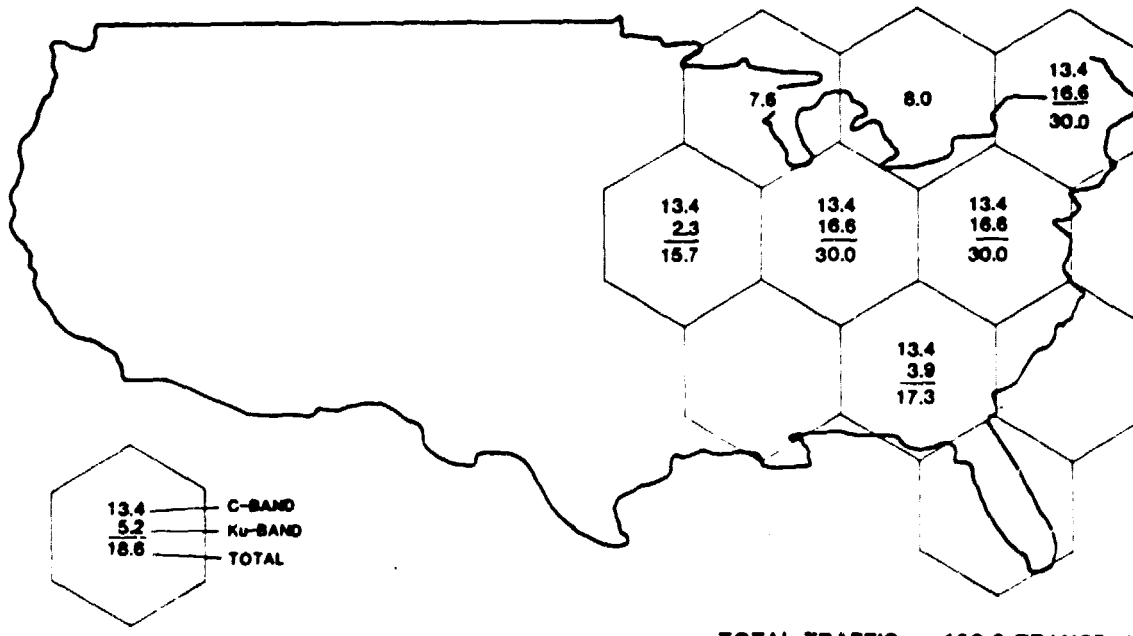
TRAFFIC ON PRIMARY PATH SATELLITE AT C-BAND AND Ku-BAND ONLY OFFLOADED SYSTEM

(36 MHz Transponders)



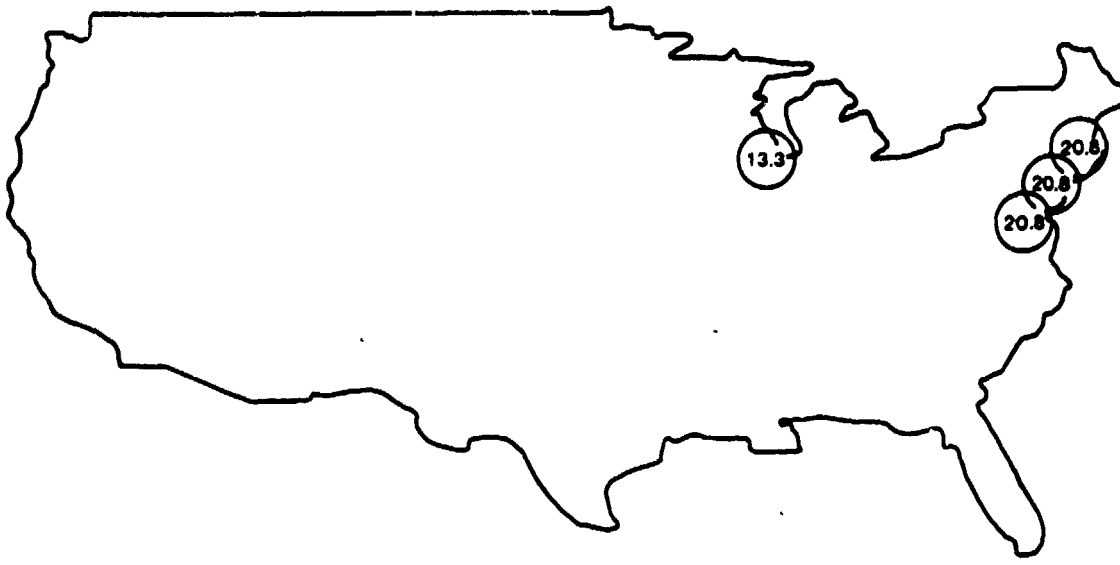
TOTAL TRAFFIC = 102.2 TRANSPONDERS

Figure 6-10
TRAFFIC ON PRIMARY SATELLITE AT Ka-BAND
(36 MHz Transponders)
OFFLOADED SYSTEM



TOTAL TRAFFIC = 138.6 TRANSPONDERS

Figure 6-11
TOTAL TRAFFIC ON EAST COAST SATELLITE AT C-BAND AND Ku-BAND ONLY
(36 MHz Transponders)
OFFLOADED SYSTEM



TOTAL TRAFFIC = 75.7 TRANSPONDERS

Figure 6-12
TRAFFIC ON EAST COAST SATELLITE AT Ka-BAND
(36 MHz Transponders)
OFFLOADED SYSTEM

6.6 Space Shuttle Launch Considerations

This section examines the capabilities of the STS, and the charging philosophy adopted by NASA for Shuttle flights.

Capabilities

The Shuttle has a payload capacity of 65,000 pounds to low earth orbit. The cargo bay is 60 feet in length and 15 feet in diameter.

Table 6-2

Examples of High Capacity Domestic Satellites for CONUS

	All CONUS System	Offloaded System: CONUS Satellite	Offloaded System: East Coast Satellite
Number of Spot Beams*			
4/6 GHz	38	44	14
11/14 GHz	17	27	8
18/30 GHz	4	6	4
Total	59	77	26
Number of 500 MHz Bands			
4/6 GHz	20.3	23.5	7.5
11/14 GHz	11.3	18	5.3
18/30 GHz	6.7	10	6.7
Total	38.3	51.5	19.5
Theoretical Capacity (Transponders)			
4/6 GHz	243.6	282	90
11/14 GHz	135.6	216	64
18/30 GHz	80.4	120	80.4
Total	459.6	618	234.4
Usable Capacity (Transponders)			
4/6 GHz	223.1	271.1	82.6
11/14 GHz	96.8	205.5	56
18/30 GHz	67.3	102.2	57.1
Total	387.2	578.8	195.7
Fill Factor (Percent)			
4/6 GHz	92	96	92
11/14 GHz	71	95	87
18/30 GHz	84	85	71
Average	84	94	83

*includes dual-polarization, where used, as additional beams

The basic capability will remain at 65,000 pound load into low earth orbit of 160 nautical miles. The early flights during 1980 and 1981 will have a significantly lower weight capability. Subsequent flights will offer gradual upgrading, first, by operating the Space Shuttle main engine at higher thrust rating and later by the addition of a light weight external tank and then a lighter weight orbiter. For the time period of 1985 and later, it is expected that thrust augmentation by means of solid rocket booster strap-ons will increase the basic payload weight capability to 70,000 or even 85,000 pounds. This increased weight, however, is not usable for geostationary missions since the Shuttle landing capability is not likely to increase above 65,000 or 70,000 pounds. Any of the flights must be capable of being aborted at their early stages and accordingly, the landing capability will be one of the limiting factors. For these reasons, it was agreed that a weight capability of 65,000 pounds will be used in the FSI studies for missions in the late 80's and early 90's.

Figure 6-13 illustrates the STS capability evolution as currently envisioned.

One of the results of the work performed by General Dynamics has been that communications payloads will be volume rather than mass limited on the STS. This is especially so when the payload does not include the transfer vehicle, but also holds for single-Shuttle launches. This is mainly due to the need for deployable structures such as antennas and associated masts and feed assemblies. Such structures cannot presently achieve a packing density high enough to escape the volume limitation.

Costs

The Shuttle price is $18 million plus $4.2 million for commercial users. The $18 million is in 1975 dollars and must be escalated to the time at which each of the progress payments is being made. The $4.2 million is a fixed charge, not subject to escalation. The charge for government users is the same except that the $4.2 million is not applicable. It is expected that the Shuttle price will be adjusted

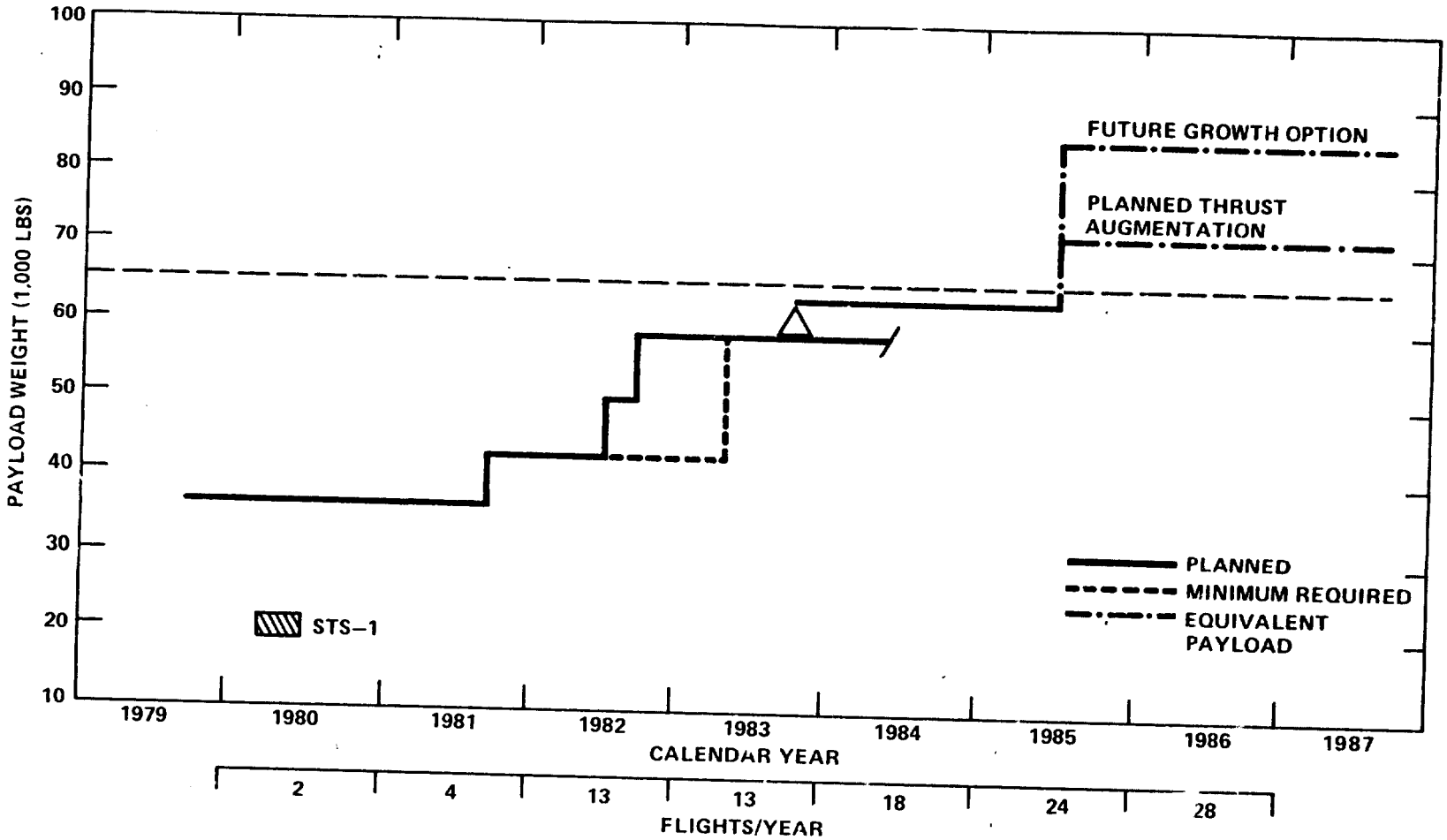


Figure 6-13
SPACE SHUTTLE CAPABILITY EVOLUTION

Source: NASA Headquarters

after the fourth year of operation. Initial estimates were based on a total of 460 flights over a 12-year period peaking at about 50 flights per year.

Table 6-3 shows the schedule of progress payments to NASA for various lead times. Figure 6-14 illustrates the method used to calculate the charge factor if less than the full Shuttle is used.

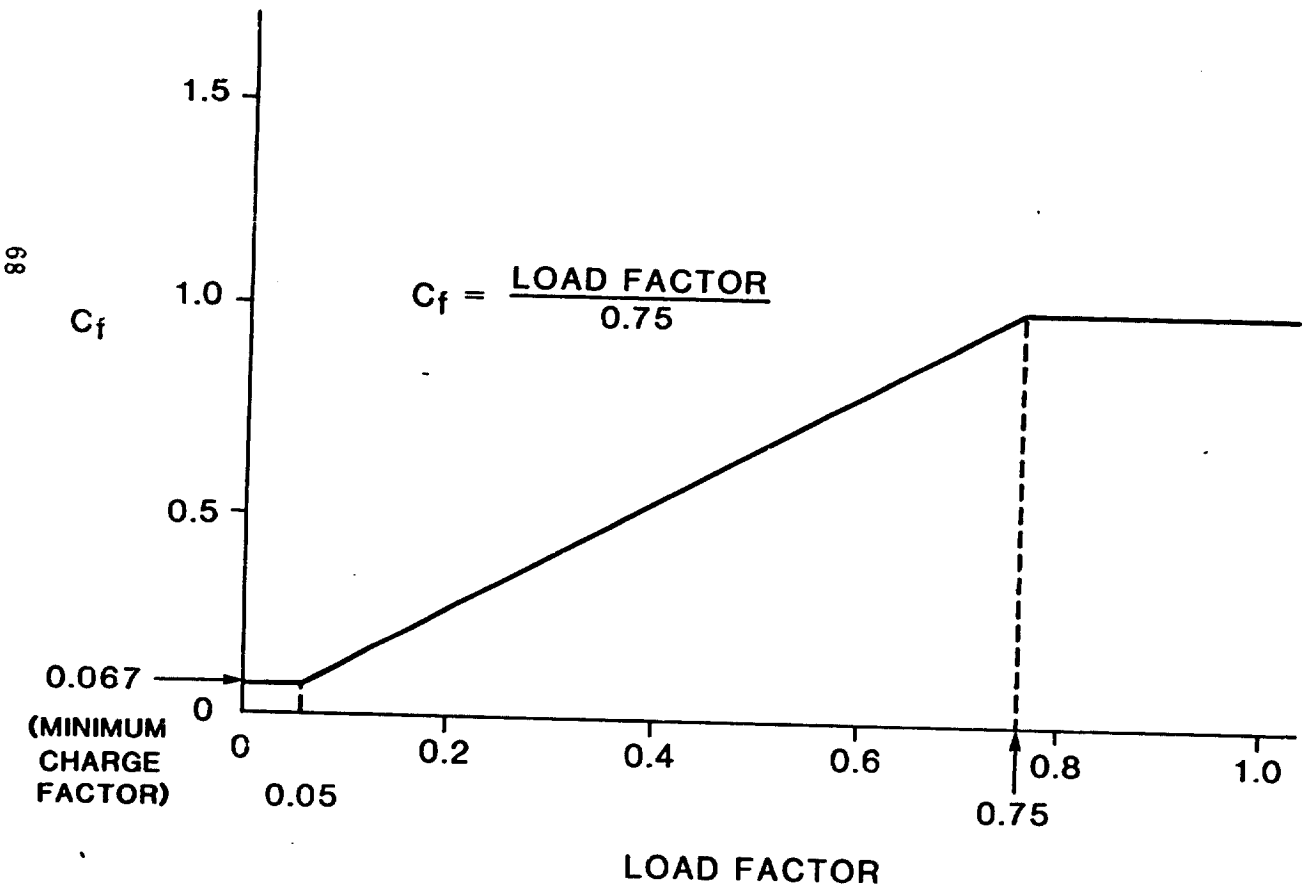
The first Shuttle flight is now expected for June 1980 as a test flight. The first operational flight which will launch TDRSS 1 will take place between July and September 1981. The second orbiter will becomes available in September 1982.

Table 6-3
Reimbursement Schedule

Number of months before launch flight is scheduled	Percent of Price					
	Months prior to scheduled launch date					
	33	27	21	15	9	3
33 Months or More	10	10	17	17	23	23
27-32 Months	-	21	17	17	23	23
21-26 Months	-	-	40	17	23	23
15-20 Months	-	-	-	61	23	23
9-14 Months	-	-	-	-	90	23
3-8 Months	-	-	-	-	-	122

$$\text{PRICE} = C_f \times \text{DEDICATED PRICE}$$

$$\text{LOAD FACTOR} = \left\{ \begin{array}{l} \dfrac{\text{PAYLOAD WEIGHT, LBS.}}{\text{SHUTTLE CAPACITY}} \\[2ex] \dfrac{\text{PAYLOAD LENGTH, FT.}}{60} \end{array} \right\} \text{WHICHEVER IS GREATER}$$



SHUTTLE CAPABILITY	
Inclination in Degrees	Weight in Thousands of Pounds
28.5	65
56	57
90	37
104	30

Source: NASA Headquarters

Figure 6-14

DETERMINATION OF CHA

The minimum turn-around time of the Shuttle is 230 hours for nominal missions. This does not include time required for unique changes or periodic maintenance. Typical turn-around times for each orbiter initially will be 4 to 5 weeks. Through 1984 it is expected that each orbiter will provide about 10 flights. After some operational experience it can be expected that basic turn-around times would be reduced to less than 200 hours by curing certain bottlenecks which will require some design changes in the launch pad facilities.

Upper Stages

Several types of upper stages with varying capabilities are planned for use with the Shuttle. Among these are the Inertial Upper Stage, (IUS) and possibly the Centaur.

The IUS which is being built by Boeing for the Air Force has a weight lifting capability of 5,000 pounds in synchronous orbit. It uses various combinations of solid rocket engines with inertial control.

Special combinations of solid stage rockets are used for planetary missions and some optimization may be possible to increase the weight lifting capability also for geostationary orbit.

The present costs for the IUS, turn-key including all services, is estimated at $16 million for a 1981 launch in then-years dollars. No policy has been established yet for payment schedules. On a typical IUS launch it can be expected that an additional $1 million may apply in optional charges for special payload requirements. Costs past 1981 should be inflated.

Due to the high thrust provided by the solid-fuel motors, the IUS is not well suited for structures deployed at LEO. The structures would need to be considerably strengthened to withstand the relatively high acceleration.

Studies have been conducted by NASA for the use of the Centaur as an upper stage. The Centaur should be able to provide a capability of 10,000 to 12,000 pounds of payload in geostationary orbit. Estimates of unit costs are $20 million in 1980 dollars.

6.7 Spacecraft Characteristics

The spacecraft weight and power budget is shown in Table 6-4. Where available, a comparison is made with other design studies. Major characteristics of ADS are shown in Table 6-5.

6.8 Offloaded System*

The traffic handling capacity of the offloaded system is higher, and more physical transponders are required aboard the spacecraft. The major characteristics of the Primary ADS and the East Coast satellite are shown in Tables 6-6 and 6-7. The total spacecraft power and weight will need to be increased for the offloaded system. With careful design, this increase should still be within the single-Shuttle launch constraints. An advanced transfer vehicle will probably be needed.

6.9 Cost Estimates

We have used the SAMSO model to calculate the development and recurring costs for the ADS spacecraft. These numbers must be regarded with some caution for several reasons. First, the weight and power of the ADS exceed those of even the largest satellite used in the SAMSO data base. Second, the SAMSO model is slightly weighted toward noncommunications satellites, and third, the development cost does not take into account the additional technology advances needed for ADS.

The cost estimates are shown in Table 6-8 along with estimates for other related satellite projects.

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* Excess traffic is offloaded onto additional satellites over the Atlantic Ocean, which do not have full CONUS visibility. Connectivity is established by means of intersatellite links.

Table 6-4

U.S. Domestic Platform/Satellite Mass and Power Comparison

Item	NASA/ MSFC	Edelson/ Morgan	Previous FSI Model	18/30 GHz Only				GD Concept #1	ADS
				Hughes Trunking	Hughes DTU	Ford Trunking	Ford DTU		
Mass (kg)									
Antennas and Feeds			500	217	23	*	*	*	200
Transponder Electronics and Switching Equipment			2,500	212	667	*	*	*	1,150
Total Communications System	2,050	2,210	3,000	429	690	206	435	1,387	1,350
Power Supply Subsystem	1,220	1,247	1,190	183	911	101	218	473	700
Thermal Control		350	300	*	*	*	*	177	170
Attitude/Reaction Control	1,691	779	1,630	265	273	121	108	880	800
Telemetry and Command	186	90	100	58	29	23	23	200	100
Mission Support Structure	500	600	500	*	*	*	*	*	220
Main Structure	2,342	930	1,200	979	964	102	214	1,167	1,100
Total BOL Mass	7,989	6,206	7,920	1,914	2,867	679	1,203	4,718	4,440
Power (kW)									
Total EOL Power	15	20	17	0.4	12	1	3.2	7.5	11
Total BOL Array Capability	20	28	26						15
Solar Array Area, m^2	165	235	213						130

*included in other items

Table 6-5

Major Characteristics of ADS

Antennas

C-band	1 - 6 meters transmit 1 - 4 meters receive
Ku-band	1 - 2.5 meters transmit 1 - 2.0 meters receive
Ka-band	3 - 3 meters transmit 3 - 2 meters receive

Receiver Electronics (Wideband, one per beam per polarization)

38 at C-band, G/T = 10 dB/K
17 at Ku-band, G/T = 7 dB/K
4 at Ka-band, G/T = 10 dB/K

Power Amplifiers (one per physical transponder)

72 at C-band, 5 watts each
28 at Ku-band, 36 watts each
17 at Ka-band, 35 watts each

Switching Network

SS/TDMA RF Switch - 25 x 25

Multi-carrier IF Switch - 100 inputs x 100 outputs with 6.3 MBps switching blocks.

Power Budget

Transponder Electronics	1	kW
Power Amplifiers	5.5	kW
Switching	3	kW
Spacecraft Power	0.5	kW

Intersatellite Link

Frequency: 23 GHz
32 GHz

Communication with one or two other satellites in geostationary orbit.

Table 6-6

Major Characteristics of ADS with Offloading

(Primary Satellite)

Antennas

C-band	1 - 6 meters transmit 1 - 4 meters receive
Ku-band	1 - 2.5 meters transmit 1 - 2.0 meters receive
Ka-band	3 - 3 meters transmit 3 - 2 meters receive

Receiver Electronics (Wideband, one per beam per polarization)

44 at C-band, G/T = 10 dB/K
27 at Ku-band, G/T = 7 dB/K
6 at Ka-band, G/T = 10 dB/K

Power Amplifiers (one per physical transponder)

85 at C-band, 5 watts each
52 at Ku-band, 36 watts each
25 at Kaband, 35 watts each

Switching Network

SS/TDMA RF Switch - 25 x 25

Multi-carrier IF Switch - 140 inputs x 140 outputs with 6.3 MBps switching blocks.

Power Budget

Transponder Electronics	1.3	kW
Power Amplifiers	10	kW
Switching	4	kW
Spacecraft Power	0.5	kW

Intersatellite Link

Frequency: 23 GHz
32 GHz

Communication with one or two other satellites in geostationary orbit.

Table 6-7

Major-Characteristics of East Coast Satellite

Antennas

C-band	1 - 6 meters transmit 1 - 4 meters receive
Ku-band	1 - 2.5 meters transmit 1 - 2.0 meters receive
Ka-band	3 - 3 meters trasmit 3 - 2 meters receive

Receiver Electronics (Wideband, one per beam per polarization)

14 at C-band, G/T = 10 dB/K
8 at Ku-band, G/T = 7 dB/K
4 at Ka-band, G/T = 10 dB/K

Power Amplifiers (one per physical transponder)

26 at C-band, 5 watts each
14 at Ku-band, 36 watts each
15 at Ka-band, 35 watts each

Switching Network

SS/TDMA RF Switch - 10 x 10

Multi-carrier IF Switch - 45 inputs x 45 outputs with 6.3 MBps switching blocks.

Power Budget

Transponder Electronics	0.5	kW
Power Amplifiers	3.5	kW
Switching	1	kW
Spacecraft Power	0.5	kW

Intersatellite Link

Frequency: 23 GHz
32 GHz

Communication with one or two other satellites in geostationary orbit.

Table 6-8

Costs of Advanced Satellites

(Millions of 1980 Dollars)

Satellite	Development Cost	Unit Cost
NASA/MSFC Platform	78	89
Edelson/Morgan	78	89
Previous FSI Design	137	107
Hughes 18/30 Trunking	31	30.3*
Hughes 18/30 DTU	36.5	58.1*
Ford 18/30 Trunking	60	30.6*
Ford 18/30 DTU	85	54 *
General Dynamics Concept #1	(not available)	
Current FSI ADS	150	98

*includes profit and incentives; average for 3 spacecraft

Launch costs are not included.

6.10 Transmission Link Calculations

Tables 6-10 and 6-11 present sample link calculations for 250 MBps and 6.3 MBps transmissions. The modulation in all cases is 4-phase PSK with rate 7/8 coding. The link noise budget is shown in Table 6-9.

Table 6-9
Noise Budget

Theoretical E_b/N_o for uncoded 4-phase PSK at a bit error rate of 10^{-4}	8.6	dB
Modem implementation margin	1.0	dB
Intersymbol distortion	3.0	dB
Coding gain for rate 7/8 forward error control coding	2.4	dB
Practical E_b/N_o for 4-phase PSK with rate 7/8 coding at a bit error rate of 10^{-4}	10.2	dB
Bandwidth to baud ratio	1.12	
Carrier-to-noise ratio in the receiving bandwidth for a bit error rate of 10^{-4}	12.7	dB
Uplink carrier-to-noise ratio	20	dB
Downlink carrier-to-noise ratio	15	dB
Adjacent beam carrier-to-noise ratio	20	dB
Other interference carrier-to-noise ratio	25	dB

Table 6-10

Sample Transmission Link Budgets for a 250 Mbps PSK Carrier

Downlink

		Frequency Band, GHz		
		4/6	11/14	18/30
Satellite transmit RF power	Watts	5	35	35
	dBW	7	15.6	15.4
Line losses	dB	0.5	0.5	0.5
Minimum antenna gain for specified coverage	dB	39	39	43
Minimum platform transmit EIRP	dBW	45.5	53.8	57.9
Free space path loss at 30 degree elevation	dB	196.2	205	209.2
Transmission link margin	dB	3	7	10
Minimum flux density at the surface of the earth	dBW/m^2	-116.7	-114.8	-110.7
Earth station antenna diameter	m	4.5	4.5	4.5
Earth station antenna gain	dB	43.3	52.1	56.4
Receive system noise temperature	K	155	385	500
Earth station G/T	dB/K	21.4	26.2	29.4
Receive noise bandwidth	MHz	130	145	145
Downlink carrier-to-noise ratio	dB	15	15	15

Table 6-10, Continued

Sample Transmission Link Budgets for a 250 Mbps PSK Carrier

Uplink

		Frequency Band, GHz		
		4/6	11/14	18/30
Earth station transmit RF power	Watts	140	1100	3300
	dBW	21.4	30.2	35.1
Line losses	dB	1.0	1.0	1.0
Antenna diameter	m	4.5	4.5	4.5
Antenna gain	dB	46.8	54.2	60.8
Earth station transmit EIRP	dBW	67.2	83.4	94.9
Free space path loss at 30 degree elevation	dB	199.6	207	213.7
Transmission link margin	dB	3	10	15
Flux density at the satellite	dBW/m^2	-98.4	-87.1	-83.1
Minimum antenna gain for specified coverage	dB	39	39	43
Receive system noise temperature	K	1150	2200	3000
Satellite G/T	dB/K	8.4	5.6	8.2
Receive noise bandwidth	MHz	130	145	145
Uplink carrier-to-noise ratio	dB	20	20	20

Table 6-11

Sample Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(per carrier)

Downlink

		Frequency Band, GHz		
		4/6	11/14	18/30
Satellite transmit RF power (per carrier)	Watts	0.15	1.0	1
	dBW	-8.2	0	-0.2
Line losses	dB	0.5	0.5	0.5
Minimum antenna gain for specified coverage	dB	39	39	43
Minimum satellite transmit EIRP	dBW	.3	38.5	42.3
Free space path loss at 30 degree elevation	dB	196.2	205	209.2
Transmission link margin	dB	3	7	10
Minimum flux density at the surface of the earth	dBW/m^2	4.1	9.5	26.3
Earth station antenna diameter	m	11	7	7
Earth station antenna gain	dB	51	55.9	60.2
Receive system noise temperature	^oK	110	195	500
Earth station G/T	$dB/^oK$	30.5	32.9	29.4
Receive noise bandwidth	MHz	4.1	4.1	4.1
Downlink carrier-to-noise ratio	dB	15	15	15

Table 6-11, Continued

Sample Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(per carrier)

Uplink

		Frequency Band, GHz		
		4/6	11/14	18/30
Earth station transmit power (per carrier)	Watts	4.2	30	791
	dBW	6.2	14.6	19.6
Line losses	dB	1.0	1.0	1.0
Antenna diameter	m	4.5	4.5	4.5
Antenna gain	dB	46.8	54.2	60.8
Earth station transmit EIRP	dBW	52	67.8	79.4
Free space path loss at 30 degree elevation	dB	199.6	207	213.7
Transmission link margin	dB	3	10	15
Flux density at the satellite	dBW/m^2	-113.6	-102.7	-98.7
Minimum satellite antenna gain	dB	39	39	43
Receive system noise temperature	^oK	1150	2200	300
Satellite G/T	$dB/^oK$	8.4	5.6	8.2
Receive noise bandwidth	MHz	4.1	4.1	4.1
Uplink carrier-to-noise ratio	dB	20	20	20

6.11 Transition to the A.D.S. System

Assuming the the development of the A.D.S. system is begun in the near future, it should be possible for carriers to plan on transition to this system by the late 1980's. Figures 6-15 and 6-16 show the growth of demand and in-orbit capacity for the high and low traffic scenarios. First launch of an A.D.S. spacecraft is assumed to occur in 1987. The fine-grain variations in capacity in later years is caused by the demise of conventional spacecraft launched in the early 1980's.

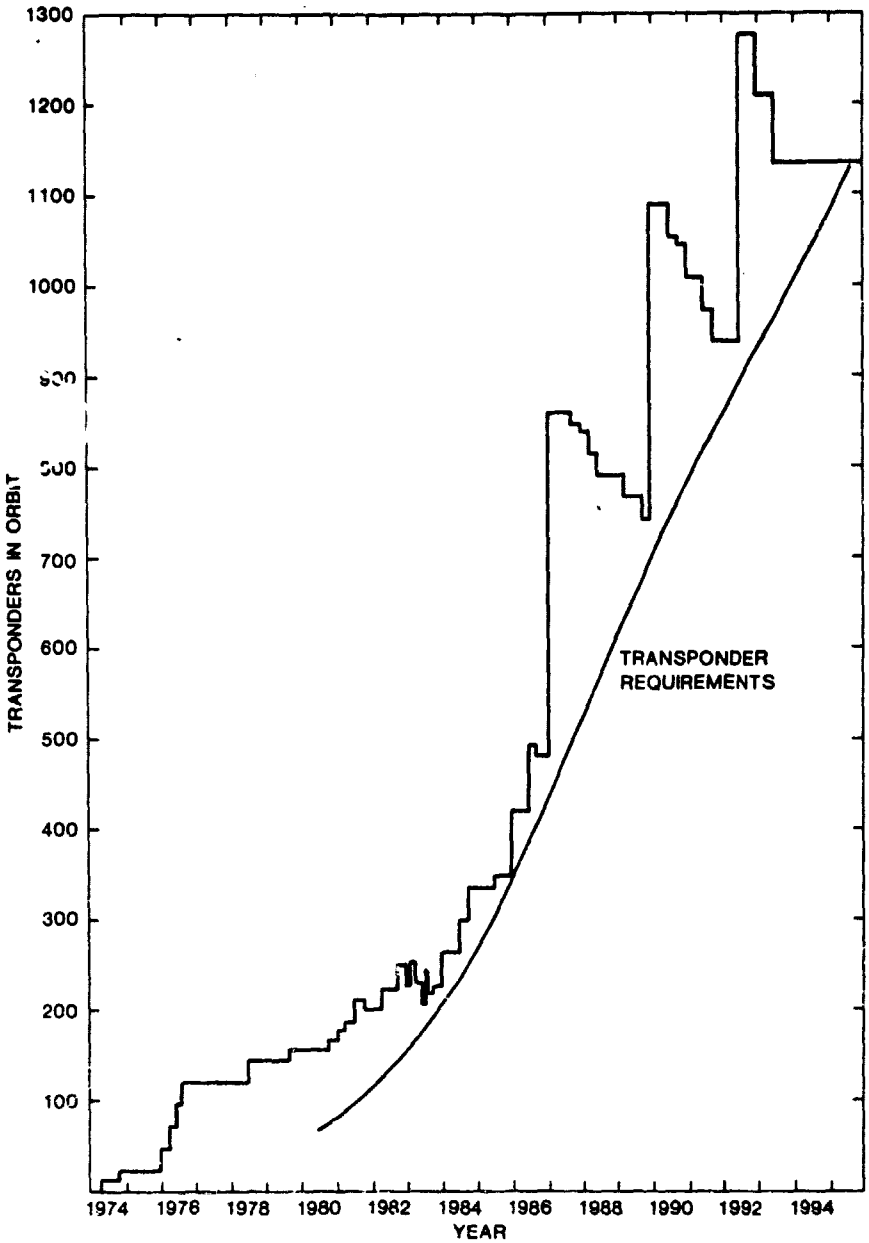

Figure 6-15
GROWTH INTO ADS SYSTEM
LOW TRAFFIC SCENARIO

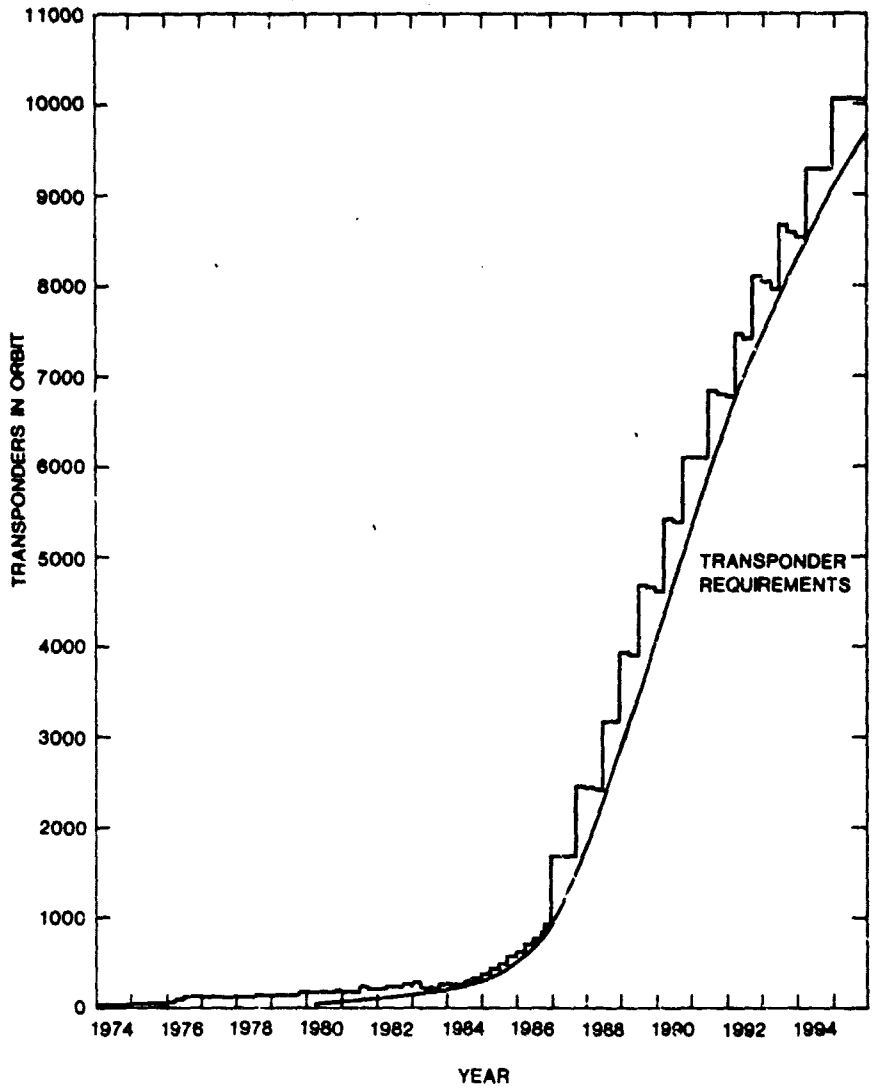

Figure 6-16
GROWTH INTO ADS SYSTEM
HIGH TRAFFIC SCENARIO

SECTION 7
EARTH STATION NETWORK CONFIGURATION

Any of the existing earth stations in the U.S. domestic satellite communications systems will be able to operate with the ADS. In addition, a large number of new earth stations will be constructed, and most of the new stations will serve light traffic links.

In this section we have shown examples of typical earth stations. The satellite-switched TDMA earth station imposes the least complexity upon the satellite switch but results in the greatest complexity on the ground. The multi-carrier PSK earth station will be simpler and less costly than the satellite-switched TDMA station if the number of carriers is small. If a single carrier is provided for each transmission link, the switch would provide routing at IF.

All earth stations employ a basic front end consisting of an antenna (including mount, feed, and combiner), an LNA, a down-converter and an up-converter, and final RF amplifier.

7.1 Satellite-Switched TDMA Earth Stations

The terminal equipment for a typical satellite-switched TDMA (SS/TDMA) earth station consists of the following subsystems:

Mux/demux
Common control equipment
QPSK modern

A functional block diagram for this type of station is shown in Figure 7-1, and a brief discussion of the terminal equipment subsystems follows.

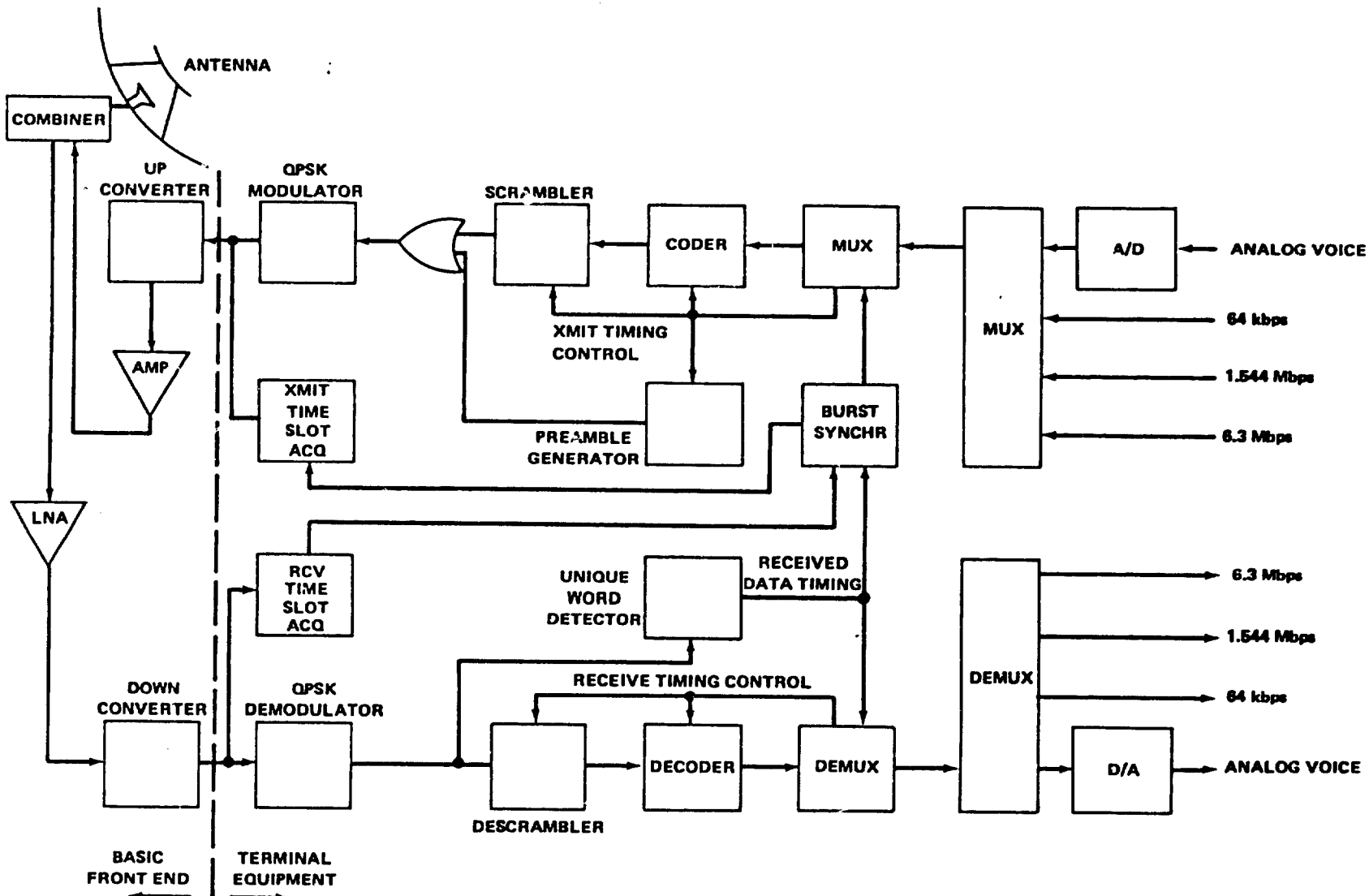

Figure 7-1

TYPICAL SS/TDMA EARTH STATION
(Functional Block Diagram)

The first multiplexing process accepts traffic consisting of analog voice and digital bit streams at rates of 64 kbps, 1.544 Mbps and 6.3 Mbps and combines this traffic into a single digital bit stream at a significantly higher rate. The second multiplexer provides compression buffering for the continuous-to-burst rate conversion, as well as transmit burst timing control via network memories. The first demultiplexing process provides the reciprocal functions of receive burst timing control and burst-to-continuous rate conversion. The second demultiplexer accepts the continuous single digital bit stream and breaks it down into separate traffic outputs consisting of analog voice and bit streams at rates of 64 kbps, 1.544 Mbps, and 6.3 Mbps.

The common control equipment performs functions associated with the establishment and maintenance of frame synchronization, as well as the treatment of data in order to obtain improved system performance. This equipment consists of five main parts:

Burst synchronizer and time slot acquisition unit
Preamble generator
Unique word detector
Scrambler/descrambler
Forward acting error correction codec

The burst synchronizer and associated time slot acquisition unit perform the function of acquisition and steady state synchronization of burst transmissions from the earth station so that no TDMA burst overlapping occurs at any time. The preamble generator assembles the overhead bits which are inserted prior to the encoded and scrambled data from the second multiplexer. It is turned on and off by a timing pulse from the multiplexer which is, in turn, controlled by data loaded into its network plan memory. The time reference for the multiplexer is furnished by the burst synchronizer. The unique word detector monitors the incoming data burst to identify the unique words which precede actual data transmission. The scrambler/descrambler is included in the system to make the transmitted data stream more random in content, thereby avoiding the generation of high power discrete spectral lines in the transmitted RF spectrum. The forward acting error correction codec provides for improvement in the bit error rate performance.

The QPSK modem performs reciprocal functions. It accepts a bursted data stream and modulates this information onto a suitable IF carrier using quadrature phase shift keying. Alternately, it can take a QPSK modulated spectrum and produce a bursted data stream output.

7.2 Multiple T-2 Carrier PSK Earth Stations

The terminal equipment for a typical multiple T-2 carrier PSK earth station consists of the following subsystems:

Mux/demux
Codec
QPSK modem
Carrier combiner and divider networks

A functional block diagram for this type of station is shown in Figure 7-2, and a brief discussion of the terminal equipment is given below.

The multiplexer accepts traffic consisting of analog voice and digital bit streams at rates of 64 kbps, 1.544 Mbps, and 6.3 Mbps and combines this traffic into a single digital bit stream at a higher data rate. The demultiplexer provides the reciprocal function.

The codec provides forward acting error correction coding to the outgoing data stream and uses such coding to improve the BER of the incoming data stream.

The QPSK modem performs reciprocal functions. It accepts a data stream and modulates this information onto a suitable IF carrier using quadrature phase shift keying. Alternately, it can take a QPSK modulated spectrum and provide a continuous data stream output.

The combiner network frequency multiplexes the several carriers before up-conversion and power amplification. The divider demultiplexes the carriers before further processing upon reception.

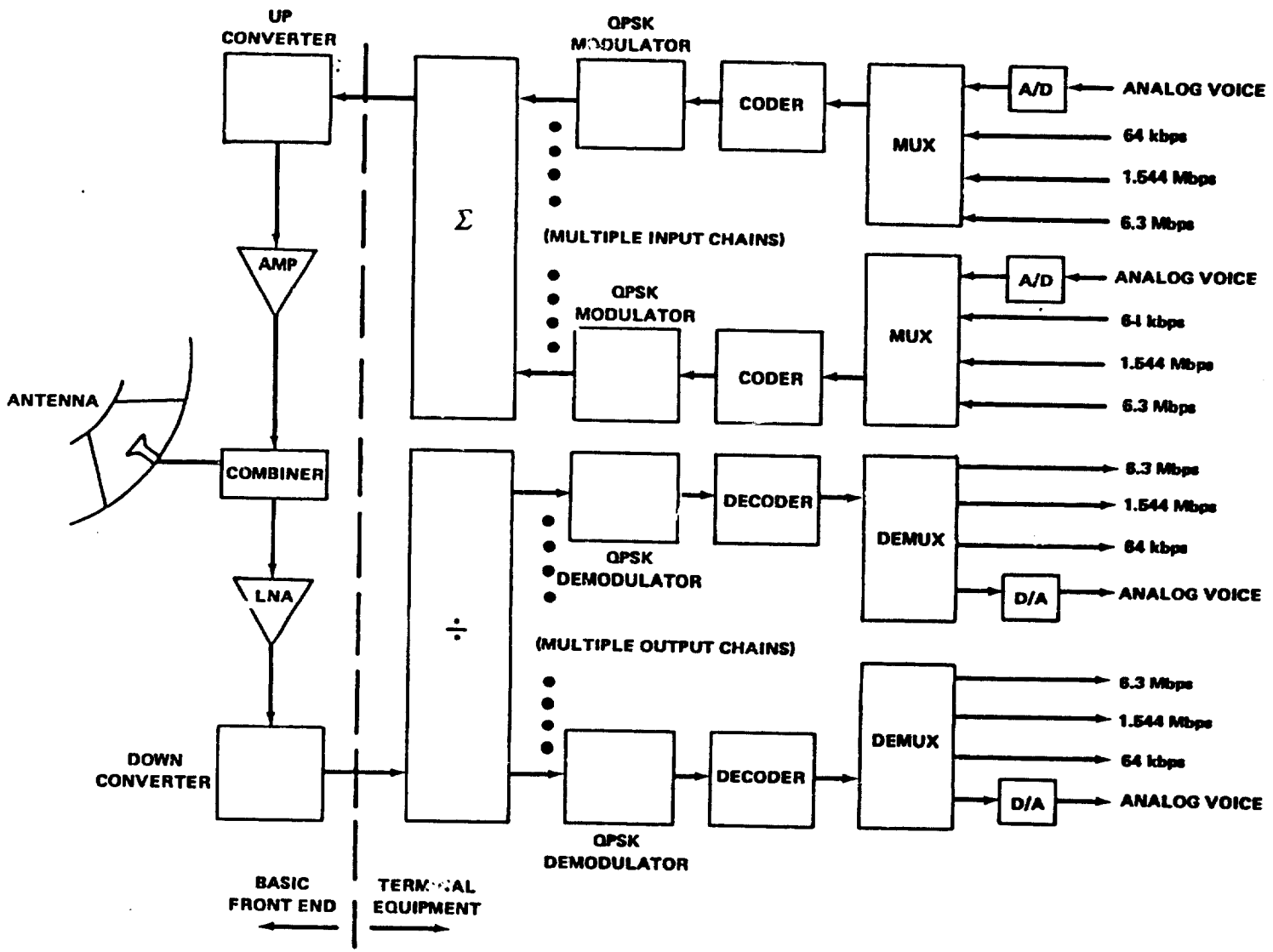

Figure 7-2

TYPICAL MULTI-CARRIER PSK EARTH STATION
(Functional Block Diagram)

7.3 Single T-2 Carrier PSK Earth Stations

The terminal equipment for a typical single carrier PSK earth station consists of the following subsystems:

Mux/demux
Codec
QPSK modem

A functional block diagram for this type of station is shown in Figure 7-3, and a brief discussion of the terminal equipment is given below.

The multiplexer accepts traffic consisting of analog voice and digital bit streams at rates of 64 kbps, 1.544 Mbps, or 6.3 Mbps and combines this traffic into a single digital bit stream at a higher data rate. The demultiplexer provides the reciprocal function.

The codec provides forward acting error correction coding to the outgoing data stream and uses such coding to improve the BER of the incoming data stream.

The QPSK modem performs reciprocal functions. It accepts a data stream and modulates this information onto a suitable IF carrier using quadrature phase shift keying. Alternately, it can take a QPSK modulated spectrum and provide a continuous data stream output.

7.4 Video Conferencing Operation

Most of the video conferencing traffic will be carried at Ku- and Ka-bands and will therefore experience rather severe rain attenuation in many parts of the U.S. Tables 7-1a and 7-1b show the system margin needed for various system availabilities. The figures in the table can be compared with the margins of 10 dB at Ku-band and 15 dB at Ka-band that the basic system provides. It can be seen that in some regions of the country these margins do not provide an acceptable availability. For such instances, the video conferencing transmission system has been so designed as to provide additional margin. This is done as follows.

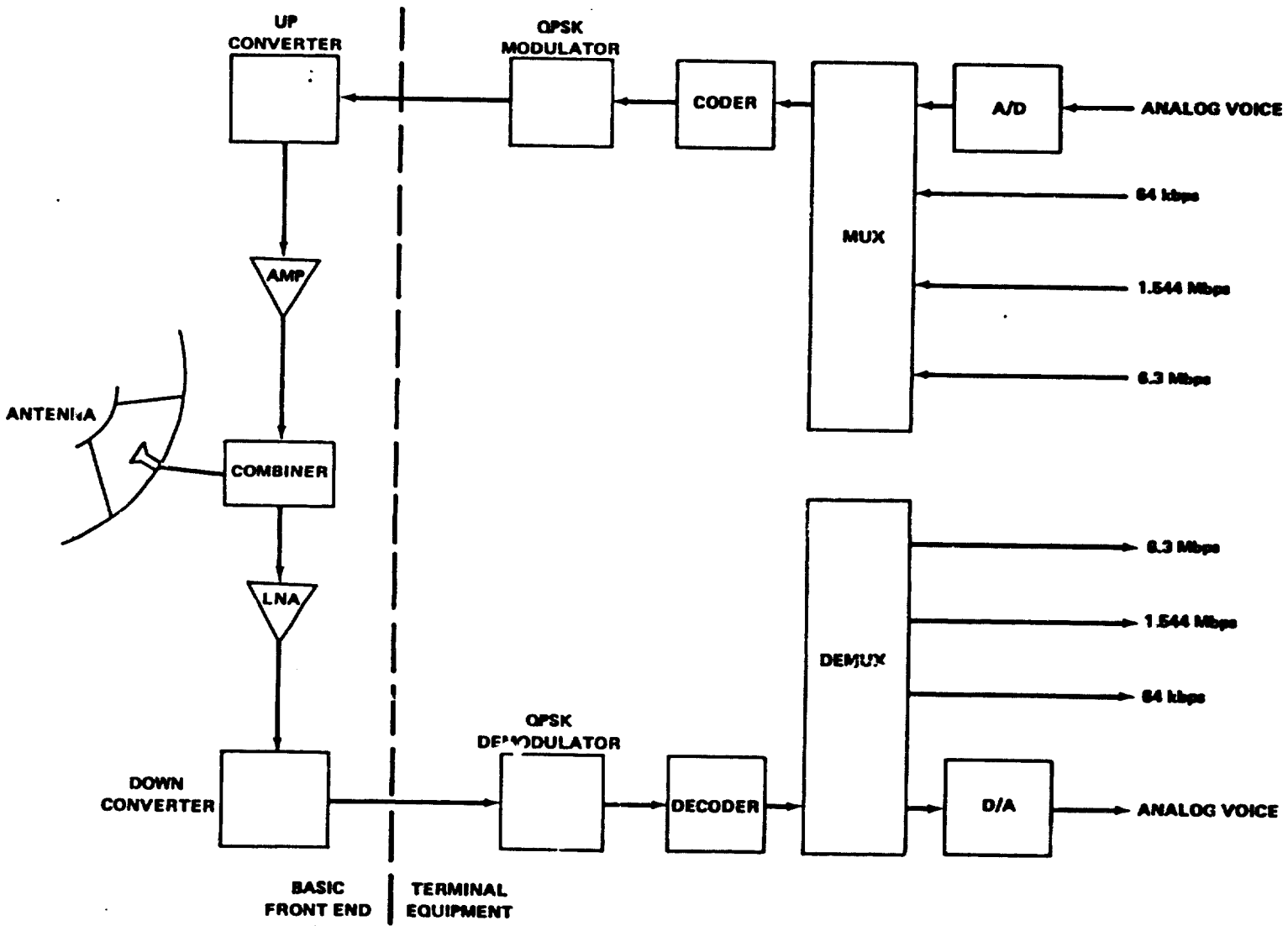

Figure 7-3

TYPICAL SINGLE CARRIER PSK EARTH STATION
(Functional Block Diagram)

Table 7-1a

Precipitation Margins Without Diversity

(Attenuation in dB, Rounded to the Nearest dB)

Frequency (GHz)	Single Availability (Percent)	Rain Zone 1	2	3	4	5	6
18*	99.0	1	2	2	3	3	4
	99.5	2	3	4	5	7	5
	99.9	4	7	8	13	19	10
	99.95	6	9	13	20	26	12
	99.99	13	23	35	49	54	28
30**	99.0	2	6	6	8	8	12
	99.5	5	8	11	14	17	16
	99.9	13	17	24	38	50	26
	99.95	18	25	35	65	75	34
	99.99	36	66	86	111	121	75

*A minimum margin of 3 dB is recommended for 18 GHz links.

**A minimum margin of 7 dB is recommended for 30 GHz links

Table 7-1b

Precipitation Margins Without Diversity

(Attenuation in dB, Rounded to the Nearest dB)

Frequency (GHz)	Single Availability (Percent)	Rain Zone 1	2	3	4	5	6
12*	99.0	1	1	1	1	1	2
	99.5	1	1	2	2	2	3
	99.9	2	3	4	6	9	4
	99.95	3	4	6	11	14	5
	99.99	6	11	17	23	25	14
14*	99.0	1	1	1	1	2	3
	99.5	1	1	2	3	3	4
	99.9	3	4	5	9	12	6
	99.95	4	5	8	16	19	8
	99.99	8	16	23	31	35	19

*A minimum margin = 1dB

The system will monitor some indicator of the performance, either the received signal level or the bit error rate. When a preset threshold is exceeded, the transmission bit rate will be reduced from 6.3 Mbps to 64 kbps each way. The IF bandwidth will be reduced accordingly. This will provide an additional 20dB of margin for the reduced bit rate signal and will enable the conference to proceed using audio only. The resulting outages and availabilities are shown in Table 7-2. Figure 7-4 shows the CONUS rain zones.

Table 7-2

Video Conferencing System Availabilities

Frequency (GHz)	Rain Zone 1	2	3	4	5	6
12	99.99*	99.99	99.99	99.99	99.99	99.99
14	99.99*	99.99	99.99	99.98	99.97	99.99
18	99.99*	99.99	99.99	99.97	99.96	99.99
30	99.98	99.96	99.95	99.8	99.7	99.95

* Video service retained

The practical aspects of this arrangement are less formidable than it may seem at first. The development of an all-digital modem covering the desired range in which even the filters are implemented digitally is likely by as soon as 1982. This will enable instantaneous alteration of the system transmission rate. In addition, the minutes of the year during which the system will operate at the reduced rate will be spread over the year and over the 24 hours of the day. Some will occur at night or during relatively light usage periods; thus we expect that the average user will experience an actual inconvenience only about one-half as often as Table 7-2 indicates.

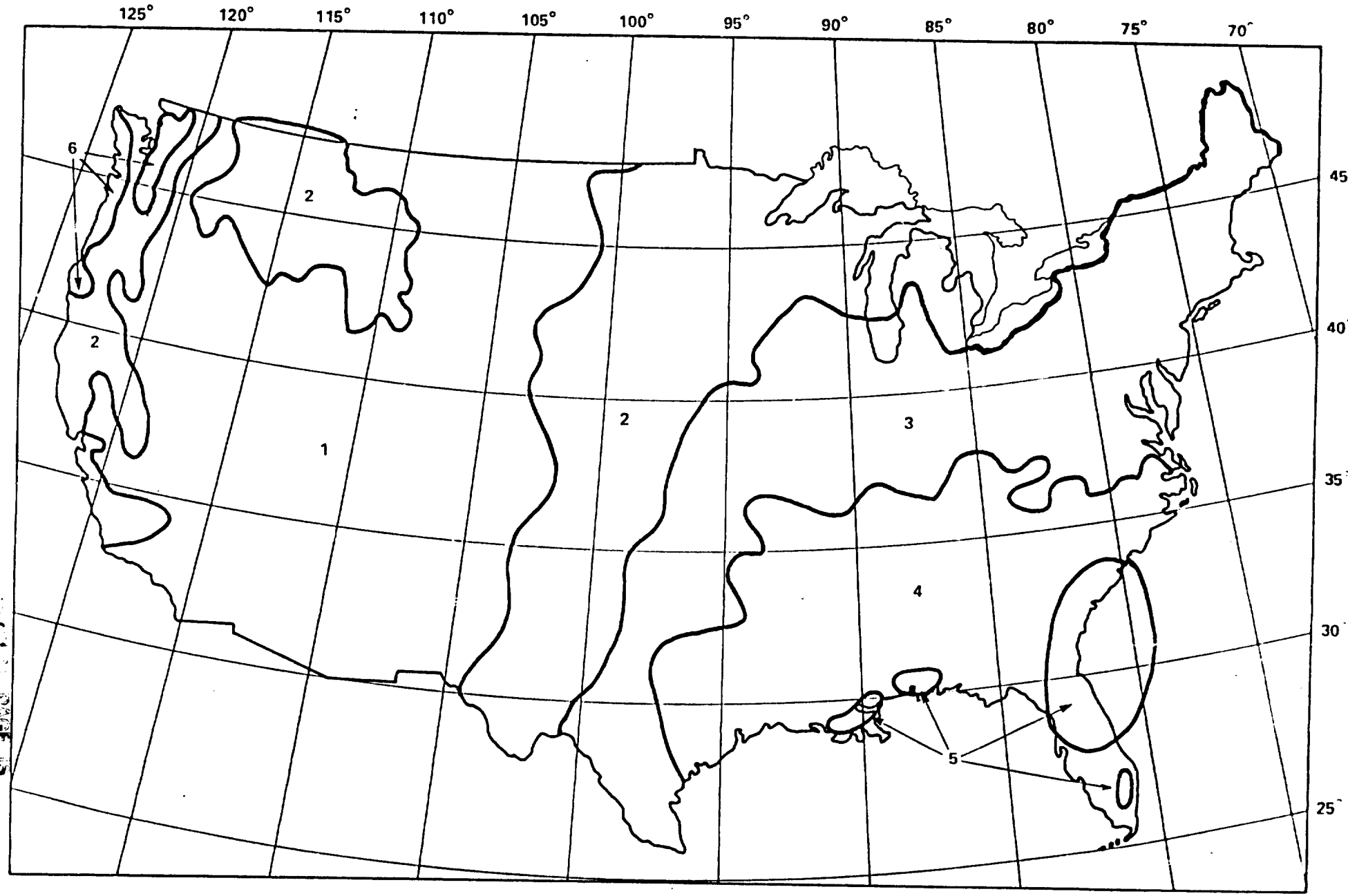

Figure 7-4

CLIMATOLOGICAL ZONES FOR CONUS

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7.5 Earth Station Cost Estimates

Typical earth station costs are shown in Table 7-3. Cost trends are shown in Table 7-4. All costs are for equipment only. An operational station must include, for example, installation, transportation, integration, documentation, and spares. Our economic model has assumed a factor of 40 percent of the equipment costs to account for these additional cost items.

Table 7-3

Typical Earth Station Equipment Costs in 1987

(Thousands of 1980 Dollars)

Quantity = 1,000

Item	Station Types		
	Single Carrier PSK	Multi-Carrier PSK	SS/TDMA
Front Ends			
Antenna System			
4/6 GHz	10	10	10
11/14 GHz	15	15	15
18/30 GHz	20	20	20
RF equipment			
4/6 GHZ	4	4	20
11/14 GHz	5	5	40
18/30 GHz	6	6	60
Terminal Equipment (excluding mux/demux)	5	25	50
Mux/demux	3	15	3
Totals:			
4/2 GHz	22	54	83
11/14 GHz	28	60	108
18/30 GHz	34	66	133

Table 7-4

Cost Trends for Typical Earth Station Equipment

(Thousands of 1980 Dollars)

	Year Purchased		
	1980	1987	
Quantity:	1	1000	1
Station Type			
Single Carrier PSK			
4/6 GHz	52	22	37
11/14 GHz	65	28	48
18/30 GHz	80	34	58
Multi-Carrier PSK			
4/6 GHz	132	54	90
11/14 GHz	138	60	100
18/30 GHz	160	66	110
SS/TDMA			
4/6 GHz	152	83	139
11/14 GHz	197	108	180
18/30 GHz	244	133	222

We estimate that the cost of baseband equipment and modems for the dual bit-rate operation will be about 20 percent higher than for single-rate operation. Due to the increased flexibility of all-digital equipment, we expect such items to become commonplace by the mid 1980's.

7.6 Access Arrangements

The access arrangements used with the ADS system will vary according to the type of earth station. The SS/TDMA stations will be used primarily for trunking operation and video conferencing among larger cities. Access to these stations will depend on the frequency band of operation. At C-band the stations will probably not be located within the larger cities due to frequency coordination problems. Interconnection to such stations will be via conventional terrestrial microwave or fiber optics. Typical costs for such links are shown in Table 7-5 and Table 7-6.

Table 7-5

Fiber Optic Costs per Meter in 1980 Dollars for a 1987 System

(Installed)

(Rounded to Nearest Dollar)

Duplex Capacity (MBps)	Installation Cost Rural $3/m	Suburban $7/m	City $10/m
90	8	12	15
100	9	13	16
270	12	16	19
360	13	17	20

Table 7-6

Terrestrial Microwave Costs

Item	High case Cost Per site	Low case Cost Per site
Land (including access)	$ 5,000	$10,000
Site Building	45,000	5,000
Tower	12,500	7,400
Generator	45,000	—
HVAC	3,000	—
Radio	40,000	6,000
Antenna	4,500	400
Waveguide	1,480	560
Mux	—	4,800
Auxiliary link	9,400	—
Supervisory system	9,000	—
Test equipment and spares	7,700	1,000
Installation	20,800	4,600
Total	$203,400	$39,760

Stations which operate exclusively at Ka-band, and some stations which operate at Ku-band. can be located in large downtown areas. Access to these stations could be via fiber optics links. Fiber optics links offer large transmission bandwidths, and the capacity that is installed is relatively independent of installation costs.

Single-carrier PSK and some multi-carrier PSK stations will be co-located with the customer's premises. These stations will be used primarily for private line voice and data networks and for video conferencing. No special access arrangement will be needed for these stations.

SECTION 8
SYSTEM COSTS

8.1 Cost Model

Engineering cost calculations were made using the following cost model:

1. Revenue requirements were calculated for each of the 10 years of the study period, 1987 to 1996. Revenue requirements are the sum of depreciation, operation and maintenance costs, and rate of return on investment.

2. Straight-line depreciation over 10 years was used on all investments based on an assumed ADS and earth station useful life of 10 years. These calculations will yield conservative results since some earth station equipment will have longer lifetimes.

3. All calculations were made in constant 1980 dollars. The allowance for inflation was included in the proper choice of rate of return on investment and present value factor.

4. Cost per circuit was calculated for each year and for the total 10-year program period.

5. Net investment was calculated as the difference of cumulative investment and accumulated depreciation. In this manner, residual systems value was also determined.

6. The sum of all revenue requirements and the sum of the present values of all revenue requirements were calculated as an overall measure of systems costs.

7. Progress payments were required during the course of platform or spacecraft development and production, ground segment construction, and for Shuttle launches. Our cost estimates represent the present value of the sum of these progress payments referred to the date of deployment of space and ground segment, and they are expressed in 1980 dollars.

Investment and O&M Schedule

The following assumptions were made in addition to those listed in Sections 6 and 7 of this report regarding the investment and O&M schedule:

1. Shuttle Launch Costs

   For ADS, the requirement is one Shuttle launch per satellite. The total cost is $30 million plus an additional $20 million for the transfer vehicle (Centaur).

2. Satellite Control Center and TT&C Investment Costs

   In 1987 there will be four operational control centers and TT&C systems operated by Western Union, RCA American Communications, AT&T, and SBS. These control centers will be adequate for operations with ADS.

3. Earth Station Deployment and Costs

   In addition to the basic equipment cost, 40 percent was added to account for such costs as transportation, installation, integration, and spares.

Development and Deployment

Development costs for the ADS system were assessed only once. This is based on the assumption that NASA develops the satellite and charges their users appropriately for it.

TT&C and Operations

Costs for TT&T and operations (included under O&M in the computer model) were assessed as follows:

$3.9 million + $0.4N million
where N is the number of spacecraft in orbit including spares.

8.2 Space Segment Cost Calculations

Based on the above model and the costs for ADS calculated in Section 6 using the SAMSO model, we have computed the cost per transponder year for the ADS space segment. The transponder used is the 36 MHz reference transponder rather than the physical transponder actually used in the satellite design. The results of the computer model are shown in Table 8-3 for the low traffic and Table 8-4 for high traffic. The high traffic was modeled using the offloaded system and each primary satellite launch is also accompanied by a launch of an east coast coverage satellite. Costs for the offloaded satellite system were assumed to be the same as for the all-CONUS coverage.

Launch schedules are shown in Tables 8-1 and 8-2. A spare was launched for every four operating satellites or fraction thereof.

8.3 Ground Segment Cost Calculations

The factors that make up the annual cost of the ground segment are common to the entire system. We have thus calculated the annual costs for the ground segment of typical users rather than for the system as a whole. Costs are shown for transmission via a trunking earth station, a thin-route single carrier PSK earth station, and a thin-route multi-carrier earth station.

Table 8-1
Low Traffic Scenario Launch Schedule
(Including Spares)

Year	Launches
1988	2
1990	1
1992	1

Table 8-2
High Traffic Scenario Launch Schedule
(Including Spares)

Year	Primary	East Coast	Common Spare
1987	2	2	1
1988	1	1	1
1989	2	2	1
1990	2	2	1
1991	1	1	0
1992	2	2	1
1993	1	1	1
1994	1	1	0
1995	1	1	1

The traffic carried by the earth station was assumed to grow to a certain maximum over the 10-year period. This maximum depended on earth station type: 6.3 Mbps for the single-carrier station, 31.5 Mbps for the multiple-carrier station, and 63 Mbps for the SS/TDMA station. The growth pattern for this traffic was assumed to be the same as that for the overall U.S. domestic traffic.

Earth station installation and integration was estimated to be 40 percent of the equipment costs. This increased cost was added to the equipment

Table 8-3

Economic Model Forecast
SINGLE-SHUTTLE LAUNCH A.D.S. - LOW TRAFFIC

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per XPONDER	PV of Annual Revenue
1988	401.4	44.6	4.7	40.1	89.4	160.00	0.56	61.6
1989	356.8	44.6	4.7	35.7	85.0	277.00	0.31	55.9
1990	445.4	59.4	5.1	44.5	109.0	437.00	0.25	68.4
1991	386.0	59.4	5.1	38.6	103.1	599.00	0.17	61.8
1992	459.8	74.2	5.5	46.0	125.7	750.00	0.17	71.9
1993	385.6	74.2	5.5	38.6	118.3	972.00	0.12	64.6
1994	311.4	74.2	5.5	31.1	110.8	1051.00	0.11	57.8
1995	237.2	74.2	5.5	23.7	103.4	1128.00	0.09	51.4
1996	163.0	74.2	5.5	16.3	96.0	1211.00	0.08	45.6

Total of Revenue Requirements = 941
Total Present Value of Revenue = 539
Average Cost per XPONDER per Year = 0.14

Note: Traffic is in XPONDER
Cost is $millions per XPONDER per year

Table 8-4

Economic Model Forecast
SINGLE-SHUTTLE LAUNCH A.D.S. - HIGH TRAFFIC

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per XPONDER	PV of Annual Revenue
1987	801.0	89.0	5.9	80.1	175.0	537.00	0.33	126.3
1988	1111.6	133.4	7.1	111.2	251.7	1402.00	0.18	173.4
1989	1644.2	207.4	9.1	164.4	380.9	2625.00	0.15	250.5
1990	2102.8	281.4	11.1	210.3	502.8	3984.00	0.13	315.6
1991	2087.8	311.0	11.9	208.8	531.7	5287.00	0.10	318.6
1992	2442.8	385.0	13.9	244.3	643.2	6622.00	0.10	367.8
1993	2457.4	429.4	15.1	245.7	690.2	7748.00	0.09	376.8
1994	2294.4	459.0	15.9	229.4	704.3	8771.00	0.08	367.0
1995	2235.0	503.4	17.1	223.5	744.0	9408.00	0.08	370.0
1996	1731.6	503.4	17.1	173.2	693.7	10091.00	0.07	329.3

Total of Revenue Requirements = 5317
Total Present Value of Revenue = 2995
Average Cost per XPONDER per Year = 0.09

Note: Traffic is in XPONDER
Cost is $millions per XPONDER per year

investment. This investment was depreciated over a 10-year period. The cost of operations and maintenance for the earth station was estimated to be 20 percent of the investment per year. A 10 percent return on investment over and above the O&M costs was also used. Tables 8-5 through 8-7 show the computer modeling of the typical user costs.

8.4 Total Costs

We have combined the results of Sections 8.2 and 8.3 to obtain typical total costs for transmission via the ADS system. Table 8-8 shows these total costs per year for voice channels, data (per kbps), and video conferencing channels.

8.5 Comparison with Current Transmission Techniques

We have compared the cost of transmission using the Advanced Domestic Satellite with the costs of using current transmission links: conventional satellite, terrestrial microwave, and fiber optics. Tables 8-9 through 8-11 show typical costs for these conventional techniques. Figures 8-1 and 8-2 present a comparison of these with the ADS system on a per-channel per-year per-kilometer basis. Voice, data (per kbps), and video conferencing are also shown.

Table 8-5

Economic Model Forecast
A.D.S. GROUND SEGMENT - SINGLE CARRIER STATION

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per MBPS	PV of Annual Revenue
1987	81.9	9.1	18.2	8.2	35.5	2.20	16.13	25.6
1988	72.8	9.1	18.2	7.3	34.6	2.70	12.81	23.8
1989	63.7	9.1	18.2	6.4	33.7	3.20	10.52	22.1
1990	54.6	9.1	18.2	5.5	32.8	3.70	8.85	20.6
1991	45.5	9.1	18.2	4.6	31.8	4.10	7.77	19.1
1992	36.4	9.1	18.2	3.6	30.9	4.60	6.73	17.7
1993	27.3	9.1	18.2	2.7	30.0	5.00	6.01	16.4
1994	18.2	9.1	18.2	1.8	29.1	5.40	5.39	15.2
1995	9.1	9.1	18.2	0.9	28.2	5.90	4.78	14.0
1996	0.0	9.1	18.2	0.0	27.3	6.30	4.33	13.0

Total of Revenue Requirements = 314
Total Present Value of Revenue = 187
Average Cost per MBPS per Year = 7.28

Note: Traffic is in MBPS
Cost is $ thousands per MBPS per year

Table 8-6

Economic Model Forecast
A.D.S. GROUND SEGMENT - MULTIPLE CARRIER STATION

Year	Net Invest	---------Annual-------- Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per MBPS	PV of Annual Revenue
1987	173.7	19.3	38.6	17.4	75.3	11.00	6.84	54.3
1988	154.4	19.3	38.6	15.4	73.3	13.40	5.47	50.5
1989	135.1	19.3	38.6	13.5	71.4	16.00	4.46	47.0
1990	115.8	19.3	38.6	11.6	69.5	18.60	3.74	43.6
1991	96.5	19.3	38.6	9.7	67.5	20.50	3.30	40.5
1992	77.2	19.3	38.6	7.7	65.6	22.80	2.88	37.5
1993	57.9	19.3	38.6	5.8	63.7	25.00	2.55	34.8
1994	38.6	19.3	38.6	3.9	61.8	27.20	2.27	32.2
1995	19.3	19.3	38.6	1.9	59.8	29.40	2.04	29.8
1996	0.0	19.3	38.6	0.0	57.9	31.50	1.84	27.5

Total of Revenue Requirements = 666
Total Present Value of Revenue = 398
Average Cost per MBPS per Year = 3.09

Note: Traffic is in MBPS
Cost is $ thousands per MBPS per year

Table 8-7

Economic Model Forecast
A.D.S. GROUND SEGMENT - SS/TDMA STATION

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per MBPS	PV of Annual Revenue
1987	248.2	27.6	55.2	24.8	107.6	21.90	4.91	77.6
1988	220.6	27.6	55.2	22.1	104.8	26.80	3.91	72.2
1989	193.1	27.6	55.2	19.3	102.0	31.90	3.20	67.1
1990	165.5	27.6	55.2	16.5	99.3	37.20	2.67	62.3
1991	137.9	27.6	55.2	13.8	96.5	41.00	2.35	57.8
1992	110.3	27.6	55.2	11.0	93.8	45.50	2.06	53.6
1993	82.7	27.6	55.2	8.3	91.0	50.00	1.82	49.7
1994	55.2	27.6	55.2	5.5	88.3	54.30	1.63	46.0
1995	27.6	27.6	55.2	2.8	85.5	58.70	1.46	42.5
1996	0.0	27.6	55.2	0.0	82.7	63.00	1.31	39.3

Total of Revenue Requirements = 952
Total Present Value of Revenue = 568
Average Cost per MBPS per Year = 2.21

Note: Traffic is in MBPS
Cost is $ thousands per MBPS per year

Table 8-8

Typical Full Circuit Costs per Year for Space and Ground Equipment

(Thousands of dollars)

	Low Traffic			High Traffic		
	Single Carrier Station	Multiple Carrier Station	TDMA Station	Single Carrier Station	Multiple Carrier Station	TDMA Station
Voice Channels (64 kBps)	1.21	0.68	0.56	1.11	0.58	0.46
Data Channels (1 kBps)	0.02	0.01	0.01	.02	.01	.01
Video Conferencing Channels (6.3 Mbps)	119.3	66.5	55.4	109.4	56.7	45.6

Table 8-9

Costs for Conventional Satellite Transmission in 1979 Dollars

Per Circuit Month

(Earth Segment Plus Space Segment)

Channel Ends per Earth Station	Earth Station and Modulation/Access Type		
	13-Meter FDM/FM Companded	13-Meter TDMA/DSI	7-Meter SCPC/PSK
1	—	—	6,750
5	—	—	1,750
10	—	—	1,110
120	780	840	—
240	580	490	—
480	440	320	—
1,200	250	220	—

Table 8-10

Summary of Microwave Radio Costs

(1979 Dollars)

	Link Capacity in Circuits					
	10	24	120	240	480	1,200
Cost per Circuit-Month for One Hop	230	96	56	28	14	5.60
Cost per Circuit-Month per Kilometer	4.61	1.92	1.12	0.56	0.28	0.11
Multiplex Equipment Cost per Circuit-Month	53	53	53	53	53	53

Table 8-11

Fiber Optic Transmission Costs

(1979 Dollars per Circuit-Month per Kilometer)

Circuits per link	Installation Costs Rural $3/m	Suburban $7/m	City $10/m
120	2.2	3.3	4.12
240	1.1	1.65	2.06
480	0.55	0.82	1.03
1,200	0.22	0.33	0.41
2,400	0.12	0.18	0.22
3,600	0.11	0.15	0.17

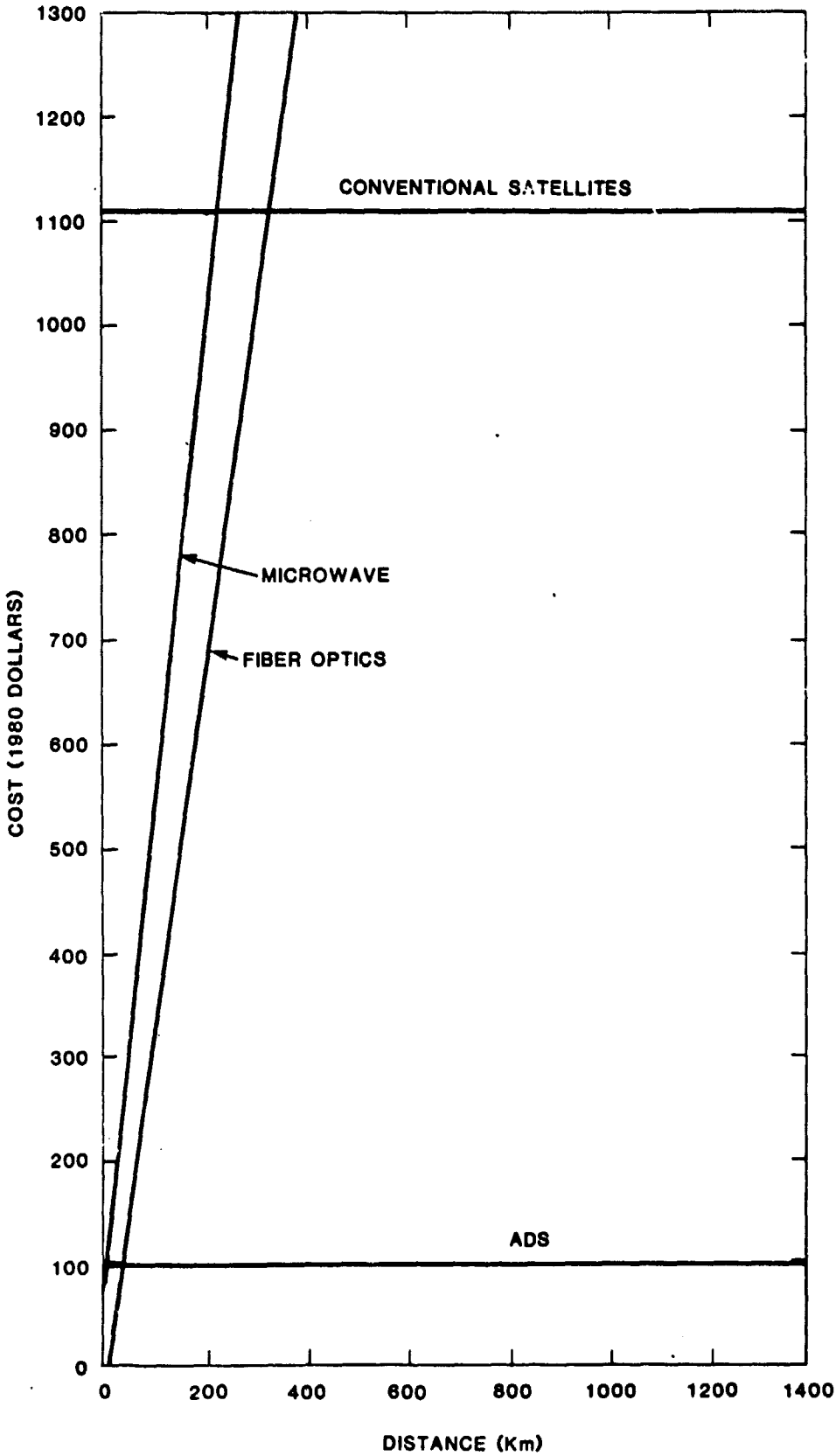


Figure 8-1

MONTHLY TRANSMISSION COSTS PER CHANNEL

10 CHANNELS PER LINK

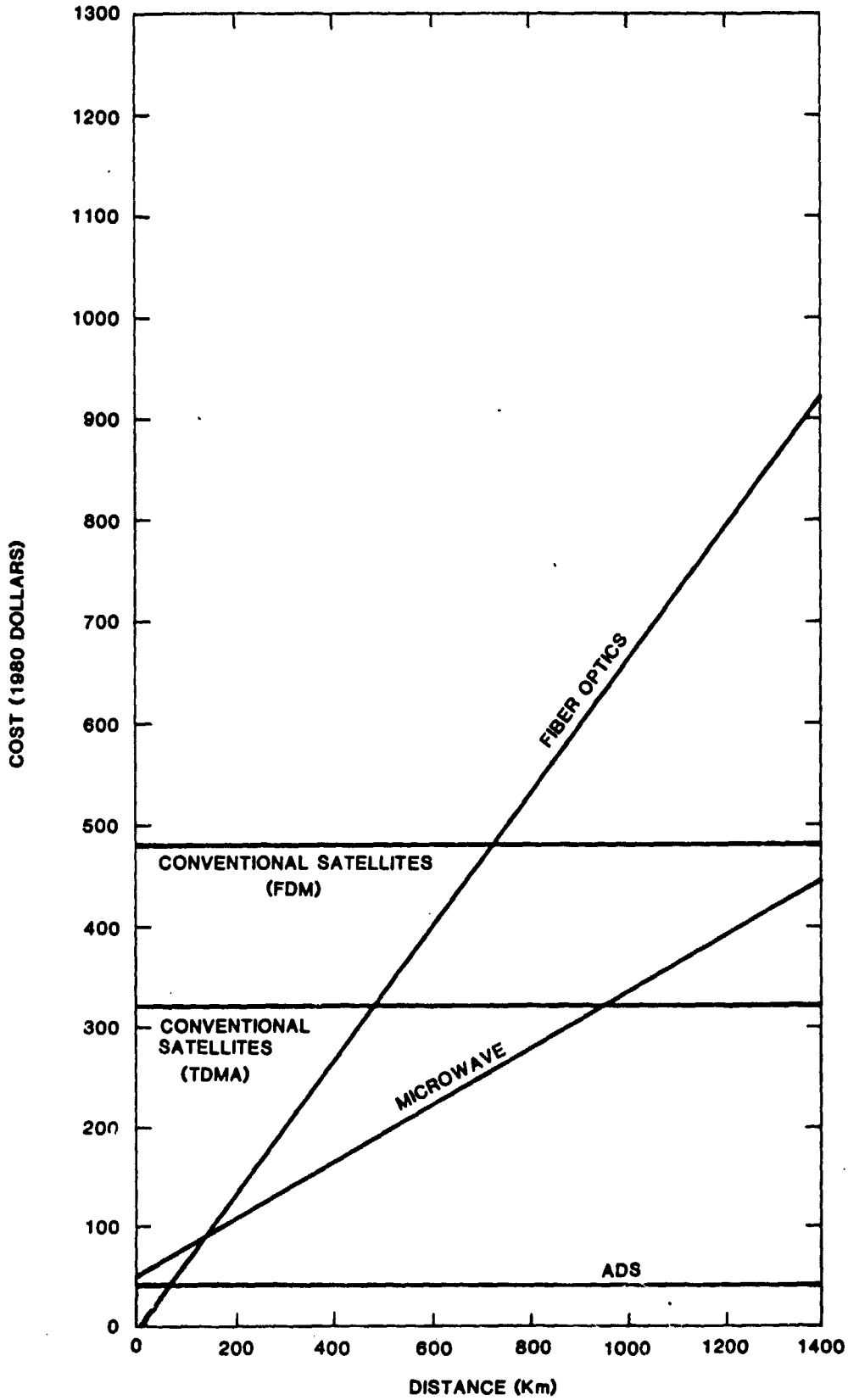


Figure 8-2

MONTHLY TRANSMISSION COSTS PER CHANNEL
480 CHANNELS PER LINK

SECTION 9
TECHNOLOGY DEVELOPMENT

This Section identifies technology which requires development before the ADS can be implemented commercially.

9.1 Spacecraft Antenna

9.1.1 Area Coverage Antennas

A spacecraft antenna design is required to provide area coverage of the U.S. (CONUS, Alaska, Hawaii, and Puerto Rico) by means of multiple spot beams at C-band and Ku-band. A nominal antenna beamwidth of 1.3 degrees at the 3 dB point will lead to CONUS coverage by means of 24 beams. Gain variation over the coverage area should be controlled for uniform transmission performance. Maximum to minimum gain variations of 4 dB would be a desirable objective, but adequate systems performance can be achieved with larger variations. This will be subject to systems trade-offs.

Ideally, a feed cluster associated with a single reflector would provide full area coverage. However, if the resulting antenna gain variation is excessive, three separate reflectors may be used to synthesize full area coverage. Separate reflectors will probably be used for the different frequency bands, transmit and receive. The C-band design is further complicated through the requirement for dual polarization.

A very important characteristic is the sidelobe behavior. The composite sidelobe level may become a major contributor to interference, both in the uplink and in the downlink. The transmission system will incorporate adequate error control coding to permit operation at low carrier to noise ratios in the presence of sidelobe interference.

Table 9-1 lists the major antenna characteristics and Figure 9-1 shows the required coverage pattern. Antenna designs must be suitable for satellites in

the orbital range of 61 to 134 degrees, but pre-launch adjustments are permitted for specific orbital assignments.

Table 9-1

Desirable Characteristics for Area Coverage Antennas

Frequency band	C-band or Kq-band
Beam center antenna gain	
Antenna gain variation over hexagonal coverage area	4 dB maximum
Diameter of hexagon (degrees as seen from satellite)	1.3^{o}
Frequency reuse pattern	1/3
Sidelobe interference ratio (total composite sidelobe gain to minimum gain in the coverage area)	30 dB
Gain Frequency Response	$\pm$ 1 dB over 400mHz
Beam pointing stability	$\pm$ 0.1 degree

9.1.2 Ka-band City Coverage Antennas

In order to reduce spacecraft power requirements, Ka-band coverage is achieved by individual spot beams aimed at the major cities and their surroundings. Coverage requirements are shown in Figure 9-2 and major characteristics are shown in Table 9-2. Pre-launch adjustments are permitted for specific orbital assignments.

The major problem is to achieve adequate beam pointing accuracy and stability for coverage of the specified cities. To avoid the complexity of individual in-orbit adjustment of beams, accurate pre-launch measurements of antenna beam pointing should be developed and pointing accuracy must be maintained in the launch environment and in orbit. The alternative solution would be various adjustment of beams in orbit by ground command.

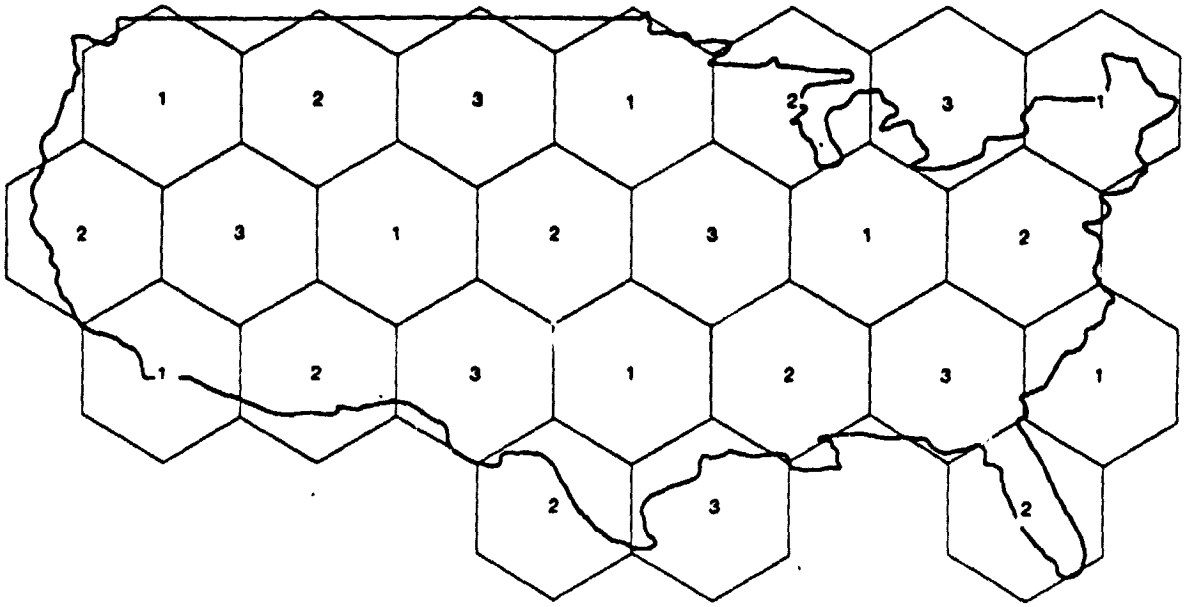


Figure 9-1
SPOT BEAM ANTENNA COVERAGE OF CONUS
(Numbers 1, 2, 3 indicate freguency assignment)

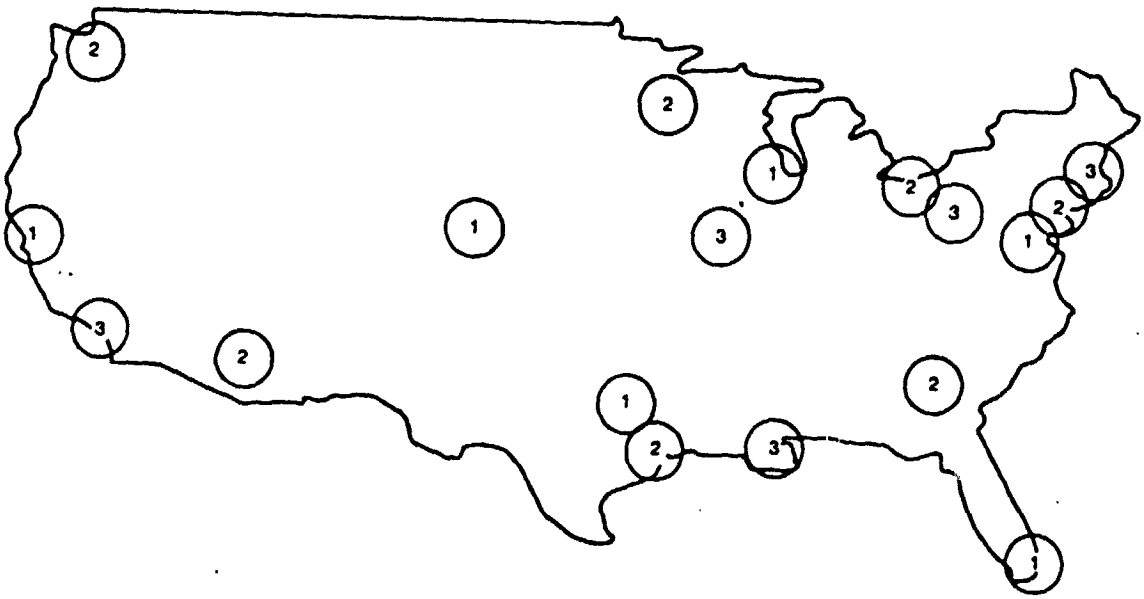


Figure 9-2
KA-BAND COVERAGE AND FREQUENCY ASSIGNMENT

9.2 On-board Switching

Interconnection of multiple beams and different frequency bands requires extensive on-board switching. To simplify the switching requirements for ADS, we have chosen to eliminate baseband processing and to provide only SS/TDMA and IF switching. The former technique will be used for high capacity stations, and the latter for thin-route stations. Interconnection between the two switches is not needed.

9.2.1 SS/TDMA Switch

The SS/TDMA switch will be an extension of the switches already designed for lower numbers of ports. Typical specifications are shown in Table 9-3.

Table 9-3
SS/TDMA Switch Specifications

Number of Inputs	25
Number of Outputs	25
Transfer Time	1 per sec.
Frequency Response	± .1 dB
Isolation	80 dB
Insertion Loss	0.5 dB
Bandwidth	500 MHz
Maintenance-free operation over a 10-year minimum life	

9.2.2 IF Switch

A block diagram of the IF switching arrangement is shown in Figure 9-3 and the major characteristics are summarized in Table 9-4. The switch is designed for a basic data rate of 6.3 Mbps. A dedicated frequency converter is provided for

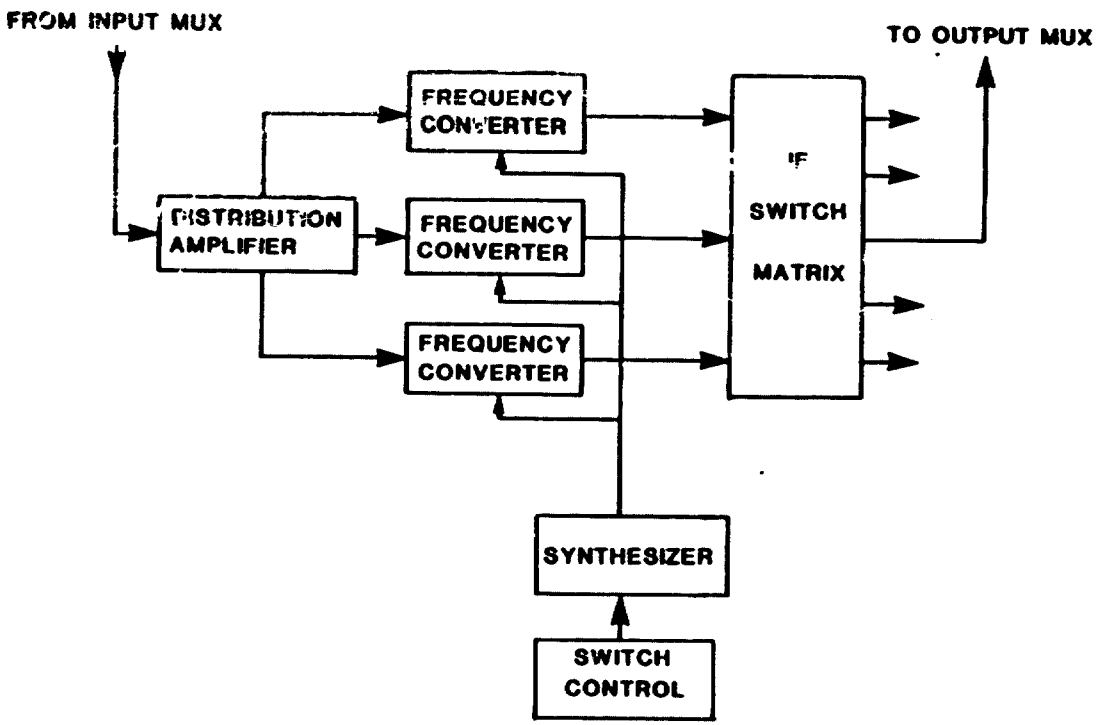


Figure 9-3

IF SWITCH SUBSYSTEM

each carrier. Translation frequencies are determined by ground controlled synthesizers. Large scale integration of analog and digital components will be required for this equipment because of the large quantity of units needed.

Table 9-4
IF Switch Characteristics

Number of Inputs	150
Number of Outputs	150
Blocking Probability	0.01
Transition Time	1 per sec.
Isolation	80 dB
Insertion Loss	0.5 dB
Bandwidth	200 MHz
Frequency Response	± 0.1 dB

Maintenance-free operation over a 10-year minimum life

9.3 Spacecraft Reliability

As the spacecraft complexity increases, spacecraft reliability becomes a question of major concern. Spacecraft lifetimes of 10 years will be desirable, and sufficient inherent reliability and redundency must be provided to achieve this lifetime without loss of vital functions. For example, a modest loss of capacity will be tolerable, but a loss of transmission links will not be acceptable. Switches will have to be designed so the alternate paths can be followed to establish a communications link in case of failure of any one individual path.

Reliability systems development will be required so that the combination of high reliable components and redundancy/diversity design will lead to the overall reliability objectives shown in Table 9-5.

Table 9-5

Spacecraft Reliability Objectives

- 10-year unserviced life
- 100% of SS/TDMA Switch connections operational after 10 years
- 90% of IF Switch connections operational after 10 years
- Full eclipse operations at 10 years
- Station Keeping and Attitude Control within specifications at 10 years.

9.4 Ka-band Technology

Ka-band operation is a necessary feature of the ADS; consequently Ka-band technology must be developed. NASA-Lewis Research Center is engaged in an extensive Ka-band technology program, and therefore, it is not necessary to consider this subject here.

9.5 Intersatellite Links

Network connectivity requires intersatellite links. For the first generation of ADS, the intersatellite links will transmit only the 6.3 Mbps carriers. Development items for intersatellite links are as follows:

20-40 GHz Moderate Power TWTA's
Wideband Communications System
Tracking Antenna Subsystem

The Lincoln Experimental Satellites #8 and #9 have successfully demonstrated the feasibility of intersatellite links in the 36-38 GHz band. Tracking antenna technology was also developed.

SECTION 10
CONCLUSIONS

In this section, we have summarized the major conclusions which can be drawn from this study.

10.1 U.S. Domestic Satellite Traffic

Based on our own investigations and the results of a number of other studies performed for NASA, substantial growth is expected in all sectors of U.S. domestic telecommunications. Telephony, while a mature service, will none the less continue to grow at substantial rates. In addition, the percentage of telephony traffic carried by a satellite will increase due primarily to the economic advantages of satellite transmission.

Data communcations is a service which is still in relative infancy. This is primarily due to the lack of interconnected networks of high speed data transmission channels. Such facilities are automatically provided in emerging domestic satellite systems. The increasing use of digital encoding for voice transmission will enable the efficient transmission of data over the same channels.

Rising costs and the inconvenience of business travel will become a strong incentive to substitute telecommunications for some travel. Video conferencing will replace some air travel and some local travel and will be used as a more efficient means of conducting business. In spite of the relative inconvenience associated with current video conferencing facilities, a number of firms in the U.S. have already made extensive use of these facilites. We anticipate that the provision of relatively low cost video conferencing channels via satellite will encourage substantial and explosive growth in video conferencing.

By 1995 a total of 120 transponders will be needed for data transmission, 1,000 transponders for voice transmission, and 8,000 transponders for video conferencing.

10.2 Orbital Arc Utilization

Due to the limited number of orbital slots available to the United States, high capacity advanced satellites will be needed to meet the rising demand during the late 1980's. The visability arc for the contiguous United States is shared with Canada and most of the South American countries as well as Mexico and the Caribbean Islands. Because of the need to minimize intersystem interference, a coordinated and logical plan for satellite antenna patterns and frequency assignments is needed. By 1987, the required average spacecraft capacity per orbital slot will reach a level of at least 38 transponders and may go as high as 100 transponders. By 1995, the average capacity will be at least 92 transponders per orbital slot and if video conferencing is provided will exceed 600 equivalent transponders per orbital slot. In addition, the use of television distribution in some slots will require the capacity of other slots to be even higher.

10.3 Satellites For Single Shuttle Launch

Studies by FSI, General Dynamics, COMSAT, and others indicate that satellites with usable capacities of 300 to 600 transponders will be feasible for launch along with an orbital transfer vehicle in a single shuttle cargo bay. These satellites will use all the available frequency bands, including frequencies recently allocated by the WARC for fixed satellite service. These satellites will have the following features:

1. Relatively large antenna aperatures, up to approximately 6 meters in diameter.
2. Frequency reuse by means of multiple spot beams.
3. Intersatellite links to enable full connectivity of the network.
4. On-board switching, both at RF for TDMA systems, and at IF for lighter traffic routes.
5. 10-year lifetime with improved reliability and station keeping accuracy.
6. Improved transmission parameters enabling the use of relatively simple, low-cost earth stations.

We expect these satellites to cost approximately $100 million apiece and about another $50 million to launch. Even considering this relatively high cost, the average cost per equivalent transponder year will be about $100,000. In addition, considerable savings will be available in the ground segment due to the improved transmission parameters, and the co-location of earth stations with customer premises.

10.4 Transmission Costs

Due to the reduced cost per transponder of the space segment, the reduced cost for the earth stations and the elimination (in many cases) of interconnect costs, break-even distances with terrestrial facilities will generally be less than 100 miles. For advanced services, such as high speed data communications or video teleconferencing, the break-even distances will be considerably lower.

10.5 Technology Development

In order for the advanced domestic system to be implemented commercially, technology development will be required in a number of areas.

Antenna Design - Multiple beam frequency reuse antennas will be required. These will provide area coverage by means of spot beams of about 1.3 degrees beamwidth and coverage of major cities by means of spot beams of about 0.5 to 0.6 degrees beamwidth. Major problems are to achieve low sidelobe levels and sufficient beam pointing accuracy and stability.

On-board Switching - Interconnection of multiple beams and different frequency bands requires extensive on-board switching. For this first generation advanced satellite, satellite switched TDMA switching at RF, and IF switching will be provided. Interconnection between the two switches will not be necessary.

Spacecraft Reliablity - As spacecraft complexity increases, spacecraft reliability becomes a major concern. The target lifetime of 10 years for this spacecraft will require substantial additional redundancy and reliability systems development in the area of power amplifiers, batteries, and station keeping and attitude control subsystems.

Other areas which require technology development are intersatellite links; light-weight, moderate power solid state amplifiers; integrated circuit microwave subsystems, which will reduce the weight of the transponder; and packaging and deployment schemes to enclosed the satellite within the shuttle orbital bay.

ANNEX A
TRAFFIC MODEL

ANNEX A
TRAFFIC MODEL

A.1 Introduction

This annex provides detailed information on the derivation of the traffic model which is presented in Section 3 of this report. Extensive use was made of the Western Union and ITT studies performed for NASA Lewis Research Center (References 2 and 3). While we have used the information provided, we have used our own judgment and other work previously performed by FSI in order to derive traffic requirements.

The present forecast covers a period of 15 years, 1980 to 1995. Since it is a long range forecast, it is important to consider the types of facilities which will likely be available during this time period. Rapid advances in communications technology are taking place at this time, and these advances will have a significant impact on the future development of communications facilities. Some examples of applicable technology advances are given below:

Fiber optics transmission links
New communications processors and switches
High capacity communications satellites
Low cost earth stations
New, low cost microwave transmission

Another important input in generating a traffic model is the regulatory environment. The following three bills addressing regulation and competition in the field of telecommunications are currently before the U.S. Congress:

S.611	Hollings, Cannon, and Stevens
S.622	Goldwater, Schmitt, and Pressler
H.R. 3333	Van Deerlin, Collins, and Broyhill

While the outcome of any new legislation affecting telecommunications is completely uncertain, it is reasonable to assume that there will continue to be some pressure to increase competition and that communications facilities brought into service by AT&T and by competing carriers will reflect this increasing competition. FSI is under contract to the Office of Technology Assessment (OTA) for certain work relating to the telecommunications study which is currently being performed for Congress, and we are therefore familiar with some aspects of pending new legislation and with inquiries by the FCC concerning competition in the MTS field

Rising energy costs will continue to have a major impact upon our lives and the way in which we use telecommunications to reduce travel. Since 1977, FSI has studied the impact of energy costs on telecommunications, and we have concluded that depletion of the world's oil reserves will continue to raise energy costs at least over the duration of this study period and that energy cost increases will be an additional stimulation of communications service demand. As travel becomes more expensive and less convenient, there will be an increasing tendency to substitute communications for some travel. This will lead to better communications facilities being offered, and once they are available, communications use will further increase and communications costs will continue to drop.

In preparing a communications traffic forecast, one must also consider the price elasticity, i.e , the sensitivity of service demand to service price. While voice communications costs are already quite low, price elasticity will have a major impact upon the use of video conferencing.

It is well known that video conferencing is much more demanding of transmission capacity than voice or data transmission. Using state-of-the-art coding equipment, the digital transmission capacity required for one video channel is equivalent to the capacity required for about 100 voice channels. Since most existing facilities have been designed for voice communications, it is obvious that these facilities are inadequate for widespread use of video conferencing, and therefore the costs per video channel are high. In turn, such high costs are a deterrence to the development of video conferencing systems.

Current technology permits the introduction of high capacity terrestrial and satellite communications systems which can reduce the costs for video transmission by at least one order of magnitude. The terrestrial solution for high capacity transmission facilities is fiber optics. The satelltie solution is the development of multi-beam satellites with multiple frequency reuse. A nationwide, high capacity satellite system is easier and cheaper to introduce than a nationwide fiber optics system. Accordingly, we have based our systems development scenario on the early expansion of satellite facilities, but we expect that a terrestrial fiber optics system will follow in due course.

The traffic forecast covers total U.S. requirements and does not address the share of individual communications carriers. There are now two terrestrial carriers (MCI and SPC) who provide MTS services in competition with the Bell System. In addition ITT has announced its intention to offer a similar service, and other carriers have MTS-type services under consideration. In many instances, the present share of the market of these specialized communications carriers is small. For example, the revenues of MCI and SPC are in the order of $100 million per year each, while the toll revenues of the Bell System are about $20 billion per year; thus these small specialized carriers have captured about 0.5 percent of the Bell System market each, but their share of the market could grow. AT&T's decisions concerning the introduction of new transmission facilities will largely determine the share of the specialized carriers; however, for the purpose of this study we have not addressed the question of market share.

A.2 Data Traffic

A.2.1 Background

While video conferencing is an entirely new application with practically no history of operational use, there is already some operational background for data communications. Although no firm data has been published by the carriers, current data communications revenues by all domestic carriers are estimated at ranging from $2.4 billion (Reference 1) to $4.7 billion (Reference 2), and data traffic is estimated to grow at 17 percent annually (Reference 2).

In 1978 NASA Lewis Research Center commissioned Western Union and ITT to perform studies of communications service demand for U.S. domestic satellite systems with special emphasis on the requirements for service at 18/30 GHz. The total contract amount of the two parallel studies was about $0.5 million, and the two carriers have probably spent additional corporate funds to perform the forecasts. These two studies represent the most detailed investigation of satellite communications service demand that is publicly available, and the results have therefore been used in this report. Future Systems Incorporated has been a subcontractor to Western Union on the preparation of information for its report, and certain FSI data has also been used by ITT in the preparation of the ITT report.

Data communications can be divided into the following categories:

Message Traffic

Message traffic is primarily composed of record communications between individuals and/or organizations. It includes TWX/Telex, facsimile, and electronic mail applications.

Computer Traffic

This category includes inquiry/response traffic between terminals and computers plus computer network traffic for distributed processing, funds transfer, and data base exchange.

Narrowband Teleconferencing

This includes image and character oriented data traffic in support of audio/graphic teleconferencing plus freeze frame television.

Data transmission requirements can be expressed in terms of information bits transmitted and in terms of transmission channel capacity. The ratio of information bits to transmission channel capacity is the transmission efficiency. For a given information rate, vastly different transmission channel capacities can result depending upon the data transmission architecture that is used.

For example, if a circuit-switched data channel is used for an interactive data communications application, the transmission efficiency may be only a fraction of a percent because of the low rate at which the human operator

types in data and interprets results and because of the transmission idle periods when the time shared CPU performs its function. This low efficiency is one of the reasons for the introduction of packet data communications networks where virtual circuits are set up and where the transmission channel is shared by several virtual channels.

Even in packet-switched networks, the transmission efficiency can be low, perhaps 10 to 30 percent because the packet fill factor is low resulting in larger transmission overhead. In some cases packet fill factors are intentionally kept low in order to reduce network response time. For example, at a 300 baud transmission speed it takes over 3 seconds to fill a typical Telenet packet of 1,024 bits. For other higher speed applications, transmission efficiencies of 50 to 70 percent are more typical.

The design of the transmission architecture, which determines the transmission efficiency, will generally be dependent upon the transmission costs. In networks where transmission costs are high, data processing and concentrating equipment will be employed to reduce transmission line capacity requirements. However, where transmission costs are low, lower efficiencies will be permitted in order to save processing equipment costs. In our forecast for data service requirements, we refer to transmission channel data rates rather than to raw information data rates.

In the case of video conferencing, we have concluded that the total traffic will be carried on satellite circuits except for intrafacility traffic. For data applications, however, it is necessary to distinguish between satellite and terrestrial traffic.

In the past the use of satellites for data applications has been handicapped by the existing protocols which did not allow for the satellite transmission delay. Satellite transmission often results in low throughput because of the relatively long waiting times for acknowledgement receipt. Modern data transmission protocols make allowance for the satellite transmission delay; thus this problem will gradually disappear.

A.2.2 Estimate of Message Service Demand

Message service demand is divided into the following categories:

TWX/Telex Traffic
Conventional Facsimile Traffic
Advanced Electronic Mail

A.2.2.1 TWX/Telex Service Demand

The demand estimate for this service category is based upon estimates of the number of terminals in use. Table A-1 lists several available estimates of terminal population along with the source of information. All estimates were converted into a number of messages per year based on the following conversion factors:

Five Messages per Day per Terminal and 250 Days per Year
$1.60 per Message

Table A-1

TWX/Telex Estimates

Period	Estimate	Conversion Factor	MSGS/ Year	Source
1975	100,000 Terminals 4-6%/yr. growth	1250 msg/yr. per terminal	125M	Business Communications, 1975-1985 May 1975, A.D. Little
1974	$200M Comm. Carrier Revenue	$1.60/ Message	125M	"
1980	$250-280 Comm. Carrier Revenue .	$1.60/ Message	156-175M	"
1977	111,000 Terminals	1250 msg/yr. per terminal	139M	Cost-Effective Switching System Design - L. Stier, Western Union Info. Systems, Telecomm. Aug. 1977
1976	108M Pgs/Yr.	1	108M	Xerox Corp. Petition for Rule Making before FCC Nov. 16, 1976, App. C
1978	$245M Comm. Carrier Revenue	$1.60/Msg.	153M	Telecomm. Market Opportunities in the U.S., 1978; Internat'l. Resource Devel. Inc., April 1978
1980	$270M	$1.60/Msg.	168M	"
1983	$295M	$1.60/Msg.	184M	"
1986	$325M Comm. Carrier Revenue	$1.60 Msg.	203M	"
1970	80,000 Terminals	1250 Msg/yr. per terminal	100M	Impacts of Electronic Comm Systems on the U.S.P.S. 1975-1985, C-80209 Feb. 14, 1977, A.D. Little, P4-9
1975	106,000 Terminals	1250 Msg/yr. per terminal	133M	"
1985	145,000 Terminals	1250 Msg/yr. per terminal	181M	"
1980	156M Msgs/yr.	1	156M	"
1971	81,000 Terminals	1250 Msg/yr.	101M	Communications News Dec. 1978, P29
1972	89,000 Terminals	"	111M	"
1973	97,000 Terminals	"	121M	"
1974	102,000 Terminals	"	128M	"
1975	105,000 Terminals	"	131M	"
1976	110,000 Terminals	"	138M	"
1977	115,000 Terminals	"	144M	"
1978	119,000 Terminals	"	149M	"

Source: Reference

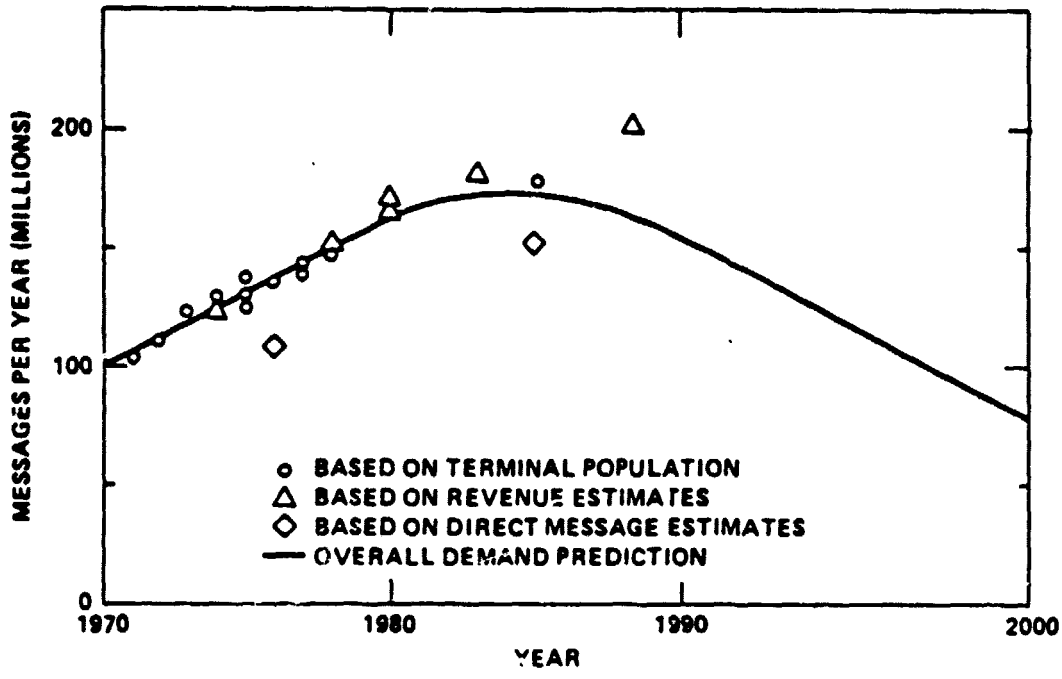
The various estimates are plotted in Figure A-1. The estimated decline in demand past 1985 is based on the expectation that current TWX/Telex terminals will be retired in favor of more efficient message terminals in future years.

The number of messages is converted into a number of bits by assuming 120 words per message, six characters per word, and eight bits per character resulting in 5,760 bits per message. Annual traffic is then converted into peak busy hour traffic by assuming 250 business days per year, 24 hours per day, and a peak to average factor of four. On this basis one busy hour Mbps at 100 percent efficiency converts into 5.4 terabits per year. Transmission line efficency is assumed to range from 1 to 10 percent. The results are shown in Table A-2.

Table A-2
Projected TWX/Telex Service Demand

Year	Messages per Year (Millions)	Traffic in Terabits per Year	Transmission Efficiencies in Percent	Busy Hour Transmission Capacity in Mbps (one-way)
1980	150	0.86	1	15.9
1985	170	0.98	2	9.1
1990	145	0.84	5	3.1
1995	120	0.69	10	1.3

Thus it is found that in terms of overall transmission capacity requirements, the TWX/Telex traffic is small. Not only do the message requirements decrease with time, but also the transmission line efficiencies increase due to increasing use of the more efficient packet networks.



SOURCE: REFERENCE 5

Figure A-1

TWX/TELEX MESSAGES PER YEAR

A.2.2.2 Conventional Facsimile Service Demand

Since the late 1960's, business use of facsimile has developed into a viable market. Table A-3 shows various estimates of the number of terminals installed, and Figure A-2 is a graphic presentation of the same information. There is a wide diversion of estimates, but the assumed growth rates are uniform at about 18 percent per year. We have averaged these estimates and extrapolated them with a gradually dropping growth rate also shown in Figure A-2. The resulting service demand is shown in Table A-4. The following conversion factors were used:

1,800 Pages per Year per Terminal

300,000 Bits per Page
(This results in 0.54 terabits per 1,000 terminals per year.)

250 Days per Year

24 Hours per Day

Peak to Average Factor = 4

As before, with 100 percent transmission efficiency, one terabit per year converts into 0.185 Mbps.

Table A-3

Estimates of Installed Facsimile Terminals

(Thousands)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Yankee Group - Market for a FAX store and forward system for ITT 1975	122	140	161	185	212	245					
A.D. Little - Impacts of Elect. Comm. Systems on U.S. Postal Service, Feb. 1977	121					240					185
Frost & Sullivan - FAX Equipment and Services in U.S.A., May 1977			102	116	131	147	163				
Creative Strategies Inc. - The FAX Industry, Mar. 1978	100	107	120 122*	135 140*	152 162*	173 189*	198 229*	234 287*			
Telautograph Corp. - Quoted in Telecommunications, pg. 77 May 1978				130							
Quantum Sciences - Office Tech. Strategy Program Vol. III 1978		146	175	208	247	290		388			
Yankee Group - Quoted in Computer Decisions pg. 36, Sept. 1978			146	188							
International Resource Devel. Via Telecom. Caswell, March 1979				195 210*		335		540			

*Pages/Year x 10^{-6}

Source: Reference 5

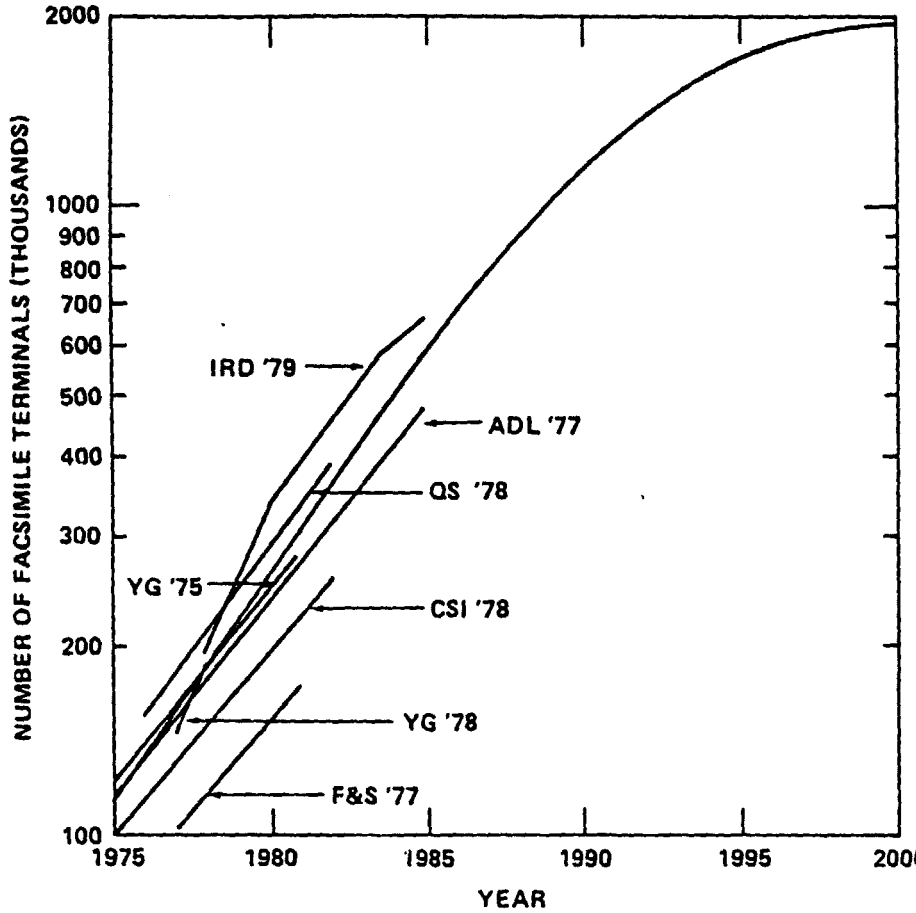


Figure A-2

FORECASTS OF FACSIMILE TERMINALS IN USE

Table A-4

Facsimile Service Demand Estimate

Year	Number of Facsimile Terminals (1,000)	Traffic in Terabits per Year	Transmission Efficiency (Percent)	One-Way Data Transmission Requirement Mbps
1980	260	140	15	173
1985	600	324	17.5	343
1990	1,150	621	20	575
1995	1,700	918	22.5	756

A.2.2.3 Advanced Electronic Mail Systems

With the introduction of new terminal types and new data transmission facilities, the development of advanced electronic mail systems is expected. The following developments are expected to take place:

1. Diversion of physical mail to electronic mail.
2. New document distribution networks.
3. Increased use of communicating word processors and character-oriented message terminals.
4. Increased use of facsimile transmissions with increased speed, convenience, and quality at reduced costs.
5. Office of the future practices by government and industry.
6. Decentralization of work locations with increased communications demands.

To some extent these advanced new services will substitute for the conventional facsimile services and the TWX/Telex services described in Sections A.2.2.1 and A.2.2.2. For this reason the growth of these conventional services was assumed to slow dowm and even reverse in later years.

Several estimates of advanced electronic mail service requirements have been made by A. D. Little, Frost & Sullivan, Xerox, George Washington University and others. A composite estimate derived from Reference 3 is shown in Table A-5.

Table A-5
Projected Traffic Demand Due to Advanced Electronic Mail Systems

		Year		
		1980	1990	2000
Business to Business First Class Mail	Mail Vol. (Pieces x 10^9)	12.5	15.2	18.6
	% Diverted to EMS	0.25%	25%	50%
	Vol. to EMS (x 10^9)	.03	3.8	9.3
Business to Home & Home to Business	Mail Vol. (Pieces x 10^9)	16.2	19.7	24.1
	% Diverted to EMS	0%	5%	20%
	Vol. to EMS (x 10^9)	0	1.0	4.8
Business to Business Private Mail	Mail Vol. (Pieces x 10^9)	38.6	51.9	69.7
	% Diverted to EMS	0.5%	60%	80%
	Vol. to EMS (x 10^9)	.19	31.1	55.8
Mail Volume Total (Pieces x 10^9)		67.3	86.8	112.4
Diverted to EMS Total (Pieces x 10^9)		.22	35.9	69.9
Percent Image/Character Modes		90/10	50/50	20/80
Projected Image Mode Pages (x 10^9)*		.20	18.0	14.0
Projected Character Mode Pages (x 10^9)		0.02	18.0	55.9
Image Mode Bits/Yr. @ 300,000 B/Pg. (x 10^{12})**		60	5,400	4,200
Char. Mode Bits/Yr. @ 20,000 B/Pg. (x 10^{12})		6	360	1,120

*Assumes one page per piece of mail
**Assumes slightly better resolution than today's typical FAX

Source: Reference 3

This estimate is translated into busy hour transmission capacity requirements in Table A-6. Based on 250 days per year and a peaking factor of 4 at 100 percent transmission line efficiency one terabit per year corresponds to 0.185 Mbps.

Table A-6
Advanced Electronic Mail
Service Demand Estimate

	Year		
	1980	1990	2000
Terabits per Year			
Image Mode	60	5,400	4,200
Character Mode	6	360	1,120
Total	66	5,760	5,320
Transmission Efficiency	30%	40%	50%
One-Way Data Transmission Requirement (Mbps)	40	2,670	1,970

To permit interpolation to other years, advanced electronic mail service demand estimate has been plotted on Figure A-3.

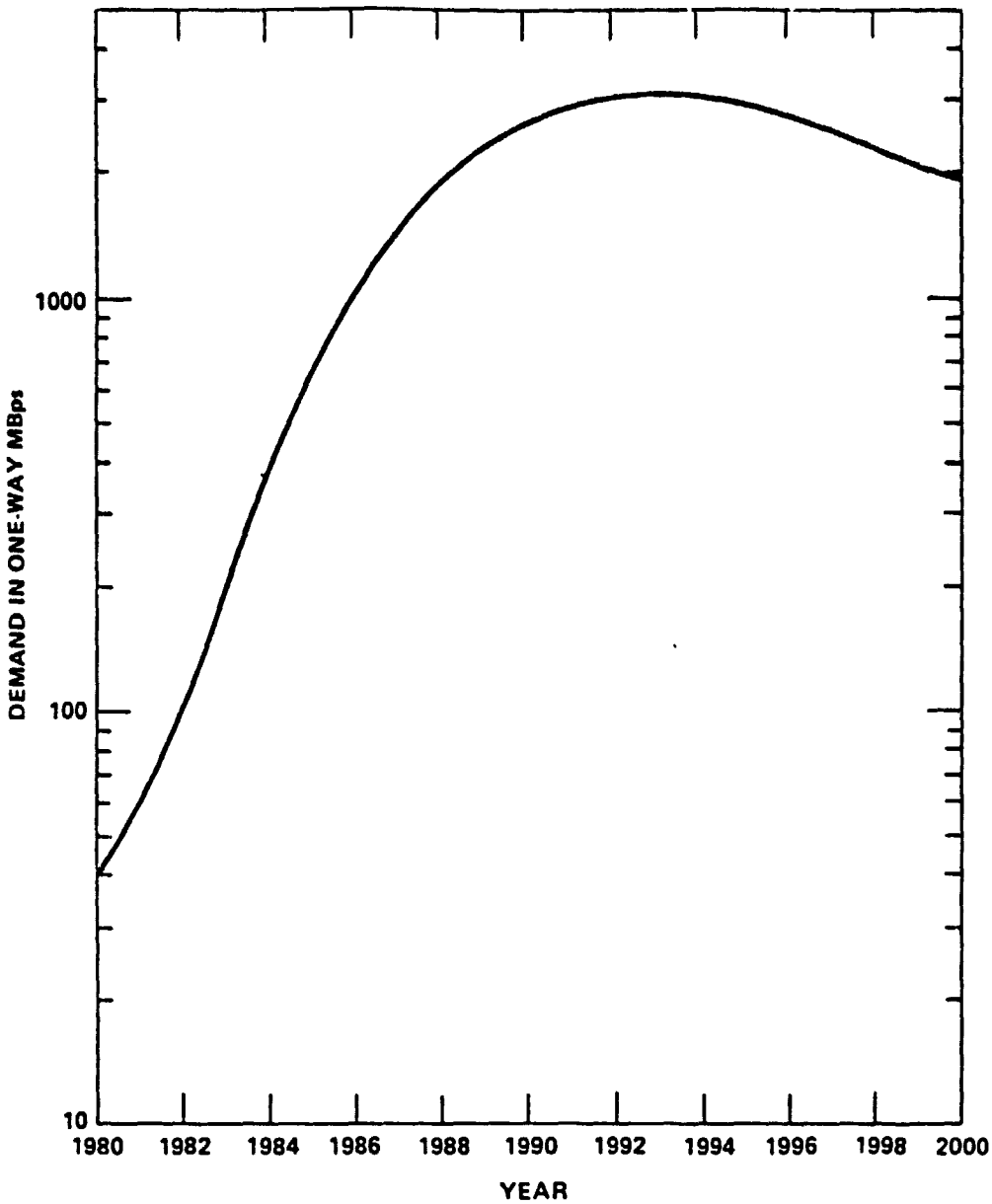


Figure A-3

ADVANCED ELECTRONIC MAIL
SERVICE DEMAND
(One-Way MBps)

A.2.2.4 Total Message Service Demand

Table A-7 lists the total message service demand in one-way Mbps.

Table A-7
Total Message Service Demand
(One-Way Mbps)

Year	TWX/Telex	Conventional Facsimile	Advanced Electronic Mail	Total
1980	16.0	173	40	230
81	14.4	205	60	279
82	13.0	235	100	348
83	12.8	265	190	468
84	10.4	305	360	675
1985	9.0	340	620	969
86	7.6	380	1,000	1,388
87	6.2	425	1,400	1,831
88	5.0	475	1,850	2,330
89	3.9	525	2,250	2,779
1990	3.0	575	2,670	3,250
91	2.2	620	2,900	3,522
92	1.7	660	3,050	3,712
93	1.4	700	3,100	3,801
94	1.3	735	3,050	3,786
1995	1.3	760	2,950	3,711

A.2.3 Estimate of Computer Communication Service Demand

Computer-related communications requirements can be grouped into several categories as follows:

Computer to Terminal Communications

This involves terminals of the interactive and remote batch type at speeds ranging up to about 19.2 kbps.

CPU to CPU Communications

This category includes primarily transfers of data base contents from one central computer facility to another.

Electronic Funds Transfer

This includes both check clearing data transfers and credit card initiated transfers.

A.2.3.1 Computer to Terminal Communications

The forecast of this segment of the computer-related requirements is based on several forecasts of the number of computer terminals in use in the next 20 years. Table A-8 shows a detailed forecast of this type. We have converted these values to a traffic estimate based on a traffic production of 380 MB per terminal per year. This factor is a composite of data production for the several terminal types shown in the table. The total forecast is shown in Figure A-4.

In converting to the data rate requirements shown in Figure A-4, we have employed the following factors:

250 business days per year

24 hours per day

Peak factor of 4 (over 24 hours)

Transmission efficiency of 70 percent, reflecting the use of advanced packet network protocols

The resulting total transmission requirement is shown in Table A-9.

Table A-8

Installed Terminals

	Year			
	1976	1980	1990	2000
Alpha/numeric CRT Single Station Nonprogrammable	260	530	2,114	5,483
Alpha/numeric CRT Single Station User Prog. On-Line	24	101	940	3,002
Alpha/numeric CRT Multi-Station Nonprogrammable	226	180	35	7
Alpha/numeric CRT Multi-Station User Prog.	85	425	1,719	4,460
Alpha/numeric CRT Single Station User Prog. Batch	39	178	719	1,866
Teleprinter Non-Programmable	425	573	933	1,519
Teleprinter User Program	51	195	1,207	3,749
Totals	1,110	2,182	7,667	20,086

Source: Reference 5

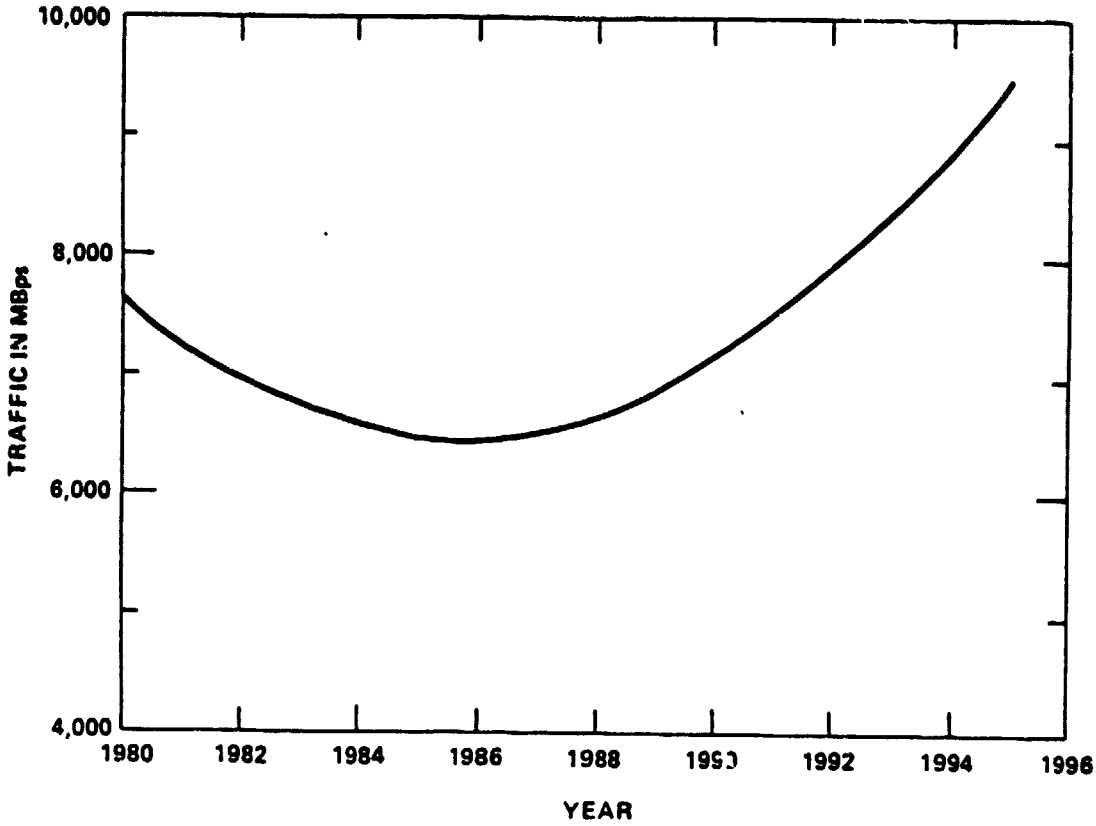


Figure A-4

TERMINAL TO CPU TRAFFIC

Table A-9

Terminal to CPU Traffic

	Year			
	1980	1985	1990	1995
Number of Terminals (1,000's)	2,180	4,600	7,670	13,600
Terabits per Year	830	1,750	2,910	5,170
Transmission Efficiency	2%	5%	7.5%	10%
One-Way Data Transmission Requirement (Mbps)	7,680	6,480	7,190	9,570

It is interesting to note that the total transmission requirement does not change greatly with time, although the information transfer increases substantially. This is due to the assumption that increasing portions of the total traffic are transmitted in the packet mode thus raising the total transmission efficiency. The efficiency of transmission in a circuit switched mode is generally less than 1 percent, while the efficiency in the packet mode may be 50 percent. However, even if 90 percent of the traffic is transmitted in the packet mode, the remaining 10 percent of the traffic with 1 percent efficiency depresses the overall transmission efficiency.

A.2.3.2 CPU to CPU Transmissions

This component of the data transmission market is quite difficult to estimate since there is very little of it in existence today. However, we have assumed that ultimately there will be a large fraction of the terminal to CPU traffic that will require data base access. In order to support this component, the

data base contents must be transferred from one central computing facility to another. The transfers will be relatively less frequent than the accesses so the data traffic generated by the data base transfers will be smaller than the traffic generated by terminal to CPU communications.

Another source for this type of traffic is distributed processing. We have expressed this type of traffic as a fraction of the terminal to CPU traffic as shown in Figure A-5. Since this traffic is transferred without human intervention, the transmission efficiencies are higher than in the terminal to CPU case. Table A-10 shows the resulting transmission requirement.

Table A-10
CPU to CPU Traffic

	Year			
	1980	1985	1990	1995
Terminal to CPU Traffic (Terabits per Year)	830	1,750	2,910	5,170
Traffic Ratio	0.05	0.07	0.13	0.26
CPU to CPU Traffic (Terabits per Year)	41	123	380	1,340
Transmission Efficiency	4%	7%	10%	15%
One-Way Data Transmission Requirement (Mbps)	190	325	700	1,650

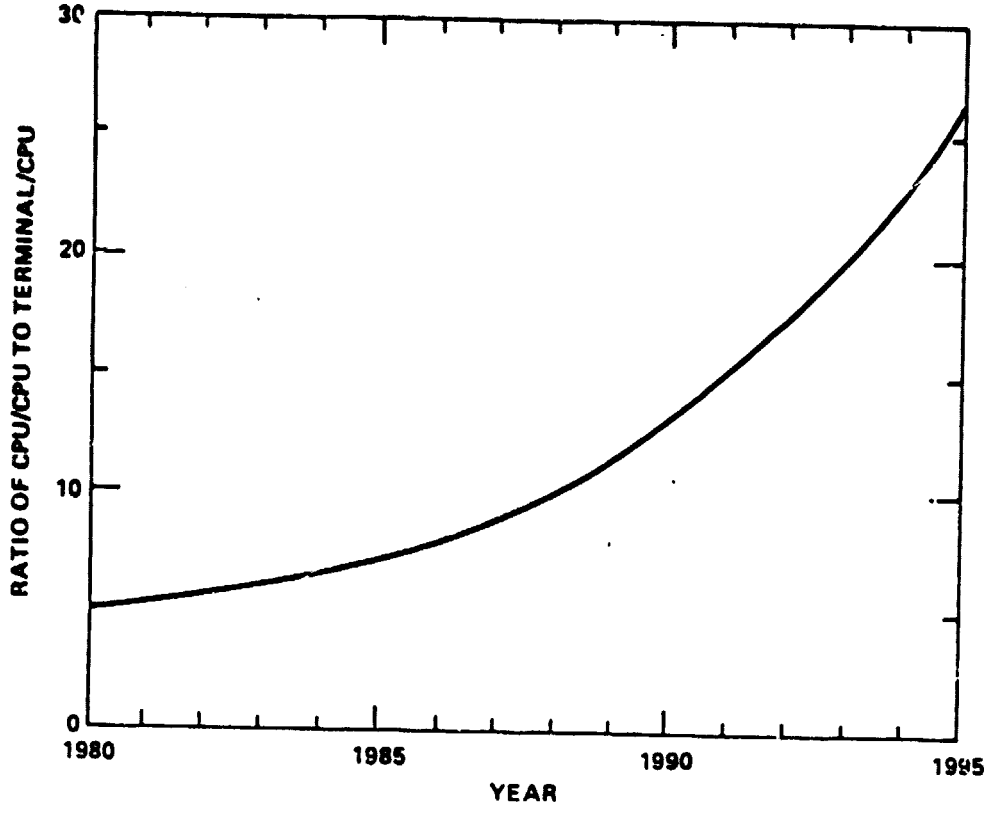


Figure A-5

CPU TO CPU TRAFFIC AS A FRACTION
OF TERMINAL TO CPU TRAFFIC

A.2.3.3 Electronic Funds Transfer

This portion of the market will be concerned primarily with the clearinghouse function for check handling and the growing volume of credit card initiated funds transfers. Most of the growth in this service will come from the gradual conversion to this method of transaction handling, since there are strong indications that the volume of transactions is reaching a saturation region with rather slow growth. The forecast from Reference 3 shown in Table A-11 has been converted to a data rate requirement as shown in Table A-12. The transmission efficiency is assumed to range from 10 percent to 30 percent, since storage and data compression techniques can eliminate the inefficiencies caused by human interaction.

Table A-11
EFT Traffic Demand

	Year		
	1980	1990	2000
Number of Checks per Year ($\times 10^9$)	36.3	50.1	63.8
Potential Traffic (Terabits) at 1,000 Bits per Check	36.3	50.1	63.8
Percent Converted to EFT	10	60	90
EFT Terabits	3.6	30.1	57.4

Source: Reference 5

Table A-12

Transmission Requirements for EFT

	Year			
	1980	1985	1990	1995
Terabits per Year	4	16	30	44
Transmission Efficiency (Percent)	10	15	20	30
One-Way Data Transmission Requirement (Mbps)	7	20	28	27

A.2.3.4 Total Computer Communications Service Demand

Table A-13 lists the estimate total computer communications service demand in one-way Mbps.

A.2.4 Narrowband Teleconferencing Service Demand

Narrowband teleconferencing is the poor cousin of video conferencing. It includes all the features of a video conferencing facility except video:

High Quality Audio, Perhaps Sterophonic
High Quality, High Speed Fax
Electronic Blackboard
Character Mode Terminals
Freeze Frame Television

Conferencing facilities of this type will be constructed with transmission bandwidth requirements ranging from 19.2 kbps to 112 kbps, two way. Table A-14 is the ITT forecast for this type of traffic.

Table A-13

Total Computer Communications Service Demand

(One-Way Mbps)

Year	Terminal to CPU Traffic	CPU to CPU Traffic	EFT Traffic	Total Traffic
1980	7,680	190	7.0	7,880
81	7,250	200	9.5	7,460
82	6,950	220	12.5	7,183
83	6,750	245	15.0	7,010
84	6,600	280	17.5	6,898
1985	6,480	325	20.0	6,830
86	6,450	380	22.0	6,852
87	6,500	440	24.0	6,964
88	6,650	510	26.0	7,186
89	6,850	600	27.0	7,477
1990	7,190	700	28.0	7,920
91	7,500	820	28.5	8,349
92	7,900	970	28.5	8,899
93	8,350	1,130	28.5	9,509
94	8,850	1,340	28.0	10,218
1995	9,570	1,650	27	11,250

Table A-14
Narrowband Teleconferencing

		Year 1980	1990	2000
1.	Enplanements	234×10^6	383×10^6	575×10^6
2.	Business Enplanements @ 40%[1]	93.6×10^6	153×10^6	230×10^6
3.	Conferences (Bus. Enplanements x .675)[2]	63.2×10^6	103×10^6	155×10^6
4.	Conferences Potentially Replaceable by Audio/Graphic Teleconf. (@ 45%)[1]	28.4×10^6	46.4×10^6	69.8×10^6
5.	Percentage Realized	1%	25%	50%
6.	Number of Audio/Graphic Teleconf.	$.284 \times 10^6$	11.5×10^6	34.9×10^6
7.	Pages per Year (@ 10 per Teleconf.)	2.84×10^6	116×10^6	349×10^6
8.	Percent Image/Character Modes	95/5	90/10	75/25
9.	Pages/Year Image Mode	2.70×10^6	104×10^6	262×10^6
10.	Image Mode Bits/Yr. (@ 400,000 Bits/Pg.)[3]	1.08×10^{12}	41.6×10^{12}	104×10^{12}
11.	Pages/Year Character Mode	$.142 \times 10^6$	11.6×10^6	87.3×10^6
12.	Character Mode Bits/Yr. (@ 20,000 Bits/Pg.)	$.003 \times 10^{12}$	$.232 \times 10^{12}$	1.75×10^{12}
13.	Teleconf. Hrs./Yr. (@ 2 Hrs./Conf.)	$.568 \times 10^6$	23.2×10^6	69.8×10^6
14.	Teleconf. Hrs./Yr. with Freeze Frame TV[4]	$.114 \times 10^6$	4.64×10^6	14.0×10^6
15.	Bits/Yr. for Freeze Frame TV[4]	7.88×10^{12}	320×10^{12}	968×10^{12}

1. Technology Assessment of Telcom./Transportation Interactions, Vol. 2-SRI May 1977.

2. Business enplanements x (2.7 Conf./Round Trip) (2 Travelers) (2 enplanements/round trip).

3. Based on 85 percent office copy quality at 300,000 bits/page and 15 percent letter quality at 1,000,000 bits/page.

4. Assumes that 20 percent of audio/graphic conferences require additional capability for freeze frame TV on each of two 9.6 kbps channels (30 - 60 sec. refresh rate with image compression).

Transmission requirements for this type of traffic are presented in Table A-15.

Table A-15

Transmission Requirements for Narrowband Conferencing

	Year			
	1980	1985	1990	1995
Terabits per Year				
Image Mode	1	19	42	69.0
Character Mode	--	0.1	0.2	1.0
Freeze Frame TV	8	135	320	555
Total	9	154	362	625
Transmission Efficiency (Percent)	10	12.5	15	20
Transmission Requirement (Mbps)	17	228	447	578

A.2.5 Satellite Versus Terrestrial Transmission

In determining the satellite capture ratio, ITT has first eliminated all traffic over distances of less than 200 miles and has then estimated the capture ratios listed in Table A-16.

Table A-16

ITT Estimate of Percent Capture by Satellite

	Year		
	1980	1990	2000
Voice	2	15	25
Video	50	60	60
Data	1	50	60

Source: Reference 5

While the overall ITT results may be correct within the estimating accuracy that can be expected, FSI experience indicates that networking aspects will be important in satellite versus terrestrial transmission trades. Once a satellite network is established with earth stations available at many locations to provide long distance communications, then it will be found convenient from a network design point of view to transmit also shorter distance traffic over the satellite network.

The distribution of interstate MTS traffic is shown in Figure A-6. It shows that the mean communications distance increases with time. The solid lines are derived from the ITT study; the dashed line is the FSI extrapolation for the year 1990. We expect that data communications traffic will follow similar patterns.

Based on FSI communications systems design experience, in a network even data links with 20-mile distance are candidates for satellite transmission; therefore, we do not consider it appropriate to eliminate any distance range from the addressable market. Instead we have estimated the overall satellite system capture ratios shown in Table A-17.

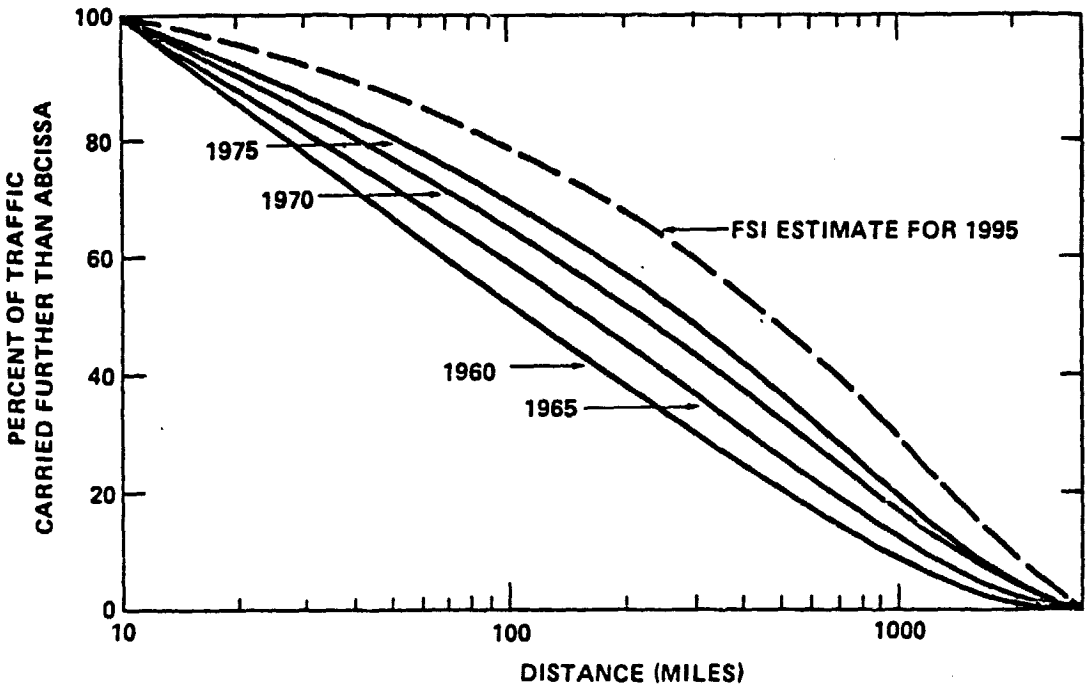


Figure A-6

DISTRIBUTION OF INTERSTATE MTS TRAFFIC
VERSUS DISTANCE AND TIME

A.2.6 Total Data Transmission Requirements for Satellite Facilities

Table A-17 summarizes the total U.S. domestic data transmission requirements and calculates satellite data transmission requirements based on estimated capture ratios. Table A-18 shows the expected capacities per equivalent 36 MHz C-band transponder and the resulting number of transponders required for data transmission. Please note that the term transponder is used only for reference purposes. Actual spacecraft will employ different transmission configurations.

Transponder capacity is expected to increase with time as a larger percentage of traffic is converted to high rate TDMA transmission.

Table A-17

Total Data Transmission Forecast

Year	Total Message Service (Mbps)	Total Computer Service (Mbps)	Narrowband Conferencing (Mbps)	Total Data Service (Mbps)	Satellite Percent Capture	Satellite Traffic (Mbps)
1980	230	7,880	17	8,027	1	80
81	279	7,460	55	7,794	2	156
82	348	7,183	95	7,626	3	229
83	468	7,010	135	7,613	6	457
84	675	6,898	178	7,751	9	698
1985	969	6,830	228	8,027	12	963
86	1,388	6,852	275	8,515	16	1,362
87	1,831	6,964	325	9,120	19	1,733
88	2,330	7,186	370	9,886	23	2,274
89	2,779	7,477	412	10,668	28	2,987
1990	3,250	7,920	447	11,617	30	3,485
91	3,522	8,349	480	12,351	33	4,076
92	3,712	8,899	510	13,121	35	4,592
93	3,801	9,509	535	13,845	37	5,123
94	3,786	10,218	555	14,559	39	5,678
1995	3,711	11,250	578	15,539	40	6,216

Table A-18

Satellite Transponder Requirements for Data Transmission

Year	Satellite Traffic (Mbps)	Average Transponder Capacity (Mbps)	Number of Transponders
1980	80	30	3
81	156	32	5
82	229	34	7
83	457	36	13
84	698	38	18
1985	963	40	24
86	1,362	41	33
87	1,733	43	40
88	2,274	44	52
89	2,987	46	65
1990	3,485	47	74
91	4,076	48	85
92	4,592	49	94
93	5,123	50	102
94	5,678	51	111
1995	6,216	52	120

A.3 Voice Service

The requirement for voice communications services is most directly correlated with population, social factors and business activity. Unlike video conferencing and data communications services, technological innovations will probably not play a major role in the growth of voice services. Major categories of voice services are:

Message Telecommunications Services (MTS)
Wide Area Telecommunications Services (WATS)
Private Line Services

Other voice services are audio program transmissions and trunk mobile audio transmissions. These services, however, are negligible compared to the three major categories and have therefore not been considered in the study.

ITT performed a major survey of voice requirements and reported the results of this survey in a study for NASA Lewis Research Center (Reference 3). FSI used the basic conclusions with respect to total voice circuit requirements as a basis for its forecast of satellite communications requirements.

The ITT study examined:

Population
Households
Gross National Product (GNP)
Population Sorted by Age Brackets
Disposable Personal Income
Employment Figures

ITT found that of all these factors, correlation with population, number of households and GNP, were most promising for projecting growth of telephone circuit requirements. Based on these factors, ITT projected total number of calls and average call durations, which determined total traffic volume. Based on historical operating statistics, peaking factors were derived in order to be able to calculate busy hour voice circuit requirements.

ITT performed separate calculations for the peak busy hour in the evening which is due to residential traffic primarily, and for the busy hour during daytime which is controlled by business communications. The study concluded that the busy hour circuit requirements determined by residential traffic were slightly higher than the daytime busy hour circuit requirements determined by business traffic. When the voice requirements are combined with data and video teleconferencing traffic, however, the business peak hour becomes the controlling factor for the total traffic. For this reason, in our forecast we have used the ITT figures for business busy hour circuit requirements. These are shown in Table A-19.

From an estimated percent of satellite capture and an assumed average number of duplex circuits per transponder, we have derived the forecast for the number of 36 MHz equivalent bandwidth transponders required to support telephony service demand for U.S. domestic communications.

Table A-19
Telephony Service Demand

Year	1980	1985	1990	1995
Total requirements in millions of duplex call circuits				
MTS	0.52	0.8	1.33	2.03
WATS	0.31	0.47	0.70	0.97
Private Line	0.28	0.38	.72	1.20
Total	1.11	1.65	2.75	4.20
Satellite Capture, percent	2.5	7.9	12	12
Average number of duplex circuits per transponder	400	450	500	500
Number of 36 MHz transponders required	70	289	660	1008

*Source: Reference 5

A.4 Video Conferencing

A.4.1 Background

Experimental video conferencing systems have been in operation in the U.S. and in other countries for some time, and experiments have been conducted to determine the value of video. It was found that for certain applications, audio supported by facsimile was adequate and that the additional value of video was judged small compared to the high cost of video transmission. Other users found that video made an important contribution to the communications process.

AT&T operates the Picturephone Meeting Service which is a public video conferencing service. In addition, AT&T operates a private video conferencing network for its own use. The AT&T conference room facilities lend themselves well to formal conferences. However, the charges for the service are high, amounting to $390 per hour, for example, for the Washington to San Francisco link. Established video transmission facilities are used on a shared basis with the TV networks. Even at the high hourly rate charged, it is not certain that the fully allocated costs would be covered if dedicated facilities are used with larger conferencing traffic volume

The main disadvantage of the current system is its lack of convenience. For example, if a suburban Washington user requires a conference with a client in Palo Alto, California, each party would incur 2 hours of automobile travel for the round trip to the conference room, perhaps with the inconvenience of rush hour city traffic and parking problems. This loss of time and inconvenience along with the high hourly rates make the value of video conferencing questionable, compared with the other alternatives of telephone conversations and long distance travel.

In order for video conferencing to become universally accepted, two developments are required:

1. Video transmission costs must be reduced substantially.
2. Conference rooms must be widely available without local travel.

FSI predicts that both these developments will take place during the time period covered by the forecast, and that as a result the basic objections to video conferencing will be removed. It is clear that even then there will be a large percentage of business people who will dislike video conferencing and will try to avoid using it. The extensive use of video conferencing will need changed behavior patterns which will take time to establish. However, even if only a small percentage of the business community uses video conferencing, the need for very substantial new transmission facilities will result.

A.4.2 Video Conferencing System Implementation

The initial users of video conferencing services on a large scale will be large corporations. These same corporations also have requirements for high volumes of voice and data communications services and will have provided dedicated earth station facilities for those services. These same earth stations can then be used for transmission and reception of video conferencing traffic at very low incremental costs.

High quality video conferencing transmission using interframe coding with compression techniques can be accomplished at the T-2 transmission rate of 6.3 Mbps per second for individual one-way channels. The video transmission coding equipment for this compressed transmission is still expensive, in the order of $50,000 per circuit end if purchased in small quantities today. During the next few years, considering larger quantity purchases, costs will go down to about $10,000 per circuit end which will make the acquisition of such units by major corporations quite practical.

Another required investment will be conference room facilities. Depending on the sophistication and complexity, the required video cameras, monitors, facsimile circuits, electronic blackboard, voice-operated audio facilities, and video recorders could bring the required investment costs to a level of perhaps $50,000 per conference room facility. In this area as well, substantial reductions in costs can be expected, and some less ambitious conference facilities will be available for an investment cost of perhaps $10,000 per conference room as soon as equipment is constructed in larger quantities.

Based on these considerations, major corporate locations will be able to add video conferencing facilities to their existing earth station system at an investment cost of about $20,000 per facility, which translates into an amortized monthly cost of about $600 per month. If the conference room is used only for an average of 3 hours per working day, the monthly cost for the facilities translates into about $10 per hour of use.

Current U.S. domestic communications satellites have very low capacity when used for video conferencing. Table A-20 shows the total number of two-way video circuits that can be transmitted through each of the existing and planned communication satellites assuming 6.3 Mbps per one-way per video transmission.

Table A-20

Video Conferencing Capacity of Existing and Planned Satellites

Satellite Type	Number of Transponders	Number of Two-Way Video Circuits*
Western Union's Westar	12	60
RCA's Satcom	24	120
AT&T's Comstar	24	120
Western Union's Advanced Westar	28**	140

*Based on a multiple access transmission rate of 63 Mbps per transponder and 6.3 Mbps per one-way video conferencing channel.

**Digital capacity is translated into transponders at 63 Mbps per transponder.

The space segment transmission costs can easily be calculated. Assuming a transponder lease charge of $1 million per year, the transponder transmission capacity of five two-way video circuits results in an annual cost per video circuit of $200,000. With 100,000 paid minutes per year, the per minute cost of the space segment would be $2, resulting in an hourly cost of $120. Even if users were willing to pay this high transmission charge, the small video conferencing capacity per satellite would make widespread use of current communication satellites for video conferencing completely prohibitive since the number of available orbital positions is too small.

Therefore, both from a cost point of view and from the point of view of use of the orbital arc, it will be necessary to make a transition to high capacity satellites of the type described in Section 3, U.S. Domestic Satellite Traffic Projections. In that section it was shown that space segment transmission costs for video conferencing circuits would be in the order of $10 per hour.

Based on these considerations, it is concluded that future video circuit transmission costs will be in the order of $30 per hour (expressed in 1979 dollars) with a cost breakdown as shown below:

Space segment transmission costs per hour	$10
Incremental earth station and conference room facilities costs per hour	10
Communications carriers administrative expenses and profit per hour of use	10
Total hourly charge	$30

A video conferencing per minute cost of 50 cents compares favorably with current long distance telephone rates of 10 cents to 30 cents per minute. Our pre ise of video conferencing use is thus based on the assumption that adequate facilities will be established leading to low costs, and that these facilities will be widely available for convenient use of video conferencing including person-to-person communications.

A.4.3 The Impact of Energy Costs on Travel and Telecommunications

The U.S. balance of payments deficit is caused largely by oil imports. Future increases in oil prices will make oil import reductions mandatory. Some substitution of telecommunications for travel and some substitution of electronic mail for physical mail delivery will be important contributions to energy conservation. A new generation of high capacity satellites will be needed in the late 1980's to permit this substitution. The universal availability of low cost communications facilities will not only reduce energy consumption, but it will also change work and life styles and will lead to a general improvement in the quality of life. For these reasons, the development and implementation of high capacity communications satellite systems will become a matter of national priority in the U.S. and perhaps in other countries.

The World Oil Shortage Starts by 1995

Figure A-7 is an estimate of the cycle of world oil consumption. It shows the oil consumption rate versus time. Starting with a very low rate around the year 1900, we experienced an exponential growth up to the current rate of approximately 20 billion barrels* of oil per year. By 1977, approximately 340 billion barrels had already been consumed. Another 560 billion barrels are known oil reserves not yet produced. It is estimated that total world oil reserves originally were about 2,500 billion barrels. Thus, to date we have consumed 14 percent of the world's total oil.

It is estimated that oil consumption will continue to increase and peak at a rate of 40 billion barrels around the year 2000. At that time we will have consumed about half of the world's oil. Thereafter oil consumption will decline, and by the year 2050 we will have consumed 95 percent of the world's initial oil reserves.

Ultimately recoverable oil reserves are an estimate of how much oil will eventually be produced. They include as yet undiscovered oil worldwide, including off-shore, and an allowance for enhanced recovery techniques. Estimates by different experts vary as can be seen from the following figures:

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*One barrel equals 42 U.S. gallons or 159 liters.

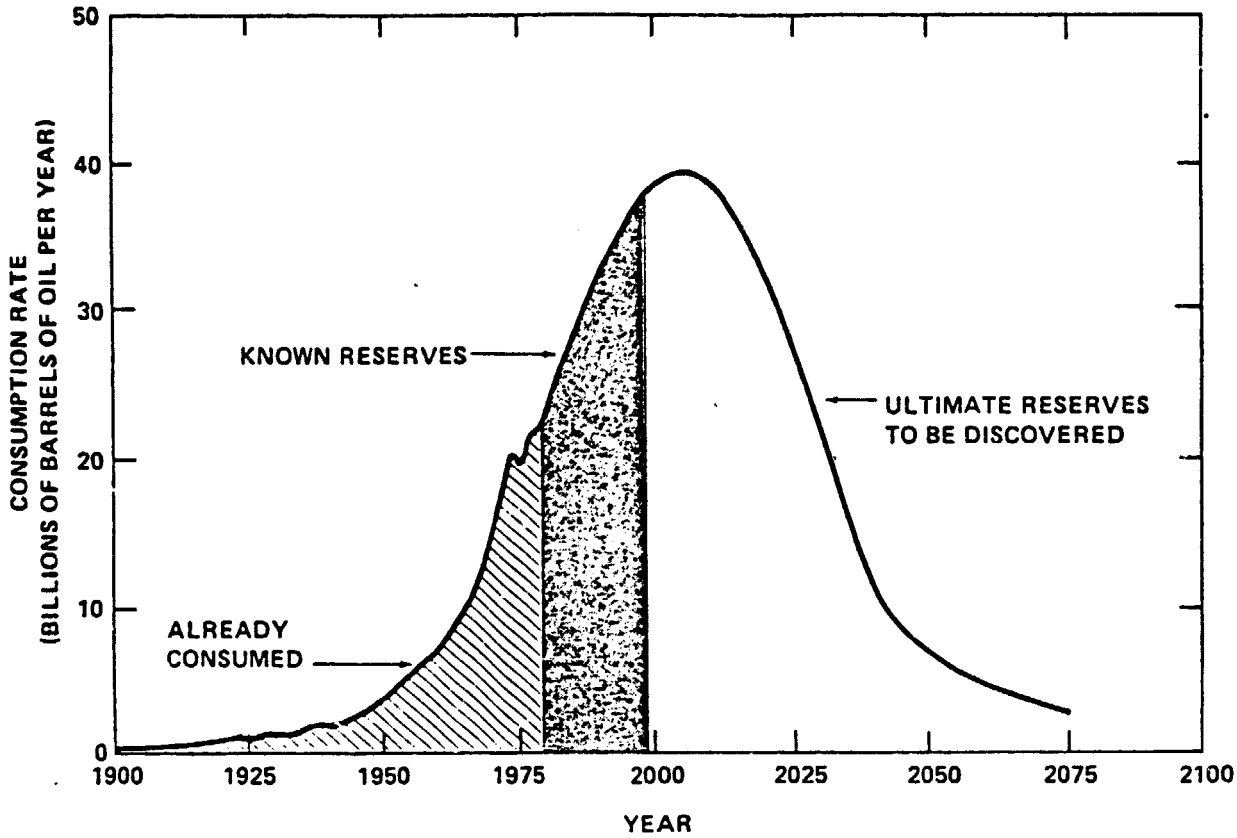

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Figure A-7

WORLD OIL CONSUMPTION CYCLE

Source	Total World Oil Reserves in Billion Barrels
Hendricks (USGS)	2,500
Ryman (Exxon)	2,090
Shell	1,800
Hubbert	2,100
Warman (BP)	2,000
Weeks	2,290
Moody & Geiger	2,000

The variation of estimates around the 2,000 billion barrel figure is small. The low estimate is 10 percent below the assumed figure, and the high estimate is about 25 percent above. These variations affect the time of oil shortfall but not the actual result. At the peak consumption rate of 37 billion barrels per year, an extra 5,000 billion barrels will only last for an extra 13 years.

Figure A-8 shows the annual oil consumption per capita plotted versus GNP per capita for 11 world model zones. As the GNP per capita of each country increases, it can be expected that the demand of oil will increase correspondingly. This information has been used to determine the future oil demand. Highlights of world energy consumption between 1950 and 1975 are shown below:

1. Total world energy consumption has grown at 5.3 percent per year.
2. Total world oil consumption has grown at 7.2 percent per year.
3. World oil consumption for transportation has grown at 7.6 percent per year.
4. The total energy produced by oil has grown from 28 percent to 43 percent.
5. In 1975, 37 percent of the total oil consumed was used for transportation.

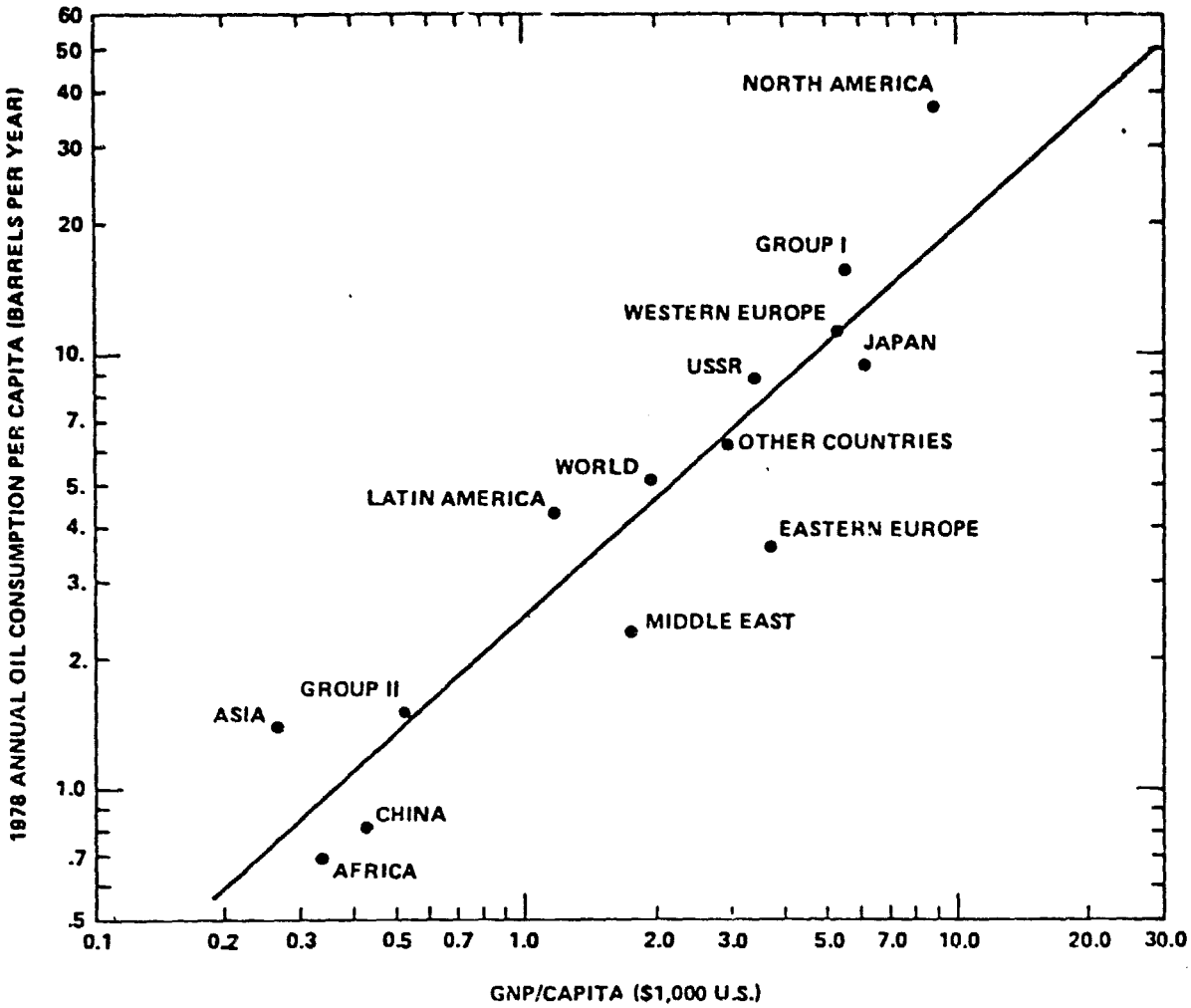


Figure A-8

OIL CONSUMPTION PER CAPITA VERSUS GNP PER CAPITA

Figure A-9 shows the annual world oil supply and demand. Starting in 1995, an increasing gap between supply and demand will develop. This approaching world oil shortage will be accompanied by continuing sharp increases in prices for oil and other forms of energy, leading to the absolute requirement for reductions of oil imports for the U.S. and for many other countries.

A.4.4 The Inconvenience of Business Travel

As a result of rising fuel costs, airlines have cut back on their number of flights. For this reason, it becomes more difficult to obtain reservations on short notice and to change travel plans in accordance with business requirements. The occurrence of overbooking of flights increases, and unless the business traveler arrives early at the airport, there is a significant chance that a confirmed flight will be unavailable due to overbooking. Airplanes are typically fully loaded as compared to the average 50 percent loading that was customary in the past. Airport facilities are inadequate, and the congestion at airports has increased. In many larger cities there are long waiting times on the runway prior to takeoff, and airplanes are stacked in a holding pattern prior to landing. All these events make air travel less and less desirable and more and more inconvenient. This trend will continue in future years.

Local travel by means of personal automobile also becomes increasingly more inconvenient, at least in the larger cities. Inadequate highway facilities for the entrance to large cities lead to extensive rush hour traffic jams, and traffic congestion periods extend well into mid-morning. Travelers to offices in cities find that parking is expensive, inconvenient and often unavailable. For these reasons local travel within or to major cities continues to become more inconvenient, more time consuming and less desirable. Public rapid transit systems have not kept pace with the commuting requirements.

The increasing inconvenience, loss of time and cost of business travel, both in terms of long distance and local travel, will become an increasingly more powerful incentive to use alternatives to travel. Telecommunications will be used extensively in lieu of long distance and local travel.

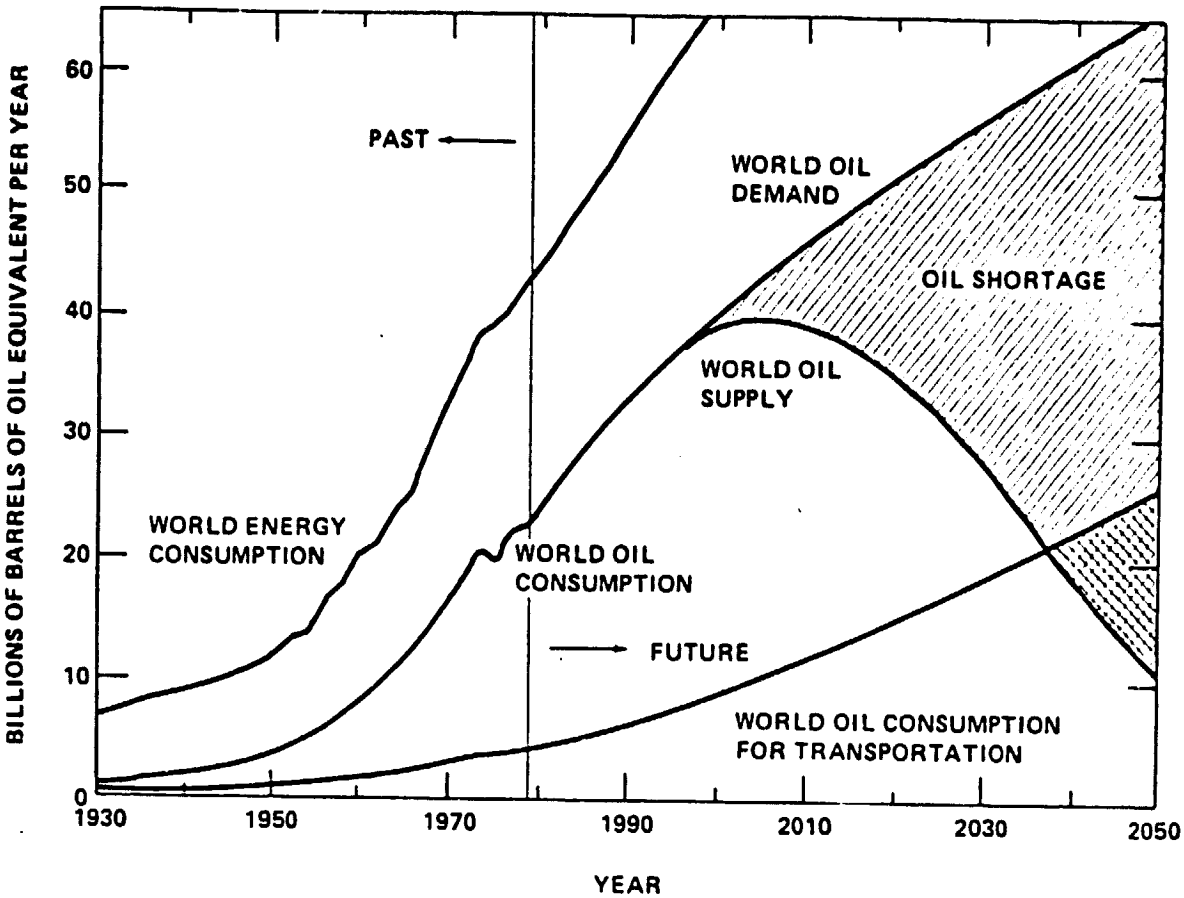


Figure A-9

ANNUAL WORLD OIL SUPPLY AND DEMAND

Once satisfactory teleconferencing facilities have been established, a further change will occur in our work and life styles which will lead to a general improvement in the quality of life. This change will consist of decentralization of work locations. A large percentage of the white collar work force will be able to live at locations of their choice regardless of locations of corporate facilities. Teleconferencing, including the use of video, will permit effective communication between workers. This trend will lead to a further increase in video conferencing service demand.

A.4.5 Video Conferencing to Replace Air Travel

The forecast of video conferencing requirements as a replacement of air travel consists of three elements:

1. A forecast for U.S. domestic air travel during the forecasting period
2. A forecast of the percentage of trips that will be replaced by video conferencing
3. An estimate of the conference requirements per replaced trip

Details on these three elements are presented below.

Air Travel Forecast

Air travel information was obtained from an FAA publication (Reference 15). Air traffic statistics were collected for the number of passengers enplaned for a 10-year period, and a correlation was developed for airline passengers per year per 1,000 population and GNP per capita. Based on GNP and population forecasts over the forecasting period, total U.S. airline passengers per year were predicted, using the correlation developed for the earlier 10-year period. The historical enplanement, GNP per capita and population data are shown in Table A-21.

Table A-21

Historical Air Traffic, GNP Per Capita and Population Data

Year	Number of Enplaned Passengers Millions	Percent Increase	GNP/Capita (1979 Dollars)	Population (Millions)
1967	132.1		8,580	198.7
68	152.2	15.2	8,870	200.7
69	159.2	4.6	9,000	202.7
1970	171.7	7.9	8,870	204.9
71	173.7	1.2	9,040	207.1
72	188.9	8.8	9,950	208.9
73	202.2	7.0	9,940	210.4
74	207.4	2.6	9,670	211.9
1975	205.1	-1.1	9,420	213.5
76	223.8	9.1	9,920	215.1

The correlation obtained from the data in Table 4-2 has been expressed by the following relationship:

$$P = 10^{\left[A \log B + C\right]}$$

where

P = Annual airline passengers per 1,000 population

A = 1.42

B = GNP/capita in 1979 dollars

C = 2.6

Forecasts for population in future years were derived from United Nations and Bureau of Census data, and future GNP/capita was based on an assumed real growth of 2 percent per year. These forecasts, along with the resulting air travel forecast, are shown in Table A-22. Of course, this forecast applies prior to the subtraction of air travel that will be displaced by teleconferencing.

Table A-22

Estimates of Future U.S. Population, GNP Per Capita and Air Travel

Year	Population (Millions)	GNP/Capita (1979 Dollars)	Number of Enplaned Passengers (Millions)	Percent Increase
1980	221.6	11,250	250	
81	223.2	11,450	262	4.8
82	224.8	11,660	272	3.8
83	226.4	11,870	285	4.8
84	228.0	12,080	295	3.5
1985	229.7	12,300	307	4.1
86	231.3	12,520	317	3.3
87	233.0	12,750	330	4.1
88	234.7	12,980	340	3.0
89	236.4	13,210	352	3.5
1990	238.1	13,450	365	3.7
91	239.8	13,690	377	3.3
92	241.5	13,940	390	3.4
93	243.2	14,190	402	3.1
94	245.0	14,440	415	3.2
1995	246.7	14,700	431	3.9

Figure A-10 shows the historical data and the forecast of annual passengers enplaned. Also shown are ITT forecasts (Reference 3), which were developed independently.

Percentage of Air Travel Replaced by Video Conferencing

Video conferencing is expected to replace some business travel. Estimates of business intercity travel as a function of total intercity travel range from 40 percent (Reference 3) to 50 percent (Reference 16). ITT estimates that 45 percent of the business travel is potentially replaceable by audio/graphic teleconferencing, and that 25 percent of this potential will be realized by the year 1990 and 50 percent by the year 2000. Experimental use indicates that teleconferencing can be employed for 50 to 80 percent of the required face-to-face meetings (Reference 17), and Interplan Corporation (Reference 18) estimates are given in Table A-22.

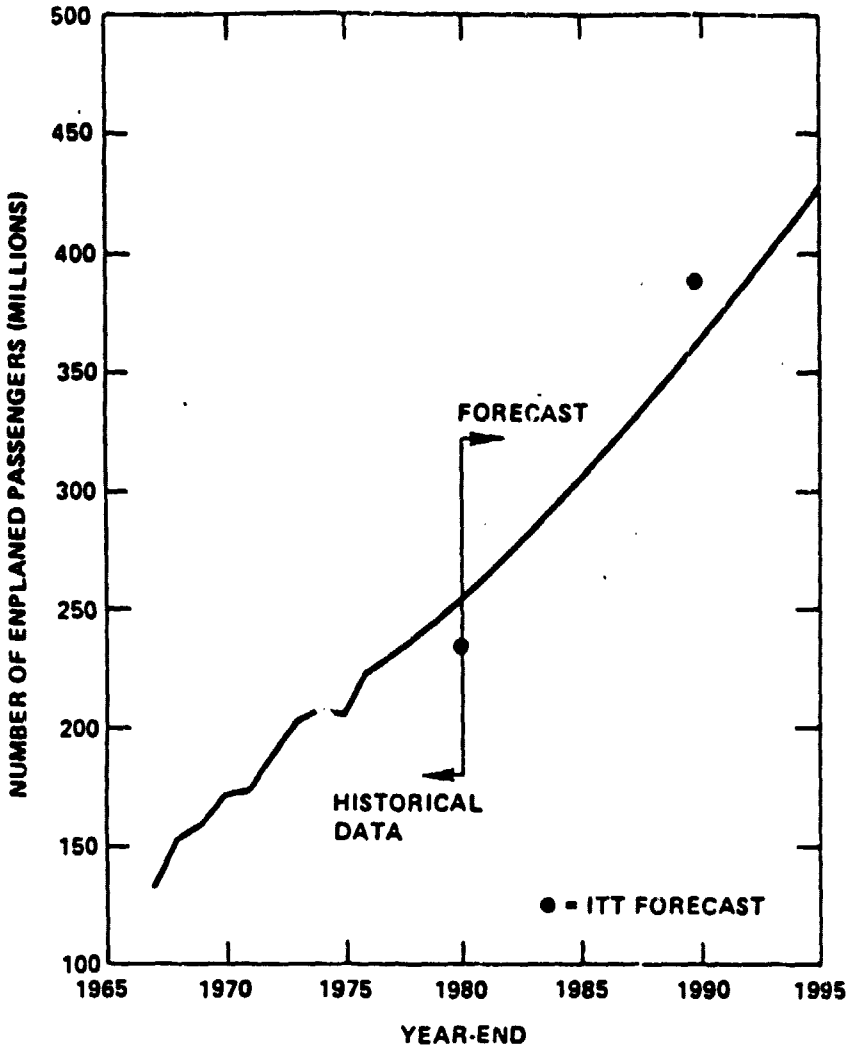


Figure A-10

HISTORICAL DATA AND FORECAST OF
ENPLANED PASSENGERS PER YEAR

Table A-22

Assumed Susceptibility of Work-Related Trips of the White Collar Work Force to Substitution by Telecommunications

White Collar Subgroups	Susceptibility of Work-Related Trips to Substitution (Percent)	Number of People Involved in Substitution
Professional and Technical	65	6,051,000
Managers, Officials and Proprietors	20	1,481,000
Clerical Workers	75	8,859,000
Salesworkers	5	227,000
Total		16,618,000

Source: Reference 18

In addition, Interplan Corporation has estimated that some nonwork related travel can also be substituted by telecommunications. These estimates are given in Table A-23.

Table A-23

Assumed Susceptibility of Nonwork-Related Trips to Substitution by Telecommunications

Purpose of Travel	Susceptibility of Travel to Communications Substitution (Percent)
Family Business	
Medical and Dental	5
Shopping	50
Other	25
Educational, Civic and Religious	25
Social and Recreational	5

Source: Reference 18

Considering the range of these estimates and the personal judgement of the FSI staff, we have assumed that 8 percent of the presently projected airline travel can be replaced by video conferencing by the year 1995.

Widespread use of video conferencing requires both capital investment and adaptation of the user. As an example of the introduction rate of a new communications medium, the growth of television in the United States is shown in Figure A-11. This statistic shows that TV receivers in the U.S. grew at 500 percent per year during the initial years after receivers became available, and growth tapered to 5 percent in later years. We have used a similar "S" curve to estimate the percentage of air travel that can be replaced by video conferencing. Our assumed transition curve is shown in Figure A-12. The high growth rate begins by 1984, and it is assumed that a high capacity satellite system will be operationally available by 1986. Early video conferencing is assumed to take place on precursor satellites.

Conference Requirements Per Replaced Trip

The ITT study (Reference 3) estimates that each business enplanement replaced by conferencing requires 1.35 conference hours. An earlier FSI study (Reference 19) assumed one conference hour per replaced enplanement. The FSI figure is derived as follows:

1. A business conference is attended by an average of two people.*
2. A conference requires a round trip, therefore four enplanements.
3. The average trip leads to two 2-hour conferences.*

Since the two estimates are close to each other, we have used the more conservative FSI figure, and we have based the conferencing requirements on 1 hour of conferencing per enplanement.

Video conferencing through satellites can be provided in one very large demand-assigned pool, and thus the circuit loading will be very high and the system will still provide an excellent grade of service. As in the case of telephony, we estimate that 100,000 paid minutes per year are possible for each circuit.

*Based on personal experience and subjective judgement of FSI staff members.

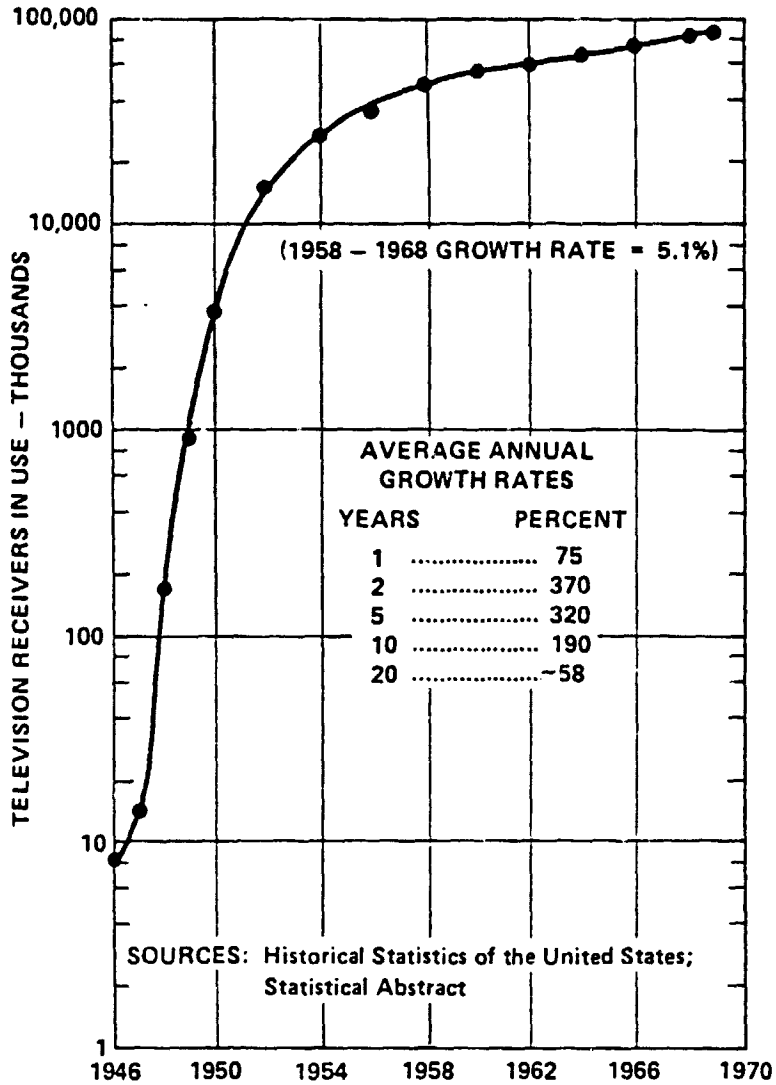


Figure A-11

GROWTH OF TELEVISION
IN THE UNITED STATES

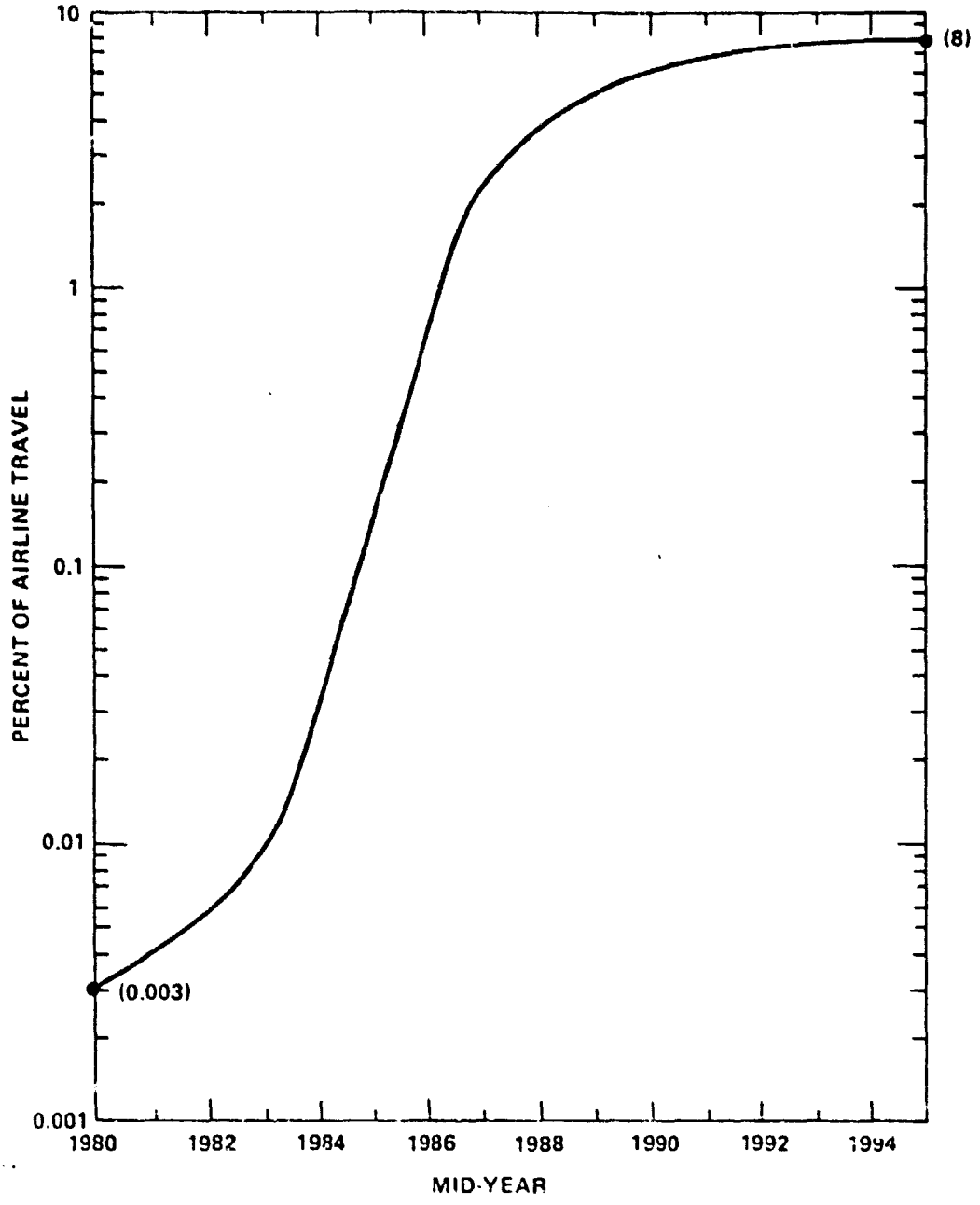


Figure A-12

ASSUMED GROWTH IN VIDEO CONFERENCING
PERCENT OF AIRLINE TRAVEL REPLACED

Assuming 250 business days per year, this would be equivalent to 6.7 hours of use per day. We expect that there will also be some weekend use, and thus the assumed use is considered reasonable. We have therefore translated video conferencing hours into circuits on the basis of 1,670 hours per circuit year.

Circuit Demand Forecast

Video conferencing circuit demand is determined as follows:

$$V = \frac{E}{1670} \cdot \frac{r}{100}$$

where

V = Number of video conferencing circuits
E = Number of passengers enplaned per year
r = Percent air travel replaced by conferencing

Resulting circuit requirements are shown in Table A-24.

Table A-24
Video Conferencing Circuits Required for Air Travel Substitution

Mid-Year	Airline Passengers Enplaned (Millions)	Percent Air Travel Replaced	Required Two-Way Video Conferencing Circuits
1980	250	0.003	5
81	262	0.004	7
82	272	0.006	10
83	285	0.01	18
84	295	0.03	53
1985	307	0.15	280
86	317	0.70	1,300
87	330	2.4	4,700
88	340	3.8	7,700
89	352	5.1	10,700
1990	365	6.0	13,100
91	377	6.8	15,400
92	390	7.3	17,000
93	402	7.5	18,100
94	415	7.8	19,400
1995	431	8.0	20,600

A.4.6 Video Conferencing to Replace Local Travel

Once video conferencing facilities are established to replace long distance travel, they can also be used to replace local travel at low incremental cost. As was shown in an earlier section, the space segment transmission costs are only about $10 per hour or $5 for a half-hour conference. The cost of time, travel and parking will be higher than this for most local travel applications. For this reason, local video conferencing could become a very large element of the total video conferencing service demand. However, to be conservative we have assumed the same low travel replacement percentages as for airline travel (Figure A-12) but with a delay of 2.5 years.

The Statistical Abstract of the United States (Reference 20) indicates that in 1978 approximately 51 percent of the work force were white collar workers, of which 22 percent were managers and administrators. Assuming that the typical corporate hierarchy consists of about five people reporting at each level and everyone above the lowest managerial level regularly engages in local travel for business conferences, then this would amount to about 4 to 5 percent of the total white collar work force engaging in regular local travel.

Table A-25 shows the number of managers or administrators for several years beginning in 1960. The percentage of managers and administrators to total blue collar workers has remained fairly constant of the time period shown. The growth in the number of managers and administrators has been at an average annual rate of 2 percent during that same time period. We have assumed that this growth rate will remain constant throughout the study period of this report. As previously described, we estimate that approximately 25 percent of managers and administrators travel regularly for local business. As such, this group comprises the potential users of video conferencing as a replacement for local travel.

Table A-25

Summary Data on White Collar Workers and Managers/Administrators

Year	Total Number of White Collar Workers (Thousands)	Managers/Administrators Number (Thousands)	Managers/Administrators Percent of Total
1960	28,522	7,067	24.8
1965	31,852	7,340	23
1970	37,997	8,289	21.8
1975	42,227	8,891	21.1
1978	46,673	10,026	21.5

Source: Reference 20

Table A-26 shows the forecast of potential video conferencing users for the period 1980 to 1995 on the basis that the users are comprised of 25 percent of all managers and administrators. It is assumed that each user would have two conferences per week for 50 weeks per year. The total number of local conferences which could be replaced by video conferences, and the forecast of actual video conferences is shown in Table A-27. As in the previous section, a video conferencing circuit is assumed to accommodate 1,670 conference hours per year.

For percent capture, we have used the growth model of Figure A-12 but with a time delay of 2.5 years. The reason for this delay is the expectation that successful local conferencing will require a much larger conferencing network than is needed for long distance conferencing. In the initial phases when there are only few conference room facilities, users will accept some limited local travel for a long distance conference. Local travel for a local conference, however, is considered to be less likely.

Table A-26

Summary of Forecasts of Managers, Administrators and Potential Video Conferencing Users for Replacement of Local Travel (1980 - 1995)

(Millions)

Year	Number of Managers and Administrators	Potential Video Conferencing Users
1980	10.4	2.6
81	10.6	2.7
82	10.9	2.7
83	11.1	2.8
84	11.3	2.8
1985	11.5	2.9
86	11.7	2.9
87	12	3
88	12.2	3.1
89	12.5	3.1
1990	12.7	3.2
91	13	3.2
92	13.2	3.3
93	13.5	3.4
94	13.8	3.4
1995	14	3.5

Table A-27

Forecast of Service Demand for Video Conferencing Circuits to Replace Local Travel

Year	Potential Video Conferencing Users (Millions)	Percent Capture	Actual Video Conferencing Users	Required Two-Way Video Conferencing Circuits
1980	2.6	0.002	50	2
81	2.7	0.002	50	2
82	2.7	0.003	80	3
83	2.8	0.004	110	4
84	2.8	0.005	140	5
1985	2.9	0.007	200	6
86	2.9	0.016	460	14
87	3	0.070	2,100	63
88	3.1	0.32	9,900	300
89	3.1	1.5	47,000	1,400
1990	3.2	3.1	99,000	3,000
91	3.2	4.5	140,000	4,200
92	3.3	5.6	185,000	5,500
93	3.4	6.4	218,000	6,500
94	3.4	7.1	240,000	7,200
1995	3.5	7.4	259,000	7,800

A.4.7 Other Sources of Video Conferencing Service Demand

Once a video conferencing network has been established, it will be used for many applications, for which no trip would have been made in absence of the network. Video conferencing will be used because it improves the efficiency of the conduct of business. Its availability will permit the further decentralization of business, permitting people to live at locations of their preference and to work near their homes. The resulting requirements will be large, and no serious effort has been made to estimate their magnitude.

Table 6-1 of this report lists the ITT estimate of toll circuit requirements for voice transmission. Based on this estimate, we have made a projection of video conferencing requirements, assuming that one-third of 1 percent of the 1995 telephone calls would be augmented by video. The growth curve used has the same "S" shape of Figure A-12 with a time delay of 2.5 years to account for a later introduction of facilities. The resulting video circuit demand is shown in Table A-28.

A.4.8 Satellite Versus Terrestrial Transmission

Considering current tariffs for high speed data transmission and for video transmission, we have concluded that essentially 100 percent of the video conferencing service demand developed in this section will be carried via satellite facilities. We believe that the existing terrestrial network will be unable to come close to the low satellite transmission costs of 50 cents per paid minute for a video conferencing call.

In the long run, terrestrial fiber optics trunks will be placed in service along with the associated switching centers and local loops. When this development has progressed to nationwide implementation, fiber optics transmission will be a viable alternative to satellite transmission. However, we have assumed that a nationwide fiber optics network will not be in place prior to 1995, and therefore the satellite network was assumed to carry the major portion of the public and private video conferencing traffic.

Table A-28

Forecast of Service Demand for

Video Conferencing Circuits to Augment Voice Circuits

Year	ITT Estimate of Duplex Toll Circuits (Millions)	Percent Capture	Required Two-Way Video Conferencing Circuits
1980	1.1	.0001	2
81	1.1	.0001	2
82	1.2	.0001	2
83	1.3	.0002	3
84	1.4	.0002	3
1985	1.6	.0004	7
86	1.8	.0008	15
87	2.0	.0038	80
88	2.2	.017	370
89	2.4	.072	1,800
1990	2.7	0.14	3,800
91	3.0	0.2	6,000
92	3.3	0.25	8,300
93	3.6	0.29	10,000
94	3.8	0.31	12,000
1995	4.0	0.33	13,000

Additional local video conferencing traffic will be carried on fiber optic intraplant facilities. Fiber optics will also be used for interconnection of the earth stations with various conferencing facilities throughout corporate establishments. This traffic is not included in the forecasts presented in this section.

A.4.9 Total Satellite Video Conferencing Service Demand

Table A-29 and Figure A-13 show the estimate of total demand for video conferencing satellite circuits.

Table A-29

Total Demand for Two-Way Video Conferencing Satellite Circuits

Year	Air Travel Replacement	Local Travel Replacement	Voice Circuit Augmentation	Total	Equivalent Number of 36 MHz Transponders
1980	5	2	2	9	2
81	7	2	2	11	3
82	10	3	2	15	3
83	18	4	3	25	5
84	53	5	3	61	13
1985	280	6	7	293	60
86	1,300	14	15	1,329	266
87	4,700	63	80	4,843	969
88	7,700	300	370	8,370	1,674
89	10,700	1,400	1,800	13,900	2,780
1990	13,100	3,000	3,800	19,900	3,980
91	15,400	4,200	6,000	25,600	5,120
92	17,000	5,500	8,300	30,800	6,160
93	18,100	6,500	10,000	34,600	6,920
94	19,400	7,200	12,000	38,600	7,720
1995	20,600	7,800	13,000	41,400	8,280

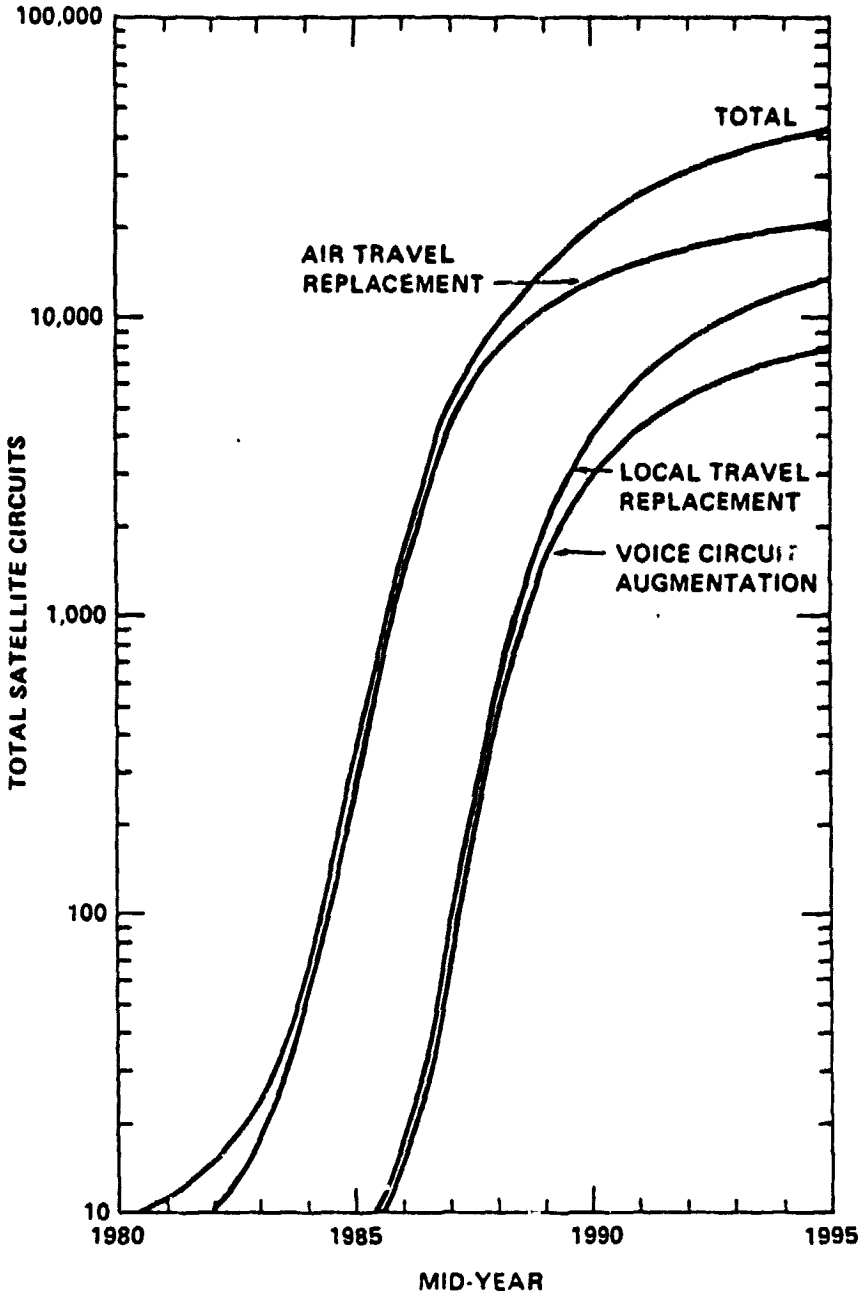


Figure A-13

TOTAL DEMAND FOR TWO-WAY VIDEO CONFERENCING SATELLITE CIRCUITS

A.5 Total Point-to-Point Traffic

A.5.1 Voice and Data

Table A-30 and Figures A-14 and A-15 show the total voice and data requirements. Figure A-14 uses a logarithmic ordinate, while Figure A-15 uses a linear ordinate to provide a better impression of the range of projected requirements. The results indicate that throughout the study period voice will be the dominant factor.

Table A-30
Satellite Transponder Requirements
(Number of Equivalent 36 MHz Transponders)

Year	Data	Voice	Total
1980	3	70	73
81	5	95	100
82	7	125	132
83	13	170	183
84	18	220	238
1985	24	289	313
86	33	360	393
87	40	440	480
88	52	520	572
89	65	600	665
1990	74	660	734
91	85	730	815
92	94	800	894
93	102	870	972
94	111	940	1,051
1995	120	1,008	1,128

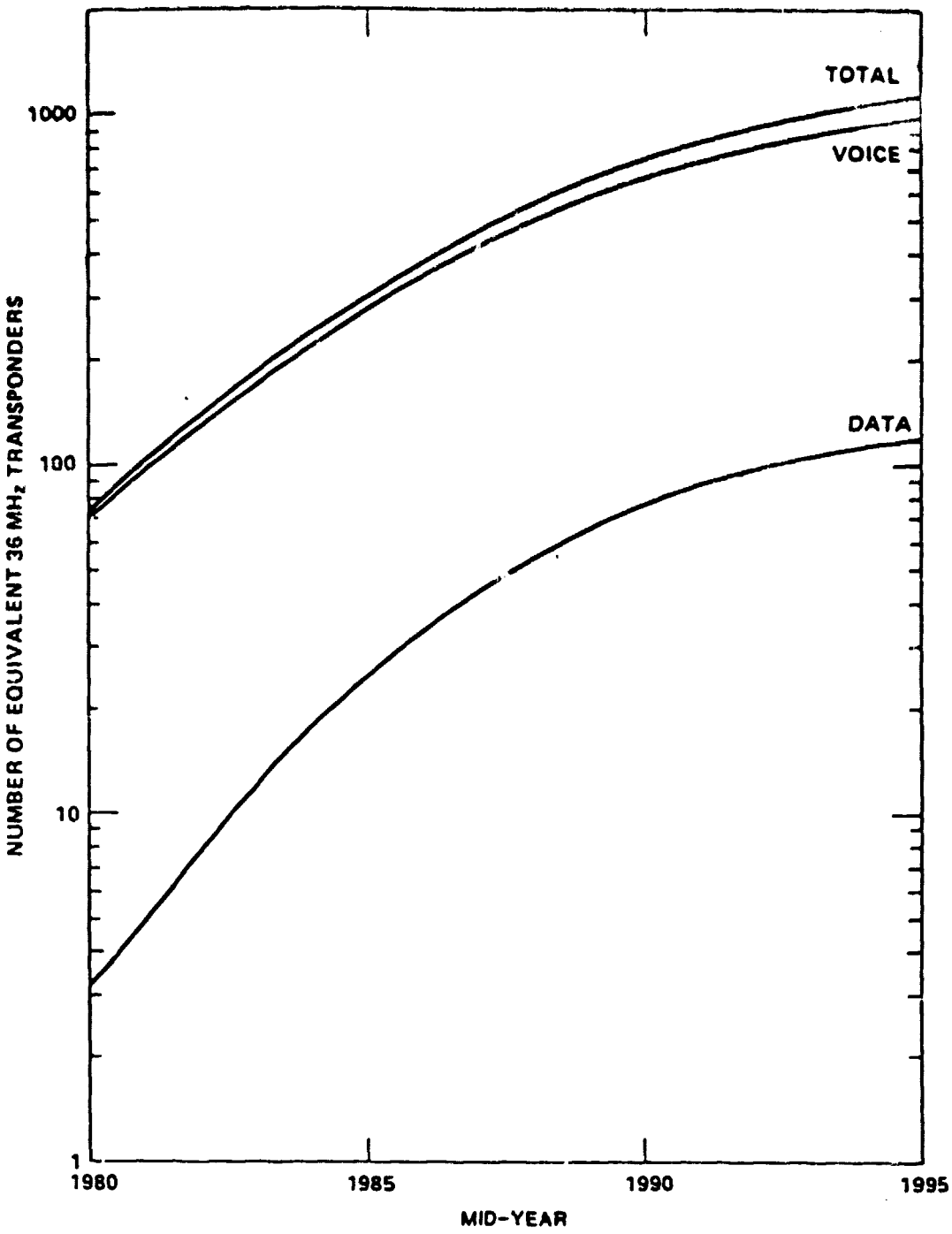


Figure A-14

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

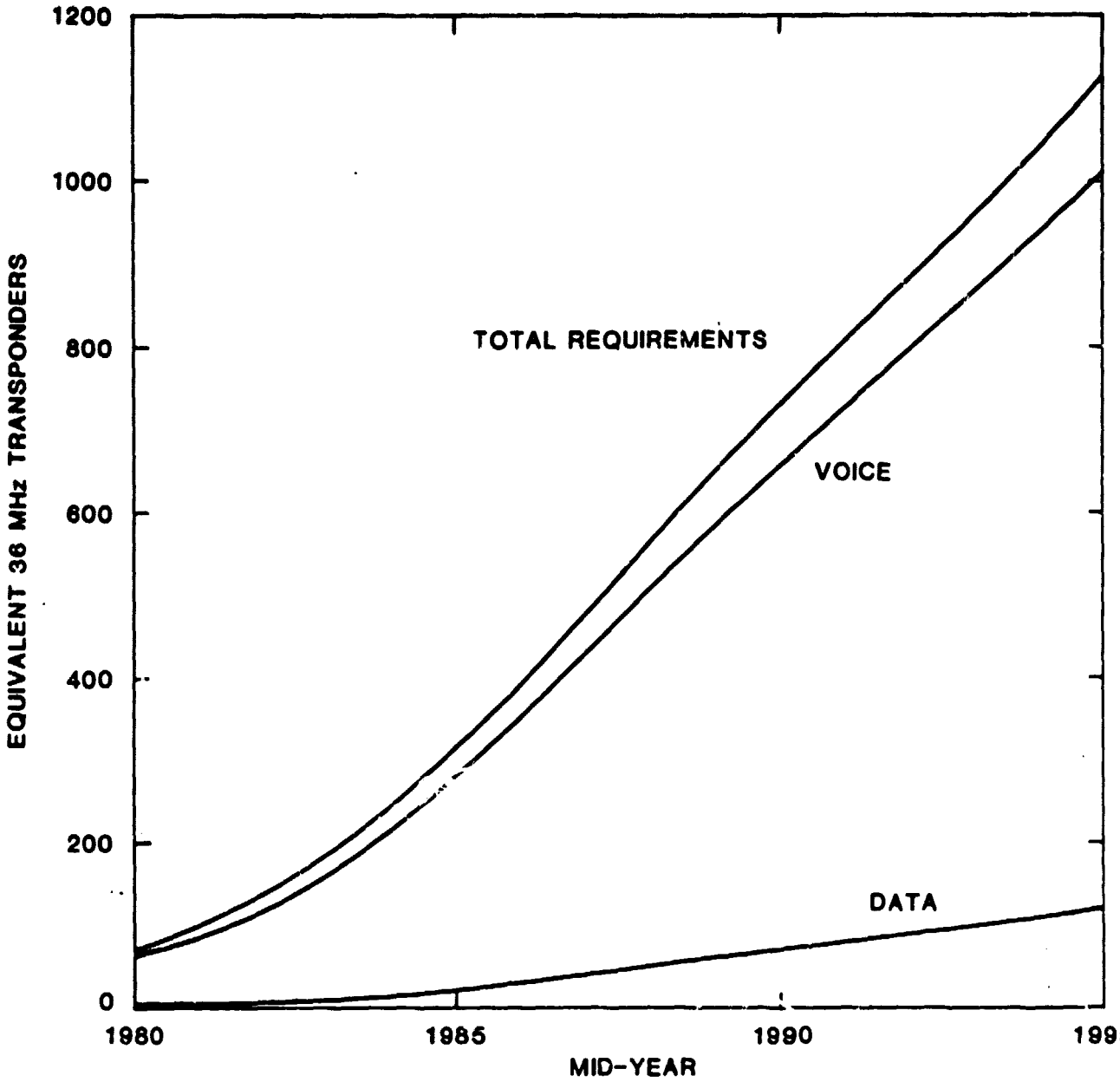


Figure A-15

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

A.5.2 Voice, Data and Video Conferencing

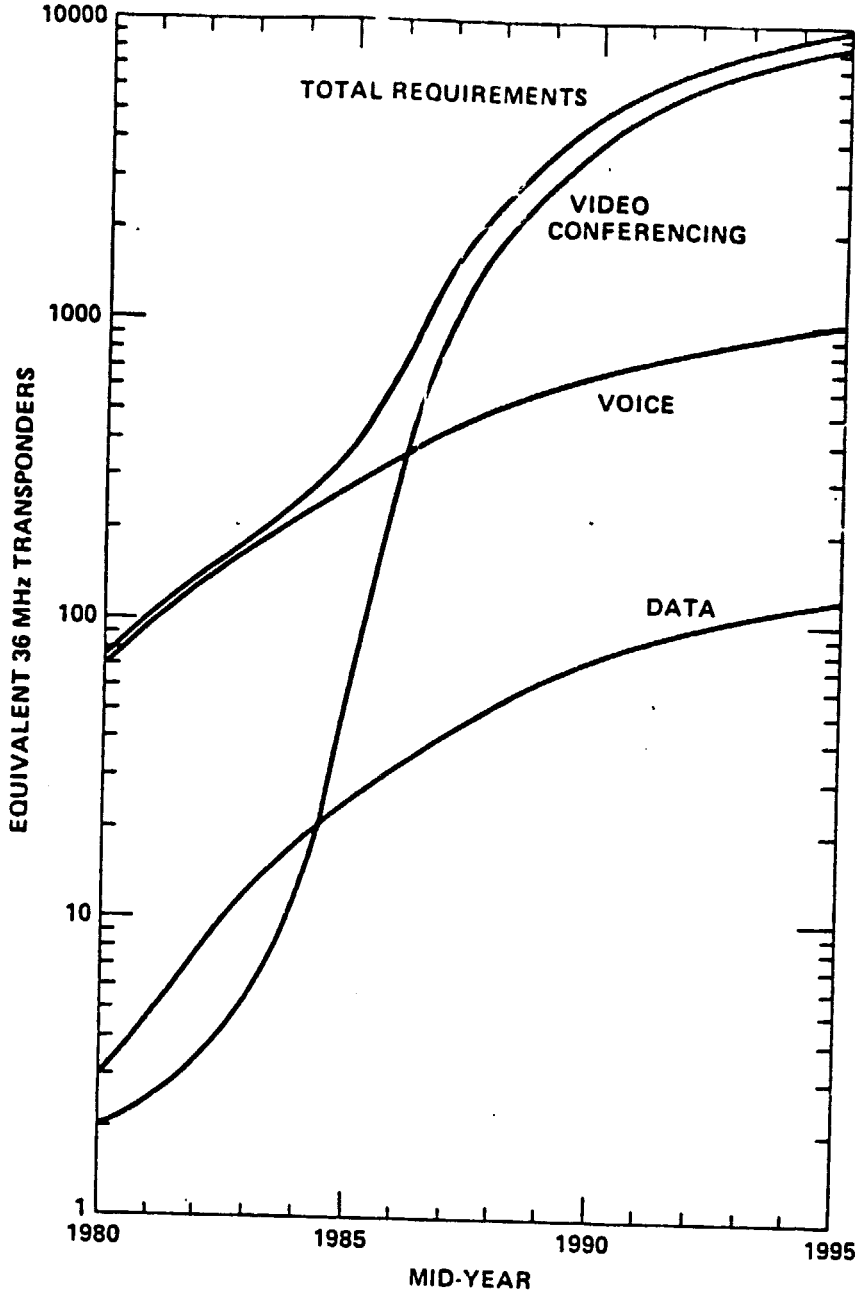
Tables A-31 and Figures A-16 and A-17 show the three major components and the total point-to-point satellite service demand. Figure A-16 uses a logarithmic ordinate, while Figure A-17 uses a linear ordinate to provide a better impression of the range of projected requirements. The results indicate that in the early years voice dominates, but video conferencing becomes the major traffic component in later years.

Table A-31

Satellite Transponder Requirements

(Number of Equivalent 36 MHz Transponders)

Year	Video Conferencing	Data	Voice	Total
1980	2	3	70	75
81	3	5	95	103
82	3	7	125	135
83	5	13	170	188
84	13	18	220	251
1985	60	24	289	373
86	266	33	360	659
87	969	40	440	1,449
88	1,674	52	520	2,246
89	2,780	65	600	3,445
1990	3,980	74	660	4,714
91	5,120	85	730	5,935
92	6,160	94	800	7,054
93	6,920	102	870	7,892
94	7,720	111	940	8,771
1995	8,280	120	1,008	9,408



(Log Ordinate)

Figure A-16

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

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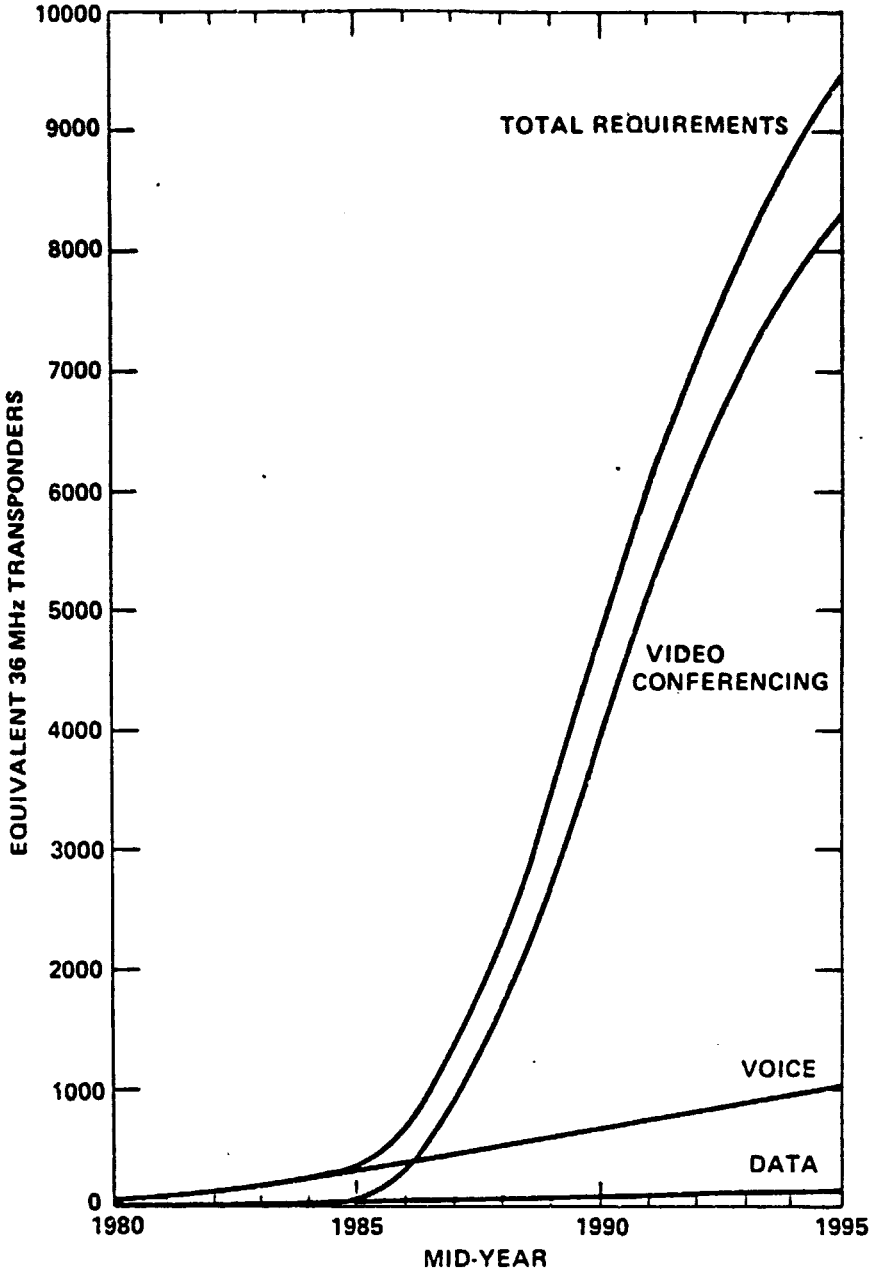

(Linear Ordinate)

Figure A-17

SATELLITE TRANSPONDER REQUIREMENTS
(1980 - 1995)

A.6 TV Distribution

This section summarizes point-to-multipoint TV distribution requirements and how they were derived. Also included in this section of the annex are the cost assumption for high capacity video transmission satellites.

A.6.1 Cost Assumption

Future video transmission satellites will provide wide area coverage beams, perhaps matched to the U.S. time zones. Each beam will provide coverage at all available frequency bands, and dual polarization will be used at the lower frequencies. The bandwidth of the transponders will be more closely matched to the TV transmission requirements than is the case today. For FM transmission, a bandwidth of 25 MHz will be adequate instead of the 36 MHz presently allocated. For digital transmission, a bit rate of about 20 Mbps will be used with advanced video compression techniques. Video compression equipment will be generally available at low cost because of the large production quantities required for video conferencing. Therefore, we expect a shift from FM to digital transmission.

As a result, each 500 MHz band will permit the transmission of 18 FM video signals without re-use, instead of the present 12. With digital transmission at 20 Mbps, 4-phase PSK and rate 7/8 forward error control coding, it will be possible to transmit 30 video channels per 500 MHz band. In both cases, allowance has been made for guardbands between transponders or carriers.

Over the four time zones of CONUS, the use of four spot beams with careful beam shaping will permit dual frequency use. Making use of both polarizations at C-band and Ku-band, it will be possible to use the frequency band four times. It is not expected that polarization re-use would be employed at Ka-band. The resulting maximum TV transmission capacity per satellite is shown in Table A-32.

Table A-32

Potential TV Video Transmission Capacity

for CONUS Coverage Satellites

(Number of Video Channels)

Transmission Technique		Frequency Uses	FM at 25 MHz	Digital at 20 Mbps
C-band	(500 MHZ)	4	72	120
Ku-band	(500 MHz)	4	72	120
Ka-band	(2500 MHz)	2	180	300
Total			324	540

Assuming a three satellite program with a mix of FM and digital transmissions, the cost for the space segment per TV channel year will be under $100,000 per year or $1 per minute of transmission. Since each channel is shared by a large number of users, the transmission costs will have become negligible.

It should also be noted that the up-link inhomogeneity between multi-beam and area coverage satellites will require wide orbital spacings between the two types of satellites. TV distribution satellites can be used to occupy the intermediate spaces, provided that their up-links are furnished by narrow beams. As long as program originations remain within a few locations, this can easily be accomplished.

A.6.2 Video Channel Requirements

Satellite video channel requirements could be constrained by the following factor:

1. Transmission costs
2. Spectrum limitations
3. Programing costs
4. End-user requirements

As shown in Section A.6.1, satellite transmission costs will be reduced to less than $100,000 per video channel year. When this charge is divided among 100 users or more, the monthly cost per user is less than $100, so that satellite transmission costs will cease to be a limiting factor. Table A-33 shows TV transmission requirements for the years 1980, 1990 and 2000 as estimated by Western Union, ITT and FSI.

Table A-33

Estimates of TV Transmission Requirements

Source		Western Union[1]	ITT[2]	FSI[3]
1980	Networks	45	10	
	Occasional Use	29	15	
	CATV	79	35	
	Total	153	60	50
1990	Networks	52	12	
	Occasional Use	39	18	
	CATV	84	50	
	Total	175	80	200
2000	Networks	59	12	
	Occasional Use	40	19	
	CATV	88	60	
	Total	187	91	500

[1] Reference 2, total demand
[2] Reference 3, total demand
[3] FSI estimate of satellite demand

Spectrum limitations will continue to apply for TV retransmission by the broadcast stations but will not be important in the case of cable TV.

Programming costs have been a major factor in limiting the establishment of additional TV networks. The primary reason for the high programing costs is the fact that each of the three commercial networks has only one channel and must use it to succeed in the rating competion. In order to achieve an acceptable rating, the single program must appeal to the largest possible number of TV viewers. If a network could have several channels at its disposal, it could attract a larger total number of viewers by catering to more specialized interests, which do not coincide with those of the majority viewer. Such specialized programing can often be accomplished at a fraction of the cost of some of the major shows. As soon as CATV is more widespread, networks will have the ability to deliver several channels to the viewer and will at that point introduce multiple programs.

One of the end-user requirements is to be able to see a given program at a convenient time. This requirement can be met by recording and retransmission. The viewer may record the program, or an intermediate operator may offer recording and retransmission, or the program originator may transmit the same program several different times. The latter case will become practical once the satellite transmission costs have been reduced, as shown in Section A.6.1, and provided that local distribution is feasible, that is, via CATV systems. Multiple transmission of the same program leads to an increase in channel requirements without an increase in programing costs.

Limitations in bandwidth in the radio spectrum are the main reason for the relatively poor quality of video. With the advent of cable TV, it will become possible to offer higher resolution and better quality video systems. Efforts will be made to make video presentations more lifelike, including attempts to offer three-dimensional images. Better quality or three-dimensional transmission will increase the effective satellite transmission requirements.

In summary, transmission capacity requirements will increase for a combination of the following reasons:

1. Development of more programs
2. Multiple transmission of programs at different times
3. Increased transmission quality

The FSI estimate is based on the premise that increasing affluence will make society more leisure oriented, leading to a large increase in the entertainment industry. Repeated transmission of an increasing number of programs will lead to a multiplication of transmission channel requirements. Further increases in the late 1980's and early 1990's will result from the introduction of higher quality sysems.

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