FSI REPORT NO. 221

N79-2111

LARGE COMMUNICATIONS PLATFORMS

VERSUS

SMALLER SATELLITES

February 1979

Prepared for

NASA HEADQUARTERS
Office of Communications Programs
Washington, D.C.

Prepared by

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ACKNOWLEDGEMENTS

This study was performed with direction from Mr. Samuel W. Fordyce, NASA Technical Contract Monitor. In addition, FSI had the opportunity of discussing the study and the systems concepts described in the report with individuals from the organizations listed below. Suggestions and recommendations received from these individuals have contributed substantially to this report, and these contributions are greatfully acknowledged. FSI alone, however, accepts full responsibility for all contents of the report. Only main contacts are listed for each organization, although in many cases additional individuals participated in the discussions. Valuable data on the use of dual polarization at C-band was received from RCA American Communications.

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WHAT IS A LARGE COMMUNICATIONS PLATFORM?

In a general sense, the term "large communications platform" has been used to describe a geostationary platform that may contain payloads for a variety of applications. In addition to fixed and mobile communications, it may provide broadcast services, navigation, meteorology, earth observation and scientific payloads.

The aggregation of many diverse payloads and missions poses institutional as well as scheduling and management problems. One concept provides for a "teleoperator" to add payloads and to perform maintenance in geostationary orbit as required. Details concerning the feasibility of the teleoperator concept are not yet available.

For the purpose of this study we have limited the missions of the large communications platforms to the provision of fixed communications services. In addition, we have selected such missions which can readily be provided by a single entity, such as INTELSAT, AT&T and a joint venture of various specialized communications carriers. This approach minimizes the institutional, scheduling and management problems.

The distinction between the "large platform" as used in our study and conventional satellites is capacity, connectivity and switching capability. The "large platform" provides high capacity by means of multiple spot beams. It provides good connectivity for a wide range of communications users, and it offers very substantial in-orbit switching capability, far beyond that attainable by conventional satellites.

The mission selection made for the purpose of this study does not imply any judgement concerning the desirability of including a wide range of other missions on communications platforms.

OTHER RELATED NASA COMMUNICATIONS STUDIES

At the present time, several other related communications studies are being performed for NASA, as shown below:

1. Geostationary Platform Feasibility Study, performed by The Aerospace Corporation for NASA Marshall Space Flight Center.
2. Geostationary Platform Mission and Payload Requirements Study, performed by COMSAT Laboratories for NASA Marshall Space Flight Center.
3. 18/30 GHz Fixed Communications Service Demand Studies, performed for NASA Lewis Research Center in two parallel efforts by Western Union and ITT.
4. 18/30 GHz Fixed Communications Service Systems Studies, performed for NASA Lewis Research Center in two parallel studies by Ford Aerospace & Communications Corporation and by Hughes Aircraft Company.

FSI has attended review meetings at which interim results of these studies were presented to NASA, and FSI has incorporated applicable results in this present study. Final study results on the above six contracts were not available prior to the completion of the present report.

ABSTRACT

Scope

This report describes the results of a study which compares communications systems using large platforms with systems using conventional satellites. Systems models were generated and compared for U.S. domestic application and for INTELSAT's international and domestic transponder lease application. Significant technology advances were assumed not only for the platforms but also for the evolution of conventional satellites.

Platform System Design

Only fixed communications services were included on the platform missions. Sufficient redundancy was incorporated to permit a 10-year mission life without in-orbit maintenance. Area coverage was provided by antenna beams with 1.1 and 1.8 degrees width. Transponders were provided at 4/6 GHz and at 11/14 and 18/30 GHz as required. The total usable capacity of the U.S. domestic platform is 375 equivalent C-band transponders with 36 MHz bandwidth, or 375,000 one-way telephony channels. This represents over 15 times the capacity of the Comstar satellites, over 30 times the capacity of Westar satellites, over 13 times the capacity of Advanced Westar/TDRSS and over 50 times the capacity of the SBS satellites with presently planned utilization. Earth stations with antenna diameters of 4.5 meters are used at C-band, and smaller size antennas are possible at the higher frequencies. Initial platform operation by 1987 was assumed, and two operating platforms carry the total U.S. satellite traffic through 1996. A third platform serves as a common spare.

The platforms for INTELSAT use have a usable capacity of 540 transponders mostly at 4/6 GHz and 11/14 GHz and only a few high traffic density beams at 18/30 GHz. This platform provides 540,000 one-way telephony channels, which is over 20 times the usable capacity of INTELSAT V. A single platform has

sufficient capacity for all of INTELSAT's international Atlantic traffic and for transponder lease applications for Latin American and African countries through 1996. A second platform is operated to provide for diversity operation and as an in-orbit spare.

Conventional Satellite Systems

It was assumed that the conventional satellites for U.S. domestic operation have a usable capacity of 72 transponders, which is 3 times the capacity of Comstar or 2.6 times the capacity of Advanced Westar/TDRSS. Conventional satellites for INTELSAT international use were assumed to have a usable capacity of 96 transponders, which is over 3 times the capacity of INTELSAT V.

System Cost Comparison

Platform systems are significantly cheaper than systems with conventional satellites. The cost ratio of conventional systems to platform systems for U.S. domestic application is at least 2 to 1, including costs for space segment, ground segment and terrestrial interconnection over the 10-year study period. On a cumulative basis, the development and operation of a U.S. domestic platform system will save $4.5 billion over the 10-year study period, with further savings in later years. For the INTELSAT System, cost savings due to platform operation were calculated to amount to $1 billion over the 10-year study period.

Use of the Orbital Arc

Because of their higher capacity, platform systems make more efficient use of the frequency spectrum and the orbital arc. In 1996, conventional satellites for U.S. domestic services will require 5.3 times the orbital arc than platform systems. Conventional satellites require 64 degrees, which represents 64 percent of the total service arc for North and South America, while platforms require only 12 degrees or 12 percent of the total service arc.

The INTELSAT platforms for Atlantic service require 8 degrees of orbital arc, compared with 104 degrees which would be required by conventional satellites providing the same services by 1996. For this case, the platforms are 13 times as efficient in orbital arc use as the conventional satellites.

Connectivity

Terrestrial systems achieve connectivity by tandem connection of transmission facilities. Satellite systems are limited to single-hop operation and can therefore achieve connectivity only by:

1. High capacity on a single satellite or platform
2. Intersatellite links
3. Multiple ground antennas

The platform systems achieve high connectivity by means of high capacity on each platform and interconnection of platforms by intersatellite links. Systems with conventional satellites require multiple antennas or multi-feed torus antennas to achieve connectivity. Although the conventional satellite systems were configured to provide full connectivity within each domestic application, these systems lack connectivity between domestic and international circuits. This feature could become a major impediment in the development of satellite communications systems. Platform systems, however, provide full connectivity between domestic and international facilities by on-board switching and intersatellite links.

Technology Development

The implementation of platform systems requires technology development in the following areas:

Antenna design:	To achieve area coverage by means of multi-beam antennas with contiguous coverage without gaps.

On-board switching:	To provide flexible interconnection of transmissions through multi-beam antennas and at different frequency bands.
Long life and reliability:	Components with long life and high reliability are required to achieve a mission life of at least 10 years without in-orbit maintenance. Switch design with sufficient redundancy and reliability will be an exceptional challenge.
In-orbit maintenance:	Development of a teleoperator will become important for second generation platforms.

Timing of Implementation

Preliminary studies show that initial platform operation for U.S. domestic systems by early 1987 appears to be optimum, since this timing provides an economical transition from conventional satellites to a platform. If the 1987 date is missed, at least two communications carriers will likely have to launch follow-on satellite generations, which would greatly increase the total systems costs for later transition to platforms.

Transition to platforms becomes progressively more difficult as the orbital arc becomes more congested. This is due to the fact that larger orbital separations are required between platforms and conventional satellites because of the higher sensitivity of the platforms than between homogeneous satellites or platforms.

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SECTION 1
EXECUTIVE SUMMARY

This report describes a study which compares communications systems using large communications platforms with systems using conventional satellites. Platform feasibility and payload requirements studies are being performed separately for NASA by other contractors, and the results of these studies are not yet available. For this reason the results of the present study must be considered as preliminary. According to NASA planning, a first generation platform could be operational in 1987, and we have used this date as one of the inputs to the study.

1.1 System Considerations

A communications platform is technically capable of carrying an aggregation of many diverse missions. Fixed and mobile communications services could be provided, along with broadcasting, space research, meteorology, earth observation and navigation services. Many countries could be served by the same platform. For example, a platform located around 90 degrees west longitude could provide service to the U.S., Canada and all of Latin America. A total of over 100 different missions would be possible on a single platform, and preliminary NASA analyses have shown that substantial space segment cost savings could result, due to economies of scale, from the aggregation of many missions on a single platform. However, we believe that due to institutional, scheduling and reliability problems it is unlikely that a first generation platform will contain that many missions.

The Teleoperator

One concept that could solve some of these problems is the teleoperator. A teleoperator could be designed by NASA to provide unmanned maintenance services. It would fly from low earth orbit to geostationary orbit, dock with the platform, add new payloads, replace failed or obsolete payload modules, add stationkeeping propellant and replace failed housekeeping modules. In this manner, the reliability problem would be solved by in-orbit maintenance, and the scheduling problem would be reduced by permitting the later addition of payloads when required. The institutional problem would also be reduced by permitting a few institutions to start the project and other institutions could join when they are ready. The INTELSAT System, for example, started in this manner. A few countries led by the U.S. started the System and over the years other countries joined, and today the INTELSAT System includes over 100 member countries.

Unfortunately at this time the teleoperator concept is in a preliminary design phase. Many problems have to be solved for the teleoperator to be useful for the communications platform, including:

Docking without loss of antenna pointing
Maintenance without loss of communications service
Access to many points on the platform
Connector problems
Maintenance of RF equipment near each antenna

At this time it is not certain that the teleoperator will be available for a first generation platform to be operational by 1987. For this reason, we have selected a platform concept with fewer missions and with sufficient redundancy to permit 10 years of operation. However, we believe that manned or unmanned maintenance of geostationary platforms will become feasible in the future, will permit the aggregation of many diverse missions and will lead to significant benefits. We believe that the development of in-orbit maintenance of platforms can be useful for later platform generations.

Selected Platform Concept

For the purpose of this study we have selected a platform concept which we consider feasible for a first generation to be operational by 1987. The mission design lifetime is 10 years without in-orbit maintenance. Only fixed telecommunications services are provided at three frequency bands: 4/6 GHz, 11/14 GHz and 18/30 GHz. Both trunk and direct-to-the-user service is provided on all frequency bands and the services are fully interconnected. Intersatellite links provide connection between platforms.

One application is the U.S. domestic system. Our model consists of one platform operated by AT&T, a second platform operated by a group of specialized common carriers and a third platform serving as a common spare. Another application is the Atlantic INTELSAT System. Two platforms are operated to provide diversity operation and in-orbit spare capacity. Domestic and INTELSAT platforms are interconnected by intersatellite links. This concept is shown in Figure 1-1.

Institutional problems are minimized by this arrangement. Both AT&T and INTELSAT as single entities can own and operate platforms if they so choose. Sharing of facilities by carriers is already practiced today, both for satellite and terrestrial facilities. If it is found to be in the public interest, it is probable that joint ownership of a platform by several carriers can be made possible by legislative or regulatory measures.

The INTELSAT System provides international, regional and domestic services. Since the platform has a substantial switching capability, any earth station can access the international systems as well as the domestic and regional systems.

Area coverage is provided by means of multiple spot beam antennas. These antennas constitute one of the technology tasks. Development of reliable on-board switching equipment is another, and perhaps a more difficult technology development task for this platform.

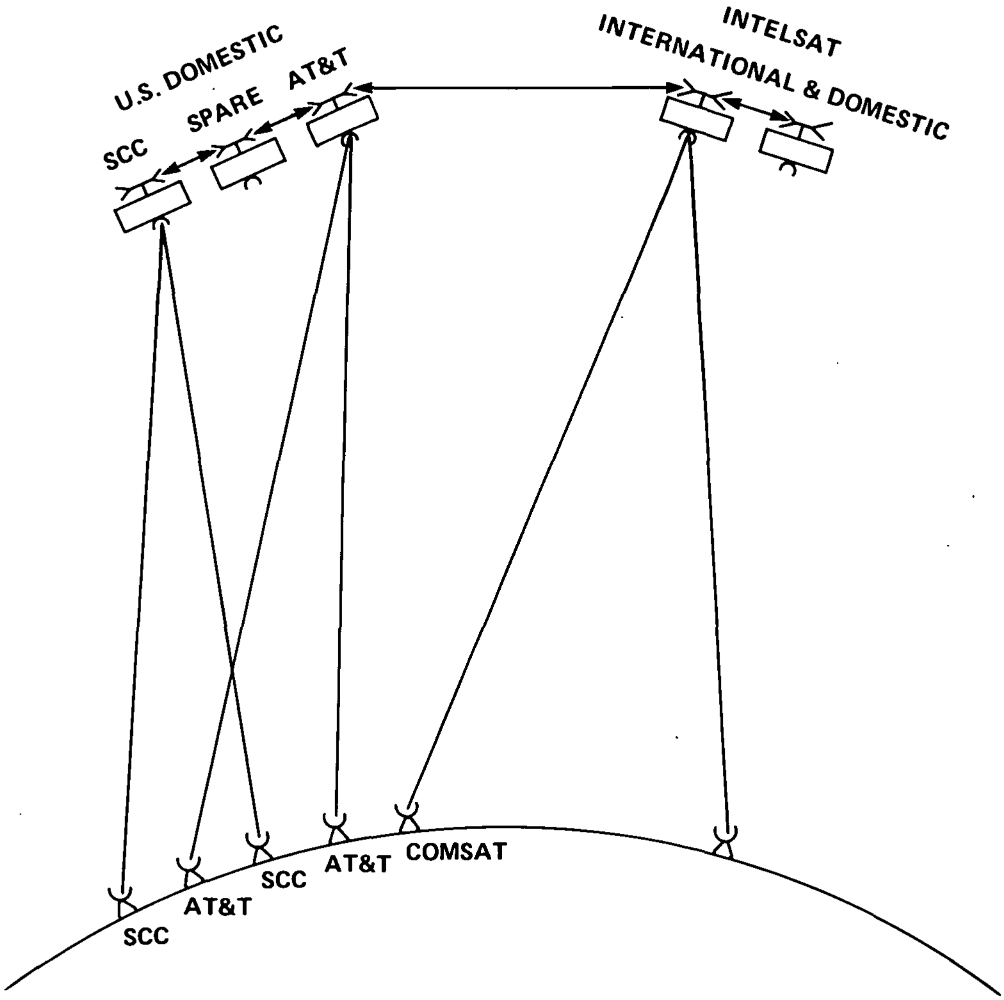


Figure 1-1

CONNECTIVITY OF U.S. DOMESTIC AND INTELSAT PLATFORMS

1.2 Traffic Models

Traffic models had to be generated in order to be able to perform economic comparisons of communications satellite systems configurations. The U.S. domestic traffic model is shown in Table 1-1. Traffic is expressed in terms of equivalent C-band transponders, each being capable of carrying about 1000 one-way telephony channels. The derivation of this traffic model is shown in Table 1-2. The present U.S. domestic satellite systems carry less than 2 percent of the total long distance traffic. It was assumed that the use of the satellite systems would grow until about 8 percent of the total long distance traffic is carried on satellites. We believe that this is a very conservative assumption and that actual satellite traffic could become much larger.

The INTELSAT traffic model is shown in Table 1-3. It includes international and domestic services. Again, traffic is expressed in terms of equivalent C-band transponders with a nominal capacity of 1000 one-way channels. The model for domestic services provided for developing countries within the INTELSAT System was based on the assumption that up to 15 percent of the long distance traffic in Latin American and African countries would be carried on satellites. We believe that this assumption is also conservative and that actual satellite use could become larger, leading to greater satellite capacity requirements.

None of the traffic models described above include video conferencing traffic. If video conferencing should become an important service offering, total capacity requirements would increase greatly from the figures shown.

Table 1-1

Total Transponder Requirements for U.S. Domestic Services

Mid Year	Number of Transponders	Annual Growth in Percent
1978	41	
1979	70	70.7
1980	108	54.3
1981	146	35.2
1982	187	28.1
1983	224	19.8
1984	262	17.0
1985	298	13.7
1986	334	12.1
1987	368	10.2
1988	404	8.9
1989	433	7.2
1990	465	7.4
1991	498	7.1
1992	532	6.8
1993	576	8.3
1994	620	7.6
1995	665	7.0
1996	700	5.3

Table 1-2

U. S. Domestic Traffic Model Statistics

	1978	1983	1988	1993	1998	2003
Population (millions)	218	227	234	242	251	261
GNP/Capita (1978 U.S. Dollars)	9,703	10,713	11,828	13,059	14,418	15,918
GNP (Billions of 1978 U.S. Dollars)	2,119	2,428	2,772	3,164	3,619	4,159
Long Distance Calls per $1000 GNP	6.3	8.0	9.7	11.6	13.7	16.7
Total Long Distance Calls (millions)	13,314	19,349	26,952	36,651	49,762	69,266
Percent of Traffic Via Satellite	1.8	5.7	7.2	7.7	7.9	8.0
Total Satellite Call Minutes (millions)	2,157	9,926	17,465	25,399	35,381	49,872
Total Telephony Traffic (transponders)	38	173	304	442	616	868
Data Requirements (transponders)	3	51	100	134	162	188
Total Transponder Requirements	41	224	404	576	778	1,056

Table 1-3

Total Transponder Requirements for INTELSAT's Atlantic Ocean Region International and Domestic Traffic

Year End	Number of Transponders International	Domestic	Total
1978	16	12	28
1979	20	17	37
1980	25	22	47
1981	28	29	57
1982	33	36	69
1983	39	45	84
1984	45	54	99
1985	52	66	118
1986	60	78	138
1987	70	91	161
1988	81	103	184
1989	94	118	212
1990	109	133	242
1991	127	149	276
1992	147	169	316
1993	171	189	360
1994	198	212	410
1995	230	232	462
1996	267	270	537

1.3 Communications Platforms

U.S. Domestic Coverage

For the systems comparision we have generated a platform model for U.S. domestic communications that covers the contiguous United States (CONUS) with 39 beams of about 1.1 degrees beamwidth. Additional beams are provided for Alaska, Hawaii and Puerto Rico, as shown in Figure 1-2. At 4 GHz, a satellite antenna diameter of 7 meters is assumed.

Precipitation attenuation increases with frequency. Therefore the 4/6 GHz frequency band is more desirable than the higher frequency bands and it is therefore used for all beams. The next available frequency band is the 11/14 GHz band. It suffers more from precipitation attenuation, but it has the advantage of easier frequency clearance in congested areas. The highest frequency band used is the 18/30 GHz band. Its advantage is the wider available bandwidth, but the very high precipitation attenuation that is caused by heavy rain makes this band less desirable than the other two bands. The 18/30 GHz band is therefore used only in those antenna beam coverage areas where the available capacity at the lower frequency bands is insufficient. The total usable capacity of this platform configuration is about 375 equivalent C-band transponders. The distribution of this capacity to the three frequency bands is shown in Table 1-4.

Table 1-4

Capacity of U.S. Domestic Platforms

Frequency Band	Number of Beams Used	Usable Capacity in Equivalent C-band Transponders
4/6 GHz	42	129
11/14 GHz	25	85
18/30 GHz	16	161
Total	83	375

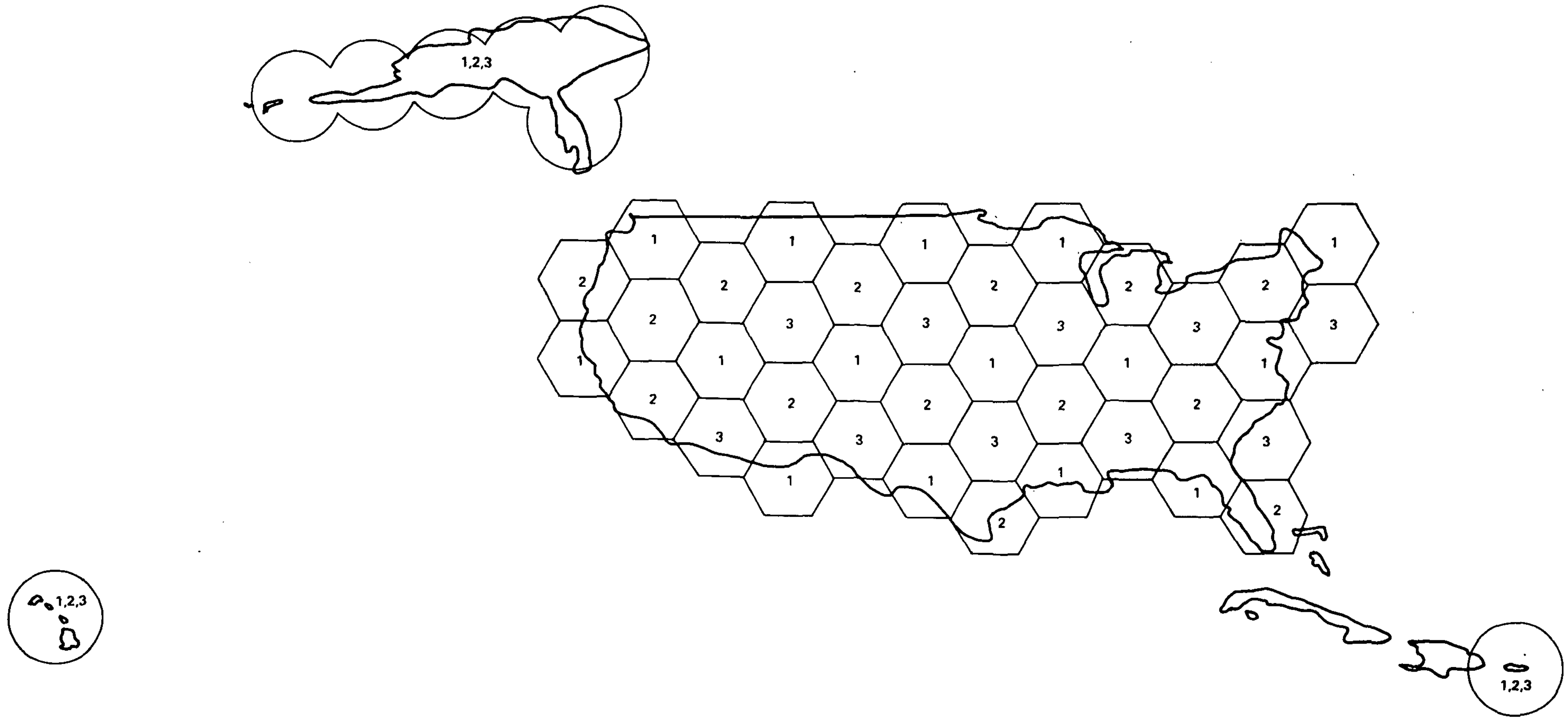


Figure 1-2

SPOT BEAM ANTENNA COVERAGE OF
CONUS, ALASKA, HAWAII AND PUERTO RICO FOR MULTI-BEAM PLATFORM
(Numbers 1, 2 and 3 Indicate Frequency Assignment)

Only one sense of polarization at 4/6 GHz is used for full time traffic assignment. The opposite sense of polarization is used for diversity switching during heavy rain. In the model, those earth stations using 18/30 GHz and requiring high link availability are equipped with a 4/6 GHz transmit and receive capability. During periods of localized heavy rain, the 18/30 GHz traffic of these earth stations is switched to the 4/6 GHz band, thus achieving high continuity of service without space diversity.

Atlantic INTELSAT Coverage

The communications platforms for Atlantic INTELSAT services cover South America and the Eastern part of North America with 64 beams of 1.1 degrees width and Europe and Africa with 48 beams of 1.8 degrees width. Dual polarization is used at 4/6 GHz and single polarization at 11/14 GHz and 18/30 GHz where needed. The antenna beam coverage is shown in Figure 1-3. The distribution of capacity is shown in Table 1-5.

Table 1-5
Capacity of Atlantic INTELSAT Platforms

Frequency Band and Polarization	Number of Beams Used	Usable Capacity in Equivalent C-band Transponders
4/6 GHz Single Polarization Use	112	247
4/6 GHz Second Polarization Use	33	105
11/14 GHz Single Polarization Use	18	75
18/30 GHz Single Polarization Use	7	114
Total	170	541

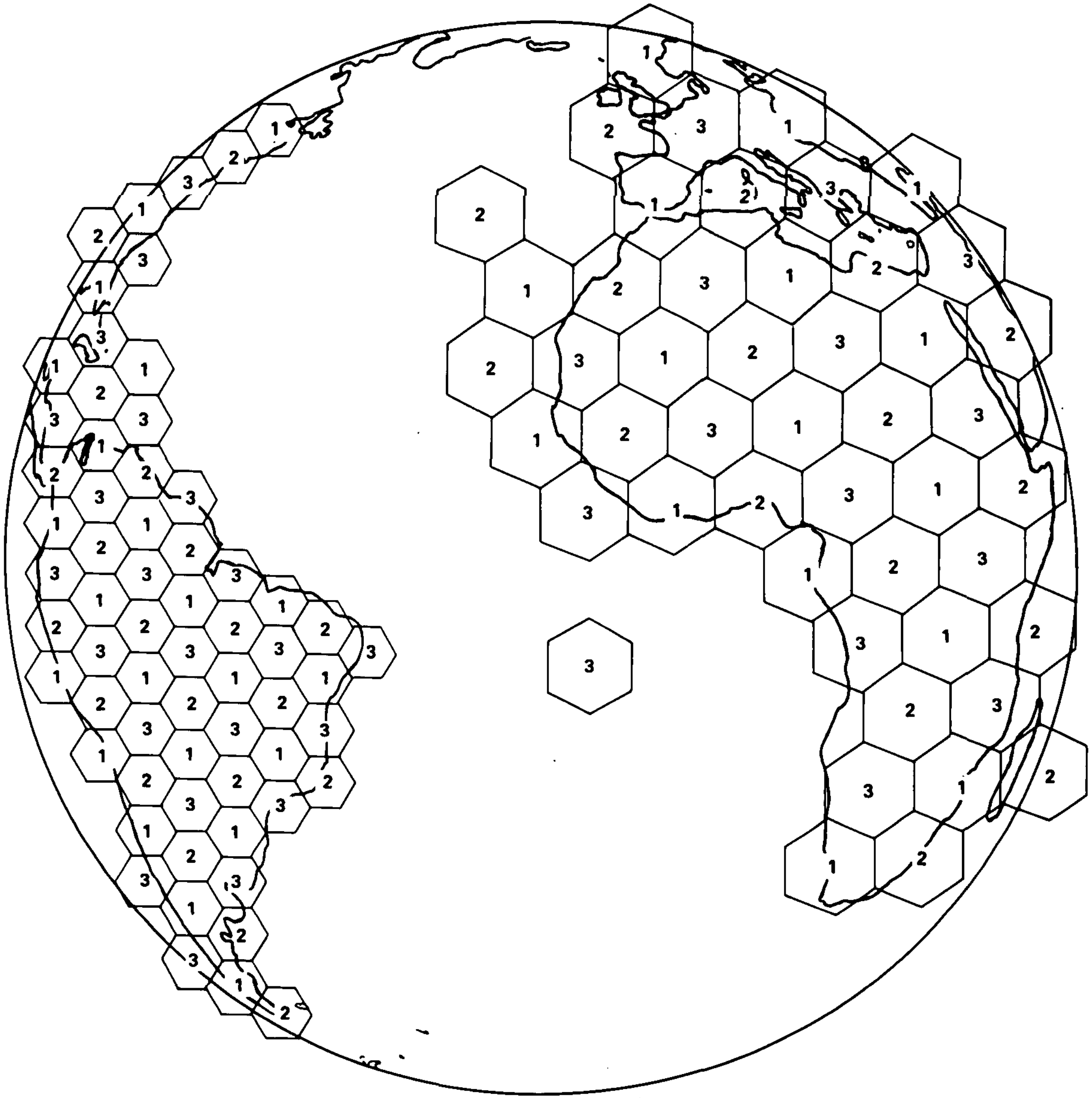


Figure 1-3

SPOT BEAM ANTENNA COVERAGE FOR
INTELSAT ATLANTIC OCEAN REGION MULTI-BEAM PLATFORM
(Numbers 1, 2 and 3 Indicate Frequency Assignment)

Platform Characteristics

Table 1-6 shows the major characteristics of the U.S. domestic and the INTELSAT platforms. The mass and power requirements for communications transponders are relatively modest; the communications switch requires the bulk of the power and mass allocation for the payload. The platform technique permits the convenient separation of transmit and receive antennas, which is desirable for optimum design of antenna coverage and for reduction of intermodulation and interference problems.

Stationkeeping is accomplished with a hybrid hydrazine/ion engine system. Nickel hydrogen batteries are employed instead of nickel cadmium batteries. The platforms are designed for a mission life of 10 years with stationkeeping to better than ± 0.1 degrees without in-orbit maintenance.

Table 1-6

Platform Characteristics

Item	U.S. Domestic Platform	INTELSAT Platform	
Antenna beamwidth, degrees	1.1	1.1	1.8
Transponder RF Power			
Watts per 62.5 MBps carrier			
at 4 GHz	0.8	0.8	2.1
at 11 GHz	5.4	5.4	14.5
at 18 GHz	18.0	18.0	48.6
Total usable capacity			
Number of equivalent 36 MHz transponders	375	540	
Mass in kg			
Antennas, transponders, switches	3,000	3,300	
Power subsystem	1,190	1,820	
Thermal control	300	300	
Attitude and reaction control systems	1,630	1,800	
TT&C subsystem	100	100	
Mission support structure	500	600	
Main structure	1,200	1,200	
Total	7,920	9,120	
Power in kW, BOL	26	26	
Cost in millions of 1979 dollars			
Development	137	149	
Recurring (per unit)	107	114	
Launch cost*	105	105	

*Assumes three Shuttle launches plus $15 million to raise the platform to synchronous orbit.

1.4 Conventional Satellites

Significant technology advances are assumed also for the alternative with conventional satellites. The characteristics of these satellites are summarized in Table 1-7. Satellites are designed for a 10-year mission life but provide lower capacity than the platforms and much less switching capability.

Table 1-7

Characteristics of Conventional Satellites

Satellite Application	U.S. Domestic	Foreign Domestic			INTELSAT International
Capacity					
Number of Equivalent 36 MHz Transponders	72	12	24	36	96
Primary Power, EOL, Watts	2350	450	925	1400	3000
Total Mass, BOL, kg	1660	600	850	1100	1900
Cost in millions of 1979 dollars					
Development Cost	70	10	22	35	90
Recurring Unit Cost	35	17	21	25	44
Launch Cost	36	13.4	18.4	23.4	36

1.5 Earth Station Design

Earth stations operating with large capacity platforms have small antenna diameters, low RF transmit power requirements and simple baseband equipment. Their costs range from $20,000 to $100,000 per earth station. The reasons for their simplicity and low costs are:

a. Platforms have high gain transmit and receive antennas, thus providing higher transmit EIRP and receive G/T. As a result the earth stations can have small diameters, low cost low noise receivers and low power transmitters.

b. Platforms have extensive switching capability, thus the earth stations can use simple baseband equipment.

Future earth stations operating with conventional satellites will be more complex than equivalent earth stations today. As the number of earth stations in the system increases, the earth station switching capability must increase in order to provide connectivity. As the systems capacity increases, several satellites must be operated, and as a result many earth stations must be able to simultaneously access several satellites. Since the satellite antennas have lower gains than the platform antennas, the earth station antenna diameters are larger and the transmit power requirements are higher. The costs of typical earth stations ranges from $200,000 to $1 million.

1.6 System Comparison

Cost

A comparison was made between a platform and a conventional satellite system, each of which would provide sufficient capacity to meet the projected traffic requirement for the 10-year period 1987 - 1996. The required number of in-orbit platforms or satellites including spares for year-end 1996 is shown in Table 1-8.

Table 1-8

Total In-Orbit Requirement of Platforms or Satellites for Year-End 1996

	Platforms	Satellites
U.S. Domestic	3	16
INTELSAT	2*	26*

*includes international plus domestic/regional traffic

A comparison of the two systems on an average per circuit per year basis shows the platforms provide the least expensive communications costs. Tables 1-9 and 1-10 show this cost comparison for both space and ground segments for the U.S. domestic and INTELSAT Atlantic Ocean Systems, respectively. Table 1-11 shows the cost ratio of conventional to platform systems.

Table 1-9

Cost Comparison of Platforms and Conventional Satellite Systems for U.S. Domestic Services for 10-Year Period 1987 - 1996*

(Thousands of 1979 Dollars Per Circuit Year)

	Platform	Conventional Satellites
Space Segment	0.46	0.55
Ground Segment	1.04	2.69
Total	1.50	3.24

*averaged over the period

Note: The current AT&T tariff for a leased voice curcuit between New York and Los Angeles is $16,450 per year. Current leased line satellite tariffs for the same link are about $12,000 per year. Various quantity discounts are presently available.

Table 1-10

Cost Comparison of Platforms and Conventional Satellite Systems for INTELSAT International and Domestic/Regional Services for the 10-Year Period 1987 - 1996*

(Thousands of 1979 Dollars Per Circuit Year)

	Platform		Conventional Satellites	
	International	Domestic	International	Domestic
Space Segment	0.52	0.52	0.78	0.91
Ground Segment	0.32	1.75	0.33	2.36
Total	0.84	2.27	1.11	3.27

*averaged over the period

Table 1-11

Ratio of Cost of a Conventional Satellite System to a Platform System for the 10-Year Period 1987 - 1996*

System	Satellite-to-Platform Cost Ratio
U. S. Domestic	2.2
INTELSAT	
International	1.3
Domestic	1.4

*averaged over the period

Orbital Arc

The use of the orbital arc is an important consideration for either platforms or satellites. A summary of orbital arc utilization for the U.S. domestic and INTELSAT systems is shown in Tables 1-12 and 1-13. Using conventional satellites with 72 transponders of capacity for U.S. domestic services and assuming that only 13 orbital slots were available, all slots would be utilized around 1994. This does not include any capacity for TV distribution or broadcast services which will further aggravate the situation and cause saturation earlier than 1994. In order to accommodate the 42 satellites required in 1996 with 4-degree orbital arc spacings, 168 degrees of orbital arc are required. Even if some locations could be shared, such as one system serving the northern hemisphere and one system serving the southern hemisphere, there would be crowding of the orbital arc.

Platforms, on the other hand, operating with 4-degree spacings would require only 20 degrees of orbital arc. This is a far better utilization of the arc, and, perhaps more importantly, it will provide sufficient arc availability for services other than fixed communications.

Table 1-12
U.S. Domestic Orbital Arc Utilization Summary

	Platforms	Satellites
Spacing (Degrees)	4	4
Total Orbital Slots Required (1996)	3	16
Orbital Arc Degrees Required (1996)	12	64
Percent of the Total Arc Required	3	18

Table 1-13
INTELSAT Atlantic Ocean Region
Orbital Arc Utilization Summary

	Platforms	Satellites
Spacing (Degrees)	4	4
Total Orbital Slots Required (1996)	2	26
Orbital Arc Degrees Required (1996)	8	104
Percent of the Total Arc Required	2	29

1.7 Sensitivity Analysis

A sensitivity analysis was performed to assess the effect of changes in assumptions on the cost comparison results. This was done for a variation in platform cost and traffic for the U.S. domestic system. The costs were increased by 50 percent and the traffic was varied by ± 50 percent. The resultant satellite-to-platform cost ratios for these variations along with those for the baseline assumptions are shown in Table 1-14.

Table 1-14
Comparison of Satellite-to-Platform Cost Ratios for Variations in Platform Cost and Traffic

	Satellite-to-Platform Cost Ratio
Baseline	2.16
Platform Cost Increased by 50 Percent	1.99
Traffic Increased by 50 Percent	2.21
Traffic Decreased by 50 Percent	2.29

In addition, the effect of adding video conferencing to the traffic model was analyzed. The average space segment cost per circuit year is shown in Table 1-15.

Table 1-15

Video Conferencing Space Segment Cost

(Thousands of 1979 Dollars Per Circuit Year)

	Cost
Platform System	13.7
Conventional Satellite System	51.4

These costs were calculated on the basis that there would be dedicated facilities to provide the service after spare capacity was fully utilized. Because many conventional satellites are required, the launch costs drive up the cost of providing this service with conventional satellites. On the other hand, the use of a platform is well suited to video conferencing in that it provides a large capacity in orbit over a longer period of time than a conventional satellite for relatively low launch costs.

If one of the C-band transponders on Westar or RCA Satcom were used for transmission of video conferencing circuits, the cost per circuit year would be at least $0.2 million, based on a tariff of $1 million per transponder year.

SECTION 2
INTRODUCTION

This report has been prepared by Future Systems Incorporated (FSI) for NASA Headquarters under Contract No. NASW-3212. The report describes a study which compares communications systems using large communications platforms with systems using conventional satellites. The context of this study within NASA's overall communications program is described below.

NASA has developed a 5-year plan for its communications program (Reference 1). This plan is designed to enable growth in the capacity and utilization of the radio frequency spectrum, to develop technology which will lead to a reduction in communications service costs and to serve as a catalyst in the creation of new services in the public interest. NASA programs consist of three phases: pre-project studies, technology verification and technology applications.

Pre-project studies consist of system assessment studies and of advanced system definition studies. The objectives for the pre-project studies are to:

1. Provide an assessment of requirements for systems capabilities
2. Provide the technical, programatic and institutional analysis for value assessment of potential operational communications satellite systems
3. Provide a focus for a communications technology program

In the area of advanced system definition studies, NASA's current effort is concentrated upon wideband systems, narrowband systems and large capacity aggregate systems (platforms). The objectives of these studies are as follows:

Wideband System

Define an economical 18/30 GHz communications satellite system to provide high capacity direct-to-the-user and trunking services in a spectrum conservative fashion.

Narrowband System

Define an economically viable and institutionally acceptable satellite system for thin-route fixed and land mobile services below 3 GHz in a spectrum conservative fashion.

Large Capacity Aggregate Systems

Assess the overall utility of using large geostationary platforms as a means of accommodating future missions and payloads in lieu of individual, smaller satellites.

It is clear that large capacity aggregate systems may well include wideband and narrowband system payloads, along with a variety of other payloads. Thus, the three systems that are being studied are not competitive alternatives but are complementary to each other, although it may be necessary to establish priorities for technology development and implementation of these systems.

The large capacity systems platforms study considers platforms with multi-discipline payloads. Depending on the size of the platform, multi-Shuttle launch may be required with consequent in-space assembly. At certain levels of complexity, periodic space maintenance will become important.

To some experts it has been intuitively obvious that large aggregate platforms will have an overall cost advantage relative to systems with small, separate satellites (Reference 2). In addition, Marshall Space Flight Center has conducted a cost benefit analysis for the space segment only of large communications platforms relative to smaller, separate satellites (Reference 3). This analysis showed that for the specific set of assumptions made, the large platform concept offers significant advantages over smaller, separate satellites. However, prior to the present FSI study there has been no systematic analysis of overall cost benefits of large platform systems relative to systems with smaller, separate satellites including ground segment as well as space segment.

The purpose of the present FSI study has been the cost comparison of large capacity communications platforms with separate, smaller satellites on a systems basis, considering total costs to the end user. The cost comparison has been performed for two specific systems: a system to provide communications for U.S. domestic applications and a system to serve the Atlantic INTELSAT requirements. These platform applications have been selected because they minimize associated institutional problems. Of course they do not exploit the full advantages that can ultimately be obtained from large platforms with multi-discipline missions; however, to the extent that these simple platforms demonstrate cost benefits, such benefits can be further enhanced by the addition of other payloads to the platforms.

SECTION 3
SYSTEMS CONSIDERATIONS

3.1 General Geostationary Platform Mission Capabilities

Possible Platform Missions Identified by Marshall Space Flight Center

According to Reference 4, geostationary platforms may provide the following mission capabilities:

Fixed Communications Satellite Service (Point-to-Point)

- C-band as provided by Comstar, Satcom, Westar and Anik
- 11/14 GHz as planned for Advanced Westar and SBS
- 18/30 GHz as in the wideband system studied by NASA Lewis Research Center
- S-band thin-route communications, as in the system studied by NASA Goddard Space Flight Center

Mobile Satellite Communications Service

- L-band for communications with ships as in Marisat and as planned for Marots and Inmarsat
- VHF and L-band communications with aircraft as was planned for Aerosat
- L-band for land mobile services*

Broadcasting Satellite Services

- S-band TV broadcasting, as conducted on ATS-6 and as planned for Insat
- 11/14 GHz broadcasting, as conducted on CTS and on Japan's BS Program

Space Research, Meteorology and Earth Observation

- Space-to-space communications experiments, for example, at 60 GHz
- Follow-on program to provide the TDRSS function
- Meteorology, as in the SMS and GOES Programs
- Earth observation from geostationary orbit

*NASA studies for land mobile satellite communications have recently been considering the 806 to 902 GHz and the 928 to 947 GHz bands allocated to land mobile communications in the U.S.

Possible Platform Missions Identified by Morgan and Edelson

A similar set of services listed in Reference 5 is shown below:

Intercontinental Trunking
Regional and Domestic Trunking
Regional and Domestic Networks
Business Networks
Maritime Services
Aeronautical Services
TV Distribution
TV Broadcast
Educational TV
Bush Voice
CB/Amateur
Intersatellite
Standard Time/Frequency
Disaster Communications
Navigation
Meteorology
Earth Exploration

In addition to providing a large variety of service types as identified in the above-mentioned references, platforms can provide the same type of service for diverse geographical locations. As identified in Reference 5, a platform for the Americas can provide domestic communications services for the U.S., Canada and for all Latin American countries. The same is true for other services such as meteorology and earth observation. Thus, a single platform can provide about fifteen different services and many of them to perhaps ten different countries as well as international and regional services. A total of over 100 different missions is possible on a major platform system. However, it is not likely that a first generation platform system will contain that many missions, primarily for institutional reasons.

3.2 Platform Missions Considered in this Study

In order to improve the probability of an institutional solution to the platform problem, we have included only a small subset of the possible platform missions in this first analysis. Two platform categories configured for the missions are identified below:

Platform Type A: U.S. Domestic Communications Services

This platform provides the following service categories:

Trunk service at C-band
Trunk service at 11/14 GHz
Trunk service at 18/30 GHz

Direct-to-the-user service at C-band
Direct-to-the-user service at 11/14 GHz
Direct-to-the-user service at 18/30 GHz

Intersatellite links to other platforms

Geographical coverage is provided for CONUS, Puerto Rico, Hawaii and most of Alaska. Trunk and direct-to-the-user services are interconnected and all frequency bands are interconnected. Intersatellite links permit the interconnection of any earth station with other platforms for domestic and international services. Since the future location of trunking and direct-to-the-user earth stations cannot be determined at this time, continuous coverage of all land areas is provided at all frequency bands. Thin-route fixed services are provided with low cost earth stations.

Specifically excluded from this model are international and regional services, foreign domestic services, broadcasting services, land mobile services, space research, meteorology and earth observation. This exclusion does not imply any judgement concerning the desirability of including such services in an operational system. Also excluded are TV distribution services based on reasons described in Section 3.3.

Platform Type B: INTELSAT Atlantic Services

This platform provides the following service categories:

- INTELSAT's international services based on an extension of its present traffic data base
- New international services made practical by the high capacity platform (e.g., video conferencing)
- Domestic and regional services for African and Latin American countries

Geographical coverage is provided to all land masses visible from a geostationary position over the mid Atlantic. International, regional and domestic services are fully integrated to provide full systems connectivity from any earth station in the network. Intersatellite links provide connectivity to other platforms of the INTELSAT System and of domestic systems in order to avoid the double-hop problem without the use of terrestrial extensions. Thin route services are possible with low cost C-band earth stations. A capability at 11/14 GHz is also provided.

Excluded from this model are maritime and aeronautical communications services, broadcast services, TV distribution services, land mobile services, space research, meteorological and earth observation services. As for Platform Type A, this choice does not imply any judgement concerning the desirability of providing such services, except for TV distribution.

3.3 Exclusion of TV Distribution Services

During the past 2 years, and especially during the past 6 months, there has been a very rapid increase in TV distribution services in the U.S. domestic satellite communications systems of RCA American Communications and Western Union Telegraph Company. The RCA System alone uses almost a full RCA Satcom satellite with 24 transponders for full time TV distribution. This rapid increase has exceeded most earlier forecasts. The costs of TV receive-only earth stations have dropped to the range of $20,000 to $30,000 installed, and by 1979 it is expected that over 1,000 such stations will be in operation in the USA.

High capacity platforms achieve their capacity primarily through frequency re-use by means of multiple beams. This capacity multiplication works only for the case of point-to-point service. Multiple beams do not provide the same advantage when wide area distribution of a signal is required, as in the case of TV distribution. For this reason we expect that TV distribution will be provided by separate, small satellites even after large communications platforms have become operational. Satellites of the RCA Satcom type with 24 transponders may be close to ideal for this purpose. Future satellites for TV distribution will probably be modified for smaller transponder bandwidth, since 36 MHz is more bandwidth than is needed for TV transmission. In addition it is possible that the antenna coverage will be adjusted to conform to the time zones so as to provide more flexibility in program distribution. The resulting satellites will have 36 to 48 TV transponders and will have a mass of about 700 kg beginning of life (BOL) in synchronous orbit.

We expect, however, that platforms will be used for some TV distribution applications where coverage requirements are localized. Platforms will also be used for the transmission of TV origination signals (news and sports events) to the network studios. This requires transportable earth stations which should operate into high gain satellite receive antennas. Several steerable antennas of the type used in TDRSS would be provided on the platform for reception of remote TV origination.

3.4 Complexity Inversion

A study performed by McDonnell Douglas for NASA Langley Research Center (Reference 6) identified the gradual complexity inversion in satellite communications. Initial commercial communications satellites had an extremely simple payload, leading to large and very expensive earth stations. As space technology progressed it became economical to increase spacecraft complexity and reduce earth station costs. This trend will be accelerated with the introduction of space platforms. Lower earth station costs will lead to a proliferation of earth stations, which means that more earth stations will be located closer to the end user. The result is a reduction in requirements for terrestrial extensions and interconnect facilities. This is especially important in cases where suitable terrestrial facilities do not exist and are difficult to implement, as is the case in developing countries for all communications services and in the U.S. for high speed data and video conferencing applications.

3.5 Modulation/Access Techniques

To date, very little work has been done on the optimization of modulation/access techniques for large communications platforms. A discussion of promising modulation/access techniques is given below.

Satellites which operate with a single transmit and receive antenna beam can be designed to operate with a wide range of modulation/access techniques. However, satellites with many different antenna beams require provision for beam interconnection, and the method of beam interconnection affects the choice of modulation/access techniques. For example, INTELSAT V uses filter matrices to interconnect transmit and receive antenna beams. This limits the flexibility of traffic redistribution with changing demand and makes the system less suitable for TDMA transmission. On the other hand, Advanced Westar employs satellite-switched TDMA as modulation/access technique, and beam interconnection is accomplished by means of time division switching. This system provides excellent flexibility since the switch timing can be ground controlled, but the transmission system must rely exclusively upon satellite-switched TDMA transmission. It cannot use the single channel per carrier technique (SCPC) which is cheaper than the TDMA technique for low transmission volume per earth station.

For the communications platforms in this study, the number of antenna beams is much larger than for INTELSAT V or Advanced Westar. For example, a total of 39 beams is employed for CONUS coverage alone, with additional requirements for Alaska, Puerto Rico, Hawaii and for interconnection of the different frequency bands within individual beams. On a satellite with 50 beams, the required number of beam interconnect links is 1,275. With 100 beams a total of 5,050 interconnect links are required. The general expression is given as follows:

$$L = b(1 + \frac{b-1}{2})$$

where

L = Number of interconnect links

b = Number of antenna beams to be interconnected

This equation assumes that each beam must be connected to itself and to each other beam on the platform.

With a requirement of over 1,000 interconnect links, the INTELSAT V technique which uses interconnection by means of filters is not practical. Likewise, the Advanced Westar technique of satellite-switched TDMA has certain limitations:

1. Because of the large number of switch modes required, the number of synchronization and overhead bits is very large. Thus, the frame efficiency would be low unless long frame times are chosen which require additional storage capability.

2. Earth stations have to transmit at a high bit rate and have to handle receive data which is of no interest. This increases earth station costs.

For the purpose of the present study, we have considered the following modulation/access techniques:

a. Satellite-Switched TDMA

   This technique places the least demand on the spacecraft switch but is more demanding on the ground system. It is expected that it will be used for a range of applications that have used TDMA in the predecessor systems, such as the Advanced Westar and the SBS systems.

b. Satellite Switching at IF

   With this technique, the earth stations must transmit at least one carrier per link, and this carrier is converted to a common IF frequency and switched to the desired down-link beam.

c. Satellite Switching at Baseband

   With this technique, all carriers must be demodulated and switching occurs at baseband. Switching may be performed on individual channels or on larger channel groups, for example, using the Bell System T-carrier hierarchy.

Some of the switching systems can be implemented to work with FM carriers, and it may be desirable to implement part of the platform in this manner in order to facilitate easy transition of FM systems to the platform. For the largest part of the traffic, however, we assume that PSK will be used as the modulation technique, and we have assumed that forward error control coding will be used to permit operation in the interference environment that results from the large number of sidelobes in a multi-beam system.

3.6 Demand Assignment Versus Pre-Assignment

Figure 3-1 shows the Erlang load versus number of channels on a link. The ratio of number of pre-assigned channels to Erlangs is the concentration ratio that is achievable in a large demand assignment pool.

The Figure shows that very large concentration ratios are possible with small numbers of channels per link, but little concentration is available with large numbers of channels per link. For this reason traffic on large links will be pre-assigned, while traffic on low capacity links will be demand assigned.

3.7 Earth Station Concept

Depending on the selected system, earth stations may become very simple. Earth station antenna diameters can be small because the satellites have narrow-beam, high-gain transmit and receive antennas. At C-band, an antenna diameter of about 4.5 meters is adequate to permit operation of satellites with a spacing of 4 degrees. At higher frequencies it is possible to employ smaller diameter antennas inversely proportional to the frequency and still maintain a 4-degree satellite spacing; however, EIRP requirements may require the use of 4.5-meter antennas. Earth station HPA's will be replaced by low level amplifiers, often below 5 watts RF power.

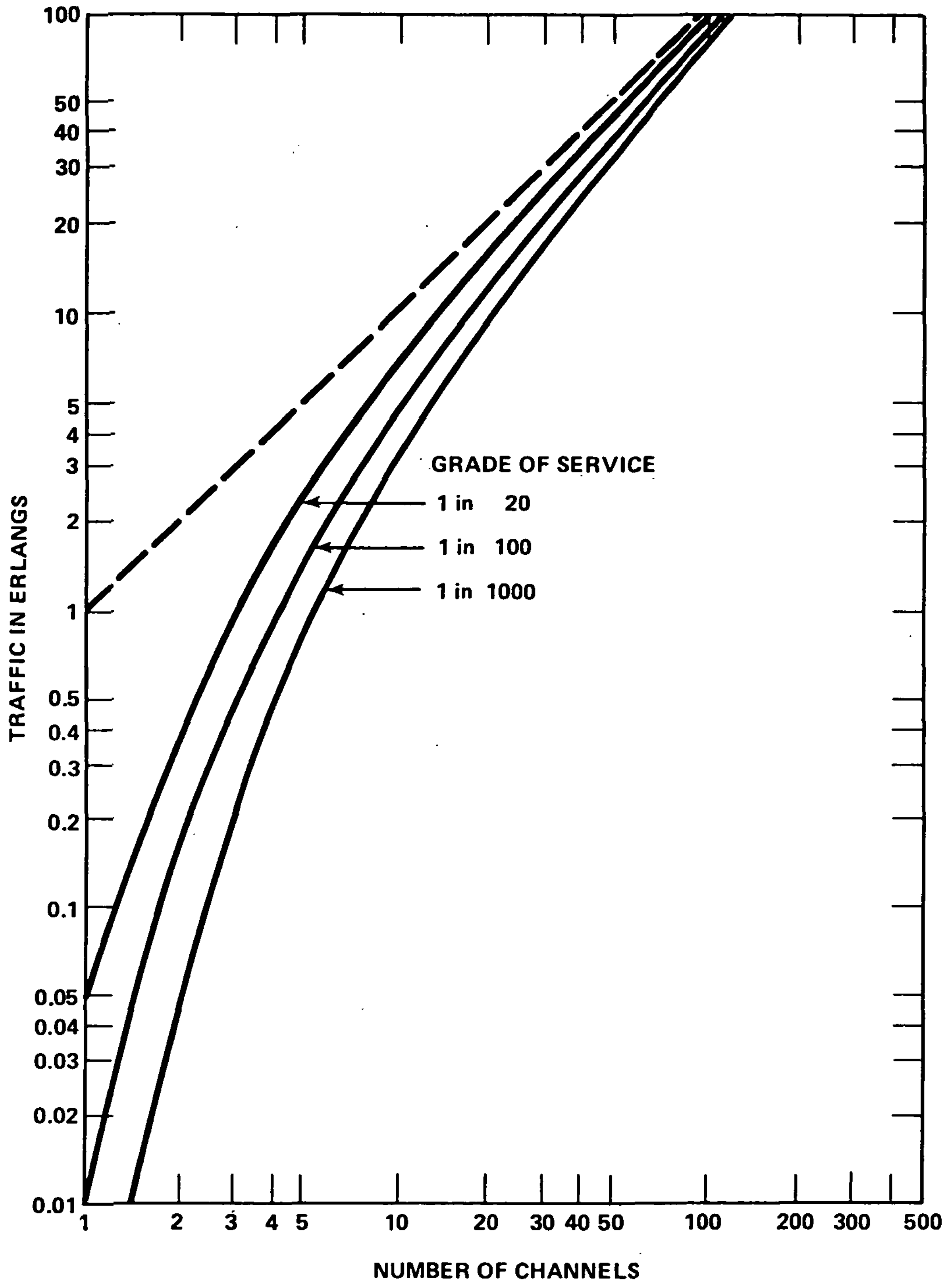


Figure 3-1

ERLANG LOAD VERSUS NUMBER OF CHANNELS

Since the platform satisfies a substantial portion of the switching requirement, earth station baseband equipment is greatly simplified. Lower earth station costs will induce a proliferation of earth stations, and the larger production volumes will lead to further cost reductions. Typical earth station costs will range from \$20 k to \$100 k installed.

3.8 Platform Concept

One basic requirement for the platform antenna design is to provide continuous coverage of all land masses as compared to coverage of specific cities. This requirement follows from the inability of the carriers to predict where earth station locations will be selected in the future. The generation of the required beam patterns at six frequency bands will be a difficult task and may well lead to an implementation with several separate antennas, as has already been envisaged in the various artist's concepts that were presented in the literature (References 2, 5 and 7). If the platform is not sufficiently rigid, finepointing of individual antennas or feedclusters may be required.

In our baseline model we have assumed antenna beams with a minimum 3 dB width of about 1 degree. Beam pointing stability should be better preferably by 1 order of magnitude. It was assumed that beams of this width represented an adequate challenge to antenna and spacecraft designers, and while narrower beams are possible, they will probably be used only on later platform generations. Even with our assumptions the antenna design will be one of the difficult technology developments.

As described in Section 3.5, interconnection of the large number of beams is another technology development problem, probably more difficult than the antenna design, taking into account the requirement for high reliability and continuity of service.

With a large communications platform it is probable that the component count will increase much more rapidly than the component reliability can be improved. This would lead to a reduction of platform lifetime unless in-orbit maintenance is introduced. Short lifetimes of expensive platforms will not be desirable, and therefore the platform concept includes either a high level of redundancy or in-orbit maintenance. This represents the third technology development problem, perhaps even more severe than that of the antenna and the switch design.

For later generations of platforms it is possible that a permanently manned geostationary maintenance center will be used to service several or perhaps all platforms in orbit. The maintenance center could be made to drift at a rate of 2 to 3 degrees per day, thus permitting visits to all space stations in 6- or 4-month intervals. A small manned mobile unit would detach from the maintenance center (whose drift rate is not changed) and would dock with the communications platform to perform the required maintenance, which had been planned based on telemetry information. Maintenance center crew changes would be combined with scheduled restocking of maintenance modules. Failed and obsolete equipment would be removed from synchronous oribt. The maintenance center could be operated by an international venture.

For the first platform generation, however, manned maintenance has been judged to be too expensive, and NASA is considering plans for an unmanned teleoperator. This device would be designed for initial application in low earth orbit but could later be adapted for operation in geostationary orbit. It would dock with the platform and would replace modules as required. The platform and payloads would have to be designed specifically to permit teleoperator maintenance. Docking and maintenance maneuvers should not disrupt communications. Special attention will have to be given to the reliability of those platform and payload elements which are not subject to teleoperator maintenance. This applies, for example, to connectors, interconnect cabling and antenna feeds. As mentioned above, the alternative to in-orbit maintenance is adequate redundancy to achieve reliable long-life operation. In our model we have assumed platforms with a 10-year mission life without in-orbit maintenance.

3.9 Diversity Operation

3.9.1 Satellite Diversity

Communications systems operators have traditionally sought to design their systems so as to provide path diversity. The objective is to minimize disruptions of the communications network in case of transmission link or switching node failure. From this point of view, the concentration of all traffic of a given entity on a single platform will be an undesirable if not an unacceptable feature, regardless of cost savings.

In order to maintain diversity, we expect that space and terrestrial transmissions will continue to be developed in a balanced fashion. This applies to international as well as to domestic telecommunications. In addition, we expect that there will continue to be a requirement to split traffic on high density routes among two or more satellite paths, as is now the case in the INTELSAT System where Primary and Major Path satellites are used in this fashion. It is especially important to avoid major losses of communications capacity in an automatic exchange telephone system, since the attempt to re-dial by a large number of users who experience a busy signal could lead to a temporary breakdown of the complete system. For this reason, in assigning traffic to platforms, a minimum of two platforms will have to be used, or one platform augmented by smaller satellites.

3.9.2 Ground Diversity

In the past, ground diversity has also been used as a protection against earth station failure. For example, the satellite traffic between the U.S. and major European countries has been split between the Primary and the Major Path satellites, which are accessed by separate earth stations. This concept will remain in use for high traffic links; however, due to lower earth station costs a larger number of low capacity links will be established for which dual satellite and earth station operation will not be required. A balance of satellite and terrestrial facilities will always be desirable.

Diversity has also been considered as a means of avoiding propagation outages with transmission at higher frequencies. Such diversity operation is undesirable for low capacity applications because of the expense of the two earth stations separated by about 10 km and of the associated interconnect link. A more desirable form of diversity is frequency diversity, whereby normal transmission is accomplished at the higher frequencies and where the lower frequencies are used only temporarily at earth stations while they experience heavy rain. This is feasible only in systems in which the platforms provide on-board switching on a demand-assigned basis. It increases the earth station costs but it avoids the need for a second physical location and for the interconnect link. With this system, a communications user will have the option of accepting the link availability that results from single station operation at 18/30 GHz, or to pay the increased earth station cost for dual frequency operation with the resulting higher availability.

3.10 Platform Implementation Schedule

Based on discussions with various experts, initial commercial operation of large communications platforms would take place between 1987 and 1995. To the extent that large platforms lead to cost and to other systems benefits, the cumulative advantages are greater if systems operation starts earlier. For this reason we have based our study on the earlier implementation date of 1987. This implementation time of 9 years is certainly adequate from a technology development and industry capability point of view, although it may require the resolution of some institutional questions.

Before discussing the schedule question in more detail, we would like to point out that much of the advantage of technology development would be lost if a long, drawn out implementation schedule is pursued. In the 1960's and early 1970's the European aerospace industry was in this situation. Largely because of institutional arrangements, the construction of the Symphonie satellites extended over a time span during which several generations of INTELSAT satellites were brought into service. Lately, however, the program cycle of the European space program has been shortened. For example, the ECS satellites follow OTS with very little delay, and a French domestic satellite system will probably be announced within the next few months.

A 1987 operational schedule may require that the first NASA platform becomes the pilot operational system for one of the applications. This may be contrary to normal NASA practices, where NASA flies experiments and the carriers fly operational systems. In the case of the platform, the expense is such that a different approach is desirable from a cost benefit point of view. A compression of the schedule for start of commercial operation is also desirable from a public interest point of view, so that the platform's advantages are available to the public at an earlier date. Therefore, for the purpose of this study the following implementation scenario has been selected:

Program Element	Completion Date
Systems/Market Studies	September 1979
Concept Definition	December 1979
Design Program Definition	December 1981
Congressional Approval	March 1982
Design, Development and Construction	March 1986
Launch	June 1986
Pre-operational Tests	December 1986
Start of Commercial Operation	January 1987

SECTION 4
METHOD OF ANALYSIS

This section provides a brief description of the method of analysis that was used for the conduct of this study.

The first step was the generation of traffic models for the two platform applications that are included in the study, namely, the U.S. domestic application and the Atlantic Ocean INTELSAT application. Based on extensive review of historical telecommunications statistics as well as on a variety of forecasts for future communications service demand, we generated domestic and regional traffic models for the following service categories:

Telephony
Data
Video Conferencing

The traffic model for INTELSAT's international traffic is based on an extension of INTELSAT's own forecasts.

The next step was to configure satellite communications systems using large communications platforms to satisfy the traffic models. Traffic flow patterns through the platform were identified, and the resulting bandwidth and frequency re-use requirements were established. Existing information on platform technology development, power and mass requirements, maintenance concepts and cost estimating relationships as developed by Marshall Space Flight Center were used. Subsequently, FSI developed matching ground systems configurations and prepared ground segment cost estimates. Systems transition from conventional systems to the large platforms were also considered.

To permit the comparison with conventional systems, FSI configured conventional satellite communications systems using smaller satellites. Satellite categories of the Delta, Atlas Centaur and the full Space Shuttle class were considered. These systems were also assumed to benefit from technology advances that can be expected to be available for future spacecraft and earth station generations.

A systems comparison was made with respect to costs, orbital arc use and connectivity. The cost comparison consisted of annual revenue requirement calculations over the study period. They took into account initial systems value, new investment, depreciation, net investment, O&M, ROI, cost per channel and residual systems value at the end of the study period. Constant 1979 dollars were used throughout, and the comparison was made with and without present value calculations. A comparison was also made of the number of orbital arc degrees needed for each configuration.

A sensitivity analysis was performed to determine the effect of changes in the assumptions upon the results.

SECTION 5

TRAFFIC MODELS

5.1 INTELSAT Atlantic Traffic

5.1.1 International Services

The INTELSAT System started operation with 60 voice circuits on Early Bird in 1965. The year-by-year traffic and the annual growth rates of INTELSAT's Atlantic communications system are shown in Table 5-1. INTELSAT's own traffic projections through the year 1989 assume an annual growth of 16 percent. We have extended the model on the basis of continued growth at 16 percent per year through 1996, which is the end of our study period. This model is shown in Table 5-2.

Past growth of the INTELSAT System was primarily due to telephony traffic. Even though future telephony growth rates will drop, it is reasonable to expect that new services such as data transmission, facsimile, electronic mail and video conferencing will cause the composite growth rate of 16 percent to be maintained. Figure 5-1 shows the historical Atlantic INTELSAT traffic and the traffic model through 1996. Future traffic is plotted in equivalent voice circuits, including data transmission, video conferencing, etc.

Table 5-1

INTELSAT Atlantic Ocean Region International Traffic

Year End	Number of Circuits	Annual Growth in Percent
1965	60	
1966	86	43.3
1967	195	126.7
1968	346	77.4
1969	893	158.1
1970	1316	47.4
1971	1756	33.4
1972	2773	57.9
1973	3144	13.4
1974	3846	22.3
1975	4430	15.2
1976	5390	21.7
1977	6047	12.1
1978	8130	34.4

Table 5-2

Traffic Model for INTELSAT Atlantic Ocean Region Traffic

Year End	Number of Equivalent Voice Circuits	Annual Growth in Percent
1979	9,940	24.6
1980	12,300	23.7
1981	13,920	13.2
1982	16,430	18.0
1983	19,380	18.0
1984	22,480	16.0
1985	26,080	16.0
1986	30,250	16.0
1987	35,090	16.0
1988	40,710	16.0
1989	47,220	16.0
1990	54,780	16.0
1991	63,540	16.0
1992	73,710	16.0
1993	85,500	16.0
1994	99,180	16.0
1995	115,050	16.0
1996	133,460	16.0

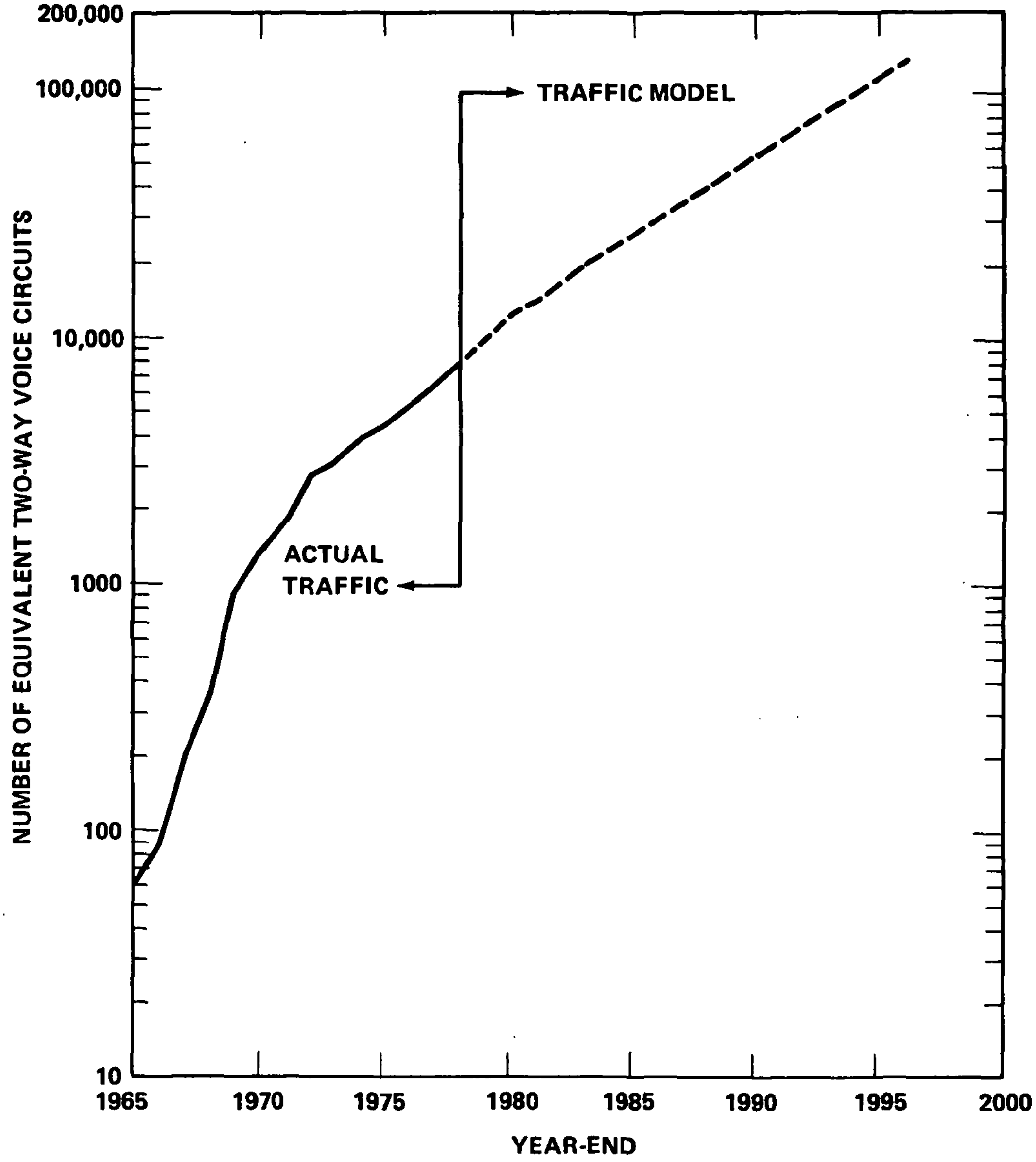


Figure 5-1

INTELSAT ATLANTIC OCEAN REGION TRAFFIC
(1965-1996)

Table 5-3 shows the distribution of INTELSAT's international traffic in the Atlantic Ocean area among the participating countries. This distribution is important for the design of the antenna configuration in a multi-beam satellite system.

Table 5-3

Distribution of INTELSAT's Atlantic Ocean Region Traffic

Country	Percent	Country	Percent
Algeria	0.3	Angola	0.3
Argentina	2.1	Austria	0.2
Barbados	0.3	Belgium	1.1
Benin	*	Bolivia	0.2
Brazil	2.7	Bulgaria	*
Cameroon	0.6	Canada	3.3
Chile (Longevilo)	1.0	Colombia	1.2
Congo	0.1	Costa Rica	0.3
Cyprus	0.1	Czechoslovakia	*
Dominican Republic	0.6	Ecuador	0.8
Egypt	0.6	El Salvador	0.1
Ethiopia	0.2	France (mainland)	6.2
France (Fr. Guiana)	0.3	France (Martinique)	1.1
Gabon	0.4	Gambia	*
Germany (Federal Republic)	4.9	Ghana	0.2
Greece	1.0	Guatemala	0.2
Guyana	0.1	Haiti	0.4
Honduras	0.2	Hungary	0.1
Iceland	0.1	Iran	2.2

*less than 0.05 percent

Table 5-3, Continued

Distribution of INTELSAT's Atlantic Ocean Region Traffic

Country	Percent	Country	Percent
Iraq	0.3	Ireland	0.2
Israel	1.4	Italy	3.6
Ivory Coast	0.7	Jamaica	1.0
Japan	0.1	Jordan	0.4
Kenya	0.3	Kuwait	0.6
Lebanon	0.1	Liberia	0.1
Luxembourg	0.1	Mauritania	0.2
Mexico	1.1	Morocco	0.2
Mozambique	0.2	Netherlands	1.2
Netherlands (Antilles)	0.2	Nicaragua	0.3
Nigeria	0.5	Nordic Countries	1.3
Panama	0.9	Paraguay	0.3
Peru	1.1	Poland	0.1
Portugal (mainland)	0.9	Portugal (Azores)	0.2
Rhodesia	*	Romania	0.1
Saudi Arabia (Taif)	2.0	Senegal	0.3
South Africa	1.5	Spain (mainland)	1.5
Spain (Canary Island)	0.4	Surinam	0.2
Switzerland	1.5	Syria	*
Togo	0.1	Trinidad & Tobago	0.5
Tunisia	*	Turkey	0.5
U.A.E. (Abu Dhabi)	0.8	United Kingdom (Antigua)	0.1
United Kingdom (Ascension)	*	United Kingdom (mainland)	9.6
United States (mainland)	27.3	United States (Puerto Rico)	3.2
Uruguay	0.2	U.S.S.R.	*
Venezuela	2.6	Yugoslavia	0.4
Zaire	0.3		

*less than 0.05 percent

The Atlantic INTELSAT System has international traffic divided among one Primary and two Major Path satellites. The approximate division of traffic for the year 1978 was as follows:

Primary Path Satellite	67 percent
Major Path Satellite No. 1	24 percent
Major Path Satellite No. 2	9 percent
Total	100 percent

It is important to note that many telecommunications administrations require path diversity so that failure of any one transmission path does not cause disruption of all traffic on a given link. Table 5-4 shows some examples of path diversity that was used in the INTELSAT System during 1978. Path diversity over at least two paths is therefore considered to be part of the requirements for the communications systems design.

Table 5-4

Examples of INTELSAT System Path Diversity

1978

(Percent of Traffic)

	Satellite		
Link	Primary	Major Path 1	Major Path 2
U.S. - U.K.	33	34	33
U.S. - Germany	54	46	0
Canada - Germany	48	52	0

5.1.2 Domestic and Regional Services Provided by INTELSAT

In 1975, INTELSAT started to lease transponders for domestic satellite communications services. This new service offering was so successful that over a period of 4 years 15 countries started to use INTELSAT transponders for domestic communications, and several other countries have service applications approved or pending. Figure 5-2 shows the countries which already use INTELSAT transponders for domestic communications.

To date, INTELSAT has not decided to procure space segment with optimized characteristics for transponder lease applications. The transponders currently offered are connected to global and hemispheric coverage antennas and provide a beam edge EIRP of only 22 to 26 dBW, compared with the 33 dBW of a typical domestic C-band transponder. Even with these relatively undesirable characteristics, the use of the INTELSAT System for domestic application is growing rapidly.

Based on our forecasts, we expect that around 1982 there will be insufficient spare INTELSAT transponder capacity available, so that INTELSAT will have to procure additional space segment in order to be able to satisfy all requirements. We expect that such new space segment will be specified to provide characteristics similar to those of typical domestic satellite systems, e.g., higher EIRP so that smaller earth station antennas can be used. As a result of the availability of new space segment with improved characteristics, we expect that the demand for service will rise even more rapidly than in the past.

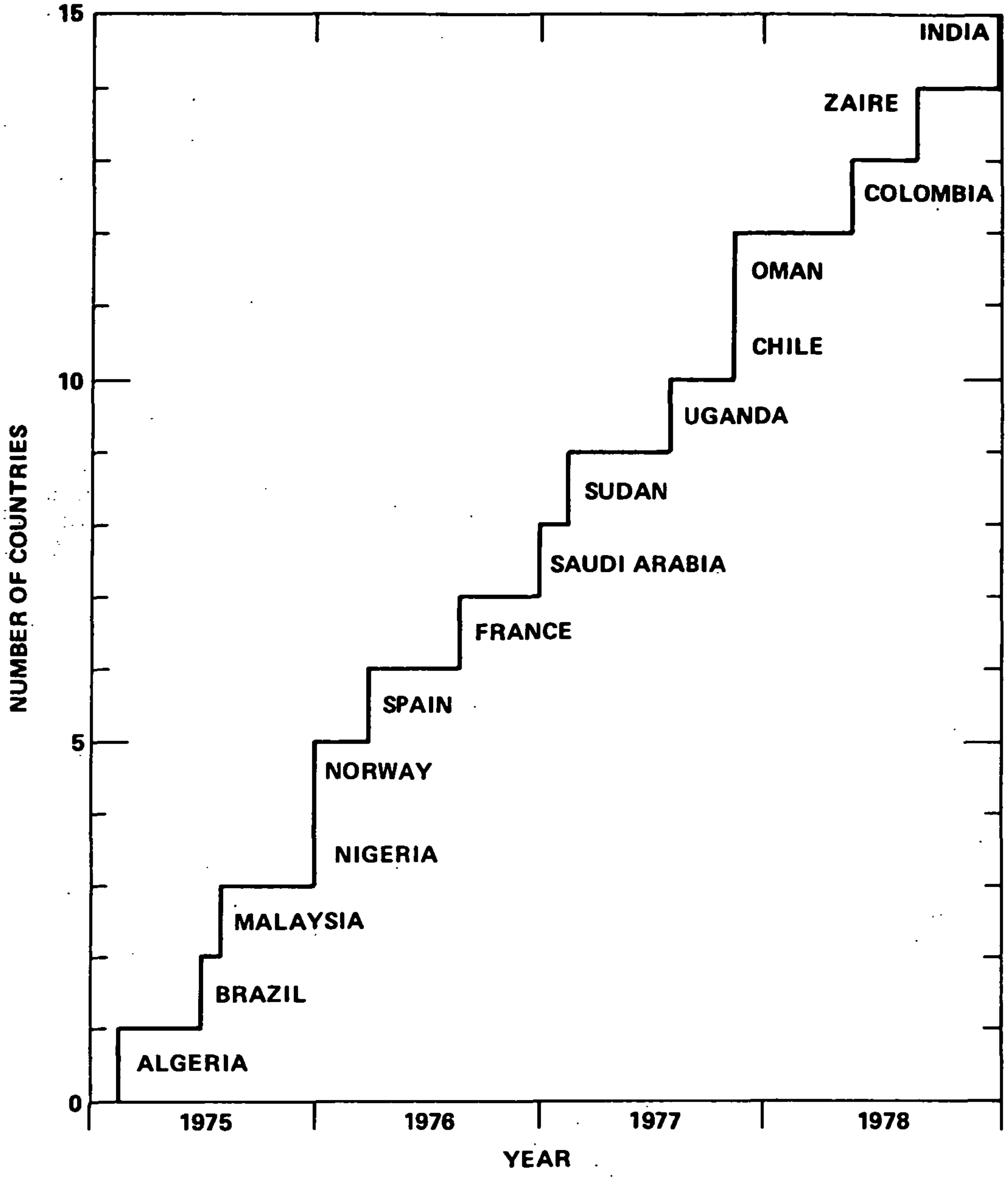


Figure 5-2

COUNTRIES THAT LEASE INTELSAT TRANSPONDERS

In the scenario generated for this study, we assumed that the Atlantic INTELSAT System will provide domestic and regional communications services for all of South America and for part of Africa. A summary of the resulting traffic model is given below and the derivation of the traffic model is presented in Annex A.

The resulting total requirements are shown in Table 5-5. Requirements are expressed in terms of transponders, where a transponder is a typical C-band domestic satellite transponder with an EIRP of 33 dBW and a bandwidth of 36 MHz, resulting in an average transmission capacity of 1000 one-way voice channels. This type of transponder is used only as a convenient reference to express capacity.

Figure 5-3 shows transponder requirements for all groups of countries, and Table 5-6 provides a listing of total transponder requirements on a year-by-year basis. Table 5-7 shows the combined transponder requirements for domestic and regional services plus international services for the Atlantic Ocean INTELSAT System on a year-by-year basis.

Table 5-5

Total Requirements (Transponders)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	3.0	21.8	56.3	104.8	168.6	252.7
Col Peru Chile	0.6	3.3	8.0	14.4	22.6	33.1
Other So. Am.	0.0	1.3	3.7	6.4	9.4	12.8
Nigeria Ghana	3.0	5.3	9.4	15.2	22.5	30.4
Ethpa Sud Zar	1.0	1.6	2.7	4.0	5.5	6.9
South Africa	0.0	1.0	7.8	17.9	33.4	60.9
Other Africa	3.0	5.4	9.9	16.0	23.8	32.0
Total	10.6	39.9	97.8	178.8	285.9	428.7

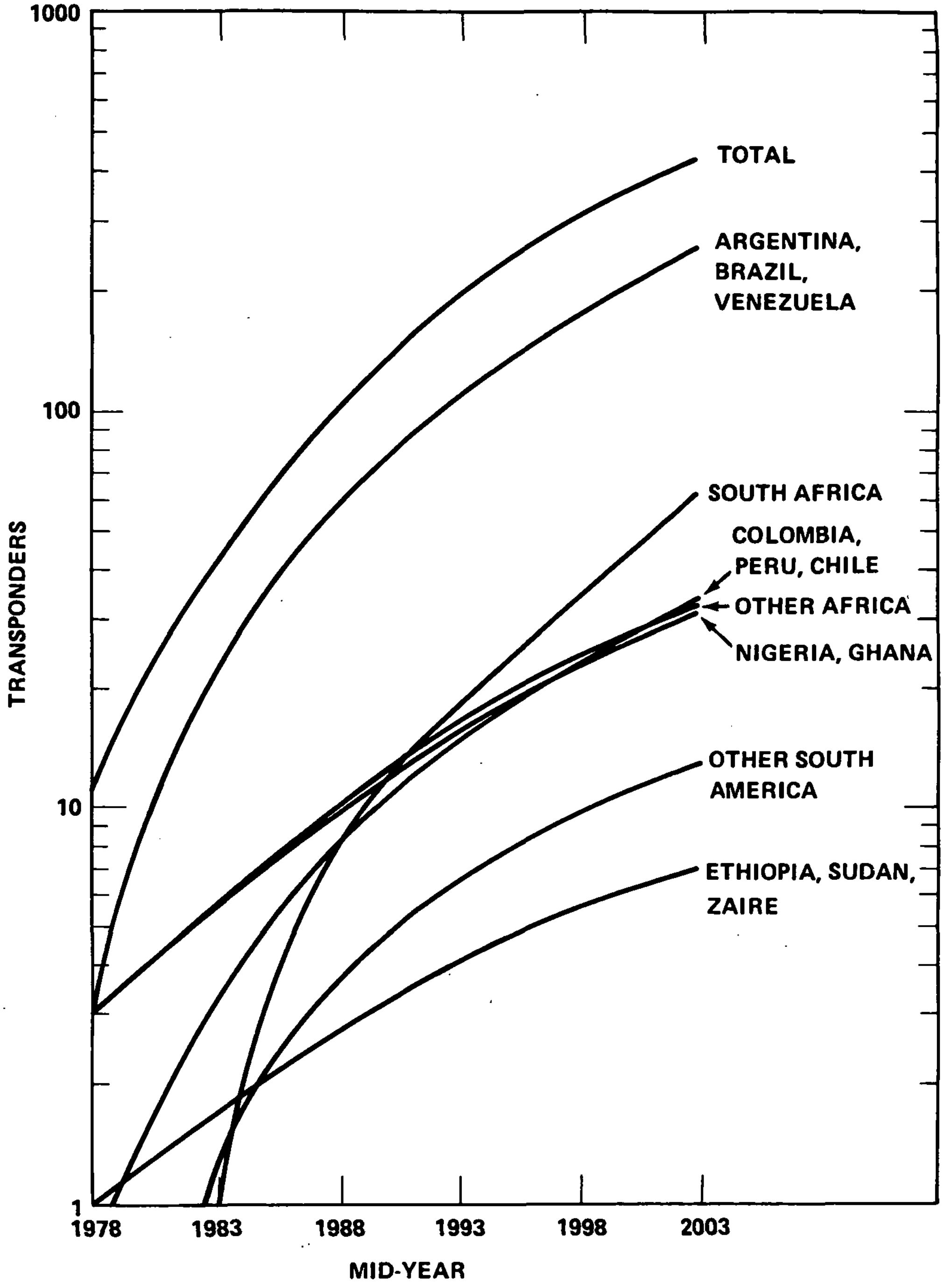


Figure 5-3

TOTAL TRANSPONDER REQUIREMENTS
FOR SOUTH AMERICAN AND AFRICAN SYSTEMS
(1978-2003)

Table 5-6
Total Transponder Requirements for Domestic and Regional Services Within the INTELSAT Atlantic Ocean System

Mid-Year	Number of Transponders
1978	11
1979	14
1980	19
1981	25
1982	32
1983	40
1984	47
1985	59
1986	70
1987	84
1988	98
1989	110
1990	130
1991	150
1992	170
1993	190
1994	210
1995	231
1996	252

Table 5-7

Total Transponder Requirements for INTELSAT's Atlantic Ocean Region International and Domestic Traffic

	Number of Transponders		
Year End	International	Domestic	Total
1978	16	12	28
1979	20	17	37
1980	25	22	47
1981	28	29	57
1982	33	36	69
1983	39	45	84
1984	45	54	99
1985	52	66	118
1986	60	78	138
1987	70	91	161
1988	81	103	184
1989	94	120	214
1990	109	140	249
1991	127	160	287
1992	147	180	327
1993	171	200	371
1994	198	220	418
1995	230	240	470
1996	267	260	527

5.2 U.S. Domestic Traffic

5.2.1 Introduction

The model for U.S. domestic traffic includes telephony and data services. Data requirements encompass a variety of services, including facsimile and electronic mail transmissions. The development of video conferencing services is in question; thus while we have shown video conferencing requirements, we have not included this traffic in the main model but have considered it only in the sensitivity analysis.

It should be noted that the future traffic volumes will certainly depend upon the service costs. Thus, the types of communications facilities that are made available will affect the service costs and therefore the service demand. This will be especially true in the case of video conferencing, where the currently existing and planned terrestrial facilities would lead to much higher transmission costs than those that result from the use of high capacity communications satellites. For this case we have assumed that low cost communications facilities will be available, and we have based our service demand forecast on this assumption.

NASA Lewis Research Center has contracted studies of U.S. satellite communications service demand to Western Union and ITT. The final results from these studies will become available in the Spring of 1979, and then they could be used for the refinement of the service demand models shown in this section.

5.2.2 Telephony and Data Traffic

The U.S. domestic traffic model has been prepared on the same basis as the foreign domestic and regional services model described in Annex A. Estimates of population, GNP/per capita and various correlation factors have been translated into voice and data service requirements, taking into account the current and the expected future utilization of satellite systems. The derivation of these requirements is shown in Table 5-8. The total number of transponders that will be needed is shown on an annual basis in Table 5-9.

Table 5-8
U. S. Domestic Traffic Model Statistics

	1978	1983	1988	1993	1998	2003
Population (millions)	218	227	234	242	251	261
GNP/Capita (1978 U.S. Dollars)	9,703	10,713	11,828	13,059	14,418	15,918
GNP (Billions of 1978 U.S. Dollars)	2,119	2,428	2,772	3,164	3,619	4,159
Long Distance Calls per $1000 GNP	6.3	8.0	9.7	11.6	13.7	16.7
Total Long Distance Calls (millions)	13,314	19,349	26,952	36,651	49,762	69,266
Percent of Traffic Via Satellite	1.8	5.7	7.2	7.7	7.9	8.0
Total Satellite Call Minutes (millions)	2,157	9,926	17,465	25,399	35,381	49,872
Total Telephony Traffic (transponders)	38	173	304	442	616	868
Data Requirements (transponders)	3	51	100	134	162	188
Total Transponder Requirements	41	224	404	576	778	1,056

Table 5-9
Total Transponder Requirements for U.S. Domestic Services

Mid-Year	Number of Transponders	Annual Growth in Percent
1978	41	
1979	70	70.7
1980	108	54.3
1981	146	35.2
1982	187	28.1
1983	224	19.8
1984	262	17.0
1985	298	13.7
1986	334	12.1
1987	368	10.2
1988	404	8.9
1989	433	7.2
1990	465	7.4
1991	498	7.1
1992	532	6.8
1993	576	8.3
1994	620	7.6
1995	665	7.0
1996	700	5.3

5.2.3 Video Conferencing

Estimates for video conferencing demand have generally been based on the assumption that video conferencing will replace some percentage of airline travel, for example, 5 to 10 percent. In order to generate a very conservative model, we have assumed that only 1 percent of the total U.S. airline travel would be replaced by video conferencing in 1996, and that the total video conferencing demand would be 50 percent higher due to requirements which are not travel related.

Figure 5-4 shows the historical U.S. airline traffic in millions of revenue passengers and a range of predictions for future air travel. The median estimate for 1996 is 375 million airline passengers. If 1 percent of the air travel is replaced by video conferencing, we obtain 1.875 million conferences per year. Assuming that the average conference duration is 2 hours and that 800 such conferences can be carried per year on one circuit, we obtain a requirement for 2,340 circuits. A 50 percent increase for conferences that do not replace travel will lead to a requirement for approximately 3,500 circuits. The demand in the first year of platform operation, 1987, is assumed to be a very modest figure of 10 percent of the final requirement, or 350 circuits. The resulting model is shown in Table 5-10.

As stated above, this model is considered to be very conservative. Actual video conferencing service demand could be much higher.

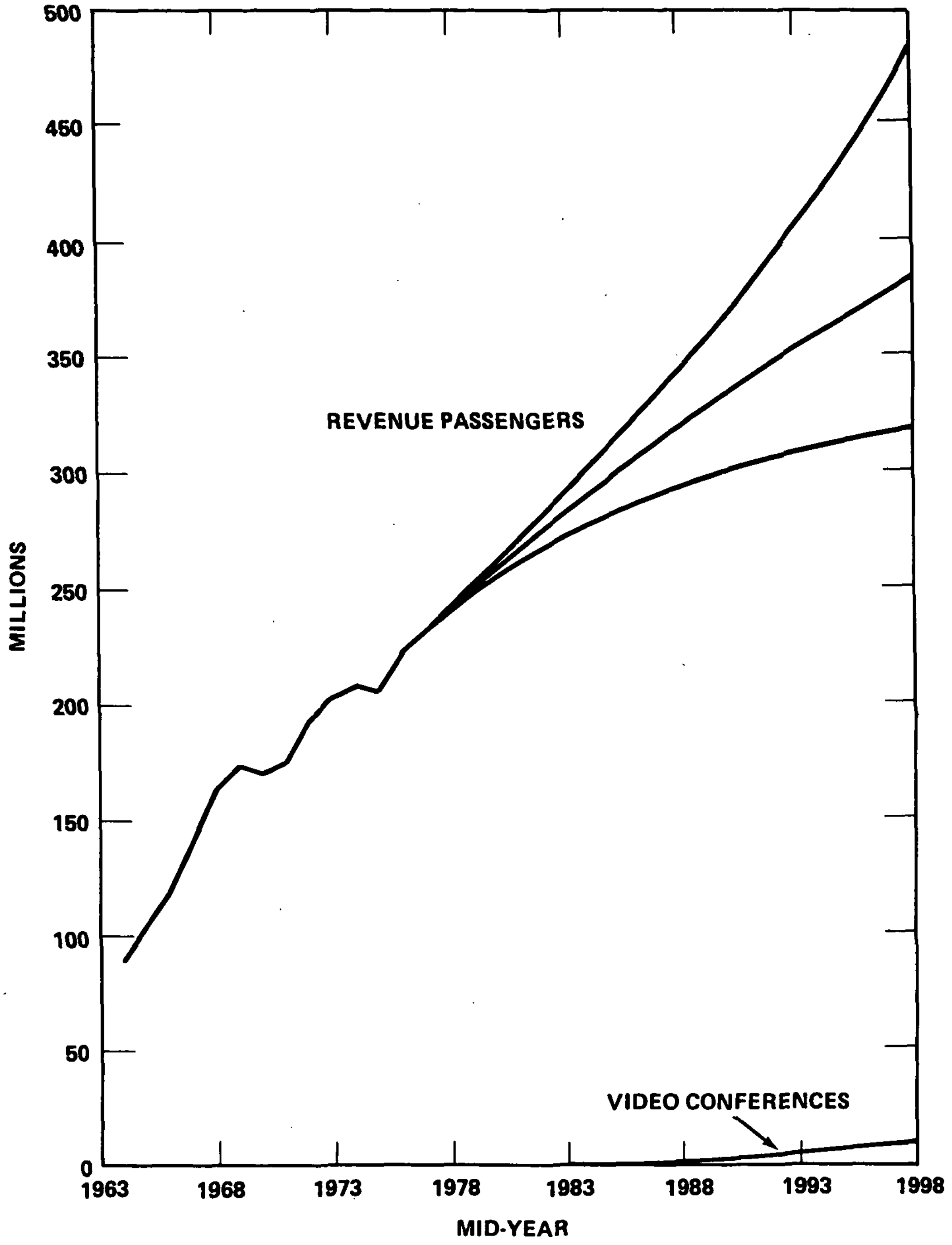


Figure 5-4

COMPARISON OF VIDEO CONFERENCING REQUIREMENTS
AND TOTAL AIRLINE PASSENGERS
(1963-1998)

Table 5-10

Total Video Conferencing Circuit Requirements

Year	Video Conferencing Circuits
1987	350
1988	550
1989	850
1990	1300
1991	1850
1992	2450
1993	3400
1994	3150
1995	3350
1996	3510

SECTION 6
COMMUNICATIONS SYSTEMS WITH LARGE CAPACITY PLATFORMS

6.1 U.S. Domestic Systems

6.1.1 Antenna Beam Coverage

The baseline design for the U.S. domestic antenna coverage is shown in Figure 6-1. Circular antenna beams of 1.1 degree beamwidth are used to cover CONUS, Alaska, Hawaii and Puerto Rico. A total of 39 beams are needed for CONUS, one beam each for Hawaii and Puerto Rico, and a composite beam generated by six feeds covering Alaska. For traffic assignment purposes, the geographical areas covered by the CONUS beams are segmented into hexagons. Identical coverage is provided at the three commercial communications frequency bands: 4/6, 11/14 and 18/30 GHz. However, the latter band is only used where needed. Linear polarization is used throughout. The 4/6 GHz frequency band is used twice, with orthogonal linear polarizations.

Each CONUS beam is assigned one-third of each frequency band. In this manner, an arrangement is possible where contiguous beams are always using different frequencies. For Alaska, Hawaii and Puerto Rico, the entire frequency band is assigned. As a result, each frequency band is used 16 times. Due to the use of dual polarization, the 4/6 GHz band is used 32 times.

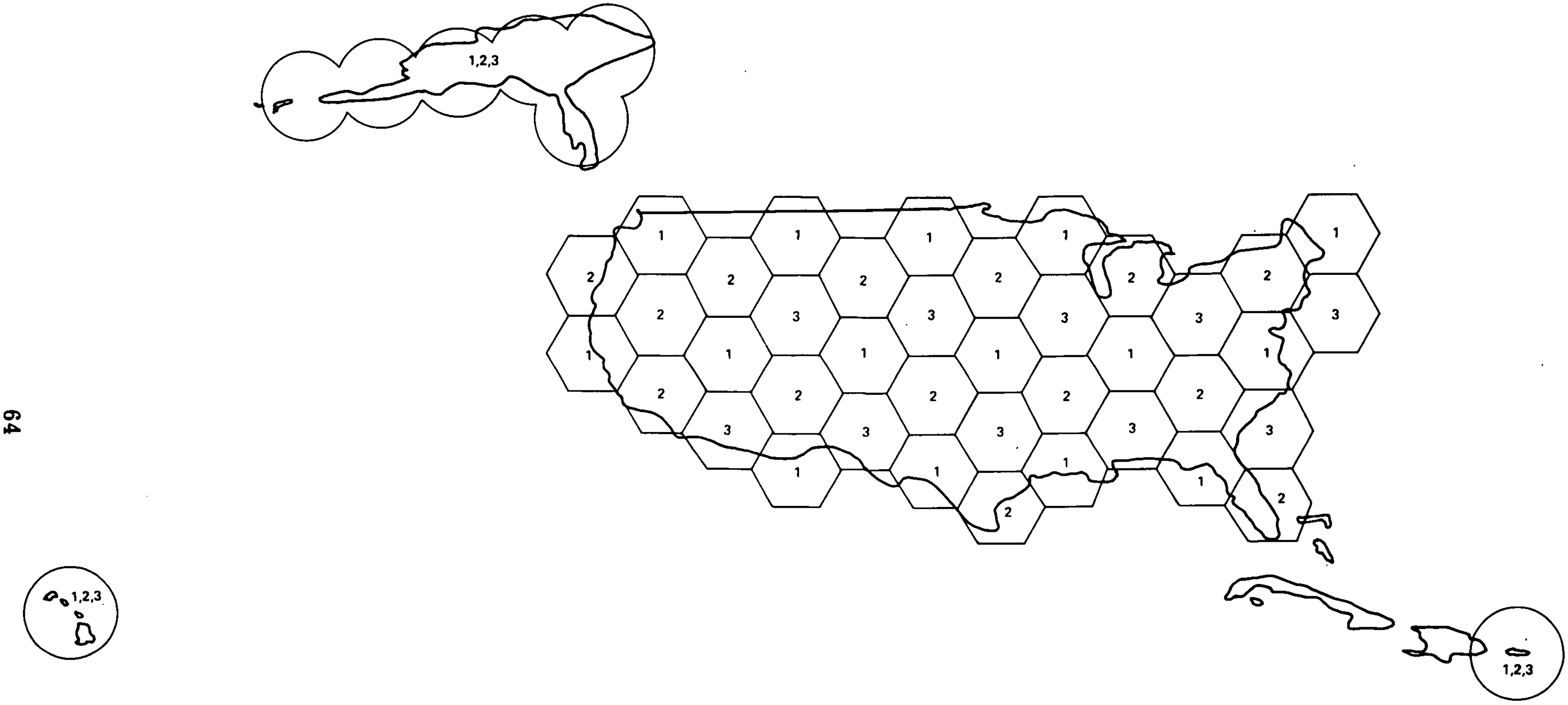


Figure 6-1

SPOT BEAM ANTENNA COVERAGE OF
CONUS, ALASKA, HAWAII AND PUERTO RICO FOR MULTI-BEAM PLATFORM
(Numbers 1, 2 and 3 Indicate Frequency Assignment)

6.1.2 Traffic Assignment for a U.S. Domestic Platform

For the purpose of this model we have assumed that traffic density would be proportional to population density. This assumption ignores the fact that a low income area will probably contribute less traffic (on a per capita basis) than a high income area. It also ignores the offsetting trend that low income areas often coincide with low population density areas, and that low population density areas will rely more heavily on satellite communications. More detailed information on traffic distribution will become available from the parallel studies which are being conducted by Western Union and ITT for NASA Lewis Research Center. In the meantime, this model provides adequate results for the purpose of estimating useful platform capacity.

Figure 6-2 shows the traffic distribution for the multi-beam platform, based on the population density for the areas covered by the beams. This distribution provides a conservative estimate of traffic, since it disregards the fact that due to the larger transmission distances, Alaska, Hawaii and Puerto Rico will rely more heavily on satellite communications than the CONUS areas.

It is evident that the beams with the highest traffic percentages will saturate first. At the point in time when one beam can no longer accept additional traffic, the platform is considered to be saturated, even though many other beams are still only lightly loaded.

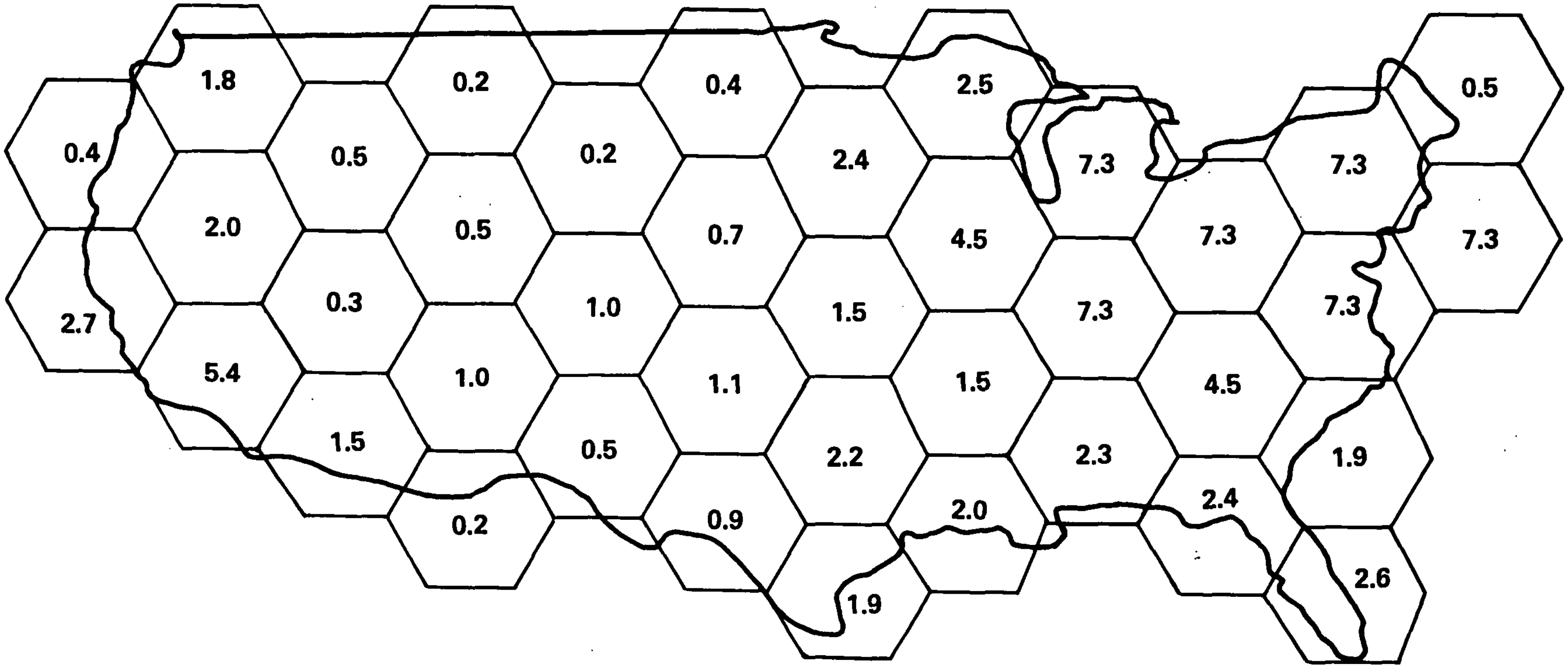


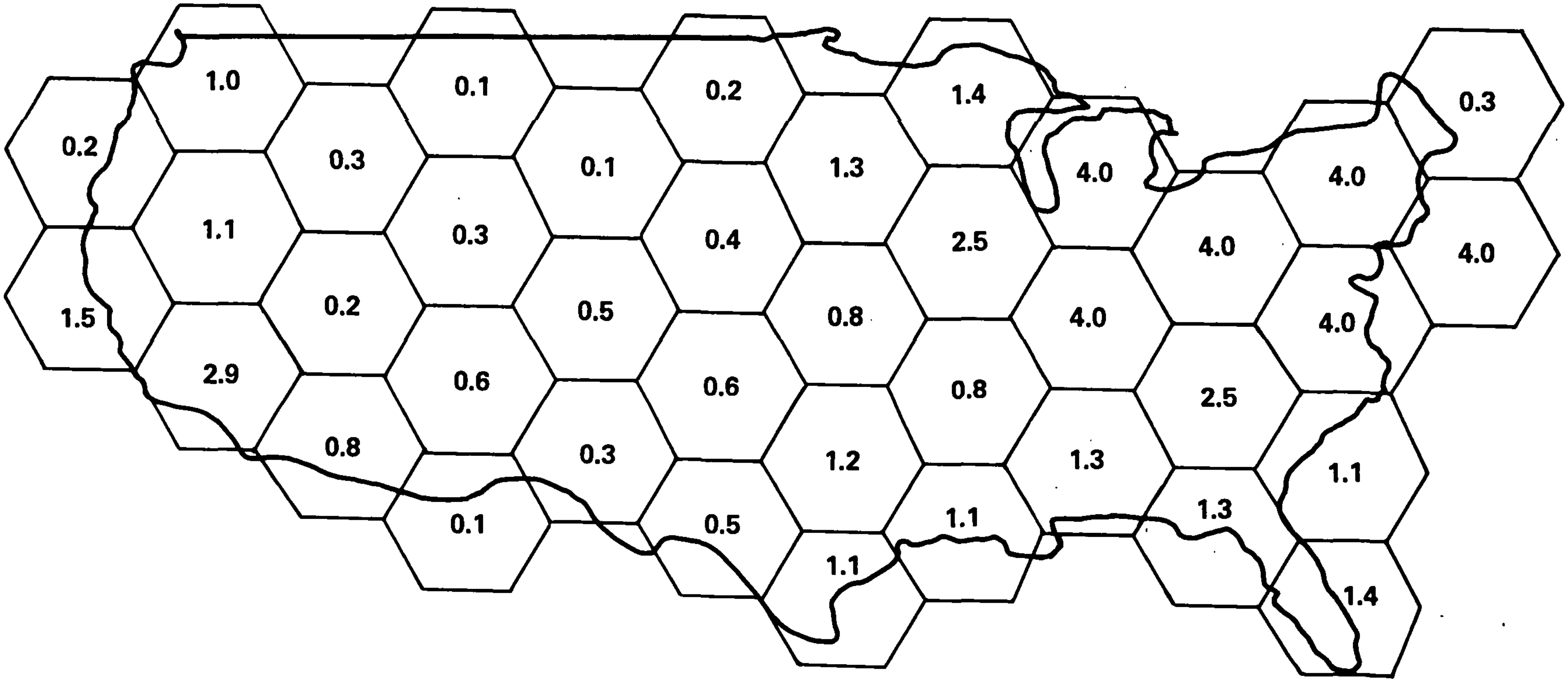
Figure 6-2

CONUS TRAFFIC DISTRIBUTION FOR MULTI-BEAM PLATFORM
(Percent)

Example 1: A Platform With 4/6 GHz Beams Only

Figure 6-3 shows the achievable capacity for this case. The traffic that can be carried in the beams covering CONUS is shown as equivalent 36 MHz transponders. Since the 500 MHz frequency band is divided into three equal parts, the maximum achievable capacity per beam is four transponders. As soon as one or more beams acquire enough traffic to fill four transponders, the system is saturated. At that time other beams are only partly loaded.

The total achievable capacity with a single sense of polarization is about 54 transponders for CONUS, plus up to 12 transponders each as required for Alaska, Hawaii and Puerto Rico. If the opposite sense of polarization is also used, this capacity can be doubled.



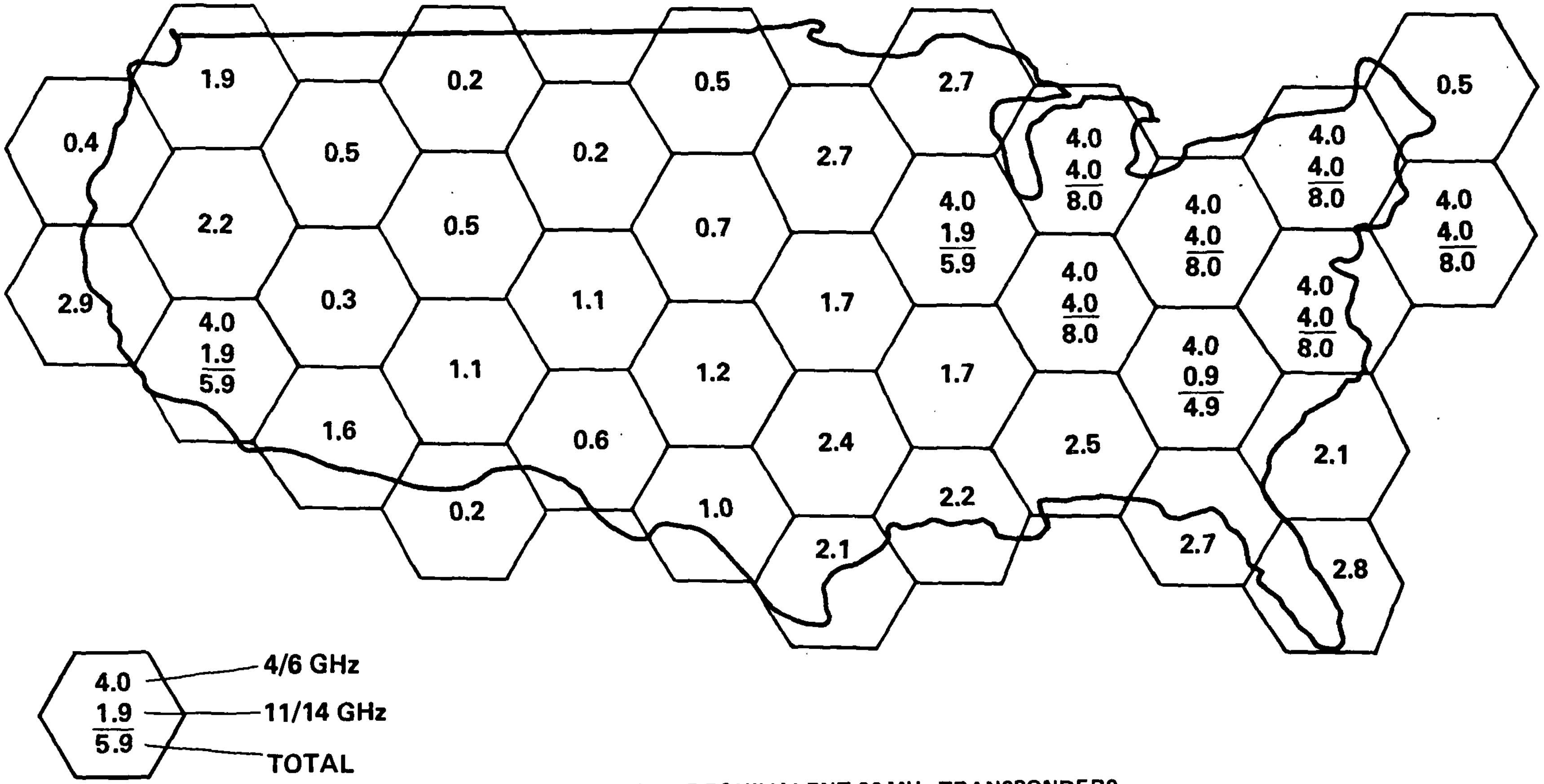
USABLE CAPACITY= 54 EQUIVALENT 36 MHz TRANSPONDERS

Figure 6-3

SINGLE FREQUENCY BAND MULTI-BEAM PLATFORM CAPACITY FOR CONUS
(4/6 GHz)

Example 2: A Platform With Two Frequency Bands

In this example a second frequency band, 11/14 GHz, has been added, and thus the satellite employs 500 MHz at 4/6 GHz and another 500 MHz at 11/14 GHz. The second frequency band is required for 9 of the 39 CONUS beams, and the total usable capacity for CONUS is 107 transponders, with additional capacity available for Alaska, Hawaii and Puerto Rico, as required. By using dual polarization at C-band, further increases in capacity would be possible. At the higher frequency bands, the use of dual polarization will not be desirable in areas of high rain rates because of the rain induced depolarization effects. The achievable capacity for this example is shown in Figure 6-4.



USABLE CAPACITY= 107 EQUIVALENT 36 MHz TRANSPONDERS

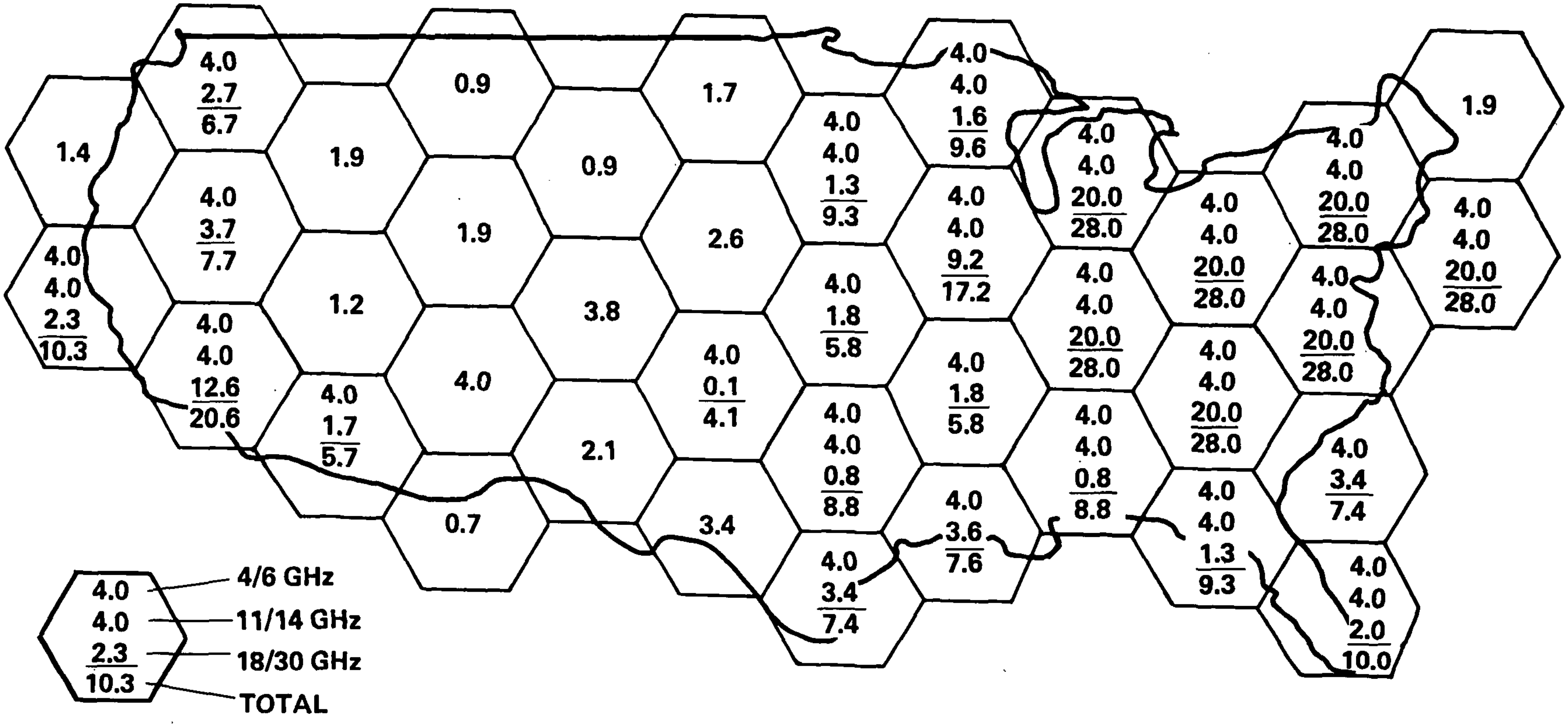
Figure 6-4

DUAL FREQUENCY BAND MULTI-BEAM PLATFORM CAPACITY FOR CONUS
(4/6 GHz and 11/14 GHz)

Example 3: A Platform With Three Frequency Bands

In this example, the platform is equipped with transponders at 4/6 GHz, 11/14 GHz and at 18/30 GHz. Dual polarization has not been used, although the platform may be equipped with dual polarization at 4/6 GHz. It was assumed that the capacity available with the second sense of polarization would be reserved for diversity switching to provide a higher continuity of service for 18/30 GHz transmissions.

In this example, 35 of the 39 CONUS beams are equipped with 11/14 GHz transponders, and 16 beams are equipped with an 18/30 GHz capability. The total usable capacity for CONUS is 375 transponders with additional capacity available for Alaska, Hawaii and Puerto Rico, as required. The achievable capacity is shown in Figure 6-5.



USABLE CAPACITY = 375 EQUIVALENT 36 MHz TRANSPONDERS

Figure 6-5

THREE FREQUENCY BAND MULTI-BEAM PLATFORM CAPACITY FOR CONUS
(4/6 GHz, 11/14 GHz and 18/30 GHz)

Summary of Characteristics

Table 6-1 summarizes the number of beams, usable capacities and fill factors of each of the three platform examples.

The total U.S. domestic traffic in 1996 of 685 transponders or 685,000 equivalent one-way voice channels can easily be carried on a two-platform configuration, with a third platform in orbit serving as a spare. Platforms are connected by intersatellite links.

Table 6-1

Examples of High Capacity Domestic Platforms for CONUS, Alaska, Hawaii and Puerto Rico

	Single Frequency (4/6 GHz)	Dual Frequency (4/6 & 11/14 GHz)	Three Frequency (4/6, 11/14 & 18/30 GHz)
Number of Spot Beams			
4/6 GHz	42	42	42
11/14 GHz	0	9	25
18/30 GHz	0	0	16
Total	42	51	83
Number of 500 MHz Bands			
4/6 GHz	16	16	16
11/14 GHz	0	3	8.3
18/30 GHz	0	0	26.7
Total	16	19	51.0
Theoretical Capacity (Transponders)*			
4/6 GHz	192	192	192
11/14 GHz	0	36	100
18/30 GHz	0	0	320
Total	192	228	612
Usable Capacity (Transponders)*			
4/6 GHz	53.5	79.3	128.6
11/14 GHz	0	27.7	85.0
18/30 GHz	0	0	161.1
Total	53.5	107.0	374.7
Fill Factor (Percent)*			
4/6 GHz	27.9	41.3	67
11/14 GHz	0	76.9	85
18/30 GHz	0	0	50.3
Average	27.9	46.9	61.2

*CONUS only

6.1.3 Platform Characteristics

The characteristics of the communications platform which is used in this model are scaled from those of two other platform proposals, the Marshall Space Flight Center Design (Ref. 9) and the Edelson/Morgan proposal (Ref. 5). The comparison of mass and power budgets is shown in Table 6-2. A detailed power budget for the FSI model is shown in Table 6-3.

Table 6-2

U.S. Domestic Platform Mass and Power Comparison

Item	NASA/ MSFC	Edelson/ Morgan	FSI Model
Mass (kg)			
Antennas and Feeds			500
Transponder Electronics and Switching Equipment			2500
Total Communications System	2050	2210	3000
Power Supply Subsystem	1220	1247	1190
Thermal Control	---	350	300
Attitude/Reaction Control	1691	779	1630
Telemetry and Command	186	90	100
Mission Support Structure	500	600	500
Main Structure	2342	930	1200
Total BOL Mass	7989	6206	7920
Power (kW)			
Total EOL Power	15	20	17
Total BOL Array Capability	20	28	26
Solar Array Area, m^2	165	235	213

Table 6-3
Detailed Power Budget for U.S. Domestic Platform
(FSI Model)

	Power (kW)
Switching System	7
Transponder Electronics	2
Power Amplifiers	6
Ion Engines	1
General Spacecraft Power	1
Total Primary Power	17
Margin for Worst Sun Angle of 23.5°	1.5
Margin for Degradation (39% in 10 years)	7.2
Total BOL Array Capability	25.7

The overall mass of the model selected by FSI is about the same as that of the NASA model. In the FSI model, the communications subsystem mass is higher due to the requirements of the communications switching equipment. Offsetting this increase is the reduced structure weight of the FSI model, since a smaller structure is possible with the reduced size communications antennas. In addition we have assumed a 10-year mission without maintenance. Stationkeeping is accomplished with a hybrid hydrazine ion engine system. A physical layout has also been scaled from the NASA design and is shown in Figure 6-6.

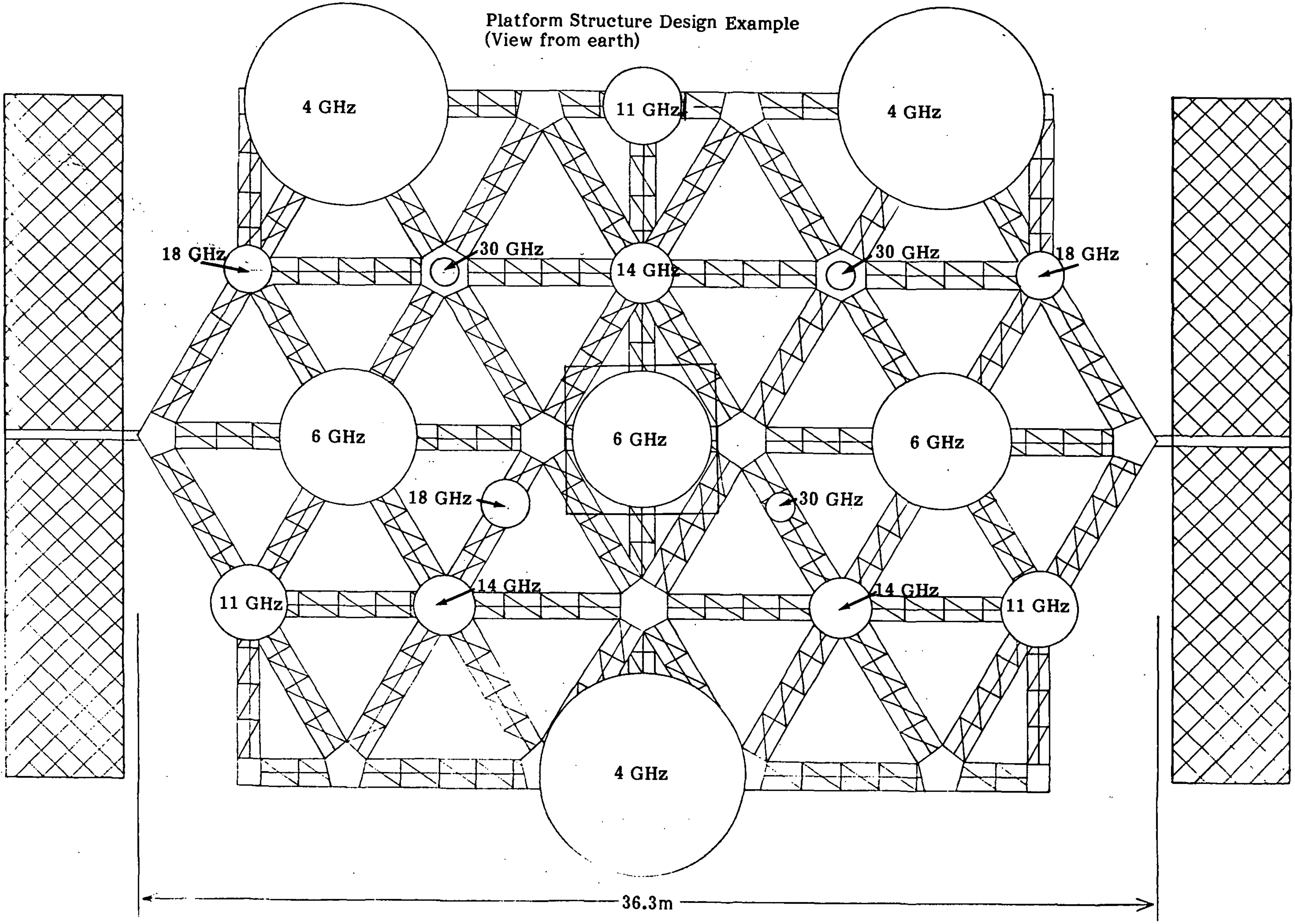
The communications subsystem is segmented into equipment for three beam switching techniques: satellite-switched TDMA, IF switching and baseband switching. Figure 6-7 is a block diagram of the communications subsystem.

As shown in Figure 6-7, a receive/transmit chain is provided for each antenna beam at each frequency and polarization sense used. The preamplifier is followed by a frequency converter and an input filter/multiplexer. The multiplexer divides the received frequency band into three parts, one for each of the three beam switching systems.

The satellite-switched TDMA band is connected to a diode switch matrix via a limiter. This system is similar in function to the Advanced Westar 11/14 GHz transmission system. However, while Advanced Westar employs a 4 by 4 matrix, the platform switch will require a larger number of ports. An increase in the number of ports accompanied by an increase in the number of accesses per port means that a longer frame time would be required in order to maintain high frame efficiency. This is true since frame efficiency is related to the number of transmitted bursts per frame. Figure 6-8 illustrates this relationship for a 250 Mbps SS/TDMA system with an overhead of 0.85 μsec per burst.

Figure 6-6

Platform Structure Design Example
(View from earth)



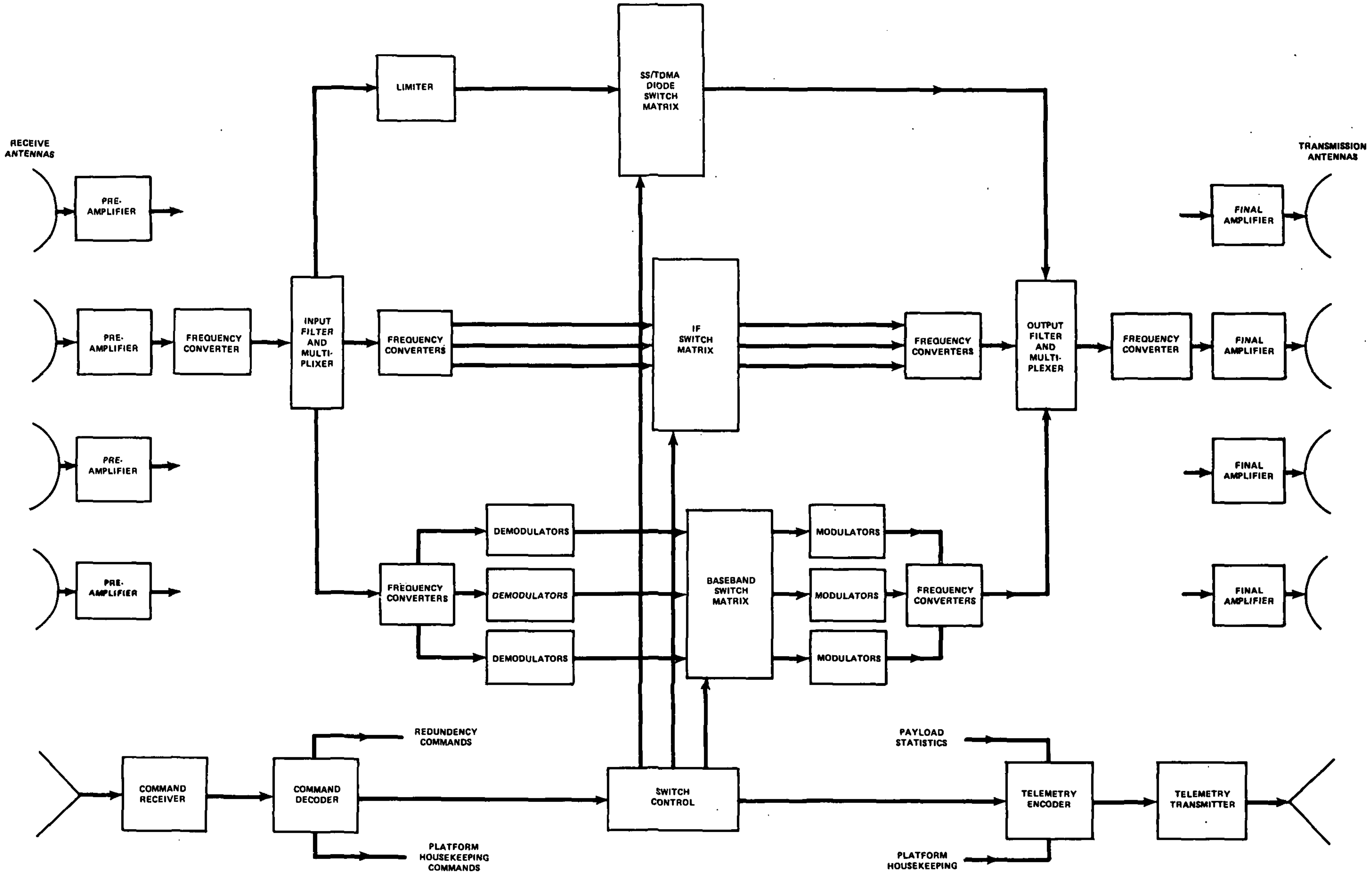


Figure 6-7

PLATFORM COMMUNICATIONS SUBSYSTEM
(Block Diagram)

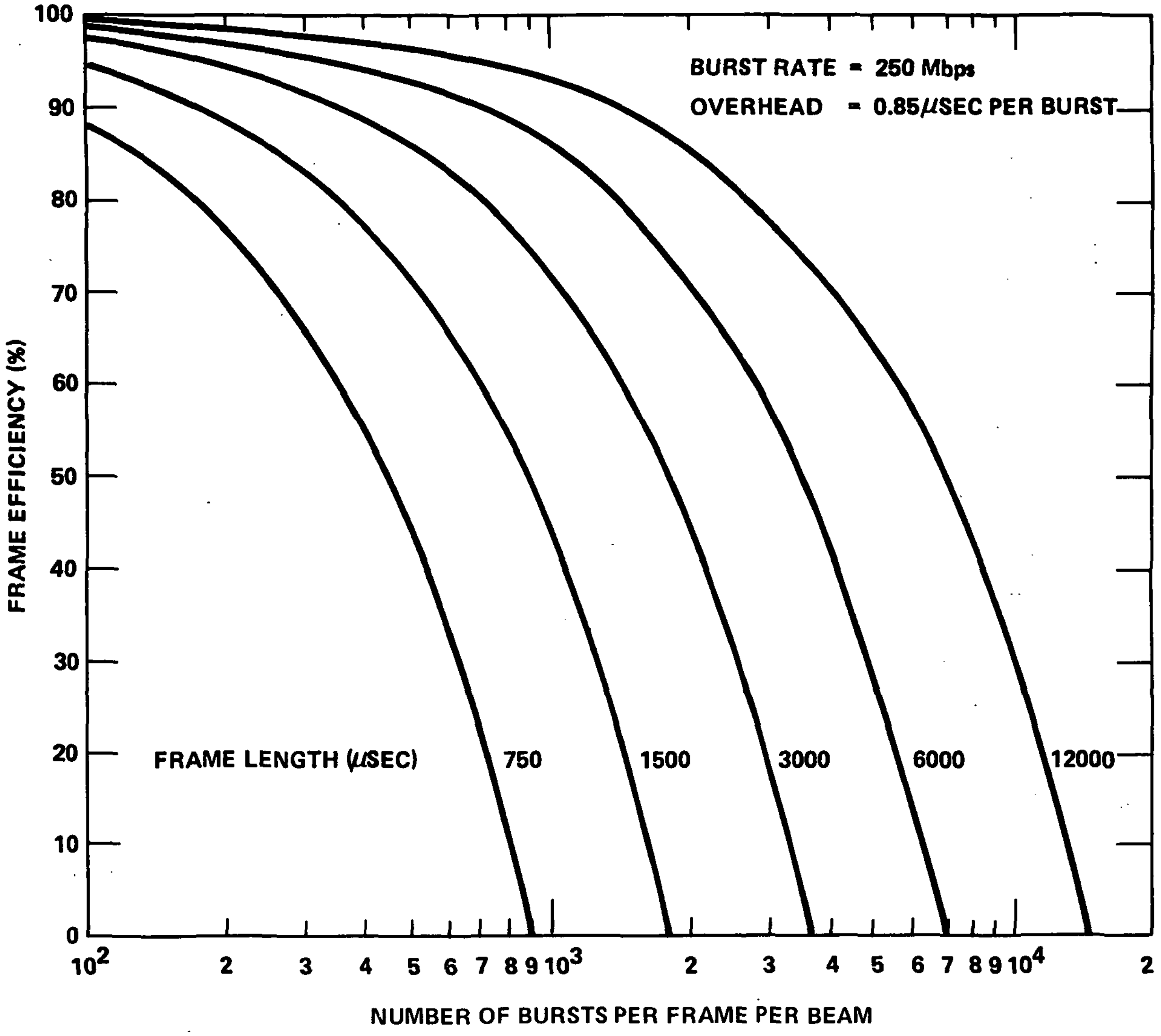


Figure 6-8

TDMA FRAME EFFICIENCY

Another frequency band is used for the IF switch system. Individual frequency converters are used for carriers or blocks of carriers which are to be switched at a common IF. The third frequency band is devoted to the baseband switching system. The switching system will be designed to accept a hierarchy of digital carrier sizes so that switching can be accomplished at the largest transmission block size possible, thus minimizing platform switch complexity.

At 4/6 GHz and 11/14 GHz the maximum satellite-switched TDMA bit rate will be determined by the general limitation of about 150 to 160 MHz per beam. At 18/30 GHz, however, about 750 to 800 MHz is available per beam, thus permitting multiple 250 Mbps TDMA systems. Power level control will be an important problem in all cases where limiters are not used, especially at the higher frequencies. From this example it is clear that significant additional work is required before an optimum communications subsystem for the platform can be defined.

Platform Costs

The platform cost estimates are based on cost estimating relationships developed by NASA/MSFC. The resulting development and production costs are shown in Table 6-4.

Table 6-4
Cost Estimates for U.S. Domestic Platform
(Millions of 1979 Dollars)

	Platform Design		
	NASA/ MSFC	Edelson/ Morgan	FSI
Development Cost	78	78	137
Recurring Cost	89	89	107

6.1.4 Earth Station Characteristics

Any of the existing earth stations in the U.S. domestic satellite communications systems will be able to operate with the large platforms. 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 several typical earth stations. The satellite-switched TDMA earth station imposes the least complexity upon the platform 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 platform switch would provide routing at IF. The simplest earth station is the single PSK carrier earth station. It would require baseband processing on the platform, which results in the greatest complexity in space.

An example of a frequency diversity station is shown in which the earth station normally operates at the higher frequency but is switched to a lower operating frequency to achieve continuity of operation during heavy rain. This system requires more extensive switching on board one platform.

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

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 modem

A functional block diagram for this type of station is shown in Figure 6-9, and a brief discussion of the terminal equipment subsystems is given below.

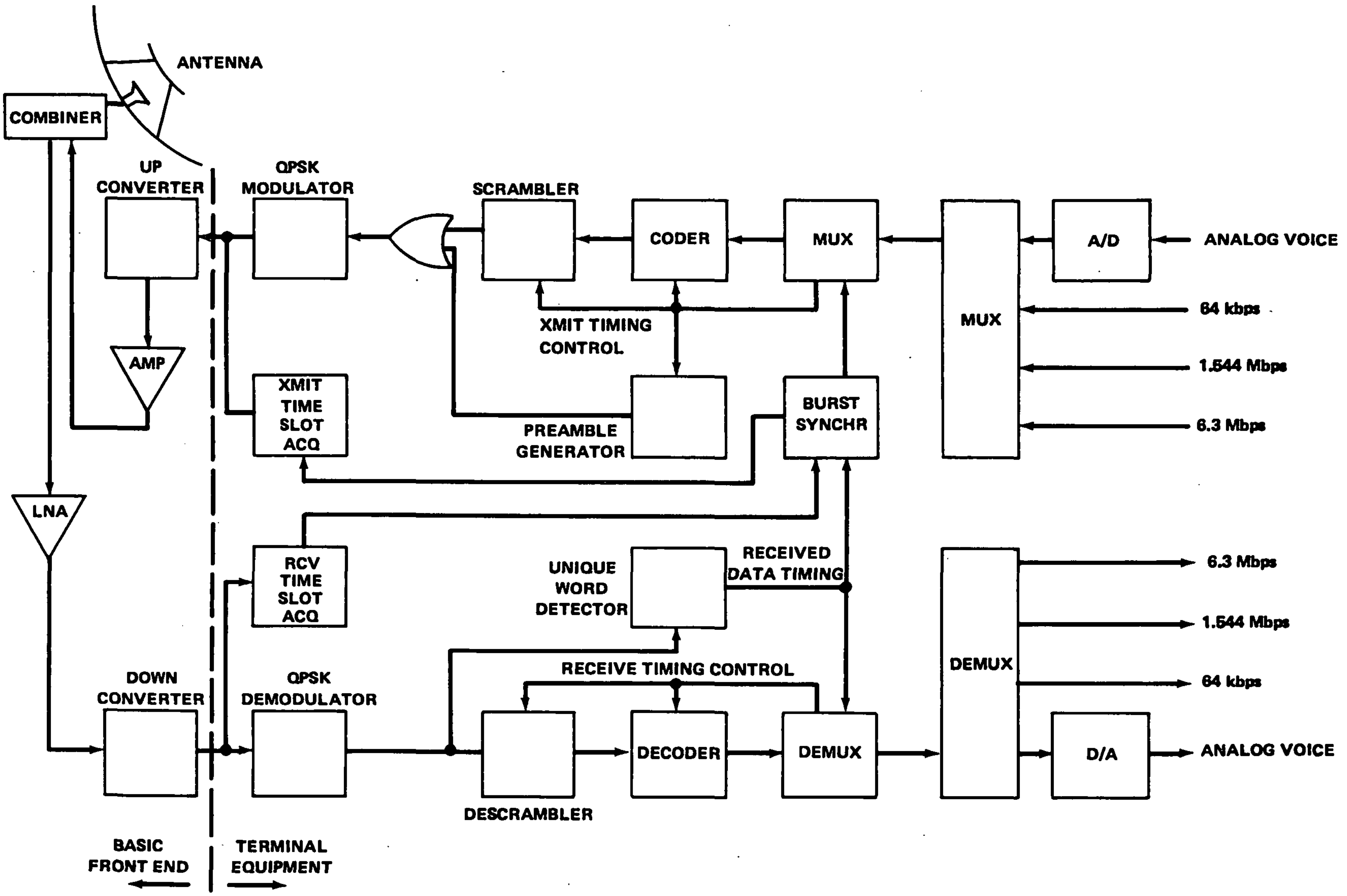


Figure 6-9

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 trafffic 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 acquistion 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.

Single 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 6-10, 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.

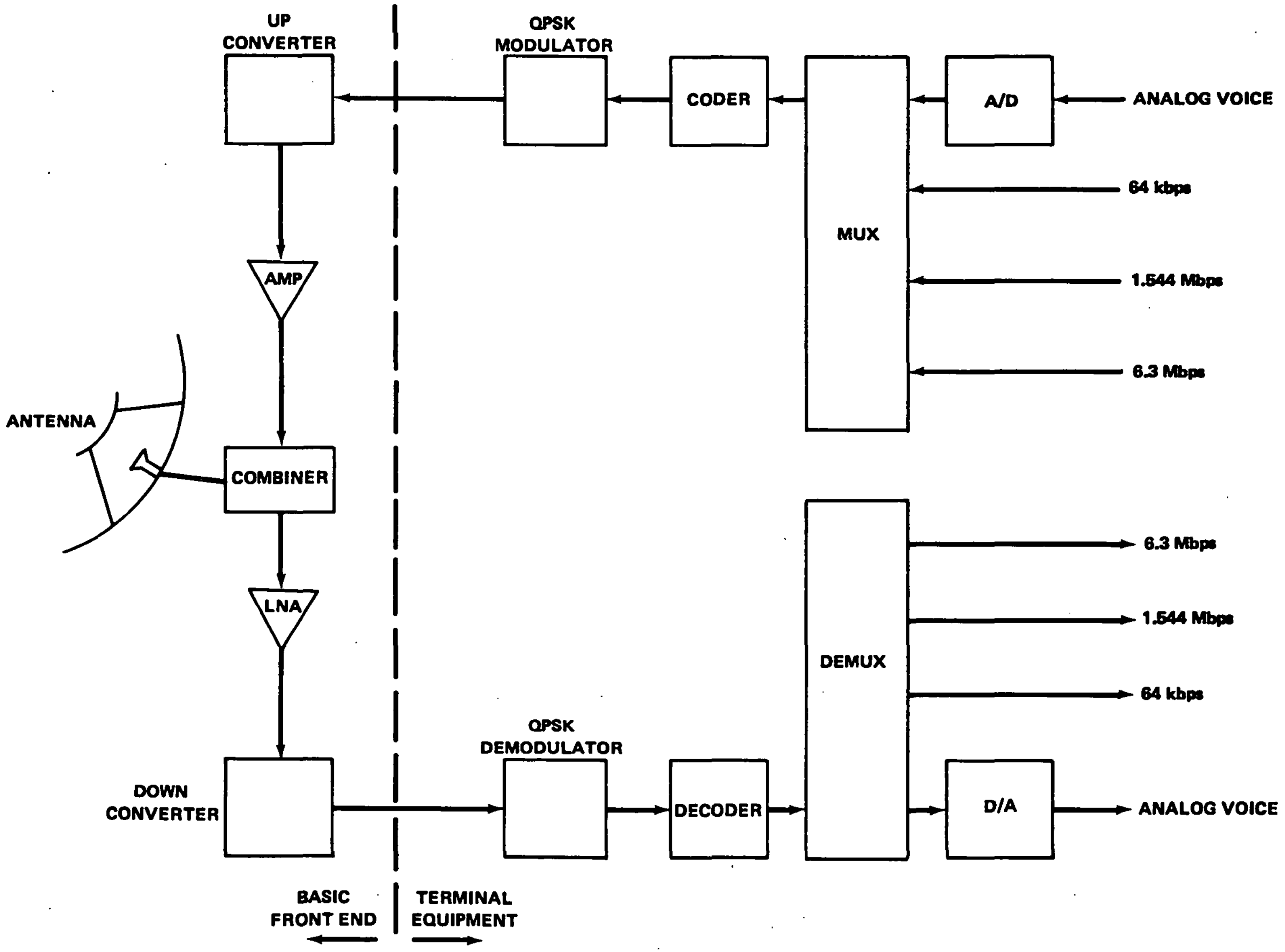


Figure 6-10

TYPICAL SINGLE CARRIER PSK EARTH STATION
(Functional Block Diagram)

Multi-Carrier PSK Earth Stations

The terminal equipment for a typical multi-carrier PSK earth station is identical to that of the single carrier PSK type except that more than one chain of subsystems is used. A functional block diagram for this type station is shown in Figure 6-11.

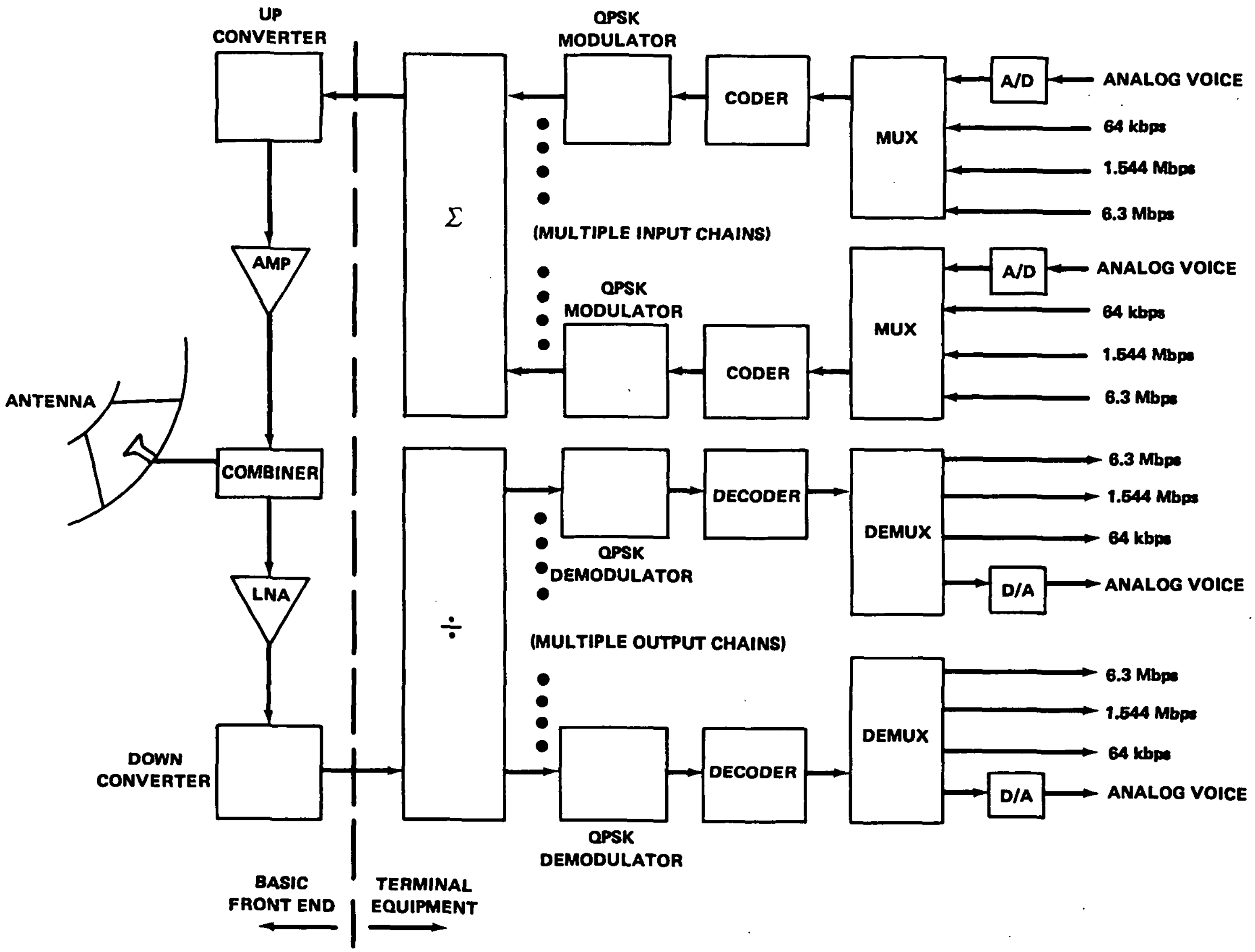


Figure 6-11

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

Frequency Diversity Earth Stations

The front end of this type station has been modified to allow the use of two different frequency bands. In addition to a dual frequency combiner and special feed assembly, additional RF chains have been added. These modifications are shown in the functional block diagram of Figure 6-12, along with an example of some terminal equipment. In this case, single carrier PSK terminal equipment has been used to accommodate the traffic. In order to provide for automatic switchover during periods of weather-related BER degradation and switchback after the BER returns to normal, a link selector unit has been included. Note that this unit also controls the uplink frequency.

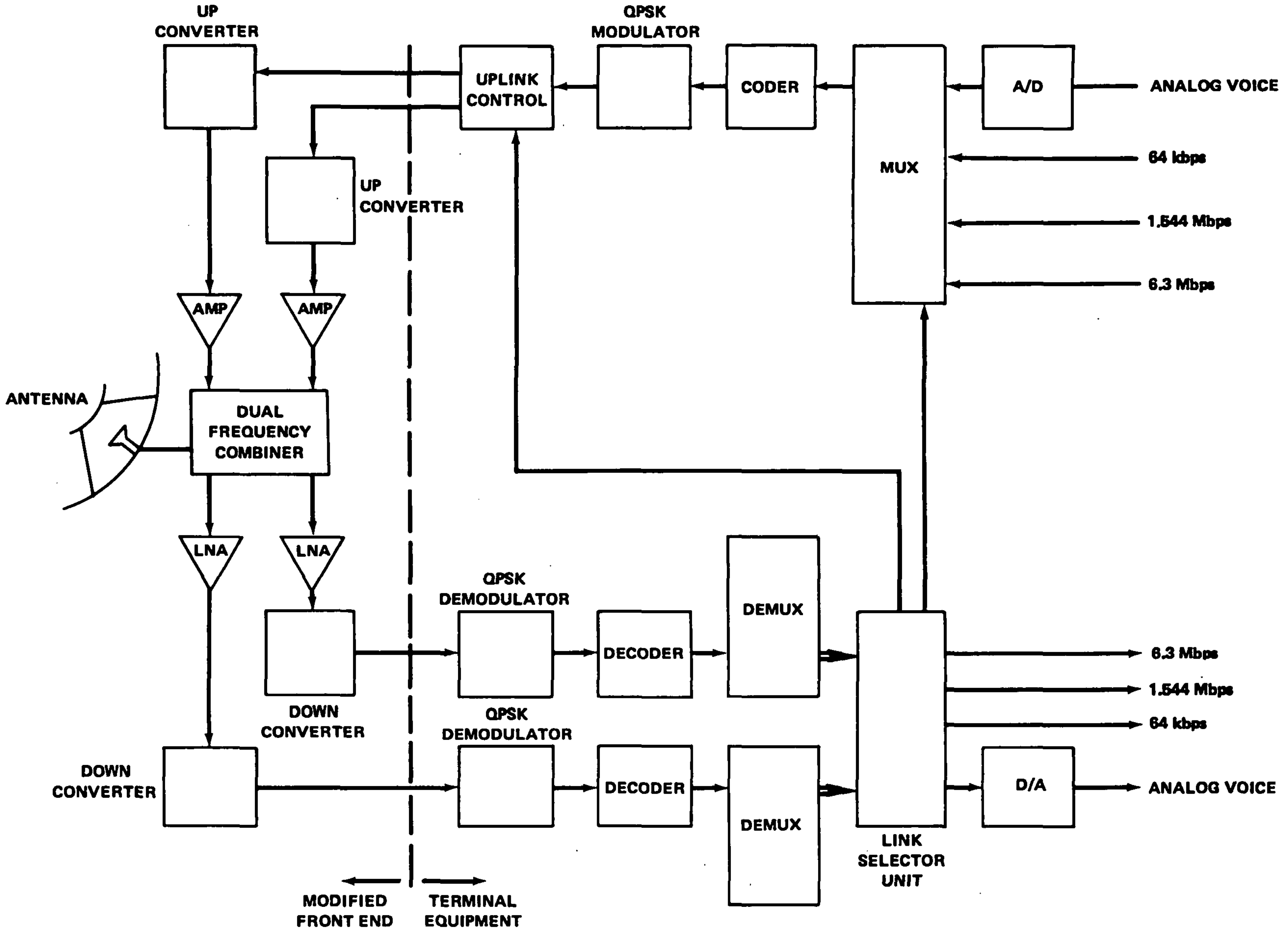


Figure 6-12

TYPICAL FREQUENCY DIVERSITY EARTH STATION
(Functional Block Diagram)

6.1.5 Transmission Link Analysis

The communications platform will be designed to operate with a wide range of modulation/access techniques and earth station sizes. Examples of some typical transmission links are shown in this section. Earth station antenna diameters of 4.5 meters have been assumed for all frequency bands, although both larger and smaller antennas may be used depending on the application.

Table 6-5 shows an example of a noise budget. It was assumed that 4-phase PSK would be used and that the total carrier-to-noise ratio at a bit error rate of 10^{-4} is 12.7 dB. This includes a modem implementation margin of 1.0 dB, an allowance of 3 dB for intersymbol distortion due to transmission of a band-limited signal through a transmission channel with non-linear amplitude and phase characteristics and a coding gain with rate 7/8 coding of 2.4 dB. This is a typical budget for a transmission rate of 60 Mbps and higher. At a lower transmission rate of 1.544 MBps, for example, the intersymbol distortion is smaller, and the bit error rate of 10^{-4} is obtained at about the same carrier-to-noise ratio without coding. However, due to intermodulation with multi-carrier operation it may be desirable to retain coding to achieve the same overall performance.

To achieve the total carrier-to-noise ratio of 12.7 dB, the downlink was allocated a carrier-to-noise ratio of 15 dB, the uplink was allocated a carrier-to-noise ratio of 20 dB, adjacent beam interference was assumed to result in a carrier-to-interference ratio of 20 dB and all other sources of interference were assumed to result in a carrier-to-noise ratio of 25 dB. The latter includes contributions from adjacent platforms and satellites, terrestrial transmissions, etc.

Table 6-5
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

A power margin must be provided in the uplink as well as in the downlink to allow for the following degradations:

Precipitation attenuation
Depolarization (if dual polarization is used)
Earth station antenna pointing variations
Satellite antenna pointing variations
Transmit power level adjustment

Precipitation attenuation is more severe at the higher frequencies and is a function of the rain rate. The amount of margin required for precipitation attenuation depends upon the desired continuity of service and upon the climatic conditions at the earth station locations. Tables 6-6 and 6-7 are summaries of precipitation attenuation data at 18/30 GHz as developed by FSI under contract to Ford Aerospace & Communications Corporation. The rain zones for CONUS are shown in Annex B.

Diversity operation can be used to reduce power margin requirements. The total link margins that were used in our sample link budgets are shown in Table 6-8. The margins used assume diversity operation, where required.

Table 6-8
Link Margins (dB)

Frequency Band	Uplink	Downlink
4/6 GHz	3	3
11/14 GHz	10	7
18/30 GHz	15	10

Table 6-9 is a sample transmission link budget for a 62.5 Mbps PSK carrier, which is a typical transmission rate in a C-band TDMA system. Power levels required for other transmission rates can be scaled directly in proportion with the transmission rate. Platform and earth station transmit power levels required at representative transmission rates are shown in Table 6-10.

Table 6-6

Precipitation Margins Without Diversity

(Attenuation in dB, Rounded to the Nearest dB)

Frequency (GHz)	Single Link 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 6-7

Precipitation Margins With Diversity

(Attenuation in dB, Rounded to the Nearest dB)

Frequency (GHz)	Single Link Availability (Percent)	Rain Zone 1	2	3	4	5	6
18	99.0	1	1	1	2	2	2
	99.5	1	2	2	3	3	3
	99.9	2	3	3	4	4	4
	99.95	3	3	4	4	4	4
	99.99	4	4	4	5	5	4
30	99.0	1	3	3	3	3	4
	99.5	3	3	4	4	4	4
	99.9	4	4	4	5	5	4
	99.95	4	4	4	5	5	4
	99.99	4	5	6	6	7	5

Note: Due to uncertainties in the diversity model, it is recommended that diversity margins be increased by 2 dB at 18 GHz and by 4 dB at 30 GHz.

Table 6-9

Sample Transmission Link Budgets for a 62.5 Mbps PSK Carrier

Downlink

		Frequency Band, GHz		
		4/6	11/14	18/30
Platform transmit RF power	Watts	0.8	5.4	18
	dBW	-0.7	7.3	12.5
Line losses	dB	0.5	0.5	0.5
Minimum antenna gain for 1.1 degree coverage	dB	40.8	40.8	40.8
Minimum platform transmit EIRP	dBW	39.6	47.6	52.8
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	-125.7	-121.6	-119.3
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	665
Earth station G/T	dB/K	21.4	26.2	28.2
Receive noise bandwidth	MHz	35	35	35
Downlink carrier-to-noise ratio	dB	15	15	15

Table 6-9, Continued

Sample Transmission Link Budgets for a 62.5 Mbps PSK Carrier

Uplink

		Frequency Band, GHz		
		4/6	11/14	18/30
Earth station transmit RF power	Watts	22	209	930
	dBW	13.4	23.2	29.7
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	59.2	76.4	89.5
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 platform	dBW/m^2	-105.9	-95.7	-87.7
Minimum antenna gain for 1.1 degree coverage	dB	40.8	40.8	40.8
Receive system noise temperature	K	1150	2200	3000
Platform G/T	dB/K	10.2	7.4	6
Receive noise bandwidth	MHz	35	35	35
Uplink carrier-to-noise ratio	dB	20	20	20

Table 6-10

Platform and Earth Station RF Transmit Power Requirements*

	Transmission Rate, Mbps					
	0.064	0.256	1.544	6.312	62.5	250
Platform RF Power (Watts)						
4 GHz	<0.001	0.004	0.02	0.08	0.8	3.5
11 GHz	0.006	0.02	0.1	0.5	5.4	22
18 GHz	0.02	0.07	0.4	1.8	18	72
Earth Station RF Power (Watts)						
6 GHz	0.02	0.09	0.5	2.2	22	89
14 GHz	0.2	0.9	5.2	21	209	851
30 GHz	1.0	3.9	23	93	930	3800

*Platform antenna coverage = 1.1 degree

Earth station antenna diameter = 4.5 meter

6.1.6 Earth Station Cost Estimates

Typical earth station costs are shown in Table 6-11. Cost trends are shown in Table 6-12. 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 6-11

Typical Earth Station Equipment Costs in 1987

(Thousands of 1979 Dollars)

	Station Types				
Item	Single Carrier PSK	Multi-Carrier PSK	SS/TDMA	Frequency Diversity Type A	Frequency Diversity Type B
Front ends					
Antenna system					
4/6 GHz	10	10	10	--	--
11/14 GHz	15	15	15	--	--
18/30 GHz	20	20	20	--	--
frequency diversity	--	--	--	30	40
RF equipment					
4/6 GHz	4	4	20	4	--
11/14 GHz	5	5	40	5	5
18/30 GHz	6	6	60	--	6
Terminal equipment (excluding mux/demux)	5	25	50	7.5	7.5
Mux/demux	3	15	3	4.5	4.5
Link selector and uplink control	--	--	--	2	2
Totals:					
4/6 GHz	22	54	83	--	--
11/14 GHz	28	60	108	--	--
18/30 GHz	34	66	133	--	--
frequency diversity	--	--	--	53	65

Notes for Table 6-11

1. All antenna sizes are 4.5 meters.
2. All stations are non-redundant.
3. Except for SS/TDMA, all stations use 5-watt transistor amplifiers to derive their final power. The TDMA terminals use 100, 500 and 2000 watt amplifiers for 4, 14 and 30 GHz, respectively.
4. Each station is assumed to handle 100 VF's.
5. Frequency diversity Type A uses 4/6 GHz to back up 11/14 GHz.
6. Frequency diversity Type B uses 11/14 GHz to back up 18/30 GHz.
7. For multi-carrier PSK operation, it is assumed that each station utilizes five carriers of 20 VF's each.
8. Costs are based on procurement of 1000 stations of each type.
9. The TDMA terminal equipment costs include the associated mux/demux and exclude the traffic interface mux/demux.

Table 6-12

Cost Trends for Typical Earth Station Equipment

(Thousands of 1979 Dollars)

	Year Purchased		
	1979	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
Frequency Diversity			
Type A	121	53	88
Type B	150	65	109

Notes:

1. Frequency diversity Type A station uses 4/6 GHz to back up 11/14 GHz.
2. Frequency diversity Type B station uses 11/14 GHz to back up 18/30 GHz.

6.1.7 Earth Station Network

We have developed a model to determine the approximate optimum number of earth stations for a given level of traffic. The following assumptions were made:

1. Uniform geographical distribution of traffic over CONUS
2. Each earth station draws traffic from a roughly circular area
3. All traffic is telephony
4. Traffic is tied in by either local loop at $30 per month per voice circuit or by leased line at current AT&T tariffs

The following formulas were used:

Coverage radius of each earth station:

$$r = \sqrt{\frac{A}{m\pi}}$$

Average tie-in distance for leased lines:

$$d = \frac{r}{2\sqrt{2}}$$

where

r = Coverage radius of each earth station
A = Area of CONUS, approximately 7,655,000 square km
M = Number of earth stations in the network
d = Average tie-in distance for leased line

Examples of total annualized earth station cost, total terrestrial interconnect cost and total network cost are shown in Figures 6-13 and 6-14 for the following earth station investment costs:

Figure	Cost Per Station ($k)
6-13	12.5 + 0.125n
6-14	100 + 1.0n

where "n" is the number of channels carried by each earth station

As can be seen from the figures, the total cost of the network reaches a null and then increases again as the number of earth stations is increased. The investment cost of earth stations was annualized by the use of a 28 percent annualizing factor, including depreciation, operation, maintenance and interest.

The traffic level used was that of 1991, the middle of the study period. The traffic forecast for U.S. domestic services in 1991 is 498 transponders or 249,000 equivalent voice circuits.

We have estimated terrestrial interconnect costs based on the number of earth stations installed. The costs are a combination of two elements: leased line tariffs and local loop charges. The average distance for a leased line is inversely proportional to the square root of the number of earth stations. The local loop charges are assumed to be $360 per circuit per year.

Since an effort would be made to install earth stations near the central telephone offices and in the area of maximum traffic density, a varying portion of the traffic would be carried by local loop. This portion has been assumed to vary smoothly, increasing as the number of earth stations increase. The cost thus approaches $360 per circuit per year as the number of earth stations is increased.

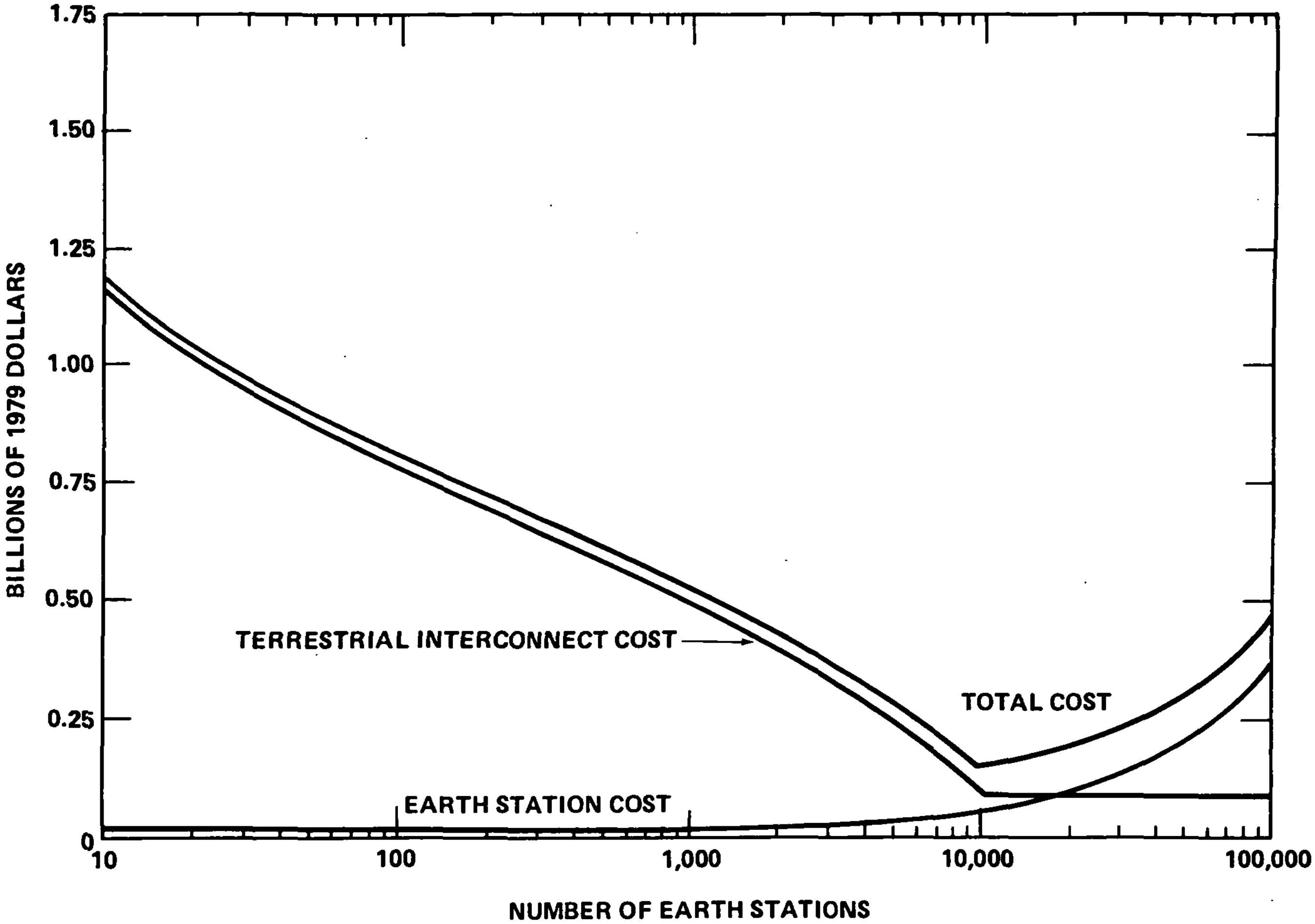


Figure 6-13

ANNUAL EARTH STATION SYSTEM COST VERSUS
NUMBER OF EARTH STATIONS FOR YEAR-END 1991
Single Earth Station Cost = $12,500 + 125N
(U.S. Domestic)

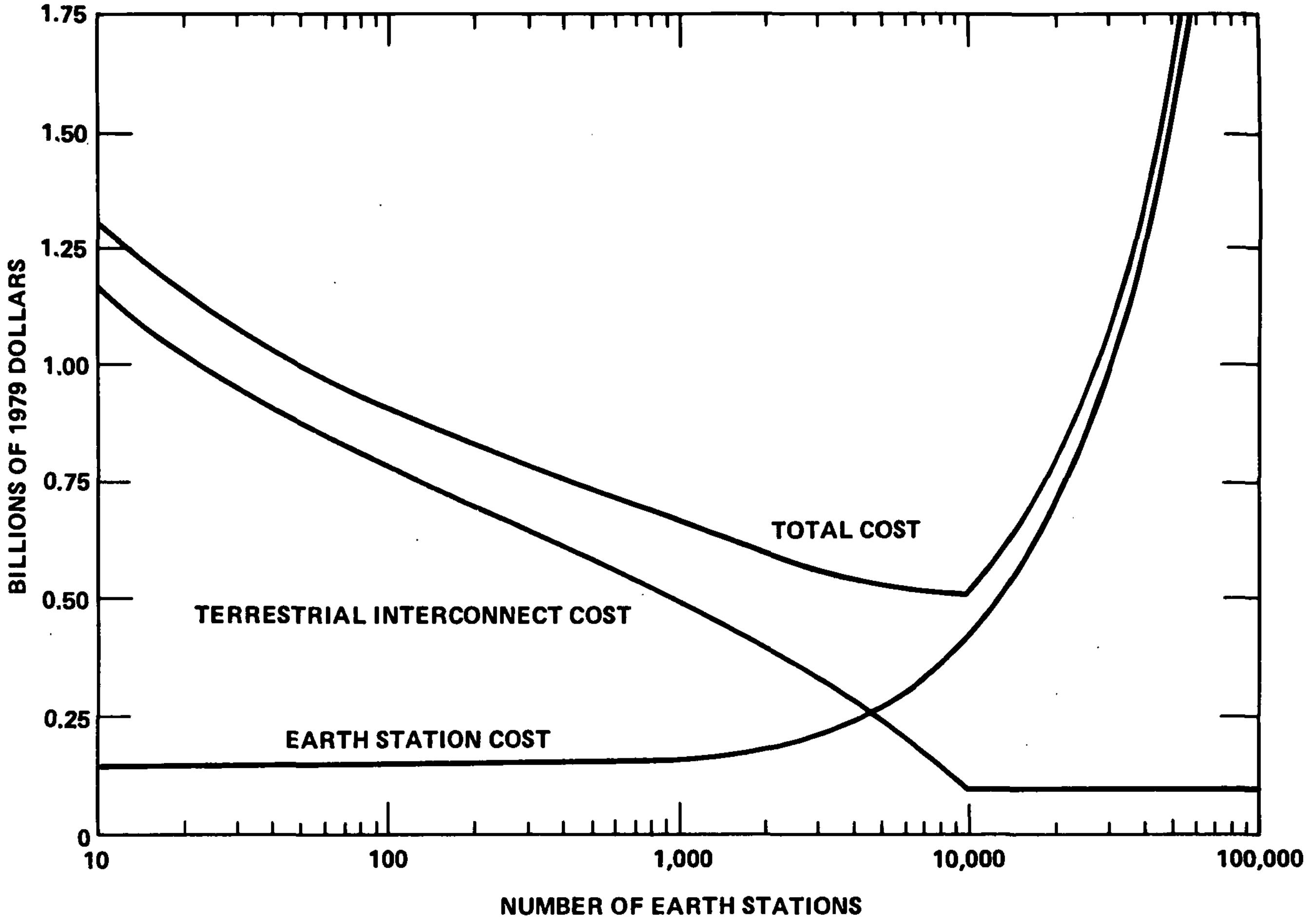


Figure 6-14

ANNUAL EARTH STATION SYSTEM COST VERSUS
NUMBER OF EARTH STATIONS FOR YEAR-END 1991
Single Earth Station Cost = $100,000 + 1,000N
(U.S. Domestic)

Optimum Network and Interconnect Costs

Based on the examples shown above, the optimum network size for the 1991 traffic level is about 10,000 earth stations. This conclusion holds for both earth station cost levels.

The total terrestrial interconnect costs for 10,000 earth stations is determined by the local loop cost. The cost values from the model are shown in Table 6-13.

Table 6-13

Optimum Annual Earth Station Network Costs for Year-End 1991

(Thousands of 1979 Dollars)

Individual Earth Station Costs	Total Cost of Earth Station Network	Interconnect Cost	Total Annual Cost
12.5 + 0.125n	52,000	90,000	142,000
100 + 1.0n	419,000	90,000	509,000

6.1.8 System Development

In our baseline concept we have assumed that in-orbit maintenance will not be used on the first generation platforms since this concept has not yet been verified. Accordingly, we have sized the platforms for a 10-year mission life, and we have assumed that sufficient redundancy can be provided to assure reliable operation over this time period.

Platform operation was assumed to start at the beginning of 1987 and extend through 1996. The systems economics calculations are based on this time frame. The total traffic for the CONUS model by year-end 1996 is 685 transponders, compared with a platform capacity of 375 transponders. The use of two operating platforms is thus required to meet the service demand of the model.

We have assumed that three platforms would be placed in orbit. The first platform would become operational at the beginning of 1987 and could, for example, be owned and operated by a joint venture of the specialized communications carriers. A second platform would be brought into service 2 years later in 1989. It could be owned and operated by AT&T. The platforms would be interconnected by intersatellite link to provide full connectivity. A third platform would be introduced by 1991 to serve as a common spare.*

Figure 6-15 shows the lack of connectivity of the current U.S. satellite systems, while Figure 6-16 shows three interconnected platforms: an SCC, an AT&T and an INTELSAT platform. In-orbit spares are not shown.

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*Operation of a common spare and interconnectivity raises some regulatory and institutional questions. We have assumed that these questions will be resolved in the public interest.

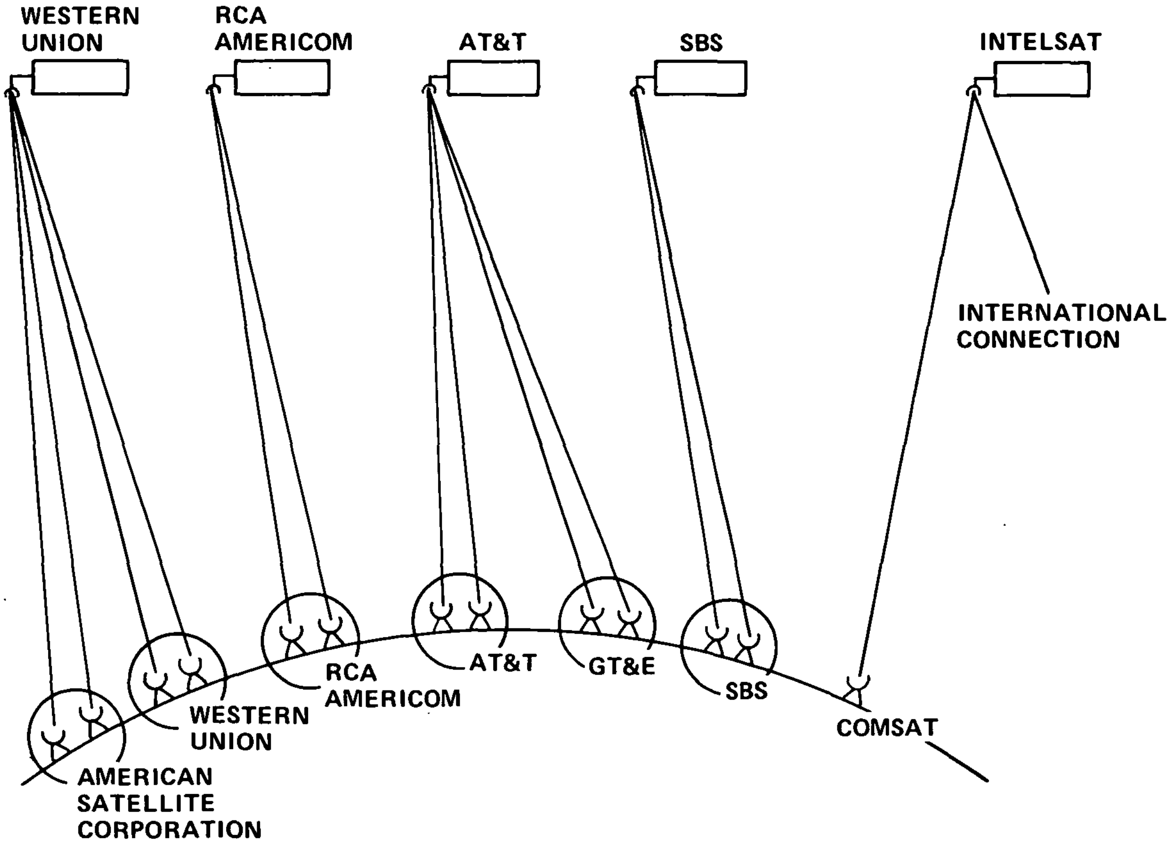


Figure 6-15

CURRENT U.S. SATELLITE SYSTEMS

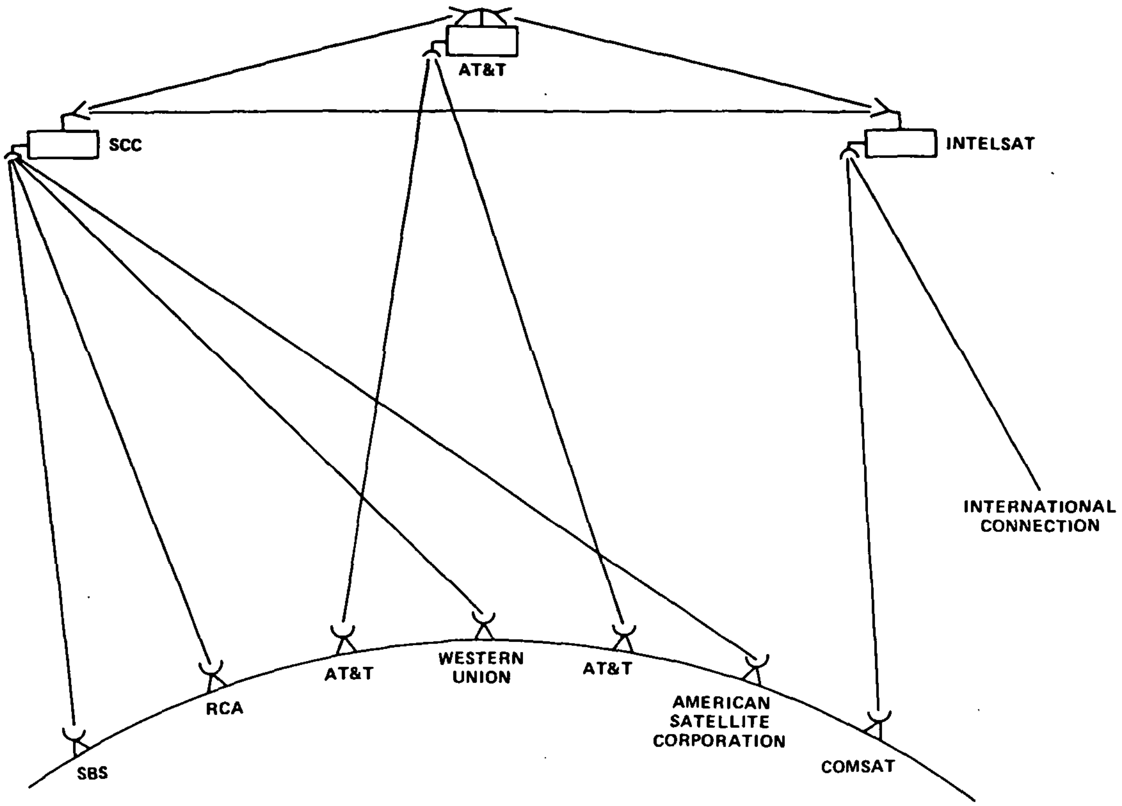


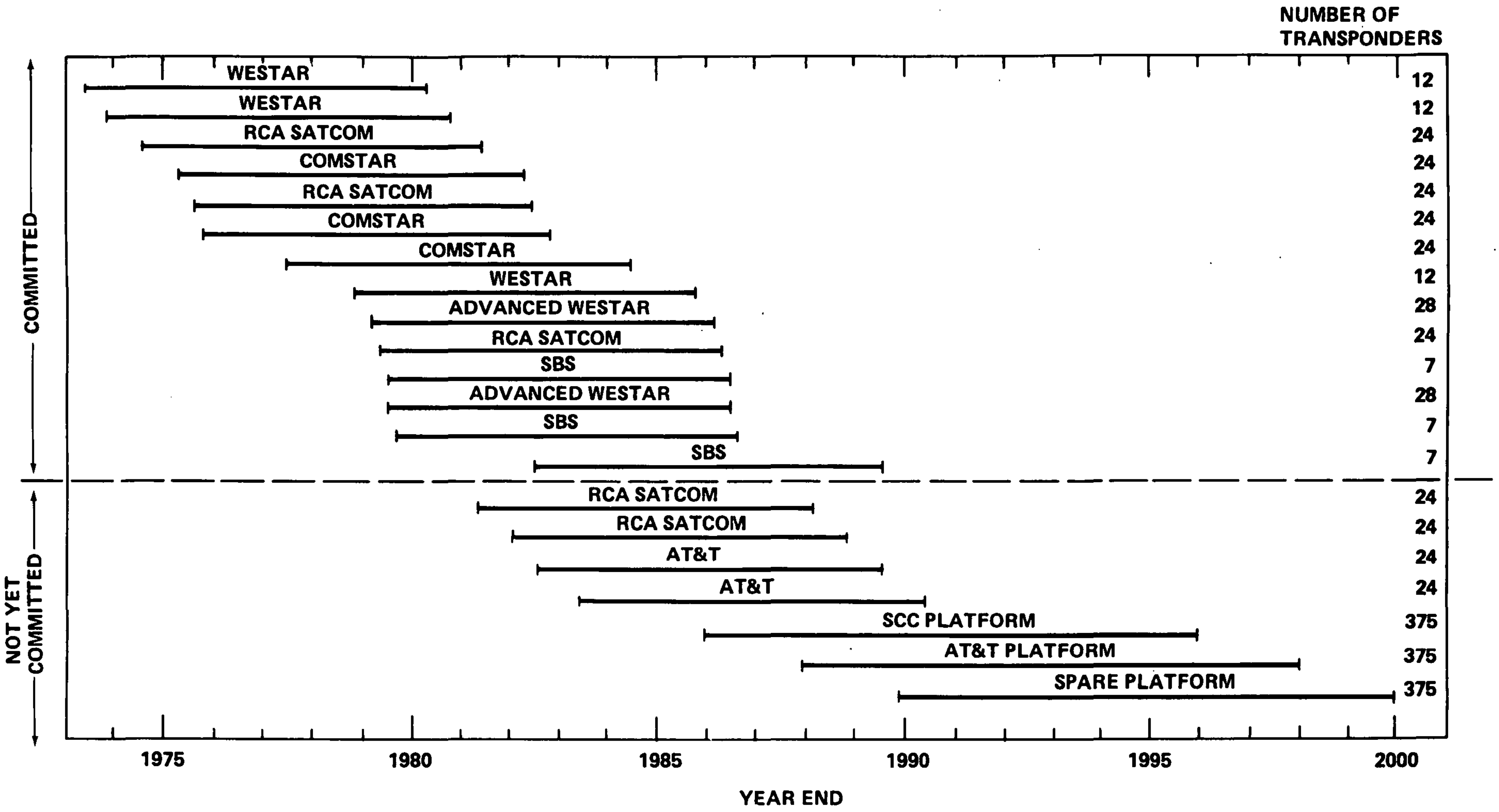
Figure 6-16

FUTURE U.S. SATELLITE SYSTEMS

Figure 6-17 shows the time span and the capacity of the current and future U.S. domestic satellite programs. For the 11/14 GHz transponders of Advanced Westar and of the SBS satellite, we have taken the design bit rate of the TDMA systems that will be used and converted the capacity to equivalent C-band transponders at the rate of 62 Mbps per transponder. All satellites were assumed to have a 7-year life although some may live longer and others may fail earlier. The Advanced Westar satellites and the first generation SBS satellites can transition directly to the platform. RCA and AT&T, however, require intermediate programs to assure continuity of service.

The launch schedule for future launches is subject to change. NASA has recently set a schedule for the launch of the third flight spacecraft of Westar and RCA Satcom for 1979, but the launch of TDRSS has been delayed. Accordingly, Advanced Westar, which is intended to be the fourth launch of the series, will probably be delayed by about 1 year from the dates shown in Figure 6-17. There is also some uncertainty regarding the launch of the SBS satellites.

Once a platform is operational, we expect that transition of traffic from predecessor satellites to the platform will occur quickly. Transition of traffic to the platforms is illustrated in Figure 6-18. Figure 6-19 shows the available capacity versus the requirement over time.



Note: The launch of TDRSS/Advanced Westar has been delayed by about 1 year from the dates shown.

Figure 6-17

SPACE SEGMENT CAPACITY OF CURRENT AND FUTURE U.S. DOMESTIC SATELLITES AND PLATFORMS

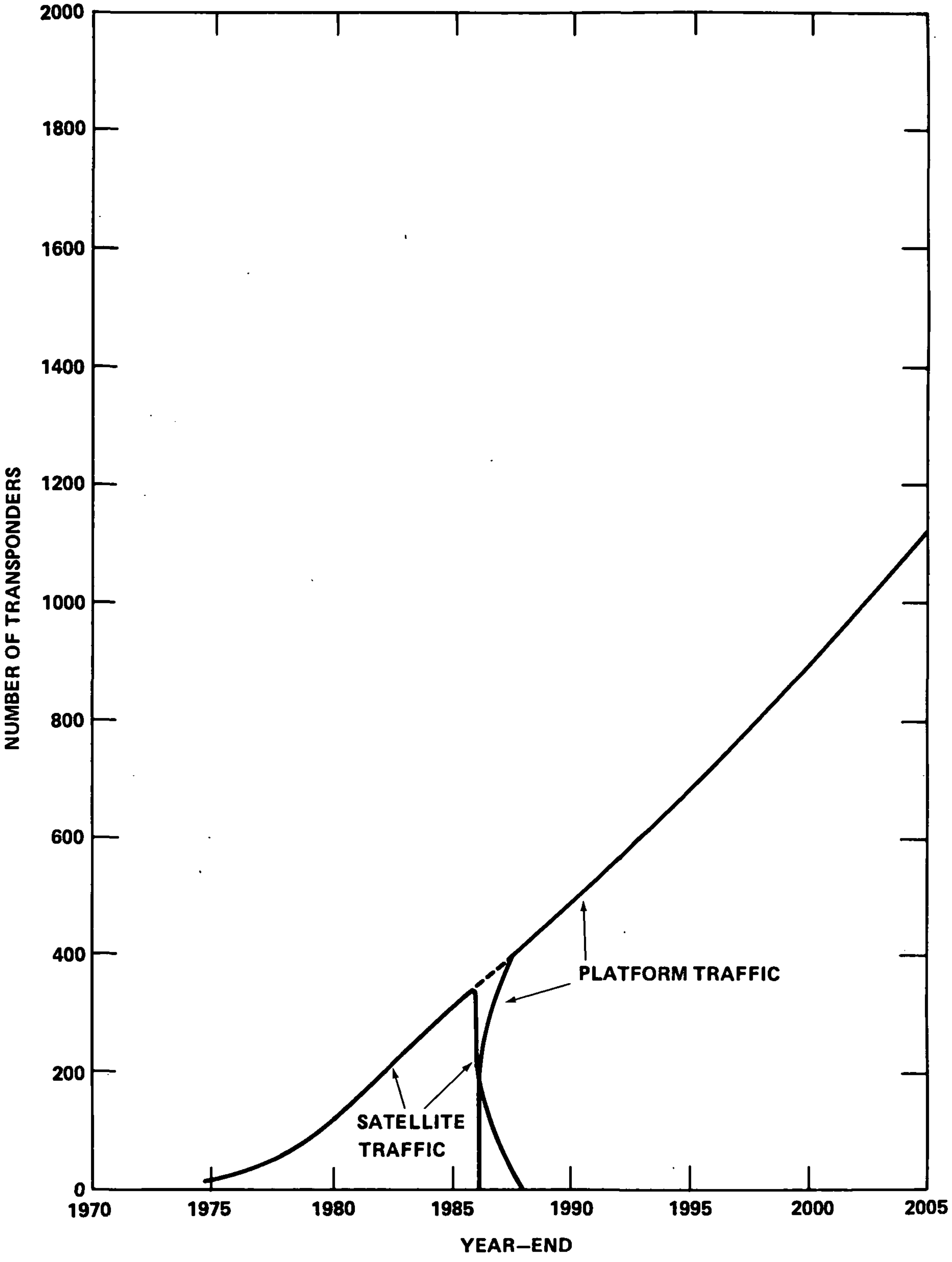


Figure 6-18

TRAFFIC TRANSITION FROM SATELLITES TO PLATFORM
FOR THE U.S. DOMESTIC SYSTEM

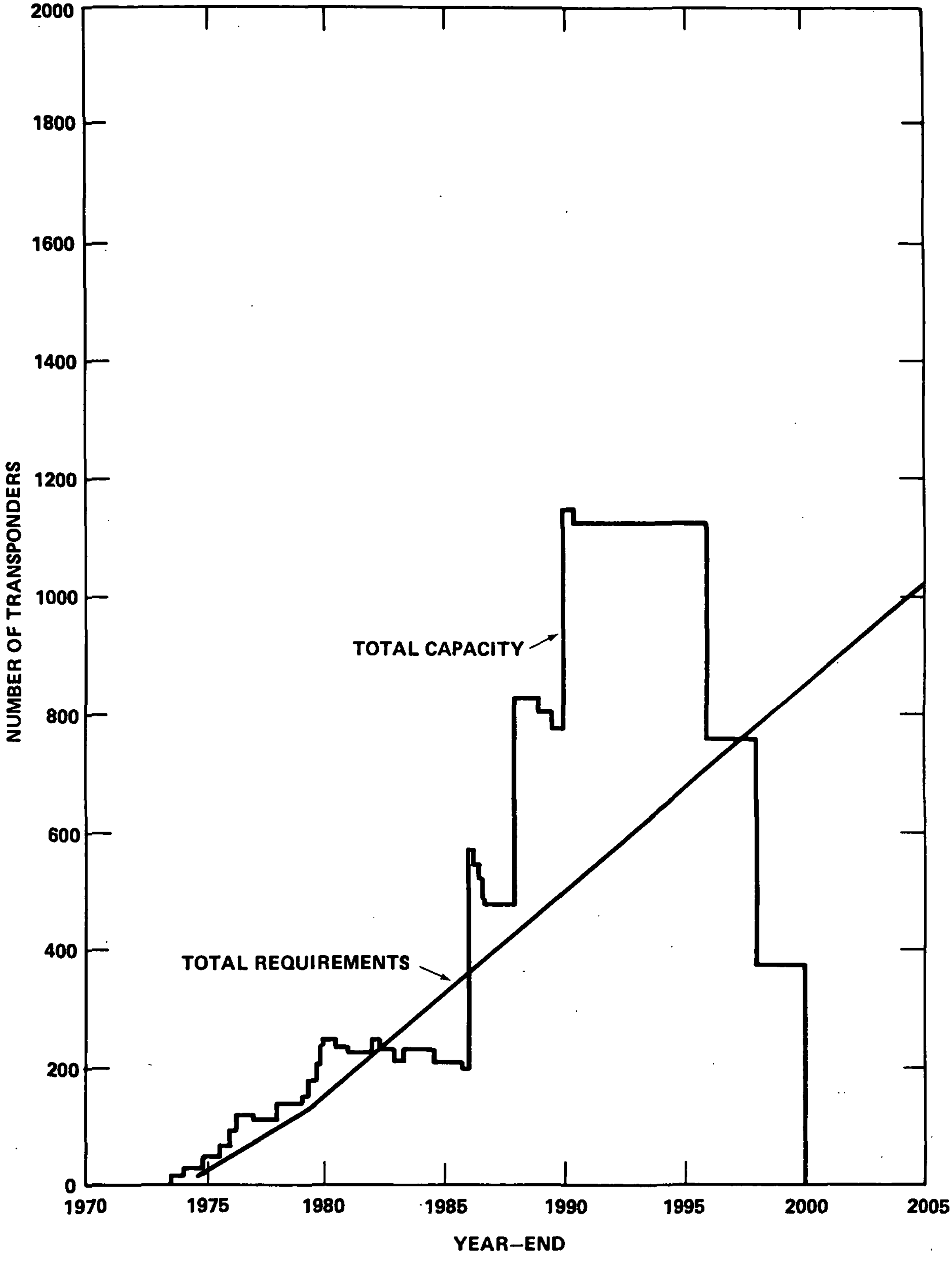


Figure 6-19

AVAILABLE AND REQUIRED TRANSPONDERS FOR U.S. DOMESTIC SERVICES VERSUS TIME

During the systems transition, the platforms cannot be operated at full sensitivity due to excess interference from the adjacent satellites which are illuminated with higher flux densities. Only after adjacent orbital slots are no longer used by low gain satellites illuminating CONUS can the platform transponders be switched to their maximum gain, thus permitting the proliferation of low cost earth stations. The assumed earth station development schedule is shown in Table 6-14.

Table 6-14

Earth Station Deployment Schedule for the U.S. Domestic Platform System

(Earth Stations in Operation)

Year-End	Total
1987	3000
1988	5000
1989	6500
1990	7000
1991	7500
1992	8000
1993	8500
1994	9000
1995	9500
1996	10000

6.2 Atlantic INTELSAT Service

6.2.1 Antenna Beam Coverage

The baseline design for the Atlantic INTELSAT system is shown in Figure 6-20. Because of the higher traffic density in the Western Hemisphere, smaller spot beams were used than for the Eastern Hemisphere. South America, Central America and the Eastern part of North America are covered by 64 beams of 1.1 degrees. Africa, Europe and some of the Atlantic Islands are covered by 48 beams of 1.8 degrees.

All beams provide coverage at 4/6 GHz. The 11/14 GHz and 18/30 GHz bands are only employed for those beams where needed to provide sufficient capacity.

Each 4/6 GHz beam is assigned one-third of the frequency band. At 11/14 and 18/30 GHz each beam is assigned one-half of the frequency band. Dual polarization is employed only for the 4/6 GHz beams. This arrangement will allow a total of 44 equivalent 36 MHz transponders per beam as follows:

	Transponders
4/6 GHz	
first polarization	4
second polarization	4
11/14 GHz	6
18/30 GHz	30
Total	44

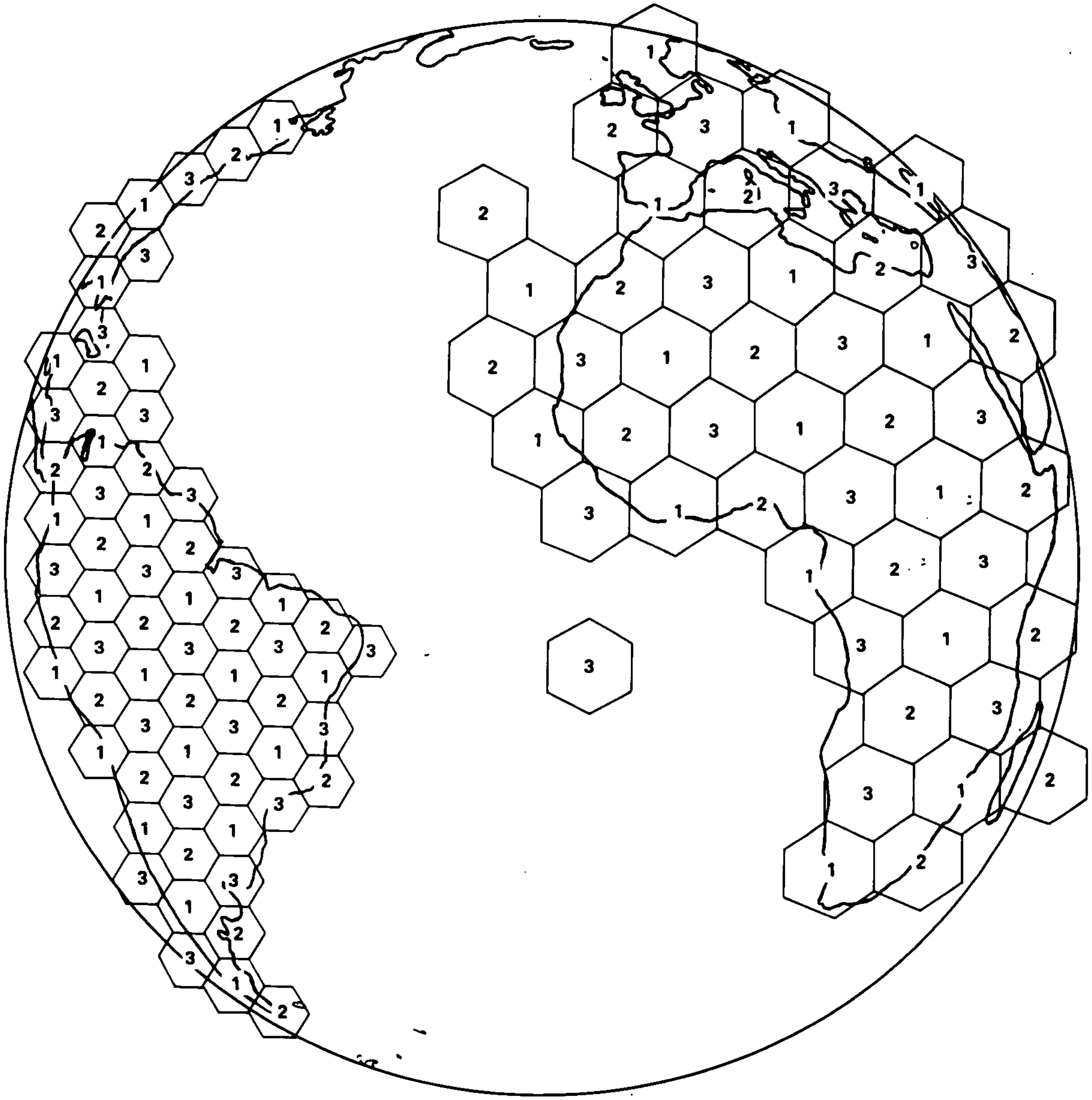


Figure 6-20

SPOT BEAM ANTENNA COVERAGE FOR
INTELSAT ATLANTIC OCEAN REGION MULTI-BEAM PLATFORM
(Numbers 1, 2 and 3 Indicate Frequency Assignment)

6.2.2 Traffic Assignment

Figure 6-21 shows the traffic assignment to each of the beams in the INTELSAT System. Traffic is shown in number of transponders, where each transponder represents the equivalent of 1000 one-way voice channels. The figures represent the total requirement, i.e., INTELSAT's international services and foreign domestic requirement for year-end 1996.

It is assumed that INTELSAT will operate a two-platform configuration, although all of the traffic can be handled by a single platform. This permits diversity operation for those links that require diversity. At the same time, the second platform serves as a spare in orbit. Platforms are interconnected by intersatellite link.

Figure 6-22 shows the polarization and frequency plan that was used to accommodate the traffic. Table 6-15 summarizes the number of beams, capacities and fill factors for each of the frequency bands and polarizations.

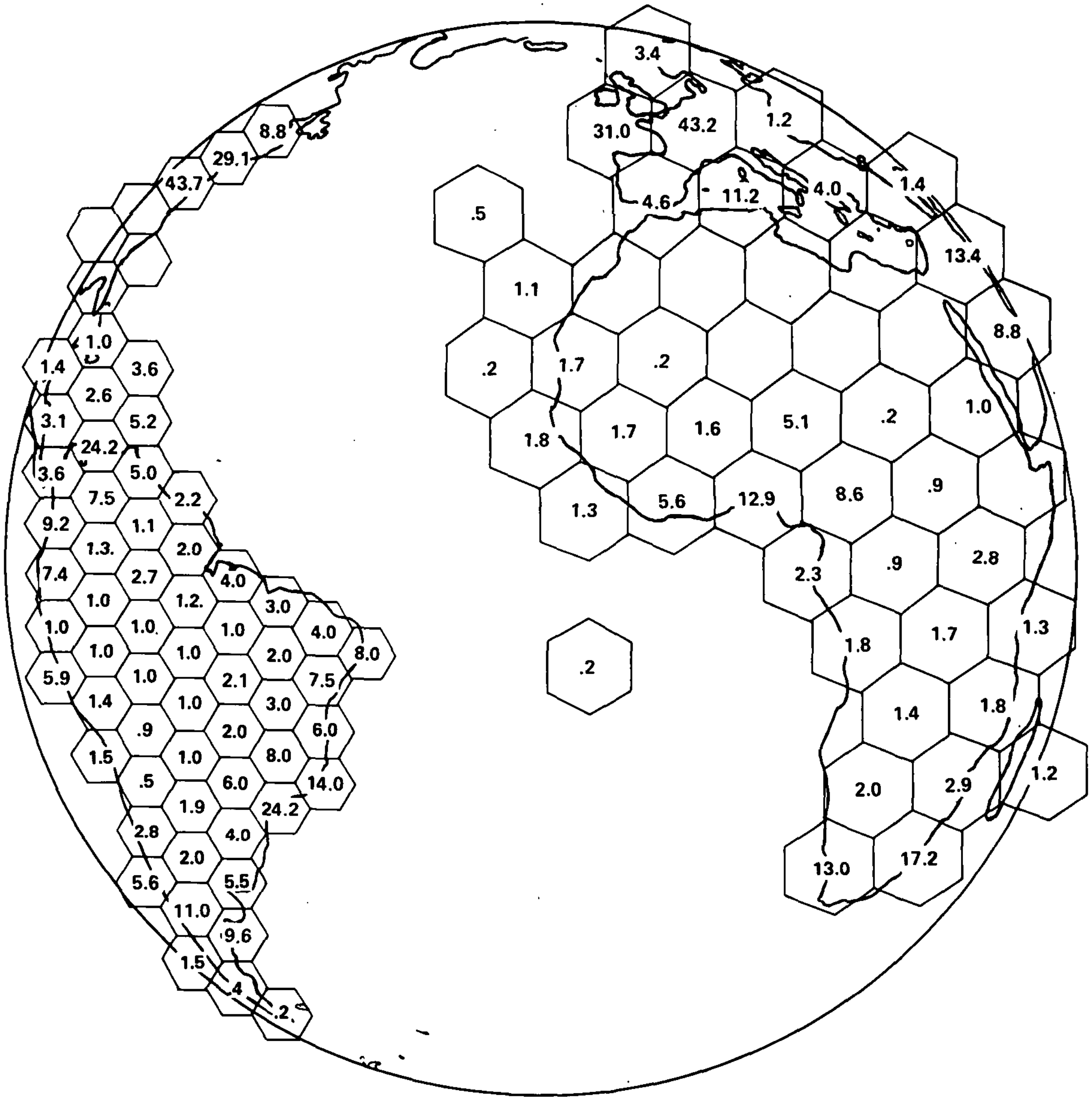


Figure 6-21

INTELSAT ATLANTIC OCEAN REGION PLATFORM REQUIREMENT
FOR YEAR-END 1996
(540 Transponders)

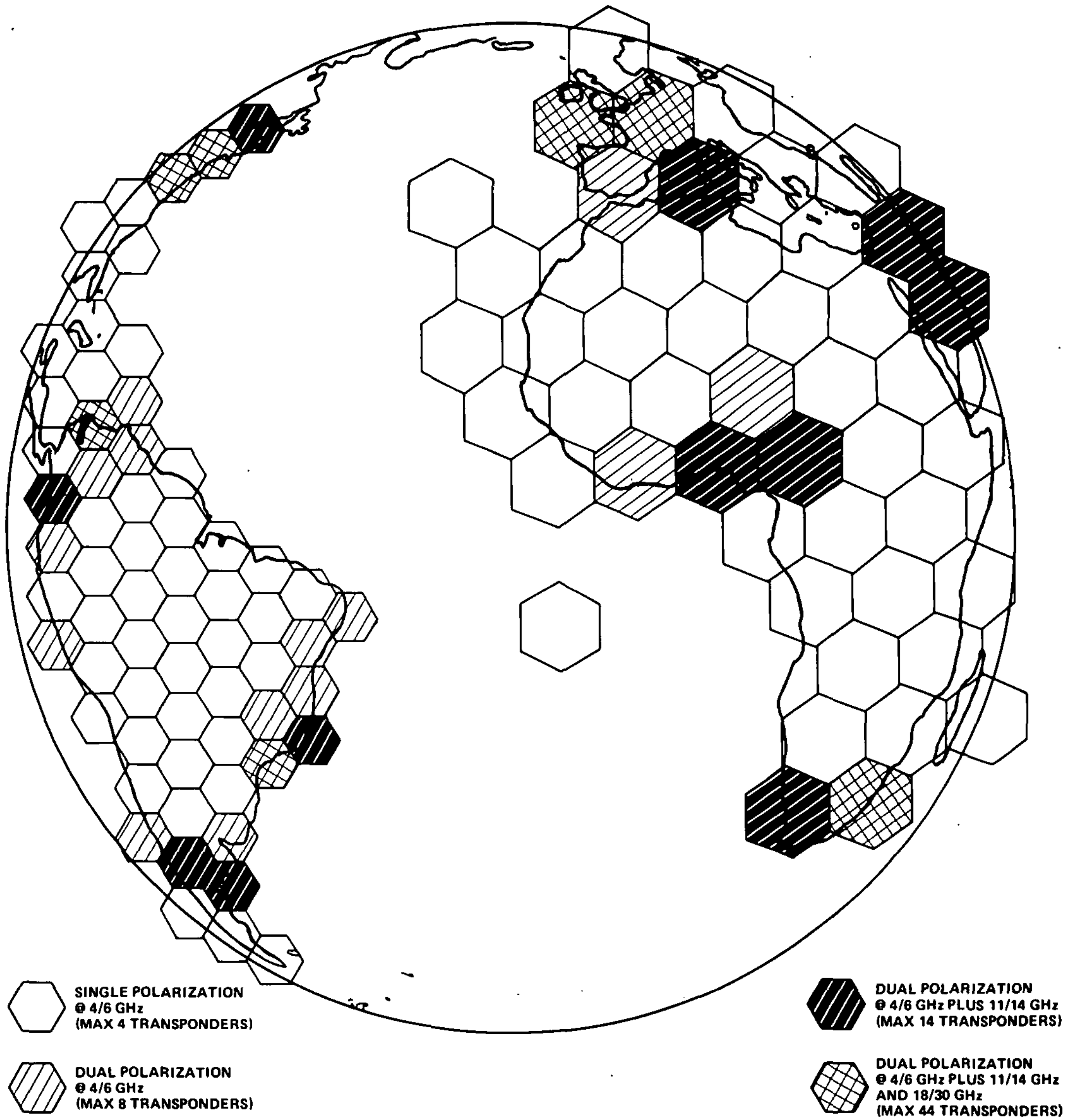


Figure 6-22

FREQUENCY AND POLARIZATION PLAN
OF INTELSAT ATLANTIC OCEAN REGION PLATFORM

Table 6-15

Example of a High Capacity INTELSAT Platform for the Atlantic Ocean Region

	Single Polarization at 4/6 GHz	Second Polarization at 4/6 GHz	Single Polarization at 11/14 GHz	Single Polarization at 18/30 GHz	Totals
Number of Spot Beams					
1.1 degrees	64	21	9	4	98
1.8 degrees	48	12	9	3	72
Total	112	33	18	7	170
Number of 500 MHz Bands					
1.1 degrees	21.3	7	4.5	10	42.8
1.8 degrees	16.0	4	4.5	7.5	32.0
Total	37.3	11	9.0	17.5	74.8
Theoretical Capacity (Transponders)					
1.1 degrees	256	84	54	120	514
1.8 degrees	192	48	54	90	384
Total	448	132	108	210	898
Usable Capacity (Transponders)					
1.1 degrees	156	65.6	36.6	65.2	323.4
1.8 degrees	90.5	39.3	37.9	49.4	217.1
Total	246.5	104.9	74.5	114.6	540.5
Fill Factor					
1.1 degrees	60.9	78.1	67.8	54.3	62.9
1.8 degrees	47.1	81.9	70.2	54.9	56.5
Total	55.0	79.5	69.0	54.6	60.2

6.2.3 System Characteristics

As shown in Section 6.2.2, a single INTELSAT platform can carry all Atlantic Ocean Region traffic through year-end 1996. A second platform can be used as a spare and also for diversity operation. The two platforms are interconnected by intersatellite links.

Based on the same scaling technique as described in Section 6.1.3, we have developed a mass and power budget for an INTELSAT platform as shown in Table 6-16. Table 6-17 shows development and recurring costs for the INTELSAT platform. These costs were based on cost estimating relationships developed by NASA/MSFC.

Table 6-16
INTELSAT Atlantic Ocean Region Platform Mass and Power Budget

Mass (kg)

Antennas and Feeds	500
Transponder Electronics and Switch Matrix	2800
Total Communications Subsystem	3300
Power Subsystem	1820
Thermal Control	300
Attitude/Reaction Control Systems	1800
T&C Subsystem	100
Mission Support Structure	600
Main Structure	1200
Total BOL Mass	9120

Power (kW)

Transponder Power Amplifiers	2.2
Transponder Electronics	3
Switching System	10
Ion Engines	1
General Spacecraft Power	1
Total Primary Power	17.2
Margin for Worst Sun Angle of 23.5^o	1.6
Margin for Degradation (39%/10 yr.)	7.3
Total BOL Array Capability	26.1
Solar Array Area, m^2	216

Table 6-17
Cost Estimate for INTELSAT Atlantic Ocean Region Platform

(Millions of 1979 Dollars)

Development Cost	149
Recurring Cost	114

Transmission link performance of the INTELSAT platforms is similar to that of the U.S. domestic system. The wider antenna beamwidth of the Eastern Hemisphere is compensated by higher RF power allocations.

Figure 6-23 shows the space segment capacity of the Atlantic Ocean INTELSAT System. It should be noted that the INTELSAT V System cannot satisfy all domestic and regional transponder lease requirements past year-end 1982, and therefore the special transponder lease satellites (LS-1 and LS-2) have been introduced. After the introduction of the platforms, these satellites can be moved for use in another ocean area or provide service to Mexico, etc. Figure 6-24 shows the traffic transition from satellites to platforms. Figure 6-25 shows the in-orbit capacity of the INTELSAT Atlantic Ocean System versus the requirement.

For comparison purposes we have selected the same start of operations date for the initial U.S. domestic and the INTELSAT platforms. If both programs were to proceed, however, it would be expected that the platforms would be introduced in a time-phased manner.

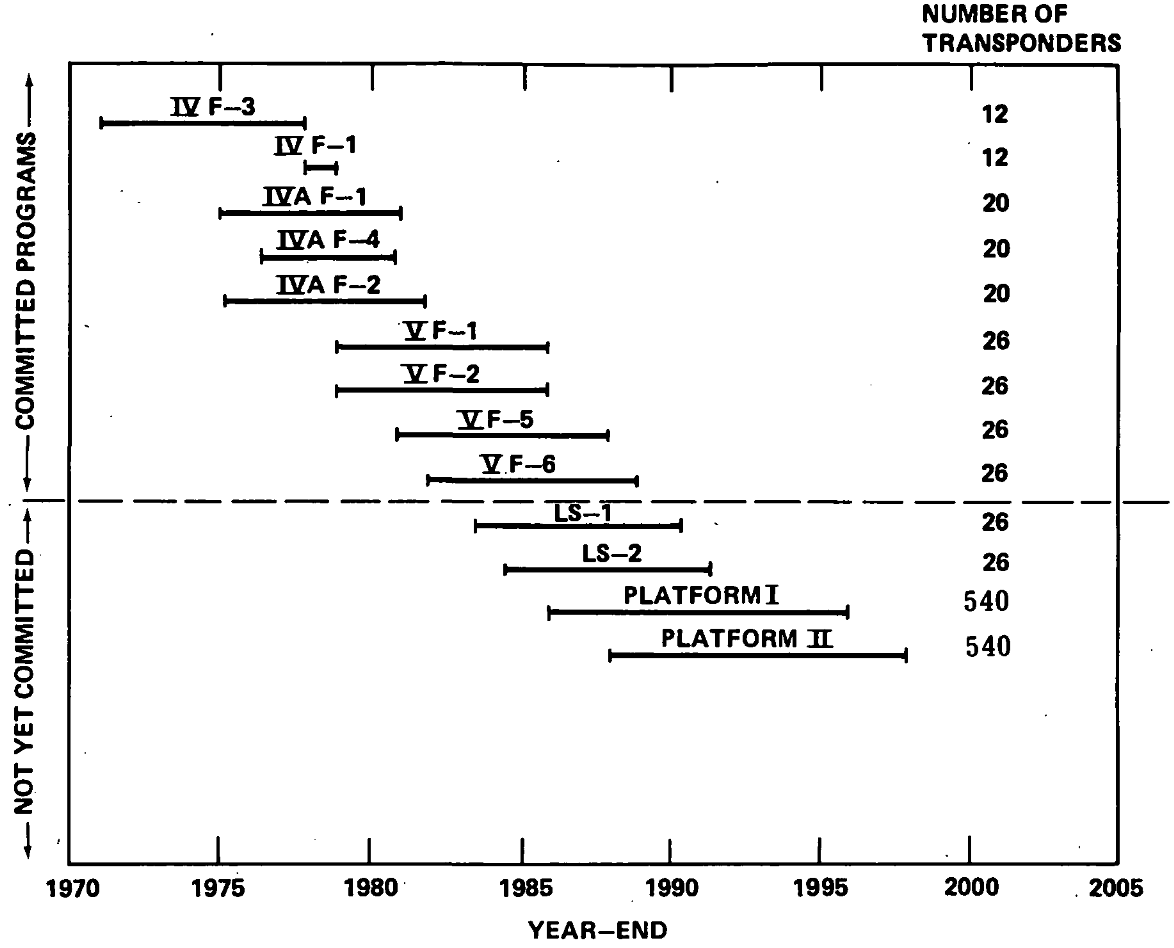


Figure 6-23

SPACE SEGMENT CAPACITY OF CURRENT AND FUTURE INTELSAT ATLANTIC OCEAN SATELLITES AND PLATFORMS

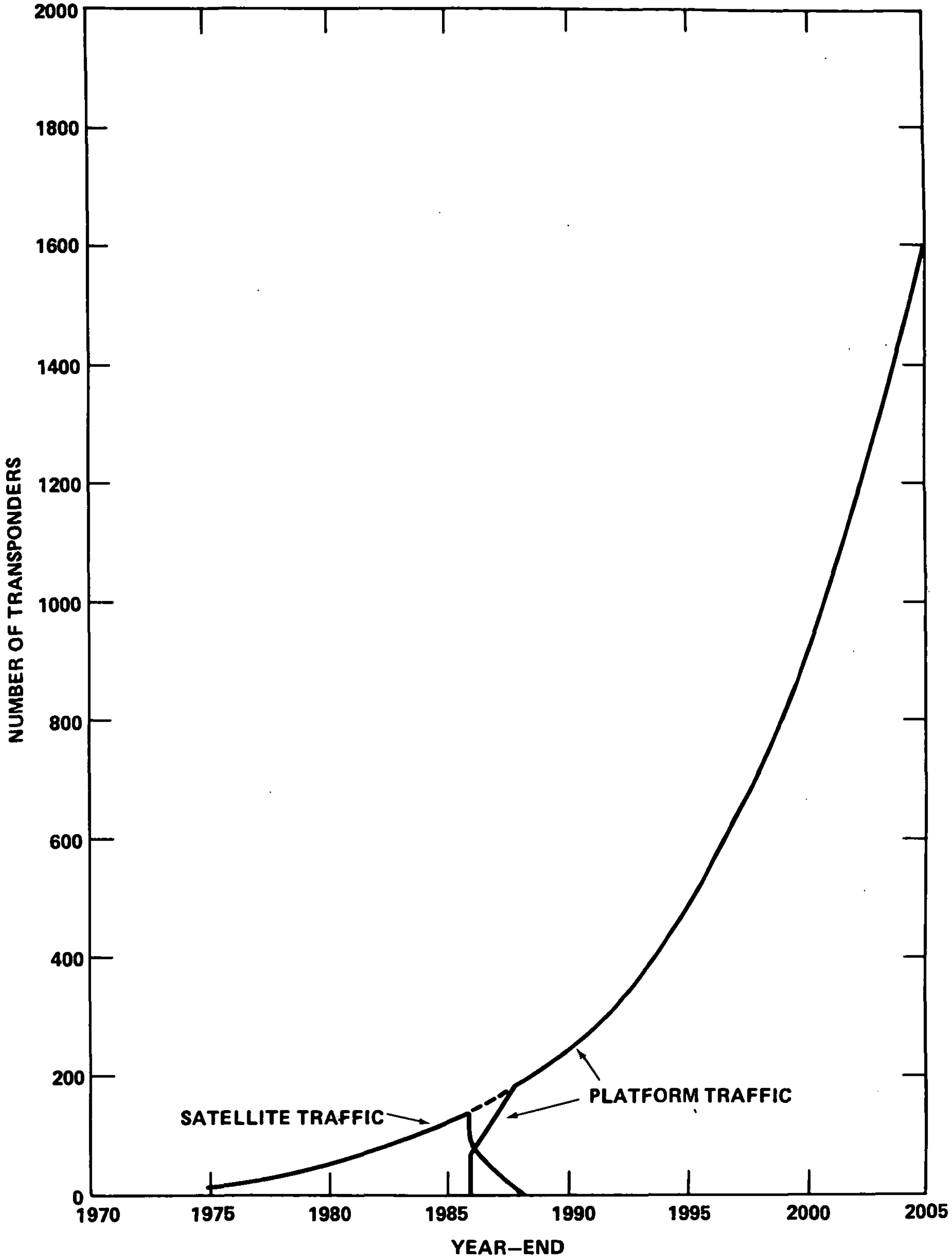


Figure 6-24

TRANSITION FROM SATELLITES TO PLATFORMS FOR THE INTELSAT ATLANTIC OCEAN REGION

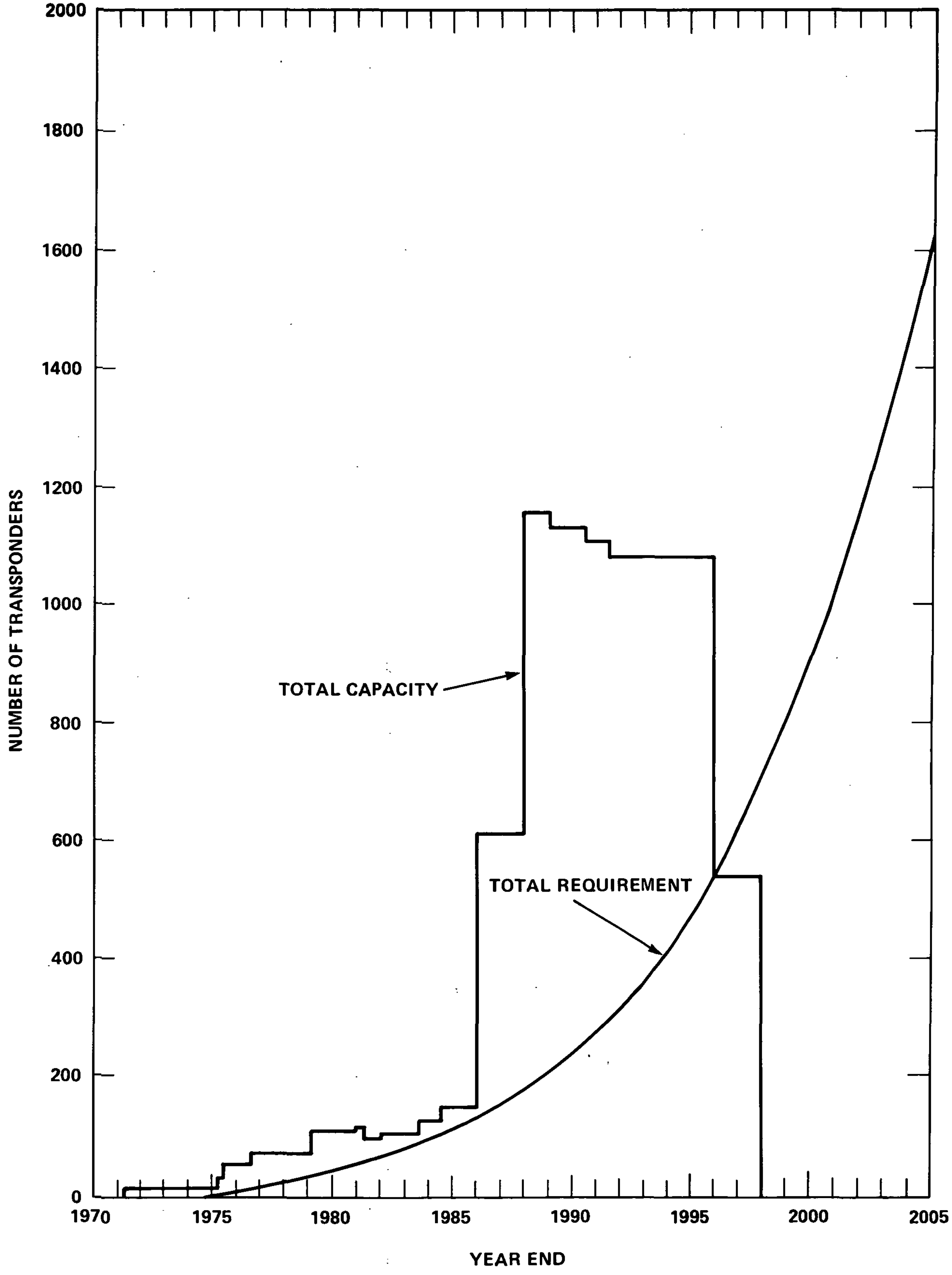


Figure 6-25

AVAILABLE AND REQUIRED TRANSPONDERS FOR THE INTELSAT ATLANTIC OCEAN REGION VERSUS TIME

6.2.4 Earth Station Network

INTELSAT's international network can benefit from the communications platform similar to the domestic systems by the use of smaller earth stations and by more dispersed earth stations. While a large number of earth stations with a 30-meter antenna diameter is already in existence, these earth stations are expensive to operate, and when the end of their useful life has been reached they can be replaced by smaller antennas.

Domestic and regional systems will use earth stations similar to those in the U.S. system. The earth station development schedule for these systems is shown in Table 6-18. The earth station deployment schedule for INTELSAT's international services is shown in Table 6-19.

Table 6-18
Earth Station Deployment Schedule for
Domestic and Regional Services Within the INTELSAT Platform System
(Earth Stations in Operation)

Year-End	Total
1987	1680
1988	2680
1989	3430
1990	3680
1991	3930
1992	4180
1993	4430
1994	4680
1995	4930
1996	5180

Table 6-19

Earth Station Deployment Schedule for the INTELSAT International Satellite System

(Earth Stations in Operation)

Year-End	Total
1987	100
1988	105
1989	110
1990	116
1991	122
1992	128
1993	134
1994	141
1995	148
1996	155

For domestic and regional traffic carried by the INTELSAT platform, we have used the same earth station distribution model as was used for CONUS, with some exceptions. The traffic level was adjusted to 149 transponders in 1991 to correspond to the INTELSAT traffic forecast. The terrestrial interconnect costs were assumed to average twice those in the U.S. because of the need in many areas to construct an entirely new terrestrial system if interconnection is desired. The area of essentially uniform traffic density was assumed to be only 20 percent of the total area covered by the INTELSAT platform. This assumption was made due to the relatively sparse population of much of Africa and a substantial portion of South America.

SECTION 7

COMMUNICATIONS SYSTEMS WITH SMALLER SATELLITES

7.1 Satellite Design and Cost

The capacity of smaller satellites will be determined by the available number of spot beams and the interconnect switch capability. We have assumed that future satellites will have the following characteristics:

U.S. Domestic Satellites

At 4/6 GHz	Twenty-four transponders with coverage of CONUS, Alaska, Hawaii and Puerto Rico, 33 dBW per transponder, 36 MHz bandwidth, dual polarization. Characteristics are similar to those of COMSAT/AT&T Comstar or RCA Satcom. The 500 MHz frequency band is used twice by utilizing orthogonal linear polarization.
At 11/14 GHz	CONUS coverage with spot beams similar to Advanced Westar/TDRSS, dual use of the 500 MHz frequency band.
At 18/30 GHz	Spot beams to the areas with highest traffic requirements, such as New York, Chicago, Los Angeles, etc.

The total usable capacity is assumed to be 72 equivalent C-band transponders. This is 3 times the capacity of Comstar, or 2.5 times the capacity of Advanced Westar, which is considered to be a reasonable technology advance for conventional satellites.

Characteristics of this type of U.S. domestic satellites are shown in Table 7-1. The satellite costs were derived by reviewing the costs of similar spacecraft and applying some engineering judgement regarding complexity. The spacecraft development and recurring costs of Table 7-1 are shown plotted versus mass and capacity in Figures 7-1 through 7-4 along with costs of current satellite systems. A launch schedule using satellites of this type which will provide sufficient capacity to meet projected U.S. service demand through 1996 is shown in Table 7-2.

Table 7-1

Characteristics of Future U.S. Domestic Satellites

Design Life, years	10
Number of Equivalent 36 MHz Transponders	72

Power (Watts)

Total RF Power	450
Total Prime EOL Power	2350
Solar Array Area, m^2	30

Mass (kg)

Communications Subsystem Mass	510
Power Subsystem Mass	250
Thermal Control System Mass	60
TT&C System Mass	40
ACS Mass	100
Hydrazine Fuel	380
Main Structure	320
Total Mass (BOL)	1660

Costs (Millions of 1979 Dollars)

Development Cost	70
Recurring Cost	35
Shuttle Cost	30
SSUS or IUS	6
Total Cost of One In-Orbit Satellite	71

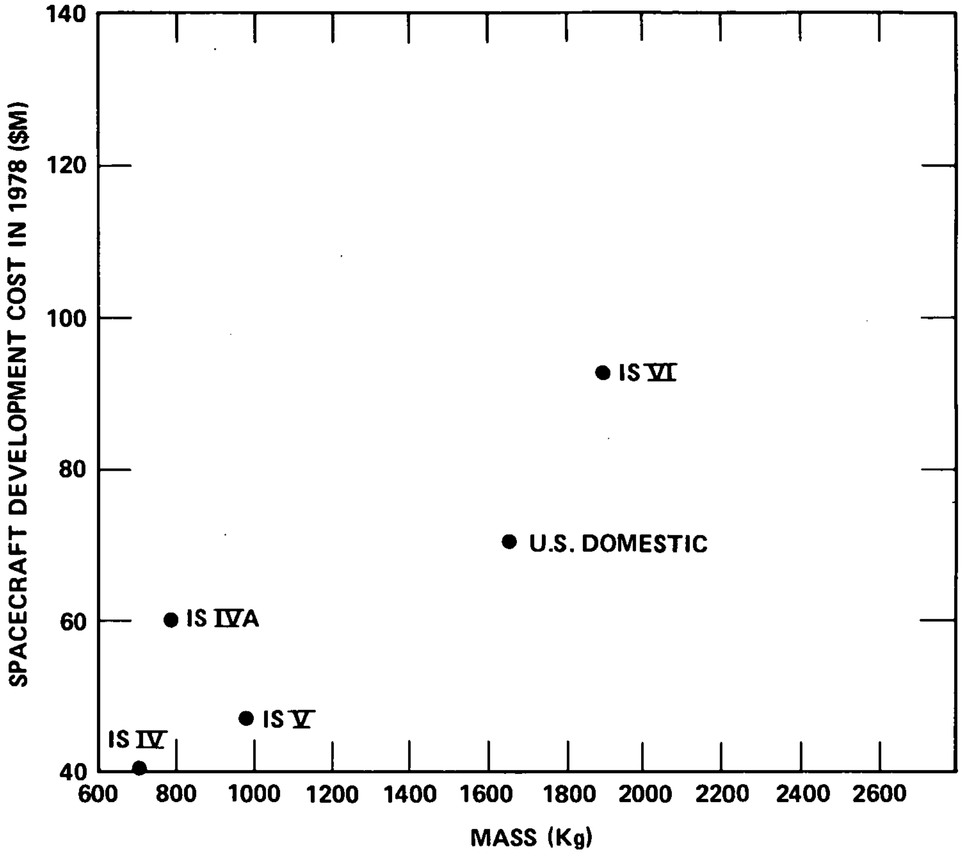


Figure 7-1

SPACECRAFT DEVELOPMENT COST VERSUS SATELLITE MASS

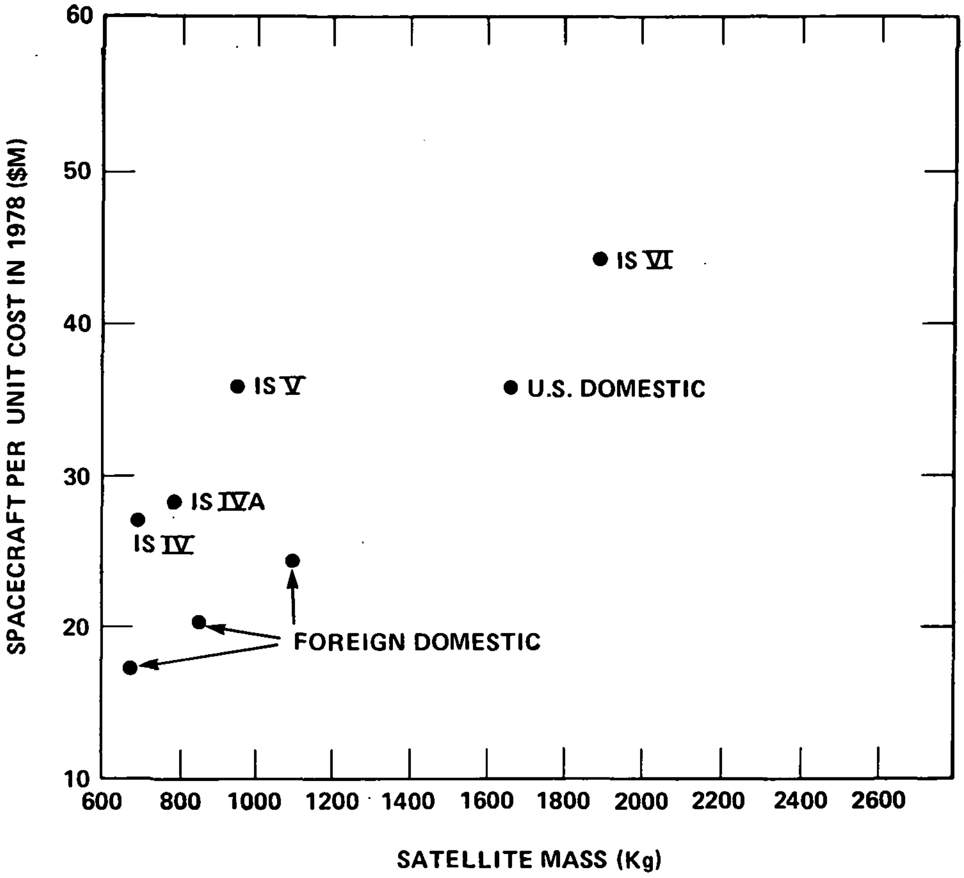


Figure 7-2

SPACECRAFT PER UNIT COST VERSUS SATELLITE MASS

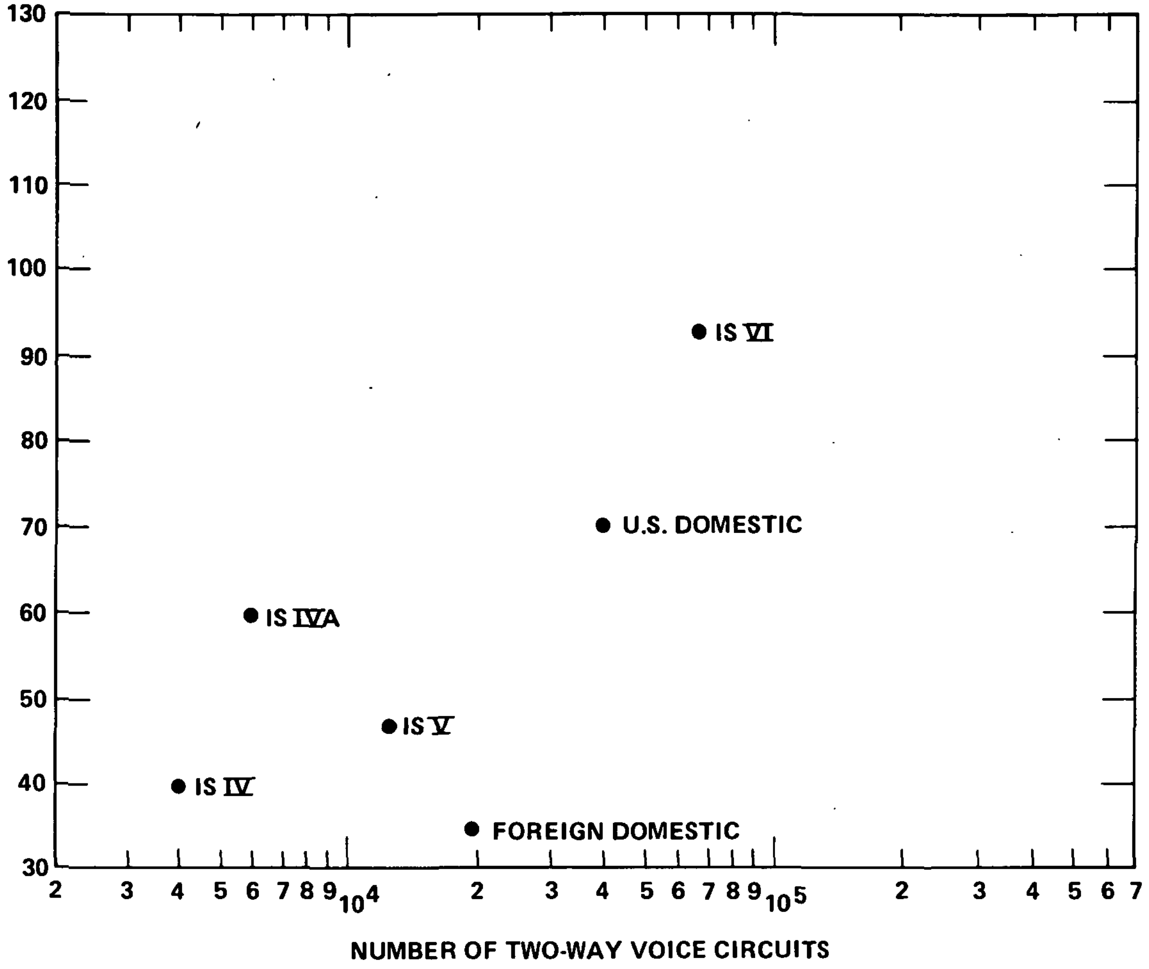


Figure 7-3

SPACECRAFT DEVELOPMENT COST VERSUS CAPACITY

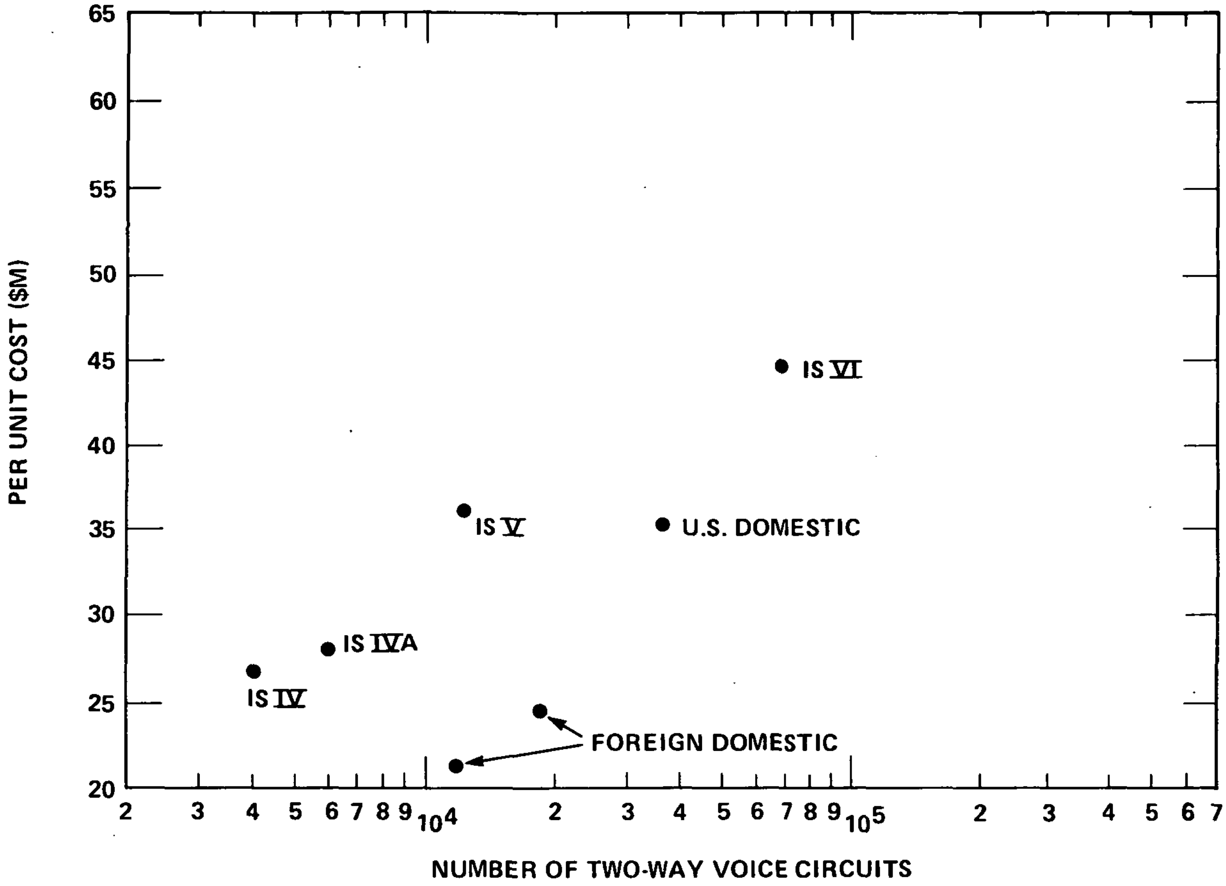


Figure 7-4

SPACECRAFT PER UNIT COST VERSUS CAPACITY

Table 7-2
Spacecraft Launch Schedule for U.S. Domestic Services Using Conventional Satellites

Year	Number of Launches
1987	2
1988	1
1989	1
1990	0
1991	2
1992	1
1993	2
1994	3
1995	2
1996	2

Foreign Domestic Satellites

For the case of the foreign domestic satellite systems, the trend will be a proliferation of lower capacity satellite systems, each providing service in accordance with a particular country's requirements. Subsequent generations of spacecraft will have larger capacities in accordance with increased requirements. Characteristics of typical satellites for foreign domestic systems are shown in Table 7-3. As for the U.S. domestic satellites, the spacecraft costs of Table 7-3 are plotted in Figures 7-1 through 7-4.

Table 7-3
Characteristics of Foreign Domestic Satellites
(Design Life = 10 Years)

Number of 36 MHz Transponders	12	24	36
In-Orbit Mass (kg)	600	850	1100
Primary Power (watts)	450	925	1400
Costs (Millions of 1979 Dollars)			
Development Cost	10	22	35
Recurring Cost	17	21	25
Launch Cost	10	15	20
SSUS or IUS Cost	3.4	3.4	3.4
Total Cost for One In-Orbit Satellite	30.4	39.4	48.4

The spacecraft launch schedule required to meet projected demand for several foreign domestic systems in the Atlantic Ocean region is shown in Table 7-4.

Table 7-4

Spacecraft Launch Schedule for Foreign Domestic/Regional Services Using Conventional Satellites

(Number of Launches)

Year	Satellite Type 12 Transponder	 24 Transponder	 36 Transponder
1987	8	0	3
1988	0	0	0
1989	2	0	0
1990	1	0	1
1991	1	1	0
1992	1	0	0
1993	1	0	0
1994	0	0	1
1995	0	0	0
1996	0	0	0

INTELSAT Satellites

The characteristics of INTELSAT satellites through INTELSAT V are summarized in Table 7-5.

Table 7-5
Characteristics of INTELSAT I Through INTELSAT V

	Satellite					
	IS-I	IS-II	IS-III	IS-IV	IS-IVA	IS-V
Year of First Launch	1965	1967	1968	1971	1975	1979
Mass in Orbit (kg)	38	86	152	700	790	967
Primary Electric Power (watts)	40	75	120	400	500	1200
Effective Bandwidth (MHz)	50	130	500	500	800	2300
Capacity (Voice Circuits)	240	240	1200	4000	6000	12000
Design Life Time (Years)	1.5	3	5	7	7	7

We assume that the INTELSAT V System will be followed by INTELSAT V-A, a satellite with slightly increased capacity, to extend systems operation of the Primary Atlantic satellite. INTELSAT VI would be introduced in 1987, and its assumed characteristics are given in Table 7-6. The development and recurring costs are plotted in Figures 7-1 through 7-4.

A launch schedule for the INTELSAT Atlantic Ocean region is shown in Table 7-7.

Table 7-6

Assumed INTELSAT VI Characteristics

Number of Equivalent 36 MHz Transponders	96
In-Orbit Mass (kg)	1900
Primary Power (watts)	3000
Costs (Millions of 1979 Dollars)	
Development Cost	90
Recurring Cost	44
Launch Cost	36
Total Cost for One In-Orbit Satellite	80

Table 7-7

Spacecraft Launch Schedule for INTELSAT's Atlantic Ocean Region Using Conventional Satellites

(INTELSAT VI)

Year	Number of Launches
1987	2
1988	0
1989	0
1990	1
1991	0
1992	0
1993	1
1994	1
1995	0
1996	1

7.2 Earth Station Design and Cost

U.S. Domestic Earth Stations

The U.S. domestic system requires approximately 10 satellites with a capacity of 72 equivalent transponders each. Since some portion of the total satellite traffic requires interconnection, it will be necessary to operate multiple earth station antennas at some locations or to employ torus antennas with multiple feeds. A block diagram of an earth station designed for multiple satellite access is shown in Figure 7-5. Table 7-8 shows typical TDMA earth station costs for a multiple satellite access earth station employing a torus antenna. Table 7-9 shows typical TDMA earth station costs for single satellite access type stations. These costs are for equipment only and do not include costs associated with installation, transportation, integration, documentation and spares. These costs are assumed to be 40 percent of the equipment costs in our economic model.

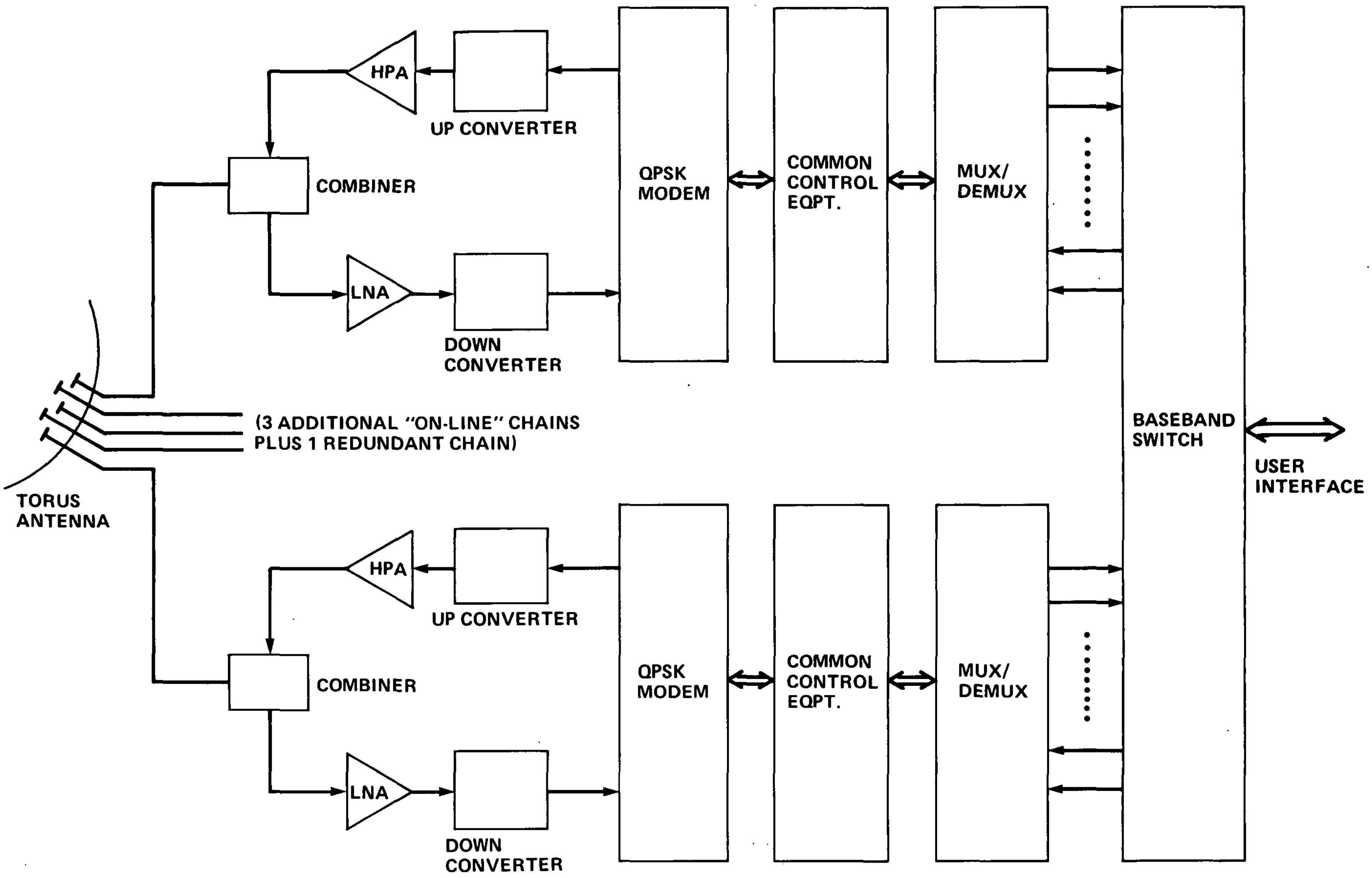


Figure 7-5

TYPICAL TDMA MULTIPLE SPACE SEGMENT ACCESS EARTH TERMINAL
(Functional Block Diagram)

Table 7-8

Typical TDMA Multiple Space Segment Access Terminal Costs in 1987

(Thousands of 1979 Dollars)

Item	Single Chain	Six Chains
11-meter torus type C-band antenna system	--	175
55 k LNA	12	72
1 kw TWTA	50	300
Up/down converter	7	42
TDMA terminal equipment	60	360
Baseband switch	--	50
Redundancy implementation	--	50
Total		1049

Notes:

1. Price reflects single quantity purchase starting in 1987.
2. TDMA burst rate = 62.5 Mbps.
3. System operates at C-band.
4. System provides five space segment accesses with an additional redundant chain.
5. TDMA terminal equipment includes QPSK modem, common control equipment and mux/demux.

Table 7-9

Typical TDMA Earth Station Equipment Costs in 1987

(Thousands of 1979 Dollars)

Item	4/6 GHz	11/14 GHz	18/30 GHz
Antenna system	70	45	60
LNA	12	20	30
1 kw TWTA	50	65	80
Up/down converter	7	8	10
TDMA terminal equipment	60	60	60
Total	199	198	240

Notes:

1. 11-meter antenna diameter used at 4/6 GHz and 7-meter antenna diameters used at both 11/14 and 18/30 GHz.
2. LNA noise temperatures of 55° k, 110° k and 375° k for 4, 11 and 18 GHz, respectively.
3. TDMA terminal equipment includes QPSK modem, common control equipment and mux/demux.
4. Burst data rate = 62.5 Mbps.
5. Price reflects single quantity purchase starting in 1987.

Multiple space segment access earth stations (Figure 7-5) will require multiple low noise amplifiers and HPA's connected to earth station antenna feeds, as well as more elaborate baseband equipment to switch traffic to the appropriate satellite in order to achieve the required interconnection. The major modulation techniques will be TDMA and SCPC, as well as single carrier per transponder PCM/PSK for heavy links. In addition, there will be a requirement for systems interconnection through satellites using different frequencies. C-band and 11/14 GHz transponders on the same satellite can be cross-strapped. The use of torus antennas for connection of one earth station to multiple satellites will be limited by the angular separation of the satellites. This limitation will be more severe at the higher frequencies, and we expect that many locations will have to be equipped with multiple earth station antennas operating at two or three frequency bands.

As a development scenario for the evolution of systems with conventional satellites, we foresee a situation of reduced earth station costs in the immediate future, where a single earth station will carry low traffic and will require very limited connectivity. As the total systems traffic increases, however, there will be an increased requirement for demand assignment and traffic routing capability, as well as a requirement for access of multiple satellites from a single location. This trend will lead to an increase in earth station equipment costs.

The earth station deployment schedule for a U.S. domestic conventional satellite system is shown in Table 7-10.

Table 7-10

Earth Station Deployment Schedule for U.S. Domestic Conventional Satellite Systems

(Earth Stations in Operation)

Year-End	Total
1987	400
1988	450
1989	520
1990	610
1991	750
1992	950
1993	1250
1994	1500
1995	1750
1996	2000

Foreign Domestic Earth Stations

The design requirements for foreign domestic earth stations will be very similar to those of current U.S. domestic earth stations. The earth station deployment schedule is shown in Table 7-11. Costs will be of the order shown in Table 7-9.

Table 7-11

Earth Station Deployment Schedule for Foreign Domestic and Regional Satellite Systems

(Earth Stations in Operation)

Year-End	Total
1987	400
1988	450
1989	520
1990	610
1991	750
1992	950
1993	1250
1994	1500
1995	1750
1996	2000

INTELSAT Earth Stations

Presently there are 73 earth stations operating in the Atlantic Ocean region carrying international traffic. The projected deployment schedule of INTELSAT international earth stations for the study period is shown in Table 7-12.

Table 7-12

Earth Station Deployment Schedule for the INTELSAT International Satellite System

(Earth Stations in Operation)

Year-End	Total
1987	100
1988	105
1989	110
1990	116
1991	122
1992	128
1993	134
1994	141
1995	148
1996	155

7.3 Transmission Link Analysis

Communications systems using conventional satellites will use combinations of many modulation/access techniques, including FDM/FM, TDMA and SCPC. Table 7-13 is a sample transmission link budget for a 62.5 Mbps PSK carrier. Satellite and earth station transmit power levels for various transmission rates are shown in Table 7-14.

Table 7-13

Sample Transmission Link Budgets for a 62.5 Mbps PSK Carrier

Downlink

		Frequency Band, GHz		
		4/6	11/14	18/30
Satellite transmit RF power	Watts	2.3	8.5	11
	dBW	3.6	9.3	10.4
Line losses	dB	0.5	0.5	0.5
Minimum antenna gain	dB	27.4	32.1	38.2
Minimum satellite transmit EIRP	dBW	30.5	40.9	48.1
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	-132.2	-121.8	-114.6
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	540
Earth station G/T	$dB/^oK$	30.5	32.9	32.9
Receive noise bandwidth	MHz	35	35	35
Downlink carrier-to-noise ratio	dB	15	15	15

Table 7-13, Continued

Sample Transmission Link Budgets for a 62.5 Mbps PSK Carrier

Uplink

		Frequency Band, GHz		
		4/6	11/14	18/30
Earth station transmit power	Watts	80	645	710
	dBW	19	28.1	28.5
Line losses	dB	1.0	1.0	1.0
Antenna diameter	m	11	7	7
Antenna gain	dB	54.6	58	64.6
Earth station transmit EIRP	dBW	72.6	85.1	92.1
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	-90.1	-75.7	-70.6
Minimum satellite antenna gain	dB	27.4	32.1	38.2
Receive system noise temperature	^oK	1150	2200	300
Satellite G/T	$dB/^oK$	-3.2	-1.3	3.4
Receive noise bandwidth	MHz	35	35	35
Uplink carrier-to-noise ratio	dB	20	20	20

Table 7-14

Satellite and Earth Station RF Transmit Power Requirements

	Transmission Rate, Mbps					
	0.064	0.256	1.544	6.312	62.5	250
Satellite RF Power (Watts)						
4 GHz	0.002	0.008	0.05	0.2	2.3	9.4
11 GHz	0.007	0.03	0.2	0.9	8.5	35
18 GHz	0.01	0.05	0.3	1.1	11	45
Earth Station RF Power (Watts)						
6 GHz	0.08	0.3	2.0	8.0	80	326
14 GHz	0.7	2.7	16	65	645	2600
30 GHz	0.8	3.0	18	71	710	2890

7.4 Terrestrial Extensions

For conventional satellite systems, we have used the same technique for determining interconnect costs as was used in the platform system. However, due to the higher earth station cost for systems using conventional satellites, and due to the larger antenna diameters and the need for multiple satellite access, the earth stations will not proliferate to the same extent as will be the case with large communications platforms. Larger antenna diameters and earth stations with multiple antennas will be less acceptable from an environmental point of view, and they will therefore not be as readily acceptable in an urban or suburban environment as the smaller antennas that can be used with high capacity platforms. These factors will lead to a smaller number of earth stations and to higher interconnect costs.

Since these larger earth stations will mostly be located outside of downtown areas and will not, in general, be co-located with a user or central office, local loop or leased line interconnect alone will not be sufficient. Instead, dedicated microwave facilities would be used to connect these remote earth stations with the central office. From this point, connection to the customer would be by leased line or local loop. Based on our investigation of FCC terrestrial microwave filings, we consider an average repeater cost of $200,000 in 1979 dollars to be reasonable. The cost of a two-hop microwave system ($400,000) has been added to the cost of these larger stations.

SECTION 8
COMPARISON OF SYSTEMS

8.1 U.S. Domestic Systems

8.1.1 System Cost Comparison

Cost Model

Engineering cost calculations were made to compare alternate systems scenarios using the following cost model:

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

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

   An initial systems value was assigned to the domestic ground segment existing at the time of transition in 1987. This value was included in the depreciation schedule.

c. All calculations were made in constant 1979 dollars. The allowance for inflation was included in the proper choice of rate of return on investment and present value factor.

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

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

f. 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.

g. The cost of terrestrial extensions was entered as an operating expense.

h. 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 1979 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:

a. Shuttle Launch Costs

For platforms, the requirement is three Shuttle launches per platform. The total cost is $90 million plus an additional $15 million to raise the unit to synchronous orbit.

Conventional satellites use the full Shuttle, and the cost is $36 million each.

b. 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 operation with any of the conventional satellite follow-on systems. It is assumed that for operation with the platforms the existing facilities would be used.

c. Earth Station Deployment and Costs

For the platform system and average earth station cost, $50,000 was used. For the conventional satellite system, a combination of single satellite access and multiple satellite access earth stations was used with the average costs being $200,000 and $1 million, respectively. In addition to these costs, an additional 40 percent was added to account for such costs as transportation, installation, integration and spares.

Development and Deployment

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

In the conventional satellite system, development costs were assessed three times, on the assumption that three different carriers would develop their systems independently.

TT&C and Operations

Costs for TT&C 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.

We have assumed that the cost for stationkeeping and operation of a platform is the same as that for a conventional satellite.

Cost Comparison

Tables 8-1 through 8-4 are the computer printouts for the cost calculations for platform systems and for conventional satellite systems. Table 8-5 is a summary comparison table.

While the space segment costs are not too different on the average, the earth segment for the platform system is much cheaper. This is due to two factors:

1. The use of low cost earth stations in the platform system, made possible by the high antenna gain of the platform
2. The large number of earth stations in the platform system

This latter factor places the earth stations much closer to the origins of traffic, thus reducing interconnect costs.

On averaging over the 10-year period, the platform system costs about one-half as much per circuit as the system with conventional satellites.

Tables 8-6 and 8-7 show total revenue requirements of the platform and conventional satellite systems with and without present value calculations.

Table 8-1

Economic Model Forecast
U.S. Platform Space Segment

Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
		----------Annual--------						
1987	314	35	4	47	86	184.00	0.47	59
1988	279	35	4	42	81	202.00	0.40	53
1989	435	56	4	65	126	216.50	0.58	79
1990	379	56	5	57	118	232.50	0.51	70
1991	514	77	5	77	159	249.00	0.64	91
1992	436	77	5	65	147	266.00	0.55	80
1993	359	77	5	54	136	288.00	0.47	71
1994	282	77	5	42	124	301.50	0.41	62
1995	205	77	5	31	113	324.00	0.35	53
1996	127	77	5	19	101	342.50	0.30	46

Total of Revenue Requirements = 1191
Total Present Value of Revenue = 665
Average Cost per Circuit-Year = 0.46

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-2

Economic Model Forecast
U.S. Platform Ground Segment

		Annual						
Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	256	28	145	38	212	184.00	1.15	146
1988	354	42	136	53	232	202.00	1.15	152
1989	406	53	142	61	256	216.50	1.18	160
1990	384	56	149	58	264	232.50	1.13	158
1991	359	60	157	54	271	249.00	1.09	155
1992	331	63	166	50	279	266.00	1.05	152
1993	299	67	176	45	288	288.00	1.00	150
1994	263	70	184	40	294	301.50	0.97	146
1995	224	74	194	34	302	324.00	0.93	143
1996	182	77	204	27	309	342.50	0.90	140

Total of Revenue Requirements = 2706
Total Present Value of Revenue = 1504
Average Cost per Circuit-Year = 1.04

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-3

Economic Model Forecast
U.S. Conventional Space Segment

	Net	----------Annual--------					Cost per	PV of Annual
Year	Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Circuit	Revenue
1987	254	28	4	38	70	184.00	0.38	48
1988	353	42	4	53	99	202.00	0.49	65
1989	374	49	4	56	109	216.50	0.51	69
1990	325	49	4	49	102	232.50	0.44	61
1991	403	64	4	60	128	249.00	0.51	73
1992	403	71	4	61	135	266.00	0.51	74
1993	461	85	4	69	158	288.00	0.55	82
1994	567	106	4	85	195	301.50	0.65	97
1995	589	120	4	88	213	324.00	0.66	101
1996	596	135	4	89	228	342.50	0.67	103

Total of Revenue Requirements = 1437
Total Present Value of Revenue = 774
Average Cost per Circuit-Year = 0.55

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-4

Economic Model Forecast
U.S. Conventional Ground Segment

Year	Net Invest	---------Annual--------				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep +	O&M +	ROI =	Revnu			
1987	155	17	315	23	356	184.00	1.93	245
1988	218	26	341	33	400	202.00	1.98	263
1989	305	39	362	46	446	216.50	2.06	280
1990	411	55	383	62	499	232.50	2.15	299
1991	582	80	405	87	572	249.00	2.30	327
1992	825	116	433	124	672	266.00	2.53	367
1993	1274	178	480	191	850	288.00	2.95	443
1994	1498	223	512	225	960	301.50	3.18	478
1995	1678	268	553	252	1073	324.00	3.31	509
1996	1814	313	592	272	1177	342.50	3.44	533

Total of Revenue Requirements = 7005
Total Present Value of Revenue = 3744
Average Cost per Circuit-Year = 2.69

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-5

Cost Comparison for Systems Providing U.S. Domestic Service

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.47	1.15	1.62	0.38	1.93	2.31	1.43
1988	0.40	1.15	1.55	0.49	1.98	2.47	1.59
1989	0.58	1.18	1.76	0.51	2.06	2.57	1.46
1990	0.51	1.13	1.64	0.44	2.15	2.59	1.58
1991	0.64	1.09	1.73	0.51	2.30	2.81	1.62
1992	0.55	1.05	1.60	0.51	2.53	3.04	1.90
1993	0.47	1.00	1.47	0.55	2.95	3.50	2.38
1994	0.41	0.97	1.38	0.65	3.18	3.83	2.78
1995	0.35	0.93	1.28	0.66	3.31	3.97	3.10
1996	0.30	0.90	1.20	0.67	3.44	4.11	3.43
Average	0.46	1.04	1.50	0.55	2.69	3.24	2.16

Table 8-6

Comparison of Total Revenue Requirements for U.S. Domestic Conventional Satellite and Platform Systems (1987-1996)

(Millions of 1979 Dollars)

	Ground Segment	Space Segment	Total
Platform	2706	1191	3897
Satellite	7005	1437	8442
Difference	4299	246	4545

Table 8-7

Comparison of Present Valued Total Revenue Requirements for U.S. Domestic Conventional Satellite and Platform Systems (1987-1996)

(Millions of 1979 Dollars)

	Ground Segment	Space Segment	Total
Platform	1504	665	2169
Satellite	3744	774	4518
Difference	2240	109	2349

8.1.2 Connectivity

The U.S. domestic satellite communications traffic model was designed to provide full connectivity between all locations. This requirement was based on the historical development of communications systems where major systems are always fully interconnected. Accordingly, both the platform system and the conventional systems were designed to provide this connectivity. Therefore, the two systems are equivalent with respect to connectivity.

8.1.3 Orbital Arc Use

The platform system and the conventional systems were both designed to permit orbital spacings of 4 degrees. The capacity of the platforms is 375 transponders, compared with 72 transponders for the conventional satellites. Thus the platforms are 5 times as efficient in the use of the orbital arc. Table 8-8 is a summary of the U.S. orbital arc utilization.

Considering the actual orbital deployment, the platform system requires three orbital locations, or 12 orbital degrees, representing 3.3 percent of the total available arc. The conventional systems require 13 operating satellites and 3 spares, or a total of 16 locations with an arc requirement of 64 degrees or 17.7 percent of the available arc. In this comparison, the platforms are 5.3 times as efficient as the conventional satellite systems.

The useful service arc for North and South America is approximately 140 degrees, extending from 0 to 140 degrees west longitude. Table 8-9 lists service arcs for coverage areas in North and South America. The service was defined as the range of longitude from which a satellite can provide service within an earth station elevation angle of 10 degrees. Figure 8-1 provides the service arc information graphically. A reference number was assigned to each service arc to permit easy correlation between tabular and graphical information. It should be noted that the easterly portion is also of use to Europe and Africa, and the arc up to about 40 degrees west longitude is required by INTELSAT. Therefore, the service arc practically available for North and South America is only about 100 degrees.

Table 8-8

U.S. Domestic Orbital Arc Utilization Summary

	Platforms	Satellites
Spacing (Degrees)	4	4
Total Orbital Slots Required (1996)	3	16
Orbital Arc Degrees Required (1996)	12	64
Percent of the Total Arc Required	3	18

Table 8-9

Service Arc for North and South America

World Region	Reference Number	Coverage Range	Visibility Arc For Minimum Elevation Angle of 10 Degrees (Degrees in East Longitude)
North America	1	Canada, Including Yukon and NW Territories	244 - 246
	2	Canada, Vancouver to Halifax	232 - 299
	3	USA, Including Hawaii, Alaska and Puerto Rico	226 - 227*
	4	USA, CONUS Only	226 - 299*
	5	USA, CONUS and Hawaii	226 - 268*
Latin America	6	Brazil	251 - 360
	7	Colombia	217 - 350
	8	Chile/Argentina	230 - 350
	9	Total Regional Coverage	251 - 350
	10	Mexico/Caribbean	217 - 314

*The visibilities for a 5-degree elevation angle for Numbers 3, 4 and 5 are 223-241, 223-304 and 223-274 degrees east longitude, respectively.

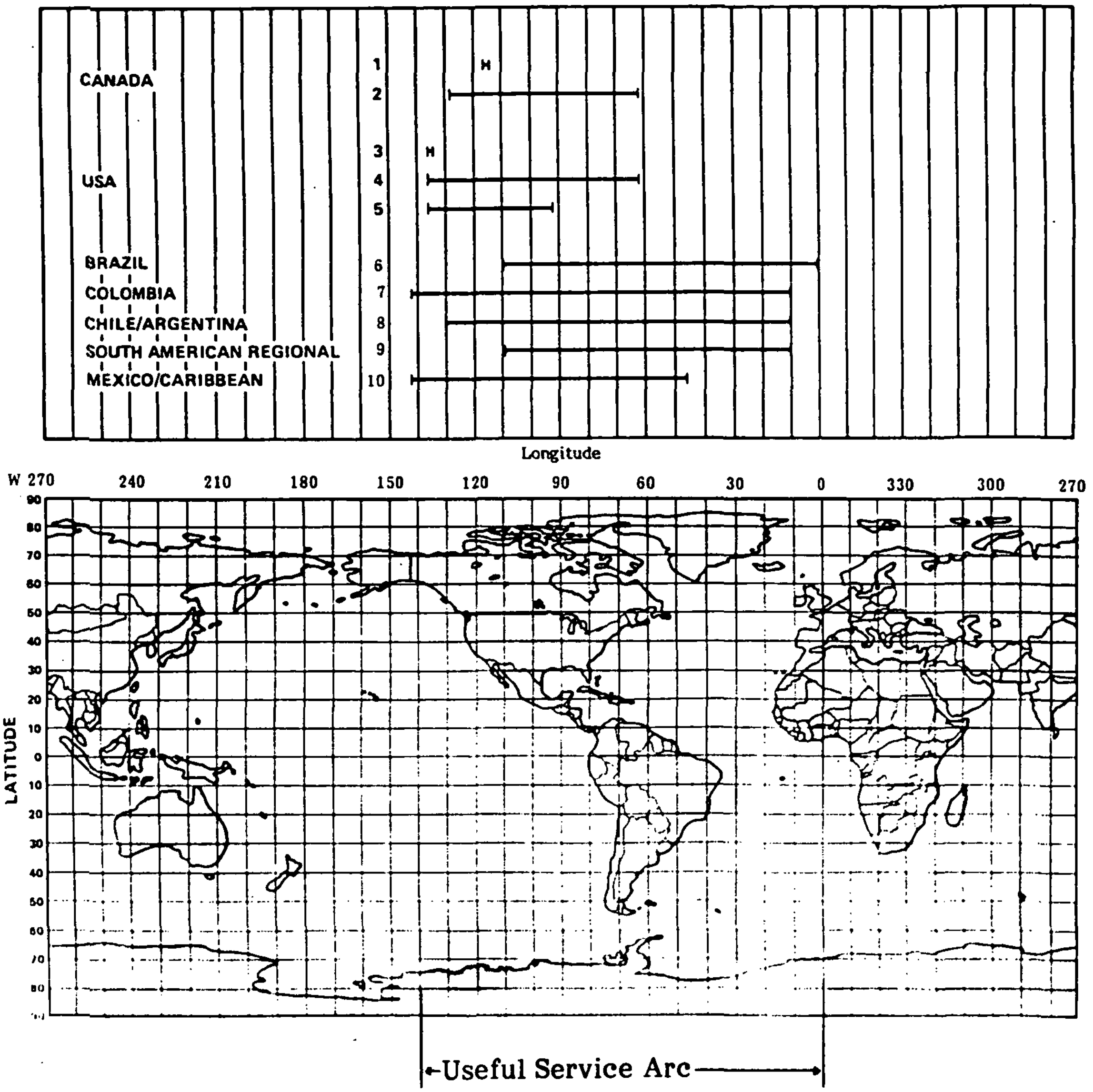


Figure 8-1

USEFUL SERVICE ARC FOR NORTH AND SOUTH AMERICA

Considering this available service arc, platform systems require 12 percent, while conventional systems require 64 percent. The platform solution is certainly more desirable since the U.S. population of 220 million is only 37 percent of the total population of North and South America of 591 million. With the platform solution, the U.S. would free the orbital arc for future growth, while with conventional satellites the U.S. would pre-empt a disproportionally large amount of the orbital arc, making it more difficult for the Latin American countries to develop their communications systems. Considerations of orbital arc usage could become an important U.S. policy consideration.

The U.S. domestic carriers are presently occupying or planning to occupy 11 slots in the orbital arc. They will likely continue to use these slots in the future. If two more slots were eventually made available for U.S. carriers, a total of 13 slots would be available. Based on the deployment for U.S. domestic satellites as shown in Table 7-2, these 13 slots would be used up by around 1994. At this point, the introduction of higher capacity satellites or platforms would be required. However, implementation of a platform at a time when the arc is congested would cause unacceptable interference. This is discussed further below. Not included in this evaluation are TV distribution, direct TV broadcast requirements and video conferencing. Consideration of any of these additional services will further aggravate the orbital arc problem.

Another consideration is the possibility of sharing orbital arc locations by countries with wide geographical separation, e.g., Canada and Argentina. This would require some agreement on satellite antenna sidelobe characteristics. In this respect, platforms are more accommodating since they use smaller antenna beamwidths which makes orbital slot sharing easier.

Because of their narrower antenna beamwidth, communications platforms have higher antenna gains, which reduce transmit power requirements both in the uplinks and in the downlinks. C-band coverage of a typical conventional satellite is about 25 square degrees, while our platform example has antennas with a coverage of about 1.2 square degrees. The resulting antenna gain difference is 13 dB, permitting a power level reduction by a factor of 20 both for the uplinks and the downlinks. Platform systems therefore cause at least 10 dB less interference into other communications systems than conventional satellite systems.

While platform systems cause low interference, they are more likely to be interfered with, especially by adjacent conventional satellite systems. This is due to the fact that conventional satellites must be illuminated by earth stations with much higher power levels with correspondingly higher off-beam axis radiation. While a 4-degree spacing is possible between satellites or platforms of homogeneous characteristics, a 4-degree spacing between platforms and conventional satellites is not desirable unless additional isolation is obtained by beam separation.

The above consideration indicates that transition to platform systems will be easier at a time when some unoccupied orbital arc is still available, than later when additional spacing between platforms and conventional satellites is no longer available.

8.2 Atlantic Ocean INTELSAT System

8.2.1 Systems Cost Comparison

For INTELSAT service, we calculated costs separately for the international and for the domestic/regional services. In the case of the international ground segment, we assumed a rate of growth of earth stations that is somewhat lower then that in effect now. We expect that many users will combine earth stations for domestic and international service; however, for the purpose of this analysis we separated the two. This results in costs for international ground segment that are not significantly different for the platform and conventional systems.

In the present INTELSAT Atlantic Ocean system there are 73 Standard A earth stations, with antenna diameters of about 30 meters. For transmission, HPA's in the kW range are used. Upon introduction of INTELSAT platforms, it would immediately be possible to reduce the transmit power levels by factors of 10 to 100 with corresponding savings in energy and tube replacement costs. Some of these earth stations have been in operation since the mid 1960's, and their antennas will eventually have to be replaced. With communications platforms, the replacement antennas can be in the 5 to 10 meter range, rather than 30-meter diameter. The smaller antennas will not require tracking, leading to simpler electronics and more reliable operation.

Operation of the space segment was assumed to be done by INTELSAT in the platform case, with the international space segment also under INTELSAT's purview in the conventional satellite system. In the latter instance, however, we included O&M costs for several separate systems, since in the event that only conventional satellites are available, the separate domestic and regional systems would have no incentive to procure service from INTELSAT. They would reason that since INTELSAT would not be offering them anything they could not obtain themselves, their national prestige would be better served by launching their own separate systems. We have assumed that during this 10-year period approximately seven separate systems would evolve. We developed launch schedules for these systems and included development costs in accordance with these schedules.

The annual O&M costs associated with the space segment for all systems combined were computed as follows:

$$\$21 \text{ million} + \$0.4N \text{ million}$$

where N is the number of spacecraft in orbit, including spares.

The INTELSAT annual costs for space segment O&M is computed as follows:

$$\$3.9 \text{ million} + \$0.4N \text{ million}$$

where N is the number of INTELSAT-operated spacecraft in orbit.

In the case of platform systems, we assumed that INTELSAT would operate the entire space segment. The separate domestic and regional customers would be induced to procure their capacity from INTELSAT due to the superior attributes of the space platform.

Table 8-10 is the printout of the computer analysis of the INTELSAT space segment for large platform systems, showing total annual per circuit costs for both domestic and international services. Tables 8-11 and 8-12 show the international ground segment and the domestic ground segment annual per circuit costs, respectively, for this case.

Table 8-10

Economic Model Forecast
Intelsat Platform Space Segment

	Net	---------Annual--------					Cost per	PV of Annual
Year	Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Circuit	Revenue
1987	331	37	4	30	71	80.50	0.88	49
1988	294	37	4	26	67	92.00	0.73	44
1989	455	59	4	41	104	106.00	0.98	65
1990	396	59	4	36	98	121.00	0.81	59
1991	337	59	4	30	93	138.00	0.67	53
1992	279	59	4	25	88	158.00	0.55	48
1993	220	59	4	20	82	180.00	0.46	43
1994	161	59	4	15	77	205.00	0.38	38
1995	103	59	4	9	72	231.00	0.31	34
1996	44	59	4	4	67	270.50	0.25	30

Total of Revenue Requirements = 818
Total Present Value of Revenue = 463
Average Cost per Circuit-Year = 0.52

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-11

Economic Model Forecast
Platform System International Ground Segment

		Annual						PV of
Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	Annual Revenue
1987	49	5	8	4	18	35.00	0.50	12
1988	48	6	8	4	18	40.50	0.46	12
1989	46	6	9	4	19	47.00	0.41	12
1990	46	7	9	4	21	54.50	0.38	12
1991	45	8	10	4	22	63.50	0.35	13
1992	45	9	11	4	24	73.50	0.32	13
1993	45	10	12	4	26	85.50	0.30	13
1994	46	11	13	4	28	99.00	0.28	14
1995	47	12	14	4	31	115.00	0.27	15
1996	48	14	16	4	34	133.50	0.25	15

Total of Revenue Requirements = 240
Total Present Value of Revenue = 131
Average Cost per Circuit-Year = 0.32

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-12

Economic Model Forecast
Platform Foreign Domestic Ground Segment

Year	Net Invest	---------Annual---------				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep +	O&M +	ROI =	Revnu			
1987	213	24	74	19	116	45.50	2.56	80
1988	252	31	71	23	124	51.50	2.41	82
1989	269	36	74	24	134	59.00	2.27	84
1990	249	38	78	22	138	66.50	2.08	83
1991	227	39	83	20	142	74.50	1.91	81
1992	203	41	85	18	145	79.50	1.82	79
1993	178	43	93	16	152	94.50	1.61	79
1994	151	45	99	14	157	106.00	1.48	78
1995	122	46	104	11	161	116.00	1.39	76
1996	91	48	109	8	165	127.00	1.30	75

Total of Revenue Requirements = 1434
Total Present Value of Revenue = 797
Average Cost per Circuit-Year = 1.75

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Tables 8-13 and 8-14 show the space and ground segment costs for international service provided using conventional satellites. Earth stations installed during this period were assumed to conform to a standard similar to today's Standard B. Tables 8-15 and 8-16 show corresponding calculations for the domestic/regional services in the Atlantic Ocean region provided using conventional satellites.

Tables 8-17 and 8-18 are comparison summaries for the two cases: international service and domestic/regional service. The system using large platforms shows a cost advantage of 1.3 to 1 for international service and 1.4 to 1 for domestic service. These ratios are lower than the corresponding ones for U.S. domestic service. This is due primarily to the greater interconnect costs assumed for the countries other than the U.S. and to the larger area to be covered.

Tables 8-19 and 8-20 show a total revenue requirement comparison of the INTELSAT platform and conventional satellite systems.

Table 8-13

Economic Model Forecast
Conventional International Space Segment

		---------Annual---------						
Year	Net Invest	Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	223	25	4	20	49	35.00	1.39	34
1988	198	25	4	18	47	40.50	1.15	31
1989	174	25	4	16	44	47.00	0.94	28
1990	220	33	4	20	56	54.50	1.03	34
1991	187	33	4	17	53	63.50	0.84	31
1992	155	33	4	14	51	73.50	0.69	28
1993	193	41	4	17	62	85.50	0.72	32
1994	223	48	4	20	73	99.00	0.73	36
1995	175	48	4	16	68	115.00	0.59	32
1996	198	56	4	18	78	133.50	0.58	35

Total of Revenue Requirements = 581
Total Present Value of Revenue = 320
Average Cost per Circuit-Year = 0.78

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-14

ECONOMIC MODEL FORECAST
CONVENTIONAL INTERNATIONAL GROUND SEGMENT

	NET	---------ANNUAL--------					COST PER	PV OF ANNUAL
YEAR	INVEST	DEP +	O&M +	ROI =	REVNU	TRAFFIC	CIRCUIT	REVENUE
1987	49	5	8	4	18	35.00	0.51	12
1988	48	6	8	4	19	40.50	0.46	12
1989	48	7	9	4	20	47.00	0.42	12
1990	47	7	10	4	21	54.50	0.39	13
1991	47	8	10	4	23	63.50	0.36	13
1992	47	9	11	4	25	73.50	0.33	13
1993	48	10	12	4	27	85.50	0.31	14
1994	48	11	14	4	29	99.00	0.29	15
1995	50	13	15	4	32	115.00	0.28	15
1996	51	14	17	5	35	133.50	0.27	16

TOTAL OF REVENUE REQUIREMENTS = 248
TOTAL PRESENT VALUE OF REVENUE = 136
AVERAGE COST PER CIRCUIT-YEAR = 0.33

NOTE: TRAFFIC IS IN THOUSANDS OF CIRCUITS
COST IS $THOUSANDS PER CIRCUIT

Table 8-15

Economic Model Forecast
Conventional Foreign Domestic Space Segm

Year	Net Invest	Annual Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	227	25	21	20	67	45.50	1.47	46
1988	202	25	21	18	64	51.50	1.25	42
1989	219	30	21	20	71	59.00	1.20	44
1990	222	34	21	20	75	66.50	1.12	45
1991	237	39	21	21	81	74.50	1.09	46
1992	210	40	21	19	80	79.50	1.01	44
1993	191	43	21	17	81	94.50	0.86	42
1994	169	45	21	15	81	106.00	0.77	40
1995	124	45	21	11	77	116.00	0.67	37
1996	79	45	21	7	73	127.00	0.58	33

Total of Revenue Requirements = 750
Total Present Value of Revenue = 420
Average Cost per Circuit-Year = 0.91

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 8-16

ECONOMIC MODEL FORECAST
CONVENTIONAL FOREIGN DOMESTIC GROUND SEG

YEAR	NET INVEST	---------ANNUAL-------- DEP +	O&M +	ROI =	REVNU	TRAFFIC	COST PER CIRCUIT	PV OF ANNUAL REVENUE
1987	138	15	113	12	141	45.50	3.10	97
1988	133	16	123	12	151	51.50	2.94	100
1989	130	18	134	12	164	59.00	2.77	103
1990	131	20	143	12	175	66.50	2.63	105
1991	139	23	150	12	186	74.50	2.50	106
1992	156	28	150	14	192	79.50	2.41	105
1993	199	36	160	18	214	94.50	2.26	111
1994	214	41	166	19	227	106.00	2.14	113
1995	224	47	170	20	237	116.00	2.05	113
1996	228	52	176	20	249	127.00	1.96	113

TOTAL OF REVENUE REQUIREMENTS = 1936
TOTAL PRESENT VALUE OF REVENUE = 1065
AVERAGE COST PER CIRCUIT-YEAR = 2.36

NOTE: TRAFFIC IS IN THOUSANDS OF CIRCUITS
COST IS $THOUSANDS PER CIRCUIT

Table 8-17

Cost Comparison for Systems Providing INTELSAT Atlantic Ocean Region International Service

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.88	0.50	1.38	1.39	0.51	1.90	1.38
1988	0.73	0.46	1.19	1.15	0.46	1.61	1.35
1989	0.98	0.41	1.39	0.94	0.42	1.36	0.98
1990	0.81	0.38	1.19	1.03	0.39	1.42	1.19
1991	0.67	0.35	1.02	0.84	0.36	1.20	1.18
1992	0.55	0.32	0.87	0.69	0.33	1.02	1.17
1993	0.46	0.30	0.76	0.72	0.31	1.03	1.36
1994	0.38	0.28	0.66	0.73	0.29	1.02	1.55
1995	0.31	0.27	0.58	0.59	0.28	0.87	1.50
1996	0.25	0.25	0.50	0.58	0.27	0.85	1.70
Average	0.52	0.32	0.84	0.78	0.33	1.11	1.32

Table 8-18

Cost Comparison of Systems Providing INTELSAT Atlantic Ocean Region Foreign Domestic Service

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.88	2.56	3.44	1.47	3.01	4.48	1.30
1988	0.73	2.41	3.14	1.25	2.94	4.19	1.33
1989	0.98	2.27	3.25	1.20	2.77	3.97	1.22
1990	0.81	2.08	2.89	1.12	2.63	3.75	1.30
1991	0.67	1.91	2.58	1.09	2.50	3.59	1.39
1992	0.55	1.82	2.37	1.01	2.41	3.42	1.44
1993	0.46	1.61	2.07	0.86	2.26	3.12	1.51
1994	0.38	1.48	1.86	0.77	2.14	2.91	1.56
1995	0.31	1.39	1.70	0.67	2.05	2.72	1.60
1996	0.25	1.30	1.55	0.58	1.96	2.54	1.64
Average	0.52	1.75	2.27	0.91	2.36	3.27	1.44

Table 8-19

Comparison of Total Revenue Requirements for INTELSAT Atlantic Ocean Conventional Satellite and Platform Systems (1987-1996)

(Millions of 1979 Dollars)

	Ground Segment	Space Segment	Total
Platform	1674	818	2492
Satellite	2184	1331	3515
Difference	510	513	1023

Table 8-20

Comparison of Present Valued Total Revenue Requirement for INTELSAT Atlantic Ocean Conventional Satellite and Platform Systems (1987-1996)

(Millions of 1979 Dollars)

	Ground Segment	Space Segment	Total
Platform	928	463	1391
Satellite	1201	740	1941
Difference	273	277	550

8.2.2 Connectivity

We assumed that the various separate domestic and regional systems would not require connectivity. This enables the use of lower cost earth stations in the conventional system. The full connectivity that the platform would provide could be considered a bonus, enabling the same earth stations to be easily used for all services.

8.2.3 Orbital Arc Use

As in the case of U.S. domestic service, the use of large platforms is more efficient with respect to the use of the geostationary arc. Using conventional satellites, 26 orbital locations are required by 1996, as opposed to 2 locations for platforms. This more effective utilization of the orbital arc is certainly of greater significance than the difference in costs. Indeed, a case could be made that even if the platform system were more costly, the conservation of the geostationary arc would stimulate its use. A summary of orbital arc utilization is given in Table 8-21.

Table 8-21

INTELSAT Atlantic Ocean Region

Orbital Arc Utilization Summary

	Platforms	Satellites
Spacing (Degrees)	4	4
Total Orbital Slots Required (1996)	2	26
Orbital Arc Degrees Required (1996)	8	104
Percent of the Total Arc Required	2	29

SECTION 9
SENSITIVITY ANALYSIS

The purpose of this section is to examine the sensitivity of the results to changes in the assumptions. For simplicity we have tested only the U.S. domestic satellite system.

9.1 Variation in Platform Costs

An economic analysis of the platform system space segment was performed with costs increased by 50 percent. This applies to both development and to unit costs; the launch costs associated with the Shuttle remain unchanged. The resulting printout is shown in Table 9-1. The remainder of the system as well as the system using conventional satellites remains the same. The summary results are shown in Table 9-2. The economic advantage of the platform system is about 2 to 1. This compares with a ratio of 2.16 in favor of the platform with the baseline costs.

Table 9-1

Economic Model Forecast
U.S. Platform Space Segment – Increased Cost

	Net	---------Annual--------					Cost per	PV of Annual
Year	Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Circuit	Revenue
1987	424	47	4	64	115	184.00	0.62	79
1988	377	47	4	57	108	202.00	0.53	71
1989	569	74	4	85	163	216.50	0.75	102
1990	495	74	5	74	153	232.50	0.66	91
1991	660	100	5	99	204	249.00	0.82	117
1992	560	100	5	84	189	266.00	0.71	103
1993	460	100	5	69	174	288.00	0.60	91
1994	360	100	5	54	159	301.50	0.53	79
1995	260	100	5	39	144	324.00	0.44	68
1996	159	100	5	24	129	342.50	0.38	58

Total of Revenue Requirements = 1537
Total Present Value of Revenue = 860
Average Cost per Circuit-Year = 0.59

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-2

Cost Comparison for U.S. Domestic Platform for Increased Cost

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.62	1.15	1.77	0.88	1.93	2.31	1.31
1988	0.53	1.15	1.68	0.49	1.98	2.47	1.47
1989	0.75	1.18	1.93	0.51	2.06	2.57	1.33
1990	0.66	1.13	1.79	0.44	2.15	2.59	1.45
1991	0.82	1.09	1.91	0.51	2.30	2.81	1.47
1992	0.71	1.05	1.76	0.51	2.53	3.04	1.73
1993	0.60	1.00	1.60	0.55	2.95	3.50	2.19
1994	0.53	0.97	1.50	0.65	3.18	3.83	2.55
1995	0.44	0.93	1.37	0.66	3.31	3.97	2.90
1996	0.38	0.90	1.28	0.67	3.44	4.11	3.21
Average	0.59	1.04	1.63	0.55	2.69	3.24	1.99

9.2 Variations of Traffic

System cost calculations were performed for traffic variations of ± 50 percent relative to the baseline assumptions. For the platform system, this leads to a change of plus or minus one operating platform, with one common spare being retained for all cases. For the conventional satellite system, the change corresponds to plus or minus five operating satellites at the end of the study period. For the ground segment it was assumed that the same number of earth stations would be retained in either case.

Tables 9-3 through 9-6 present the results for the lower traffic case, and Table 9-7 summarizes these results. The platform is lower in cost by a ratio of 2.3 to 1. Tables 9-8 through 9-11 show the computer results for the higher traffic case, and Table 9-12 summarizes the results. This case, as might have been expected, shows an increased cost advantage for the platform system. The cost ratio of conventional satellite to platform is now 2.2 to 1.

Table 9-3

Economic Model Forecast
U.S. Platform Space Segment - Lower Traffic

Year	Net Invest	---------Annual---------				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep	+ O&M	+ ROI	= Revnu			
1987	314	35	4	47	86	92.00	0.93	59
1988	279	35	4	42	81	101.00	0.80	53
1989	435	56	4	65	126	108.25	1.16	79
1990	379	56	4	57	117	116.25	1.01	70
1991	323	56	4	48	109	124.50	0.87	62
1992	267	56	4	40	100	133.00	0.76	55
1993	211	56	4	32	92	144.00	0.64	48
1994	155	56	4	23	84	150.75	0.55	42
1995	99	56	4	15	75	162.00	0.46	36
1996	42	56	4	6	67	171.25	0.39	30

Total of Revenue Requirements = 937
Total Present Value of Revenue = 534
Average Cost per Circuit-Year = 0.72

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-4

Economic Model Forecast
U.S. Platform Ground Segment - Lower Traffic

		---------Annual--------						PV of
	Net						Cost per	Annual
Year	Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Circuit	Revenue
1987	253	28	86	38	152	92.00	1.66	105
1988	304	37	84	46	166	101.00	1.65	109
1989	327	44	88	49	181	108.25	1.67	113
1990	308	46	93	46	185	116.25	1.59	111
1991	286	49	98	43	189	124.50	1.52	108
1992	261	52	103	39	194	133.00	1.46	106
1993	236	55	109	35	199	144.00	1.38	104
1994	204	57	114	31	202	150.75	1.34	100
1995	173	60	120	26	206	162.00	1.27	98
1996	138	63	126	21	210	171.25	1.23	95

Total of Revenue Requirements = 1884
Total Present Value of Revenue = 1050
Average Cost per Circuit-Year = 1.45

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-5

Economic Model Forecast
U.S. Conventional Space Segment – Lower Traffic

Year	Net Invest	---------Annual--------				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep +	O&M +	ROI =	Revnu			
1987	127	14	4	19	37	92.00	0.40	26
1988	240	28	4	36	68	101.00	0.67	45
1989	402	49	4	60	114	108.25	1.05	71
1990	481	64	4	72	140	116.25	1.20	84
1991	417	64	4	63	130	124.50	1.04	74
1992	417	71	4	63	137	133.00	1.03	75
1993	475	85	4	71	160	144.00	1.11	83
1994	390	85	4	58	147	150.75	0.98	73
1995	369	92	4	55	151	162.00	0.93	72
1996	341	99	4	51	154	171.25	0.90	70

Total of Revenue Requirements = 1238
Total Present Value of Revenue = 673
Average Cost per Circuit-Year = 0.95

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-6

Economic Model Forecast
U.S. Conventional Ground Segment - Lower Traffic

		Annual						
Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	212	24	173	32	228	92.00	2.48	157
1988	264	32	190	40	261	101.00	2.59	172
1989	335	43	205	50	298	108.25	2.76	187
1990	422	58	222	63	343	116.25	2.95	206
1991	565	80	243	85	407	124.50	3.27	233
1992	768	112	270	115	497	133.00	3.74	271
1993	1151	167	318	173	657	144.00	4.56	342
1994	1336	206	350	200	756	150.75	5.02	376
1995	1486	245	388	223	856	162.00	5.28	406
1996	1594	284	424	239	948	171.25	5.53	429

Total of Revenue Requirements = 5251
Total Present Value of Revenue = 2780
Average Cost per Circuit-Year = 4.03

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-7

Cost Comparison for U.S. Domestic Systems With Lower Traffic

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.93	1.66	2.59	0.40	2.48	2.88	1.11
1988	0.80	1.65	2.45	0.67	2.59	3.26	1.33
1989	1.61	1.67	2.83	1.05	2.76	3.81	1.35
1990	1.01	1.59	2.60	1.20	2.95	4.15	1.60
1991	0.87	1.52	2.39	1.04	3.27	4.31	1.80
1992	0.76	1.46	2.22	1.03	3.74	4.77	2.15
1993	0.64	1.38	2.02	1.11	4.56	5.67	2.81
1994	0.55	1.34	1.89	0.98	5.02	6.00	3.17
1995	0.46	1.27	1.73	0.93	5.28	6.21	3.59
1996	0.39	1.23	1.62	0.90	5.53	6.43	3.97
Average	0.72	1.45	2.17	0.95	4.03	4.98	2.29

Table 9-8

Economic Model Forecast
U.S. Platform Space Segment - Higher Traffic

Year	Net Invest	Annual				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep +	O&M +	ROI =	Revnu			
1987	314	35	4	47	86	276.00	0.31	59
1988	279	35	4	42	81	404.00	0.20	53
1989	435	56	4	65	126	324.75	0.39	79
1990	379	56	5	57	118	348.75	0.34	70
1991	514	77	5	77	159	373.50	0.43	91
1992	436	77	5	65	148	399.00	0.37	81
1993	550	98	5	82	186	432.00	0.43	97
1994	451	98	5	68	171	452.25	0.38	85
1995	353	98	5	53	157	486.00	0.32	74
1996	254	98	5	38	142	513.75	0.28	64

Total of Revenue Requirements = 1373
Total Present Value of Revenue = 754
Average Cost per Circuit-Year = 0.34

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-9

Economic Model Forecast
U.S. Platform Ground Segment - Higher Traffic

		Annual						
Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	385	43	218	58	318	276.00	1.15	219
1988	508	61	248	76	386	404.00	0.95	254
1989	444	61	194	67	322	324.75	0.99	202
1990	419	65	204	63	332	348.75	0.95	199
1991	390	69	215	59	342	373.50	0.92	196
1992	358	73	227	54	353	399.00	0.89	193
1993	327	78	242	49	368	432.00	0.85	192
1994	282	81	251	42	375	452.25	0.83	186
1995	243	86	267	37	389	486.00	0.80	185
1996	196	90	280	29	400	513.75	0.78	181

Total of Revenue Requirements = 3585
Total Present Value of Revenue = 2006
Average Cost per Circuit-Year = 0.89

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-10

Economic Model Forecast
U.S. Conventional Space Segment – Higher Traffic

	Net	---------Annual--------					Cost per	PV of Annual
Year	Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Circuit	Revenue
1987	254	28	4	38	70	276.00	0.25	48
1988	353	42	4	53	99	404.00	0.25	65
1989	438	56	4	66	126	324.75	0.39	79
1990	509	71	4	76	151	348.75	0.43	90
1991	630	92	4	95	190	373.50	0.51	109
1992	602	99	4	90	193	399.00	0.48	106
1993	695	120	4	104	229	432.00	0.53	119
1994	638	127	4	96	227	452.25	0.50	113
1995	766	156	4	115	275	486.00	0.57	130
1996	802	177	4	120	301	513.75	0.59	137

Total of Revenue Requirements = 1862
Total Present Value of Revenue = 997
Average Cost per Circuit-Year = 0.46

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-11

Economic Model Forecast
U.S. Conventional Ground Segment - Higher Traffic

Year	Net Invest	----------Annual--------				Traffic	Cost per Circuit	PV of Annual Revenue
		Dep +	O&M +	ROI =	Revnu			
1987	344	38	485	52	575	276.00	2.08	396
1988	468	56	686	70	813	404.00	2.01	535
1989	452	61	545	68	674	324.75	2.07	423
1990	533	76	569	80	725	348.75	2.08	434
1991	669	100	587	100	788	373.50	2.11	451
1992	865	133	609	130	871	399.00	2.18	476
1993	1242	190	643	186	1019	432.00	2.36	531
1994	1414	230	664	212	1105	452.25	2.44	550
1995	1556	271	699	233	1203	486.00	2.48	571
1996	1652	312	731	248	1290	513.75	2.51	585

Total of Revenue Requirements = 9063
Total Present Value of Revenue = 4950
Average Cost per Circuit-Year = 2.26

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-12

Cost Comparison for U.S. Domestic System With Higher Traffic

(Thousands of 1979 Dollars Per Circuit Year)

	Platform			Conventional Satellites			
Year-End	Space	Ground	Total	Space	Ground	Total	Cost Ratio of Conventional to Platform
1987	0.31	1.15	1.46	0.25	2.08	2.33	1.60
1988	0.20	0.95	1.15	0.25	2.01	2.26	1.97
1989	0.39	0.99	1.38	0.39	2.07	2.46	1.78
1990	0.34	0.95	1.29	0.43	2.08	2.51	1.95
1991	0.43	0.92	1.35	0.51	2.11	2.62	1.94
1992	0.37	0.89	1.26	0.48	2.18	2.66	2.11
1993	0.43	0.85	1.28	0.53	2.36	2.89	2.26
1994	0.38	0.83	1.21	0.50	2.44	2.94	2.43
1995	0.32	0.80	1.12	0.57	2.48	3.05	2.72
1996	0.28	0.78	1.06	0.59	2.51	3.10	2.92
Average	0.34	0.89	1.23	0.46	2.26	2.72	2.21

9.3 Video Conferencing

The baseline traffic model assumes that the system would not carry significant quantities of video conferencing. This section examines the impact on the space segment of including video conferencing in the traffic model (Section 5.2.3).

High quality video conferencing is possible with 6.3 Mbps per one-way channel,using interframe compression techniques. On this basis one video channel corresponds to 100 voice channels, and we obtain 10 one-way video channels per reference transponder. The baseline platform can carry about 1875 two-way video conferencing circuits, while the baseline satellite can carry about 360 two-way circuits. In the latter case, multiple satellites are needed, and earth stations encounter the familiar connectivity problem.

In providing video conferencing service through platforms, we have first used the available spare capacity in the communications platforms. The communications platforms were saturated in 1990, and at that time we introduced a dedicated video conferencing platform. Finally we placed overflow video conferencing traffic onto the spare platform. In case of failure of any platform, the video conferencing capacity of the system would then be reduced to 50 percent of the end-year requirements.

In the system using conventional satellites, there is little spare capacity on board operating satellites, and it is necessary to launch dedicated video conferencing satellites early in the study period.

Tables 9-13 and 9-14 present the economic analysis for the space segment needed to carry the video conferencing traffic. The platform system is essentially "cost free" for the first few years; in reality, some assignment of costs would be made in order to ascertain charges for this service.

We have not attempted to analyze the ground segment for video conferencing; the necessary equipment is complex, and the only feasible location for the earth station is at the point of origin of the traffic. This is due to the prohibitive cost of terrestrial tie-in for such a high speed service.

Table 9-13

Economic Model Forecast
Video Conferencing - Platform System

Year	Net Invest	---------Annual-------- Dep	+ O&M	+ ROI	= Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	0	0	0.0	0	0	0.35	0.00	0
1988	0	0	0.0	0	0	0.55	0.00	0
1989	0	0	0.4	0	0	0.85	0.47	0
1990	191	21	0.4	29	50	1.30	38.63	30
1991	170	21	0.4	25	47	1.85	25.43	27
1992	148	21	0.4	22	44	2.45	17.90	24
1993	127	21	0.4	19	41	3.40	11.96	21
1994	106	21	0.4	16	37	3.15	11.90	19
1995	85	21	0.4	13	34	3.35	10.24	16
1996	64	21	0.4	10	31	3.51	8.87	14

Total of Revenue Requirements = 285
Total Present Value of Revenue = 151
Average Cost per Circuit-Year = 13.74

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

Table 9-14

Economic Model Forecast
Video Conferencing - Conventional System

		----------Annual--------						
Year	Net Invest	Dep +	O&M +	ROI =	Revnu	Traffic	Cost per Circuit	PV of Annual Revenue
1987	64	7	0.8	10	17	0.35	49.96	12
1988	185	21	1.2	28	50	0.55	91.25	33
1989	227	28	2.0	34	64	0.85	75.86	40
1990	327	43	2.4	49	94	1.30	72.30	56
1991	348	50	3.2	52	105	1.85	56.80	60
1992	426	64	3.6	64	131	2.45	53.63	72
1993	426	71	4.4	64	139	3.40	40.97	73
1994	483	85	4.4	72	162	3.15	51.43	81
1995	398	85	4.8	60	150	3.35	44.67	71
1996	376	92	4.8	56	154	3.51	43.74	70

Total of Revenue Requirements = 1067
Total Present Value of Revenue = 567
Average Cost per Circuit-Year = 51.40

Note: Traffic is in thousands of circuits
Cost is $thousands per circuit

SECTION 10

CONCLUSIONS

The use of large geostationary platforms for satellite communications will bring several substantial changes. Some of the changes that were explored in this study are as follows:

1. The high antenna gain of the platform will drastically lower the cost of the ground segment, resulting in a proliferation of earth stations. The terrestrial interconnect costs will drop due to the co-location of traffic source and earth station. Space segment costs per channel will drop, despite the larger initial investment required.

2. The large capacity of the platforms will result in a requirement for fewer slots in the geostationary orbit. This will relieve the congestion that would result from the use of conventional satellites.

3. The switching capability of the large platforms will eliminate the need for complex switching at the earth stations. Earth stations will no longer be required to access more than one spacecraft.

The conclusions of this study are as follows:

1. The cost advantage of a platform system to a conventional satellite system for U.S. domestic services is 2 to 1.

2. The cost advantage of a platform system to a conventional satellite system for INTELSAT Atlantic Ocean services is 1.3 to 1.

3. The total cost savings over the 1987 to 1996 study period for the U.S. domestic platform system over the satellite system is $4.5 billion.

4. The total cost savings over the 1987 to 1996 study period for the Atlantic Ocean platform system over the satellite system is $1 billion.

5. Further cost savings will result in later years.

6. Conventional satellites require 5 times as much orbital arc as platforms for the U.S. domestic system.

7. Conventional satellites require 13 times as much orbital arc as platforms for the INTELSAT Atlantic Ocean system.

8. Transition from satellites to platforms should occur around 1987 to minimize the interference problems associated with operation of inhomogeneous systems.

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ANNEX A

TRAFFIC MODEL FOR DOMESTIC AND REGIONAL SERVICES WITHIN INTELSAT'S ATLANTIC OCEAN SATELLITE SYSTEM

A.1 Scope of Model

This Annex provides a model of requirements within the Atlantic Ocean area for domestic and regional public telecommunications services by potential users of the INTELSAT space segment. The model includes domestic and regional communications service requirements within those regions which have not yet made a firm committment for the provision of space segment separate from INTELSAT. It excludes requirements for service within regions which already operate systems separate from INTELSAT or have announced a committment to such systems. The rationale for including or excluding countries and regions from the model is given below.

South America	Preliminary studies aimed at the implementation of systems separate from INTELSAT have been performed by Brazil, Colombia and by ASETA. However, to date neither entity has made a firm committment in terms of space segment procurement. For this reason INTELSAT will have the opportunity to provide a large portion of South America's domestic and regional satellite communications services.
Africa (excluding Arab countries)	None of the African countries has yet made a committment towards the procurement of space segment separate from INTELSAT, and for this reason INTELSAT may provide all of Africa's domestic and regional satellite communications requirements.
Middle East (and African Arab Countries)	The Arab Satellite Telecommunications Organization has selected COMSAT General as consultant to aid in planning for and implementation of a regional communications satellite system. Iran is planning for a separate domestic satellite system. For this reason we have excluded domestic and regional requirements of the Arab countries and Iran from the INTELSAT traffic model.

U.S.	The U.S. has four domestic satellite communications systems in operation: AT&T/COMSTAR, Western Union/WESTAR, RCA/SATCOM and American Satellite Corporation. A fifth system, that of SBS, is being procured. It is therefore not likely that the U.S. will ask INTELSAT to provide domestic services during the study period.
Canada	Canada has operated its ANIK System since 1972 and has procured follow-on ANIK B and ANIK C satellites. Canada is therefore not a likely user of INTELSAT space segment for domestic purposes.
Western Europe	In early 1978 the European PTTs and the European Space Agency decided to manufacture the European Communications Satellites (ECS) to provide regional services within EUTELSAT. It is therefore not probable that INTELSAT will be asked to provide domestic and regional services for Western Europe.

Based on these considerations, we have included the domestic and regional communications requirements of the following areas in the INTELSAT traffic model:

South America
Africa, excluding the Arab Countries

A.2 Forecasting Method

FSI has developed a 25-year forecast for communications service demand for satellite transmission. The following types of services are included in the forecast:

Telephony Traffic - Domestic and Regional
Data Traffic - Domestic and Regional

As discussed in Section 3 of the report, TV distribution services will not be provided on the large platform, and we have therefore eliminated this service category from the model. Likewise, direct TV broadcasting will not be included on the platform, since the same frequency band is shared with fixed point to point services. For this reason the TV broadcast service has also been excluded from the model.

A detailed description of the development of the forecasting model is given in FSI Report No. 103, "A 25-Year Forecast for Commercial Communications Satellites and the Congestion of the Geostationary Arc". The model is based on demographic and economic indicators and on service use correlation factors. The forecasting methodology is summarized below.

The forecast of conventional telephony traffic requirements is based on correlation factors which have been derived from historical data and which are applied to forecasts of future population and GNP numbers. One very useful correlation factor was found to be the measure of GNP per telephone. It was found that this factor generally converges to similar numbers as each country progresses in its economic and technological development. Another important factor is the ratio of long distance telephone calls per telephone. Finally, we used the ratio of long distance calls per unit GNP as another correlation factor.

Applying these factors for predictions of future traffic requires assumptions of certain demographic data. Specifically, it requires estimates of future GNP and population in the countries or world regions under study. With these demographic forecasts and the correlation factors which were developed from historical telecommunication statistics, we predicted future long distance telephone traffic. Number of calls were translated into a required number of trunks by the use of information on the average call duration, number of channels per trunk and the desired grade of service.

Next it was necessary to determine the percentage of the total traffic that would likely be transmitted via satellites. This is a matter of economics and depends also on the extent of development of the terrestrial network. For example, in the U.S. the economic break-even point between terrestrial and satellite transmission is about 500 miles at this time but it will drop in the future. This means that communications of over 500 miles are cheaper via satellite. Communications between two points which are less than 500 miles apart are generally cheaper via terrestrial facilities. This is a typical figure which depends upon a variety of assumptions. In developing countries, especially in the tropics, the terrestrial transmission facilities are much less developed, and where they exist they are more costly to implement. In such countries the break-even distance is smaller, and a larger percentage of the traffic can be expected to be carried via satellites. Based on these considerations, the total telephony traffic estimates were developed.

Extrapolation of historical data leads only to a traffic estimate for the types of traffic which has been carried in the past. New technology and other changing conditions lead to the introduction of new services for which traffic estimates must be based on market forecasts and other considerations. One major category of new services is the type of data communications traffic which is the target of Satellite Business Systems (SBS). Our forecast for this type of service is based on the SBS market survey which was described in a 1976 FCC filing.

A.3 Demographic and Economic Data

Table A-1 provides a detailed listing of the population and GNP per capita for each of the countries considered.

Table A-1

Demographic and Economic Data

Country or Region	1978 Population in Millions	1978 GNP/Cap in 1978 U.S. Dollars
South America:		
Argentina, Brazil and Venezuela		
Argentina	26.3	1011
Brazil	115.2	1306
Venezuela	13.1	2890
Total Population	154.6	
Average GNP/Capita		1390
Colombia, Peru and Chile		
Colombia	25.8	672
Peru	17.1	443
Chile	10.9	542
Total Population	53.8	
Average GNP/Capita		573
Others		
Bolivia	6.1	484
Ecuador	7.8	855
French Guiana	0.1	1680
Guyana	0.1	790
Paraguay	2.9	740
Suriname	0.5	1220
Uraguay	3.2	1360
Total Population	20.7	
Average GNP/Capita		820
Total for South America	229.1	1147

Table A-1, Continued

Demographic and Economic Data

Country or Region	1978 Population in Millions	1978 GNP/Cap in 1978 U.S. Dollars
Africa:		
Nigeria and Ghana		
Nigeria	68.2	406
Ghana	11.0	607
Total Population	79.2	
Average GNP/Capita		434
Ethiopia, Sudan and Zaire		
Ethiopia	29.7	123
Sudan	17.5	240
Zaire	27.1	156
Total Population	74.3	
Average GNP/Capita		163
South Africa	28.6	1502
Others		
Angola	5.7	347
Botswana	0.7	431
Burundi	4.1	126
Benin	3.4	137
Cameroon	6.8	305
Central African Republic	1.9	242
Chad	4.3	126
Djibouti	0.2	2037
Equatorial Guinea	0.3	347
Gabon	0.6	2720

Table A-1, Continued

Demographic and Economic Data

Country or Region	1978 Population in Millions	1978 GNP/Capita in 1978 U.S. Dollars
Africa		
Others, continued		
Guinea	6.0	158
Guinea-Bissau	0.6	147
Ivory Coast	5.3	970
Kenya	14.8	250
Liberia	1.8	440
Malagasy Republic	8.8	220
Malawi	5.7	147
Mali	6.1	105
Mauritania	1.4	357
Mauritius	0.9	810
Mozambique	9.9	179
Niger	5.0	168
Republic of the Congo	1.4	546
Rhodesia	7.0	578
Rwanda	4.5	116
Senegal	5.9	410
Sierra Leone	3.5	230
Somalia	3.4	116
Tanzania	16.4	189
Togo	2.4	350
Uganda	12.8	252
Upper Volta	6.5	116
Zambia	5.5	560
Total Population	164.4	
Average GNP/Capita		283
Total for Africa	346.5	392

A forecast of population and GNP data was generated for each of the regions or groupings of countries. Population is shown in Table A-2, GNP per capita is shown in Table A-3 and total GNP is shown in Table A-4.

Table A-2

Population (Millions)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	155	174	194	213	234	255
Col Peru Chile	54	60	67	74	81	89
Other So. Am.	21	24	27	30	33	35
Nigeria Ghana	79	90	101	112	123	134
Ethpa Sud Zar	74	84	94	105	116	126
South Africa	29	34	38	40	42	46
Other Africa	164	186	209	233	256	278
Total	577	652	729	807	885	964

Table A-3

GNP Per Capita (Dollars)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	1390	1691	2058	2503	3046	3705
Col Peru Chile	573	684	816	974	1162	1387
Other So. Am.	820	910	1009	1120	1243	1379
Nigeria Ghana	434	498	572	657	754	866
Ethpa Sud Zar	163	171	180	189	199	209
South Africa	1502	1750	2038	2374	2766	3222
Other Africa	283	309	338	370	404	442
Total	693	818	963	1133	1338	1589

Table A-4

GNP (Billions of Dollars)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	215	294	398	534	712	946
Col Peru Chile	31	41	55	72	94	123
Other So. Am.	18	22	27	33	40	49
Nigeria Ghana	34	45	58	74	93	116
Ethpa Sud Zar	12	14	17	20	23	26
South Africa	43	59	77	96	118	148
Other Africa	47	58	71	86	104	123
Total	400	533	702	915	1184	1531

A.4 Telephony Traffic - Domestic and Regional

Table A-5 shows the number of long distance calls per $1,000 GNP for each of the groups of countries for the next 25 years in 5-year intervals. The telephone use per unit GNP is shown to increase with time as it has in the past. However, the model shows that for the developed countries this trend levels off in the 1990's. Table A-6 shows the total number of long distance calls per year in the same format. This Table results from multiplication of the data in Tables A-4 and A-5 (Long Distance Calls Per $1,000 GNP).

Table A-7 shows the percentage of long distance calls which will be carried on communications satellites during the 25-year study period for each of the groups of countries.

Table A-8 shows millions of satellite call minutes per year. This information was derived by multiplying the data of Table A-6 with those of Table A-7 and by multiplying the results by 9 on the basis of an average call duration of 9 minutes.

Table A-9 shows the resulting telephony traffic in transponders or units of 1,000 one-way voice channels. This information is found by multiplying the data of Table A-8 by 17.4. The derivation of the factor of 17.4 is shown below:

a. It was assumed that the total traffic is distributed over the equivalent of 2,400 busy hours per year. On this basis the Erlang load is calculated as:

   1 billion call minutes/2,400 hours x 60 = 6,944 Erlangs

b. The trunk distribution and grade of service are such that the required ratio of Erlangs to circuits is 0.8. Therefore, one billion call minutes per year require 8,680 circuits.

c. One reference transponder handles 1,000 one-way channels or 500 two-way circuits. Therefore, one billion call minutes per year requires 17.4 transponders.

Table A-5

Long Distance Calls per $1000 GNP
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	6.3	7.9	9.4	10.6	11.3	11.9
Col Peru Chile	6.3	7.9	9.4	10.6	11.3	11.9
Other So. Am.	6.3	7.9	9.4	10.6	11.3	11.9
Nigeria Ghana	2.6	3.8	5.3	7.0	8.8	10.0
Ethpa Sud Zar	2.6	3.8	5.3	7.0	8.8	10.0
South Africa	6.3	8.0	10.1	12.8	16.7	22.5
Other Africa	2.6	3.8	5.3	7.0	8.8	10.0
Total	5.4	7.0	8.6	10.1	11.4	12.6

Table A-6

Total Long Distance Calls (Millions)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	1350	2332	3750	5638	8049	11232
Col Peru Chile	193	328	517	762	1067	1461
Other So. Am.	111	174	256	351	457	581
Nigeria Ghana	91	170	306	518	814	1159
Ethpa Sud Zar	32	55	90	140	202	262
South Africa	273	475	775	1229	1967	3329
Other Africa	123	219	375	606	907	1228
Total	2173	3753	6068	9244	13463	19252

Table A-7

Percent of Traffic Carried via Satellite
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	1.4	5.8	8.7	10.7	12.1	13.0
Col Peru Chile	2.1	6.2	9.0	10.9	12.2	13.1
Other So. Am.	0.0	4.6	8.3	10.5	11.9	12.7
Nigeria Ghana	21.1	19.5	18.1	16.9	16.0	15.1
Ethpa Sud Zar	19.5	18.4	17.5	16.6	15.9	15.2
South Africa	0.0	1.2	5.6	8.3	10.0	11.0
Other Africa	15.4	15.3	15.2	15.2	15.1	15.0

Table A-8

Total Satellite Call-Minutes (Millions)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	173	1209	2940	5439	8756	13158
Col Peru Chile	37	184	420	750	1175	1725
Other So. Am.	0	72	191	333	489	666
Nigeria Ghana	172	298	498	790	1170	1578
Ethpa Sud Zar	56	91	142	210	288	359
South Africa	0	51	394	923	1766	3287
Other Africa	170	302	515	827	1232	1661
Total	609	2208	5100	9272	14877	22433

Table A-9

Total Satellite Telephony Traffic
(In Thousands of Voice Channels or Transponders)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	3	21	51	95	152	229
Col Peru Chile	1	3	7	13	20	30
Other So. Am.	0	1	3	6	9	12
Nigeria Ghana	3	5	9	14	20	27
Ethpa Sud Zar	1	2	2	4	5	6
South Africa	0	1	7	16	31	57
Other Africa	3	5	9	14	21	29
Total	11	38	89	161	259	390

The term "transponder" has been used as a convenient reference to measure traffic requirements. A transponder of this type would have a bandwidth of 36 MHz and an EIRP of 33 dBW, which is representative of current domestic C-band transponders. The capacity of such a transponder varies with the earth station sizes into which it transmits and with the modulation/access technique used. A capacity of 1,000 one-way channels per transponder represents the average capacity that is achieved with a reasonably efficient system. The measure in number of transponders is not intended to imply that the future traffic will be carried on such transponders. Actual satellite transmission systems will be optimized for different applications and may use transmission facilities which are quite different from today's transponders.

A.5 Data Transmission - Domestic and Regional

Advances in computer technology and application have introduced new data transmission services which will be in extensive use by the year 2003. These services will require space segment capacity in addition to that which has been extrapolated from the historical use of the telephone system.

In a filing with the U.S. Federal Communications Commission (FCC) in April 1976, Satellite Business Systems (SBS) shows that 415 major U.S. corporations will create a market for satellite data transmission equivalent to 100,000 voice circuits by 1985. At 1,000 one-way channels per transponder, this corresponds to 200 equivalent C-band transponders. SBS states that the market is further increased by requirements from smaller corporations and from government agencies. To be conservative we have cut this forecast in half and applied it to each country or region in proportion with projected GNP.

Table A-10

New Data Transmission Requirements (Transponders)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	0.0	0.8	5.1	10.2	16.2	23.7
Col Peru Chile	0.0	0.1	0.7	1.4	2.2	3.1
Other So. Am.	0.0	0.1	0.4	0.6	0.9	1.2
Nigeria Ghana	0.0	0.1	0.7	1.4	2.1	2.9
Ethpa Sud Zar	0.0	0.0	0.2	0.4	0.5	0.7
South Africa	0.0	0.2	1.0	1.8	2.7	3.7
Other Africa	0.0	0.2	0.9	1.6	2.4	3.1
Total	0.0	1.4	9.1	17.4	27.0	38.4

A.6 Total Transponder Requirements - Domestic and Regional

Telephony and data transmission may use similar types of satellite transponders. The total requirements for these two services can therefore be summed as shown in Table A-11.

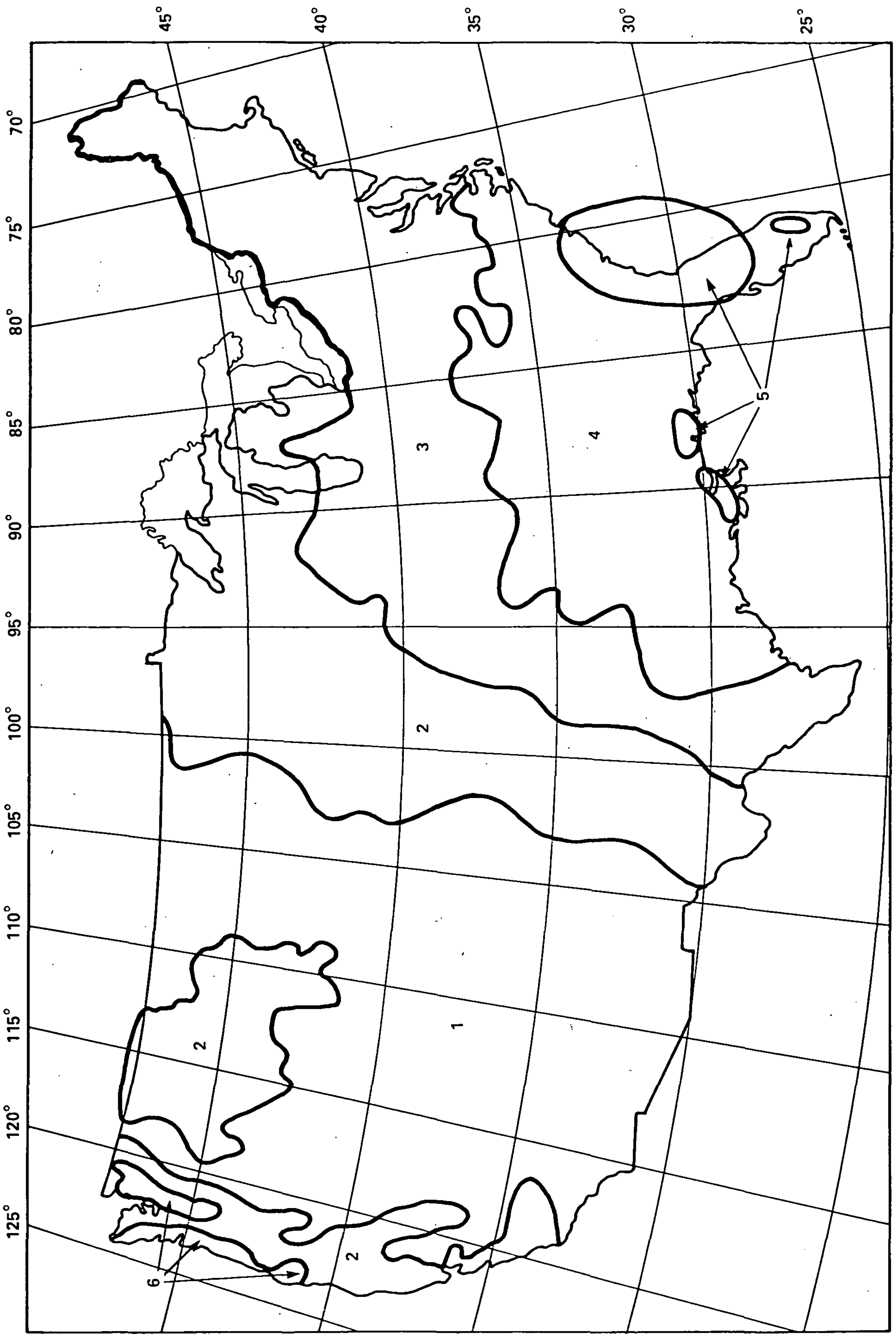
Table A-11

Total Requirements (Transponders)
South American and African Systems

Mid-Year:	1978	1983	1988	1993	1998	2003
Arg Bzl Venz	3.0	21.8	56.3	104.8	168.6	252.7
Col Peru Chile	0.6	3.3	8.0	14.4	22.6	33.1
Other So. Am.	0.0	1.3	3.7	6.4	9.4	12.8
Nigeria Ghana	3.0	5.3	9.4	15.2	22.5	30.4
Ethpa Sud Zar	1.0	1.6	2.7	4.0	5.5	6.9
South Africa	0.0	1.0	7.8	17.9	33.4	60.9
Other Africa	3.0	5.4	9.9	16.0	23.8	32.0
Total	10.6	39.9	97.8	178.8	285.9	428.7

ANNEX B
CLIMATOLOGICAL ZONES FOR CONUS

The map shown in this Annex depicts the geographical boundaries of rain zones within the contiguous United States. These zones are used to determine the required precipitation margins as shown in Tables 6-6 and 6-7 in Section 6 of this report.



CLIMATOLOGICAL ZONES FOR CONUS