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FSI Report No. 251

CROSS-IMPACT OF FOREIGN SATELLITE COMMUNICATIONS ON NASA's 30/20 GHz PROGRAM

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Prepared For

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Disclaimer

The contents of this report are the sole responsibility of Future Systems Incorporated except where explicitly identified as extracted from other work. The conclusions in general and the systems configurations in particular were formulated by FSI and should not be construed as reflecting the opinions of NASA or any of its agents.

ABSTRACT

This report considers the impact of foreign satellite communications systems on NASA's 30/20 GHz development program. The Report includes a comprehensive traffic demand forecast, a scenario for the transition process from current satellite systems to more advanced systems of the 1990's, systems configurations with and without the use of 30/20 GHz, and a comparison of these two alternatives. Conservative figures were used in computing the estimates presented herein; therefore, the total impact of 30/20 GHz development could be much greater than indicated below.

The demand forecast is based on earlier work performed for NASA Lewis and other entities. It is keyed to the relative level of development of the economies of world regions, as measured by GNP. The forecast estimates a total world demand of 5000 transponders for voice and data, and 33000 transponders for video teleconferencing by the year 2000. Transponders equivalent to those used in current domestic systems are used as a measure for demand.

The need for evolutionary improvement in satellite capacity and flexibility is indicated by a comparison of current trends with the projected traffic demand. Capacities per satellite on the order of 300 to 800 transponders are required by the year 2000, but current trends project development of satellites with much lower capacity. This clearly shows the need for the 30/20 GHz bands as well as additional technology improvements.

The addition of 30/20 GHz capability to communications satellites can be expected to have several benefits. Despite the somewhat higher cost for items of 30/20 GHz equipment, the total cost per channel will be reduced. This will occur because of the higher capacity per satellite resulting from the use of 30/20 and other techniques. Connectivity will also be enhanced at reduced cost. Furthermore, in many regions of the world, the lower frequency bands are made unaccessable by the dense terrestrial microwave networks. The many benefits of customer-premise earth stations will then be available only through the use of 30/20 GHz.

Based on our market analysis, U.S. industry could expect to sell equipment and spacecraft for use at 30/20 GHz in some regions of the world. If video teleconferencing is developed as a market, we estimate direct sales on the order of $8 billion. If only voice and data markets are considered, direct sales would total about $1 billion. Indirect benefits to U.S. industry would proceed from improved communications, particularly direct manufacturer to customer communications. These improvements could increase U.S. sales abroad in many product areas.

The major conclusions of this Report can be summarized as follows:

1) The use of 30/20 GHz will result in increased satellite capacity, which will be needed to satisfy demand.
2) The use of 30/20 GHz will decrease the transmission cost, especially for broadband communications.
3) In some areas, particularly Europe and Japan but also the U.S., 30/20 GHz is the only available frequency band for customer premise earth stations. This is because of the dense terrestrial microwave networks.
4) The development of 30/20 GHz technology will improve U.S. markets for equipment and satellites in many world regions.

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SECTION 1
EXECUTIVE SUMMARY

This report was prepared for NASA Lewis Research Center under NASA Contract NAS 3-21500. The report examines the interaction between NASA's 30/20 GHz Program and existing, planned, or possible foreign satellite communications systems. The primary consideration in this contract has been the examination of potential markets for U.S. industry which may arise as a result of the 30/20 GHz Program.

1.1 Traffic Projections

The utility of a satellite communications system can only be measured with respect to the accommodation of the traffic demand. In examining future satellite systems, therefore, it is useful to develop traffic projections. Based on earlier work performed by Western Union and ITT for NASA Lewis, FSI has prepared a traffic model for the U.S. domestic service. In the present report, this model is extended by means of economic correlation factors to encompass the entire world. This model takes into account expected technology advances and reductions in transmission costs, legislative and regulatory changes permitting increased competition, and rising energy costs which will encourage more extensive substitution of telecommunications for travel.

In global forecasting it is standard practice to segregate countries into world model regions of similar political and economic characteristics. For the FSI model, we have segregated the world into two major groups as follows:

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Group I	North America Western Europe USSR Eastern Europe Japan
Group II	Latin America Middle East China Asia Africa
Other Countries	Those not covered in Groups I and II

Satellite transmission requirements have been expressed in units of transmission capacity equivalent to a typical domestic transponder with 36 MHz bandwidth. Such a transponder is capable of transmitting approximately 1,000 one-way voice channels or 64 Mbps of one-way data.* A summary of the total requirements is shown in Tables 1-1 and 1-2 and in Figure 1-1. Since there is still some uncertainty concerning the development of video conferencing systems, we have performed the subsequent analysis for a "high traffic" model which includes video conferencing and for a "low traffic" model which contains voice and data requirements only.

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

Table 1-1

Total Requirements - Low Traffic Model

(Domestic and Regional)

(Transponders)

Mid-Year	1980	1984	1988	1992	1996	2000
North America	131	284	458	653	858	1,083
Western Europe	56	245	470	803	1,141	1,515
U.S.S.R.	11	27	52	91	169	280
Eastern Europe	0	21	66	107	140	148
Japan	46	141	236	359	460	538
Total Group I	244	718	1,282	2,013	2,768	3,565
Latin America	7	46	128	269	485	766
Middle East	3	11	28	57	113	241
China	0	2	9	23	49	97
Asia	17	38	81	164	312	579
Africa	6	15	26	41	59	78
Total Group II	33	112	272	553	1,017	1,761
TOTAL	277	836	1,568	2,590	3,821	5,376

Table 1-2

Total Requirements - High Traffic Model

(Domestic, Regional, and International)

(Transponders)

	1980	1984	1988	1992	1996	2000
Regional Traffic	277	836	1,568	2,590	3,821	5,376
INTELSAT Traffic	46	78	120	173	244	342
Video Conferencing	7	36	1,558	8,998	19,468	33,521
Total High Traffic Model	330	950	3,246	11,961	23,533	39,239

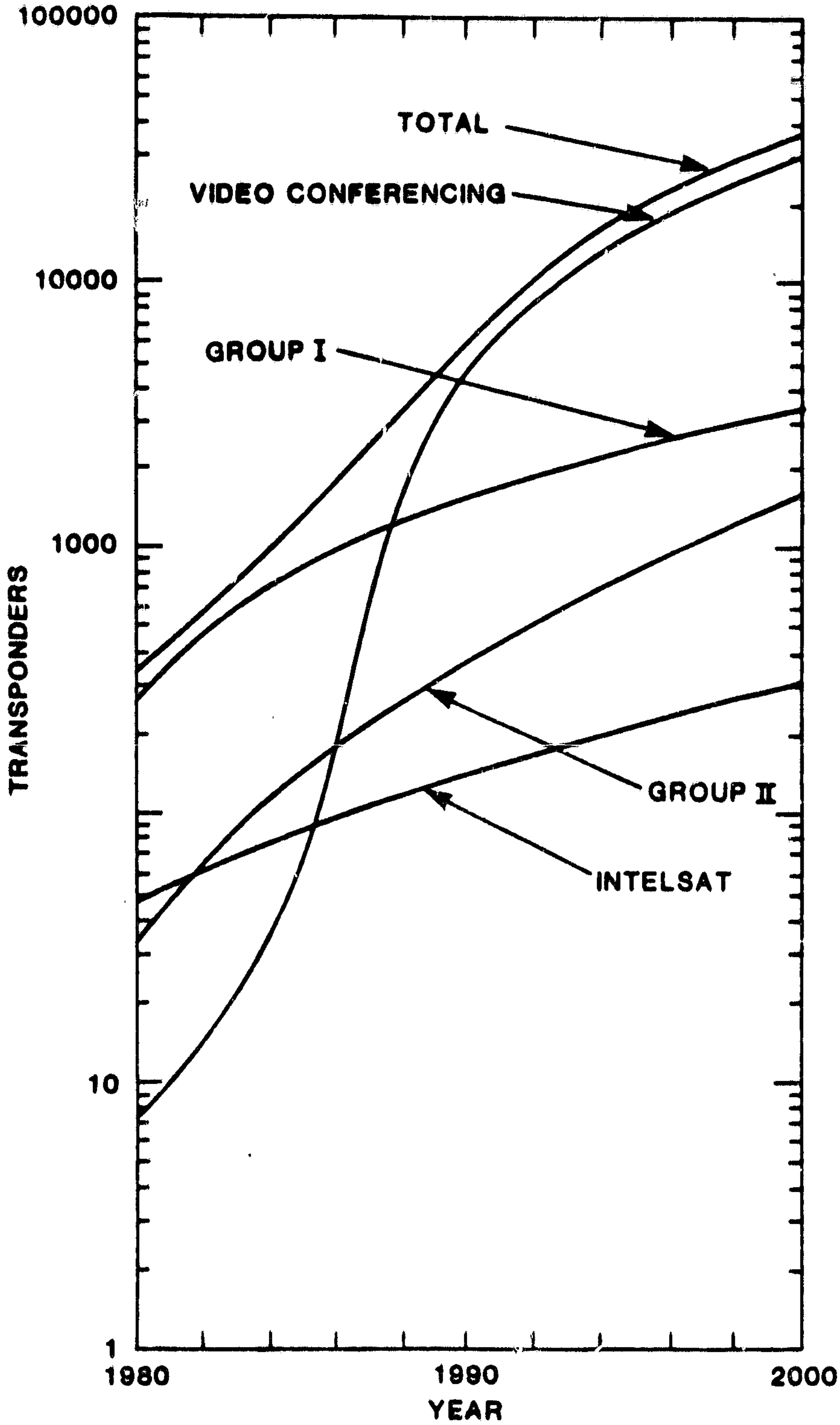

Figure 1-1
WORLD TRAFFIC DEMAND FORECAST

(High Traffic Model)

1.2 Systems Evolution

Because of increasing pressure on the limited orbital capacity, satellite systems in the developed countries will be driven to increasing levels of sophistication. The rate at which this process will occur will depend on, among other things, the development of 30/20 GHz technology. The additional frequency space afforded thereby will have several beneficial effects: in multibeam systems, capacity will be available to alleviate saturation in high traffic areas. The capacity per satellite will be increased, thus lowering the cost per transponder in orbit. In addition, in regions such as Western Europe, where the present terrestrial microwave network is quite dense both at C-band and Ku-band, 30/20 GHz will likely be the only frequency band available for widespread use. This type of coverage, where earth stations can be freely located, is essential for the development of direct-to-the-user, or customer-premises type services.

The need for additional development to increase capacity can be seen by comparing Figure 1-2, which shows our estimation of the evolutionary trends of current satellite technology (without 30/20 GHz) with Figures 1-3 and 1-4, which show the required capacity per orbital slot for the developed world regions. It is apparent that the high traffic model, which includes substantial customer-premises services such as video conferencing, cannot be satisfied using the present technology trend.

1.3 Systems Which Do Not Use 30/20 GHz

With a continuation of current trends, an advanced form of on-board switching is expected around 1990. This will enable operational satellites with multibeam technology to have capacities of about 130 equivalent transponders. Depending on the traffic density, lower, or slightly higher capacities will also be designed. Based on this premise, we have configured systems and coverages for the world model regions. The resulting satellite capacities are shown in Table 1-3.

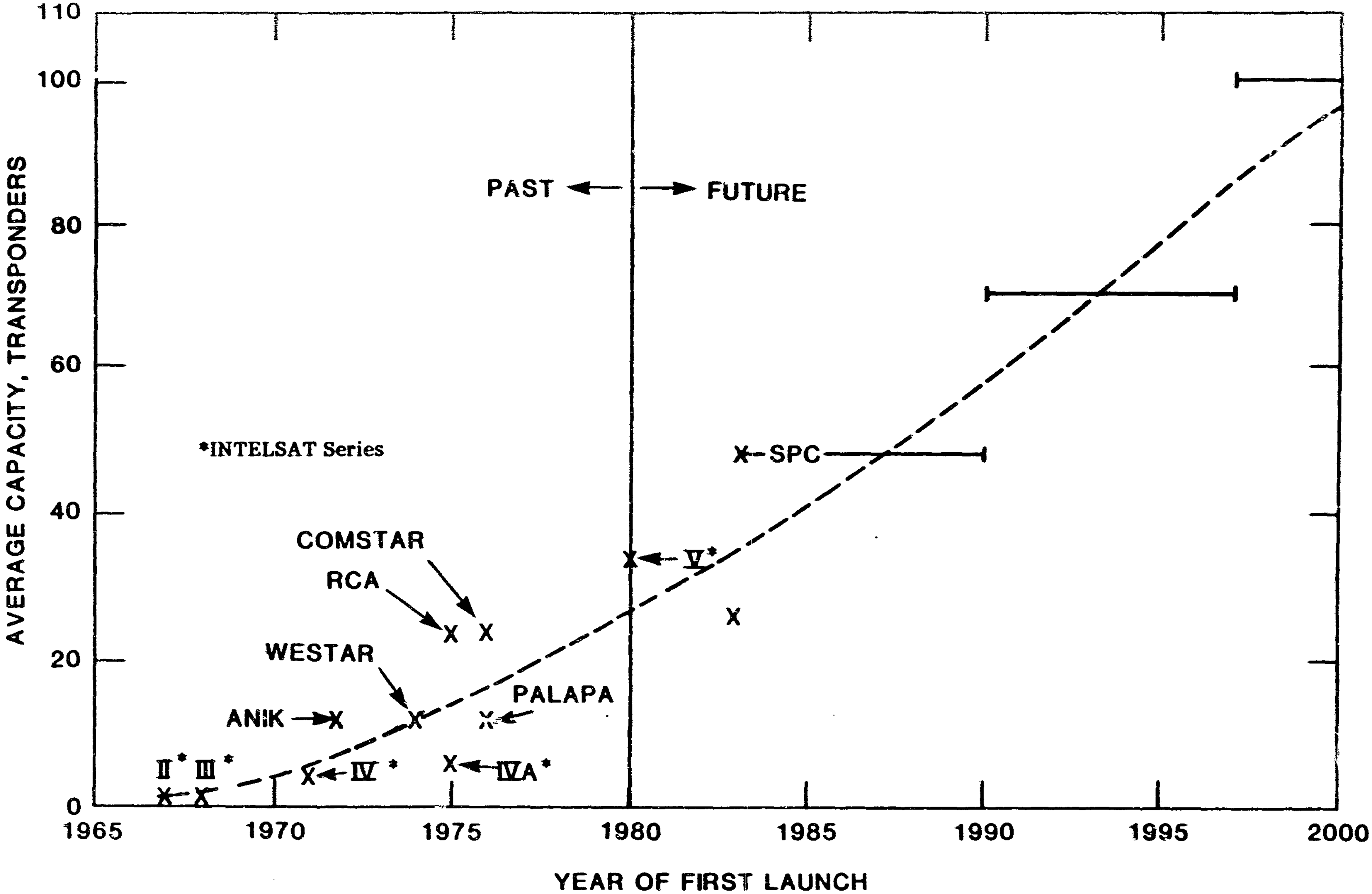

Figure 1-2
GROWTH AND TRANSITION OF SATELLITE CAPACITY (WITHOUT 30/20 GHZ)

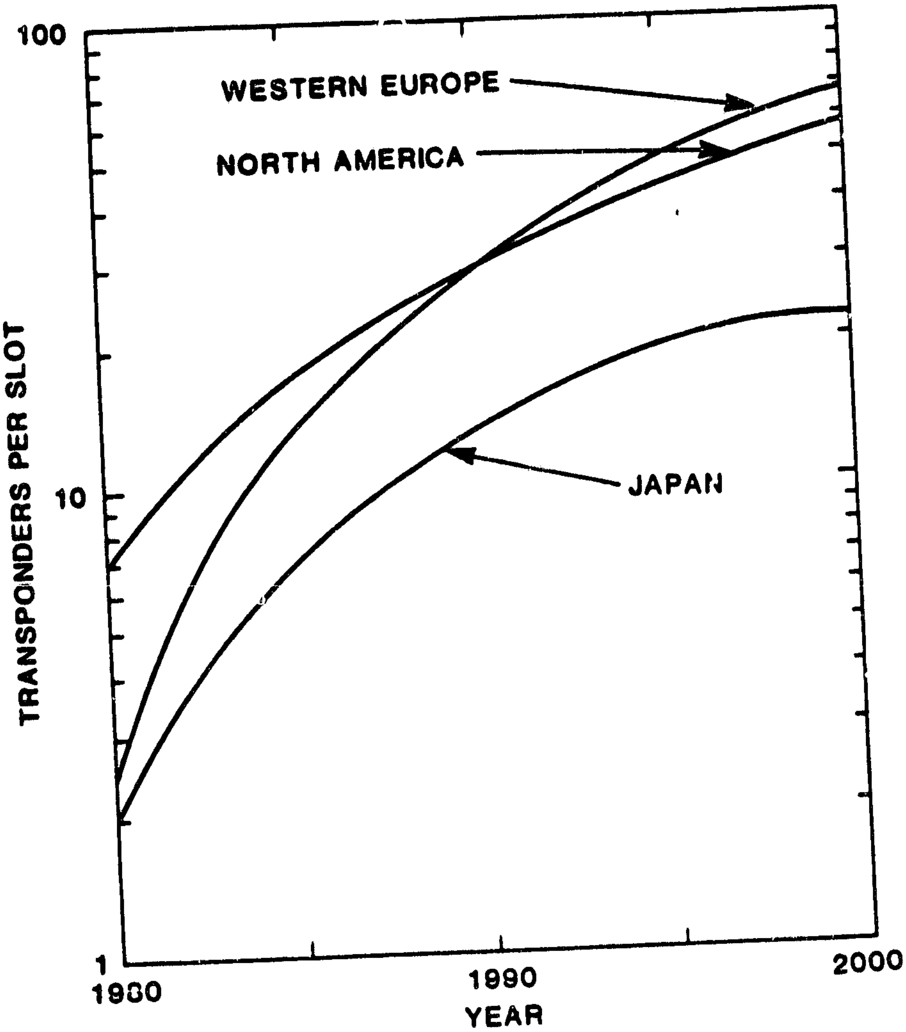

Figure 1-3

REQUIRED CAPACITY PER SLOT FOR GROUP 1 REGIONS
LOW TRAFFIC MODEL

(Communist Countries Not Considered)

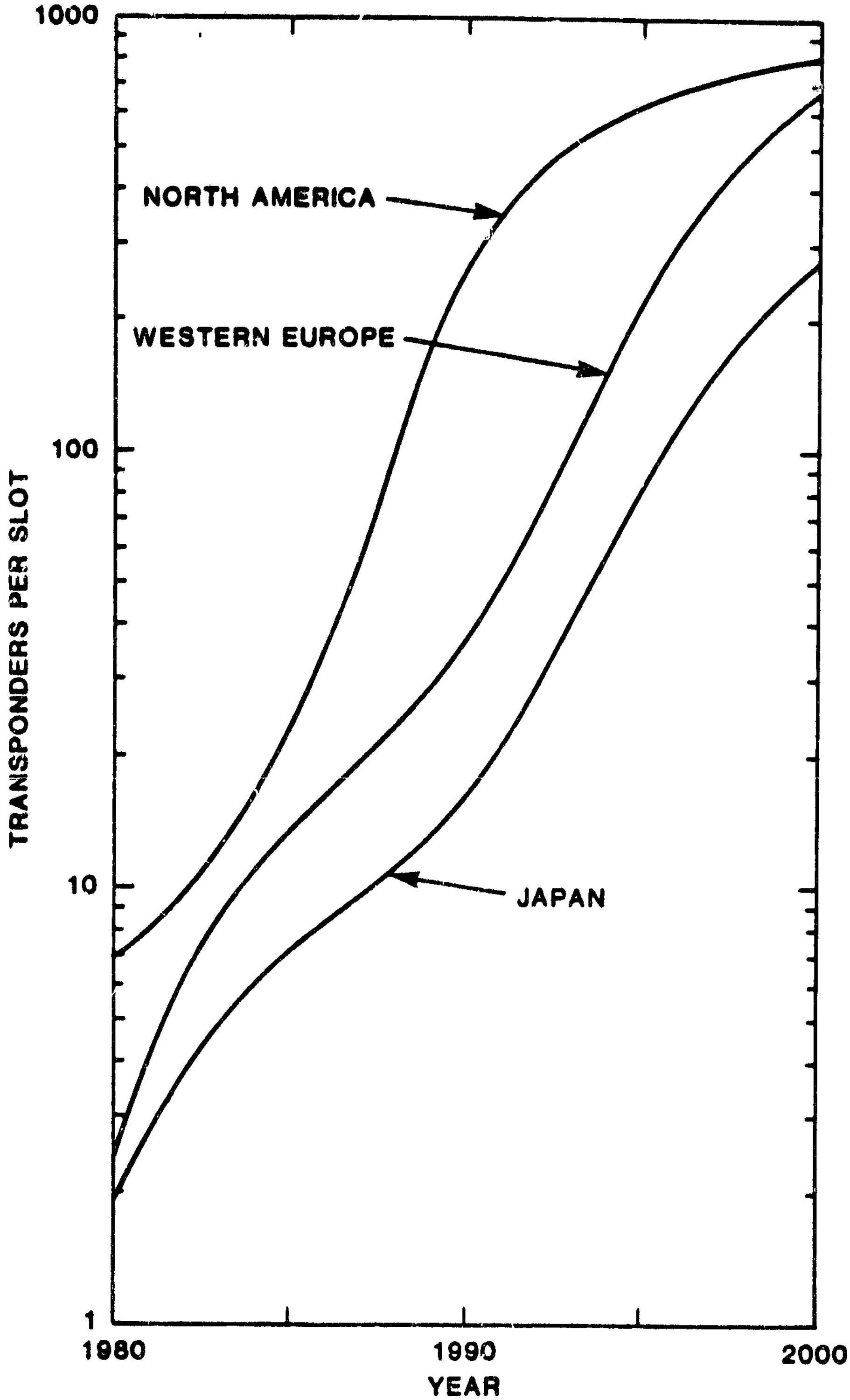

Figure 1-4

REQUIRED CAPACITY PER SLOT FOR GROUP 1 REGIONS
HIGH TRAFFIC MODEL

(Communist Countries Not Considered)

Table 1-3
Regional Satellite Capacities
Without Ka-band
(Transponders)

Region	1983-1989	1990-2000
Western Europe	24	120
Japan	64	160
Latin America	64	64
Middle East	64	64
Africa	64	64
China	64	64
Asia	64	64

Due to the low traffic levels for the less developed countries, larger satellites are not strictly needed even after 1990.

Detailed systems configurations were developed for Western Europe, Japan, and Africa, for both the high and low traffic models. A summary of satellite and system parameters is shown in Table 1-4.

A number of types of earth stations were configured for operation in the systems without 30/20 GHz. Costs for these earth stations are shown in Table 1-5. While many earth station designs are possible, we think that these provide a sufficiently wide range of facilities and costs for comparison purposes.

Table 1-4

Satellites Without 30/20 GHz

Item	Satellite Type 1	2	3
Coverage Type	Area	Area	Multiple Spot Beam
Approximate Capacity in 36 MHz Transponders	24	64	120-160
Design Life, years	7	7	10
Mass (kg)	545	1,330	2,100
Power (Watts)			
EOL	1,150	2,000	3,000
BOL	1,450	2,500	4,200
Fraction of STS Used	1/4	1/2	1
Upper Stage Used	IUS	IUS	IUS
Costs (Millions of 1980 Dollars)			
Satellite			
Development Cost	40	60	82
Per-Unit Cost	15	32	53
Launch			
Shuttle Cost	10	20	30
Upper Stage Cost	14	16	18
Total per Satellite in Orbit	39	68	101
Number Launched (Low Traffic)			
Western Europe	22	0	17
Japan	0	7	5
Africa	0	4	0

Table 1-5

Typical Earth Station Costs in 1990

(Thousands of 1980 Dollars)

(Moderate Quantity)

Item	Station Types Bush Radio	SCPC/ DAMA	Multi-Carrier PSK	SS/TDMA
Front Ends				
Antenna System				
4/6 GHz	10	12	18	18
11/14 GHz	12	15	24	24
RF Equipment				
4/6 GHz	5	6	10	24
11/14 GHz	6	7	12	47
Terminal Equipment	3	6	30	59
Mux/Demux	—	3	18	4
Totals				
4/6 GHz	18	27	76	105
11/14 GHz	21	31	84	134

1.4 Systems Which Use 30/20 GHz

The addition of 30/20 GHz technology to the advanced on-board switching and other improvements which will be available in 1990 will result in a satellite of quite high capacity. The use of the full Shuttle cargo bay will be required. Typical capacities are shown in Table 1-6.

Table 1-6

Regional Satellite Capacities with Ka-band

(Transponders)

Region	1983-1989	1990-2000
Western Europe	24*	430*
Japan	64	315
Latin America	64	126
Middle East	64	126
Africa	64	126
China	64	126
Asia	64	126

* C-band assumed not available due to frequency coordination problems.

In a manner similar to that used for systems without 30/20, we have developed configurations for Western Europe, Japan, and Africa which attempt to satisfy both the high and low traffic models. In general, this can be done more flexibly and with better results using 30/20 GHz. Indeed, the traffic forecast for Western Europe can only be satisfied using the 30/20 GHz systems, due to the restricted use of the lower frequencies. This will be true in any region where C-band and Ku-band microwave densities are similarly high.

Table 1-7 shows typical satellite parameters, costs, and number of spacecraft needed for these systems. Table 1-8 shows costs for 30/20 GHz earth stations which correspond in type to the earth stations considered earlier.

Table 1-7

Satellites with 30/20 GHz

Item	Satellite Type 4	Satellite Type 5
Coverage type	area	multiple spot beam
Approximate capacity, in 36 MHz transponders	126	315-430
Design life, years	10	10
Mass (kg)	2100	4000
Power (watts)		
EOL	3000	10kW
BOL	4200	14kW
Fraction of STS used	1	1
Upper stage used	IUS	Centaur
Costs (Millions of 1980 Dollars)		
Satellite		
Development cost	100	130
Per-unit cost	60	96
Launch		
Shuttle cost	30	30
Upper stage cost	18	20
Total per satellite in orbit	108	145
Number launched (low traffic)		
Western Europe	0	5
Japan	0	3
Africa	1	0

Table 1-8

Typical 30/20 GHz Earth Station Costs in 1990

(thousand of 1980 dollars)

(moderate quantity)

Item	Bush Radio	SCPC/ DAMA	Multi-Carrier PSK	TDMA SS/TDMA
		Station Type		
Front Ends				
Antenna System	20	24	30	35
RF Equipment	30	55	80	160
Terminal Equipment	3	6	30	60
Mux/Demux	--	3	18	4
Totals	53	88	158	259

1.5 Economic Evaluation of Alternative Systems

Based on the systems scenarios developed for systems with and without 30/20 GHz, we have evaluated the total cost per transponder-year and per voice channel-year. These calculations were performed for Western Europe, Japan, and Africa. A time-phased economic modelling program was used, which accounts for investments, depreciation, operating and maintenance costs, return on investment, and the level of loading of the satellite facilities. In addition, in the cost comparison, we have accounted for the advantage which accrues to the earth station as a result of operating with satellites of larger capacity. This comes about because full connectivity is assumed. In order to provide this without multiple-hop transmission, the earth stations must each access a certain minimum satellite capacity. With larger satellites, this can be accomplished using fewer antennas, feeds, and sets of RF equipment at the earth station, thus a cost savings results.

Table 1-9 shows the average cost per transponder-year for the various configurations. A summary of total cost (space + earth segment) per voice circuit per year is presented in Table 1-10.

1.6 Market Analysis

A solely quantitative market analysis would be of little use in a future-oriented study such as this one. The numbers so derived would essentially be little more than opinions. In order to mitigate this situation, we have included a qualitative discussion of the satellite market potential in many of the world model regions, together with a consideration of any political factors or local manufacture policies which affect the opportunities for U.S. industry. The discussion is too lengthy to include here.

Based partly on the market discussion referred to above, and partly on FSI's judgement, we have produced numerical estimates for 1) the total spacecraft and earth station markets, 2) the fraction of these markets likely to be captured by U.S. industry, and 3) the total dollar value for this portion. Table 1-11 shows the total markets for 30/20 GHz equipment worldwide, in numbers of transponders and numbers of earth stations. Relatively small differences between the low and high traffic models for the less-developed countries are a result of the very small amount of video conferencing forecast for these areas during this period.

Table 1-12 gives the estimated "capture percentages" for U.S. industry, for both earth and space segment. The combination of Tables 1-11 and 1-12 results in a total market for U.S. industry; this is shown in Table 1-13, along with the estimated dollar value ranges for this market.

Table 1-9

Average Space Segment Cost

Per Transponder-Year

(Millions of 1980 Dollars)

	Low Traffic		High Traffic	
	Without 30/20	With 30/20	Without 30/20	With 30/20
Western Europe	0.27	0.19	0.22	0.11
Japan	0.28	0.28	0.18	0.15
Africa	0.78	0.74	*	*

* Negligible video conferencing 1980-2000

Table 1-10

Average Annual Cost Per Voice Circuit

(In Thousands of 1980 Dollars)

Region	Earth Station Type	Low Traffic Without 30/20	Low Traffic With 30/20	High Traffic Without 30/20	High Traffic With 30/20
Western Europe	Bush Radio	8.9	17.6	8.8	17.4
	SCPC/DAMA	2.9	6.0	2.8	5.8
	Multi-Carrier PSK	3.7	2.6	3.6	2.4
	SS/TDMA	1.3	0.8	1.2	0.6
Japan	Bush Radio	8.6	15.8	8.4	15.5
	SCPC/DAMA	3.0	5.6	2.8	5.3
	Multi-Carrier PSK	2.4	2.6	2.2	2.3
	SS/TDMA	1.0	1.0	0.6	0.5
Africa	Bush Radio	9.6	16.8	—	—
	SCPC/DAMA	4.0	6.5	—	—
	Multi-Carrier PSK	3.4	3.5	—	—
	SS/TDMA	2.0	1.9	—	—

Table 1-11
Total 30/20 GHz Equipment Markets

	Period		
	1990-1992	1993-1996	1997-2000
Satellite Transponders			
Low Traffic	1,150	590	770
High Traffic	2,200	5,200	8,700
Earth Stations			
Low Traffic	13,900	8,100	11,000
High Traffic	26,000	50,000	84,000

Table 1-12
U.S. Industry Capture Percentages for 30/20 Equipment

Region	Satellites	Earth Station Equipment
Canada	90%	20%
Western Europe	0%	20%
Japan	0%	5%
Latin America	70%	50%
Middle East	70%	50%
China	70%	25%
Asia	50%	30%
Africa	70%	50%
Others	90%	30%

Table 1-13
Market Summary for 30/20 GHz Systems

	High Traffic	Low Traffic
Total Space Segment		
Sales - Transponders	1,450	730
1980 dollars	$900 million	$450 million
Total Earth Segment		
Sales - Earth Stations	32,000	10,600
1980 dollars	$1.7 - 8.4 billion	$0.6 - 2.7 billion
Total Market for U.S. Industry		
1980 dollars	$2.6 - 9.3 billion	$1.0 - 3.1 billion

1.7 Other Benefits From 30/20 GHz Systems

In addition to direct sales of communications equipment to foreign nations, other benefits will accrue to the U.S. industry. In many areas of Western Europe, 30/20 GHz will be the only frequency band which will enable the use of customer-premises earth stations (CPS). It is in the U.S. interest to encourage such a CPS system, since it allows direct broad- band communications between U.S. companies and their customers, ents, and subsidiaries in Europe. High-speed facsimile, electronic mail, and video conferencing are some of the services which would be made feasible.

Such communications systems would facilitate the control of business by the U.S. industry overseas and could improve the competitive posture of U.S. industry. Other communications systems could not be expected to fulfill these functions, since it is unlikely that broad-band local loops will be installed throughout Europe in the near future. Due to extensive terrestrial microwave use at C-band and even at Ku-band, 30/20 GHz offers the only real possibility for this broad-band CPS system.

In the context of the present international satellite arrangements, such direct international services could be furnished within the INTELSAT system. The customers on the PTTs would provide the ground segment, and 30/20 GHz space segment would be leased from INTELSAT. This would make the INTELSAT system a large potential customer for 30/20 GHz equipment, and could substantially increase the overall benefits to U.S. industry.

1.8 Overall Conclusions

This report indicates a substantial market outside the U.S. for 30/20 GHz equipment, both satellites and ground equipment. This market is partly available to U.S. industry because of the experience and success rate of U.S.-built satellites and earth stations. However, this market will be available only under certain conditions:

1. U.S. industry must take the lead in developing and proving technology for the 30/20 GHz bands;
2. U.S. firms must make arrangements for the satisfaction of local manufacturer/local content requirements; and
3. In cooperation with NASA, U.S. manufacturers should begin parallel incorporation of results from NASA's 30/20 GHz development program, so as to reduce the lag between NASA demonstrations of practicality and actual use in commercial satellites.

1.9 Further Work

This report has taken an initial look at the possible uses of and markets for the 30/20 GHz technologies developed in the U.S. Because of the limited detail and the numerous judgements necessary in this study, further work in this area may be desirable. A number of subjects would prove interesting and useful, as discussed below.

Europe and possibly INTELSAT are the most likely users of U.S.-developed 30/20 GHz technology. The traffic demand model for both could be examined in more detail. Refinements, as for example the identification of the types of traffic most suitable for 30/20 GHz, are possible.

Based on the above refinement of the traffic model, systems designs for Europe and INTELSAT could be formulated. These would be keyed to the actual development plans of the NASA program, so as to produce the most useful correspondence between the actual developments and the likely requirements.

One of the most fruitful areas of inquiry may be the design of an international direct-to-the-user system using the 30/20 GHz bands. This could implement direct broad-band communications between U.S. locations and customers, agents, and subsidiaries in Europe. This system would be administered by INTELSAT due to its international nature, but regional systems can also be considered.

The current traffic model indicates that teleconferencing will be the area of highest growth and maximum ultimate market in the 1990-2000 period. Due to the direct-to-the-user nature of this service, the 30/20 GHz bands are ideally suited to this application. Additional study of teleconferencing uses could also prove to be valuable.

SECTION 2
INTRODUCTION

This report, Cross-Impact of Foreign Satellite Communications on NASA's 30/20 GHz Program, has been prepared by Future Systems Incorporated under NASA Contract NAS 3-21500. This document considers the effects of NASA technology development for 30/20 GHz systems on the planning and purchases of foreign domestic satellite systems. The resulting opportunities for US industry are also examined.

The first ingredient is a model of traffic demand for the world. FSI has developed this model based on demographic correlations and the experience of our staff. The model yields estimates of telephony, data, and video conferencing traffic, and estimates of the portion of this demand that will likely be carried by satellites. The background data and results are presented in Section 3.

We have also developed a model for the transition process as systems evolve from the current, rather low capacity satellites to the higher capability spacecraft of the 1990's. This is presented in Section 4.

In order to quantify the possible advantages of the use of 30/20 GHz frequencies, we have constructed systems models which satisfy the traffic demand. One scenario uses only C-band and Ku-band; the other includes the use of 30/20 GHz. These systems models include estimates of spacecraft capacity, number of spacecraft required versus time, and space segment costs. Earth stations appropriate to the systems are also configured, with cost estimates included. Section 5 presents systems which do not use 30/20 GHz, while Section 6 covers systems which use 30/20 GHz.

Section 7 contains an economic analysis of the alternate systems. Costs for spacecraft, launch vehicles and ground segment are employed in a time-phased model to produce total costs per unit of transmission bandwidth.

In Section 8 the markets for spacecraft and earth station equipment are examined. We have estimated the size of the markets, and have included discussions of factors such as politics which affect the volume of potential sales.

The launch requirements which are covered in Section 9 follow directly from the market model. The sensitivity of market acceptance to system availability is treated in Section 10. Results of the study are summarized and conclusions drawn in Section 11.

Since the effects of rain on system availability have such a significant impact at 30/20 GHz, we have included an Annex which details the attenuation and rainfall models which we have employed. These models are extracted from a NASA document and include features which have achieved wide acceptance.

SECTION 3
DEMAND FORECAST

3.1 Introduction

This section presents a forecast of demand for various communication services to be provided by satellites. Specifically, the forecast covers demand for voice communications, data transmission, video teleconferencing, and television distribution. The telephony forecast is based on GNP and historical correlation between GNP and telephone use. The forecasts for the other components of the communications service demand are based on a detailed forecast for the U.S. demand for those services. (Reference 1) The components are scaled by the GNP, and additional factors are introduced to account for the time lag of service introductions relative to the U.S.. We used this approach because the wealth of data concerning U.S. communications is not available for other countries. Use was made of the Western Union and ITT studies performed for NASA Lewis Research Center (References 16 and 17). While we have used the information provided, we have added our own judgment and other work previously performed by FSI in order to derive traffic requirements.

The present forecast covers a period of 20 years, 1980 to 2000. Since it is a long range forecast, it is important to consider the types of facilities which will likely be available during this time period. Rapid advances in communications technology are taking place at this time, and these advances will have a significant impact on the future development of communications facilities. Some examples of applicable technology advances are given below:

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

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

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

Using these factors for predictions of future traffic requires assumptions regarding certain demographic data of the future. Specifically, it requires estimates of future GNP and population in the countries or world regions under study. Fortunately, a suitable range of these numbers is well documented and generally agreed upon by a variety of sources.

3.2 Demographic Data

In global forecasting it is standard practice to segregate countries into world model regions of similar political and economic characteristics. For the FSI model, we have segregated the world into two major groups as follows:

Group I	North America Western Europe USSR Eastern Europe Japan
Group II	Latin America Middle East China Asia Africa
Other Countries	Those not covered in Groups I and II

The detailed makeup of the world model regions is as follows:

World Model Zones

Group I

North America

Canada
United States

Western Europe

Andorra
Austria
Belgium
Denmark
Federal Republic of Germany
Finland
France
Greece
Iceland
Ireland
Italy
Liechtenstein
Luxembourg
Malta
Monaco
Netherlands
Norway
Portugal
San Marino
Spain
Sweden
Switzerland
Turkey
United Kingdom
Yugoslavia

World Model Zones (Continued)

Group I (Continued)

USSR

Eastern Europe

Albania	Hungary
Bulgaria	Poland
Czechoslovakia	Romania
German Democratic Republic	

Japan

Group II

Latin America

Argentina	Haiti
Barbados	Honduras
Belize	Jamaica
Bolivia	Mexico
Brazil	Nicaragua
Chile	Panama
Colombia	Paraguay
Costa Rica	Peru
Cuba	Surinam
Dominican Republic	Trinidad & Tobago
Ecuador	Uraguay
El Salvador	Venezuela
French Guiana	
Guatemala	
Guyana	

Middle East

Algeria	Lebanon
Bahrain	Morocco
Cyprus	Oman
Egypt	Qatar
Iran	Saudi Arabia
Iraq	Syria
Jordan	Tunisia
Kuwait	United Arab Emirates
Libya	Yemen, A.R.
	Yemen, P.D.R.

World Model Zones (Continued)

Group II (Continued)

Peoples Republic of China

Asia

Afganistan
Bangladesh
Burma
India
Indonesia
Kampuchea
Malaysia
Mongolia
Laos
North Korea
Nepal
Pakistan
Philippines
South Korea
Sri Lanka
Taiwan
Thailand
Vietnam

Africa

Angola
Benin
Burundi
Cameroon
Cape Verde
Central African Empire
Chad
Comoros
Djibouti
Ethiopia
Equitorial Guinea
Gabon
Ghana
Guinea
Guinea-Bissau
Ivory Coast
Kenya
Lesotho
Liberia
Malagasy Republic
Malawi
Mali
Mauritania
Mauritius
Mozambique
Niger
Nigeria
Republic of Congo
Re' union
Zimbabwe
Rwanda
Senegal
Sierra Leone
Somalia
Swaziland
Tanzania
Togo
Uganda
Upper Volta
Zaire
Zambia

Other Countries

Antigua	Israel
Australia	Maldive Islands
Bahamas	Martinique
Bhutan	Nambia
Botswana	New Caledonia
Brunei	New Hebrides
Bermuda	New Zealand
Dominica	Papua New Guinea
Fiji	Portuguese Timor
French Polynesia	Singapore
Gilbert Islands	Solomon Islands
Grenada	South Africa
Guadeloupe	St. Lucia
Guam	St. Vincent
Hong Kong	Tonga
	Virgin Islands
	Western Samoa

The basic demographic data that were used in this forecast are listed in Table 3-1.

Table 3-1

Population and GNP Per Capita of World Model Regions

Regions and Countries	1980 Population (Millions)	Area (Sq km) (Thousands)	Current Population Growth (% per Year)	Current Inflation (% per Year)	1980 GNP/Capita (1980 Dollars)	Current GNP/Capita Growth (% per Year)	GNP Density ($K of GNP/km)
North America	246.2	19,339	0.8	7.8	12,020	2.6	153.1
Western Europe	417.2	4,634	0.6	16.1	8,590	3.2	773.5
U.S.S.R.	266.0	22,402	0.9	9.7	4,800	3.0	57.0
Eastern Europe	112.7	1,019	0.7	8.7	4,540	4.1	502.3
Japan	117.5	372	1.0	6.2	1,419	3.8	3,776.6
Group I Total	1,159.6	47,763	0.8	8.4	8,400	3.0	203.9
Latin America	357.9	20,519	2.7	34.4	1,660	3.9	28.9
Middle East*	172.3	11,141	2.7	11.4	2,940	10.3	45.5
People's Republic of China	985.9	9,597	2.2	5.0	590	3.0	60.2
Asia**	1,307.5	10,888	2.3	11.8	360	6.2	43.1
Africa***	348.5	26,458	3.2	14.4	430	-2.5	7.0
Group II Total	3,182.1	78,603	2.4	29.2	720	5.1	31.2
Other Countries	67.8	10,827	2.1	11.3	4,190	0.1	26.3
World Total	4,399.5	137,193	2.0	10.3	2,800	3.3	93.2

*Exlcudes North Africa
**Excludes Japan and China
***Excludes South Africa and North Africa

The starting point is the GNP per capita. The numbers in this report are higher than those usually shown in national account statistics. This is because they are expressed in 1980 dollars, while many other statistics use dollars of earlier years as a reference.

The GNP growth rates are based on a consolidation of estimates and forecasts given in various references listed. Current and historic data were also derived from various references. It should be noted that all figures are rounded to avoid giving the impression of a higher degree of precision than is warranted. For this reason, the totals in each column do not add up precisely.

Some of the highlights of the forecast of economic and demographic data are summarized in Table 3-2. (Figures are rounded.)

Table 3-2
Highlights of Economic and Demographic Data
Year 2000

Population	Developed countries	20% of world population
	Developing countries	80% of world population
GNP	Developed countries	75% of world total
	Developing countries	25% of world total
GNP Per Capita	Developed countries	\$15,000
	Developing countries	\$ 2,400

Thus, even 20 years from now the disparity between the average developing countries and developed countries is still a factor of 1 to 6 in GNP per capita. However, if we compare North America with Asia and Africa, the differential is even larger, as shown in Table 3-3.

Table 3-3

North America Compared With Asia and Africa

Year 2000

	North America	Asia and Africa (average)	Ratio
1980 GNP Per Capita	12,000	375	32
2000 GNP Per Capita (in 1980 Dollars)	20,000	970	21

It should be noted that for evaluation of the relative standards of living of different countries it is generally preferred to use the Gross Domestic Product (GDP). For forecasting of communications traffic requirements, however, we consider the GNP to be a better measure. GNP data include the results of exports, while GDP data do not. Forecasts of population, GNP per capita, and total GNP are shown in Table 3-4 through 3-6.

3.3 Telephony Traffic

Since there is extensive background of conventional telephone telecommunications, the model for telephony satellite traffic is based on correlation factors which have been derived from historical data, and which are applied to forecasts of future population and GNP numbers.

Table 3-4

Population (Millions)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	246	253	260	268	275	283
Western Europe	418	428	438	447	456	465
U.S.S.R.	266	275	285	296	306	317
Eastern Europe	113	116	119	123	126	130
Japan	118	122	127	131	135	137
Total Group I	1160	1195	1230	1264	1299	1332
Latin America	358	397	437	479	521	565
Middle East	172	191	212	233	254	274
China	986	1076	1175	1283	1401	1530
Asia	1308	1429	1554	1681	1807	1930
Africa	349	395	445	499	556	615
Total Group II	3172	3489	3824	4175	4539	4914
Others	68	73	75	75	74	73
Total	4400	4756	5129	5515	5912	6319

Table 3-5

GNP Per Capita (Dollars)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	12023	13323	14763	16360	18128	20089
Western Europe	8585	9738	11045	12528	14210	16119
U.S.S.R.	4804	5413	6100	6873	7745	8727
Eastern Europe	4543	4860	5199	5561	5949	6364
Japan	11965	13730	15756	18080	20747	23808
Total Group I	8397	9436	10605	11918	13393	15045
Latin America	1656	1930	2249	2621	3054	3559
Middle East	2937	4347	6434	9524	14096	20865
China	586	659	740	832	935	1050
Asia	359	457	581	739	940	1196
Africa	429	388	350	317	286	259
Total Group II	724	892	1118	1423	1838	2403
Others	4191	4208	4225	4242	4259	4276
Total	2800	3090	3439	3868	4406	5089

<u>Table 3-6</u>

GNP (Billions of Dollars)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	2955	3375	3845	4377	4984	5684
Western Europe	3591	4170	4836	5602	6482	7491
U.S.S.R.	1277	1491	1741	2033	2373	2770
Eastern Europe	512	563	620	682	750	825
Japan	1406	1678	2001	2377	2803	3271
Total Group I	9742	11278	13043	15070	17392	20041
Latin America	593	766	984	1255	1592	2011
Middle East	506	832	1363	2220	3585	5724
China	578	709	870	1067	1309	1606
Asia	469	653	903	1242	1698	2307
Africa	150	153	156	158	159	159
Total Group II	2296	3113	4275	5942	8343	11808
Others	284	305	317	320	316	311
Total	12321	14696	17635	21332	26051	32160

Transponders are expressed in terms of typical domestic C-band transponders with an EIRP of about 33 dBW and a bandwidth of about 36 MHz which are able to carry about 1,000 multiple access one-way telephone channels as a weighted average for domestic applications. This measure was chosen merely as a convenient reference. Actual domestic satellite systems of the future will use a variety of other transponder arrangements.

The following correlation factors were found to be useful in deriving the traffic model:

GNP Per Telephone
Long Distance Calls Per Telephone
Long Distance Calls Per $1,000 Dollars GNP

These factors vary from country to country and with time, but they follow a general trend.

In estimating domestic traffic requirements, the so-called regional system requirements have been included. For example, the European traffic that will be carried on ESA's ECS satellites which will follow OTS is considered to be European domestic traffic. Likewise, the traffic on the Arab regional system, on the ANDEAN and the ASEAN Systems, etc. is lumped in the domestic category. This is not to say that such traffic could not be carried by the INTELSAT System. It may well be included in part in the INTELSAT System through transponder lease or as regular traffic, if INTELSAT were to implement a distance-dependent rate.

This inclusion permits us to construct a model in which the size of a country is not important. A large country like the USA has very little international traffic, when such traffic is expressed as a percentage of the total traffic. Smaller countries, such as those of Europe, have a much larger percentage of international traffic since by nature of their size they found it beneficial to establish close relations with their neighbors. Similar relationships will grow in developing countries. Thus, large countries have their proper domestic satellite traffic while small countries require regional systems to benefit from the same economies, and the traffic of these systems is included in the model presented in this report.

Figure 3-1 is a summary of the GNP per telephone correlation factors. North America has the most advanced telephone network, which is expected to bottom out at $10,000 GNP per telephone. Japan is about to overtake Western Europe, while Russia and Eastern Europe are lagging behind. The Middle East is expanding its telephone network rapidly, and Asia and Africa are making rapid relative progress.

Figures 3-2 and 3-3 show the number of long distance calls per $1,000 GNP. The real cost of long distance calls is dropping rapidly, and the number of calls per $1,000 GNP is therefore increasing. By the year 2000 most countries will have between 10 and 15 long distance calls per $1,000 GNP.

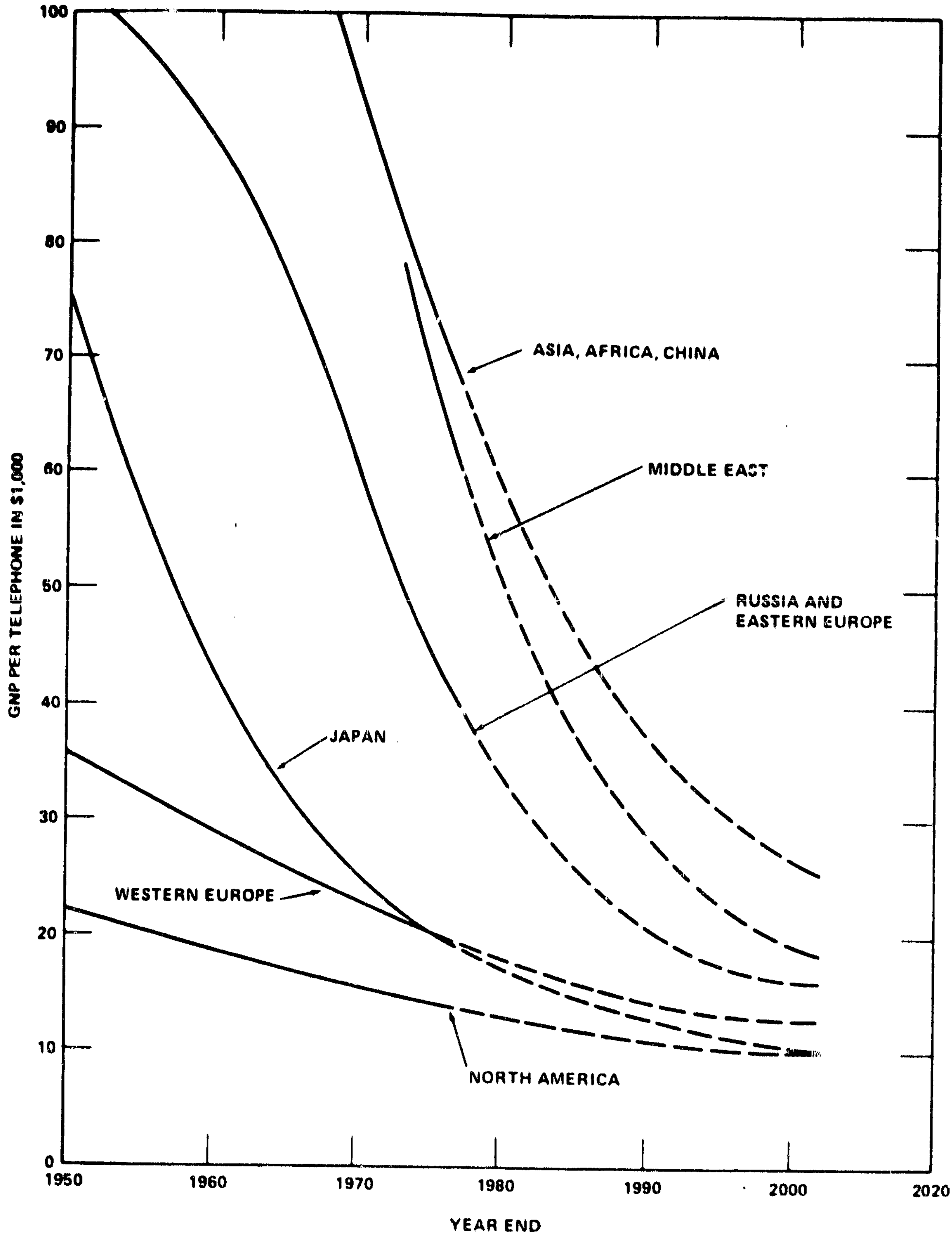


Figure 3-1

GNP PER TELEPHONE

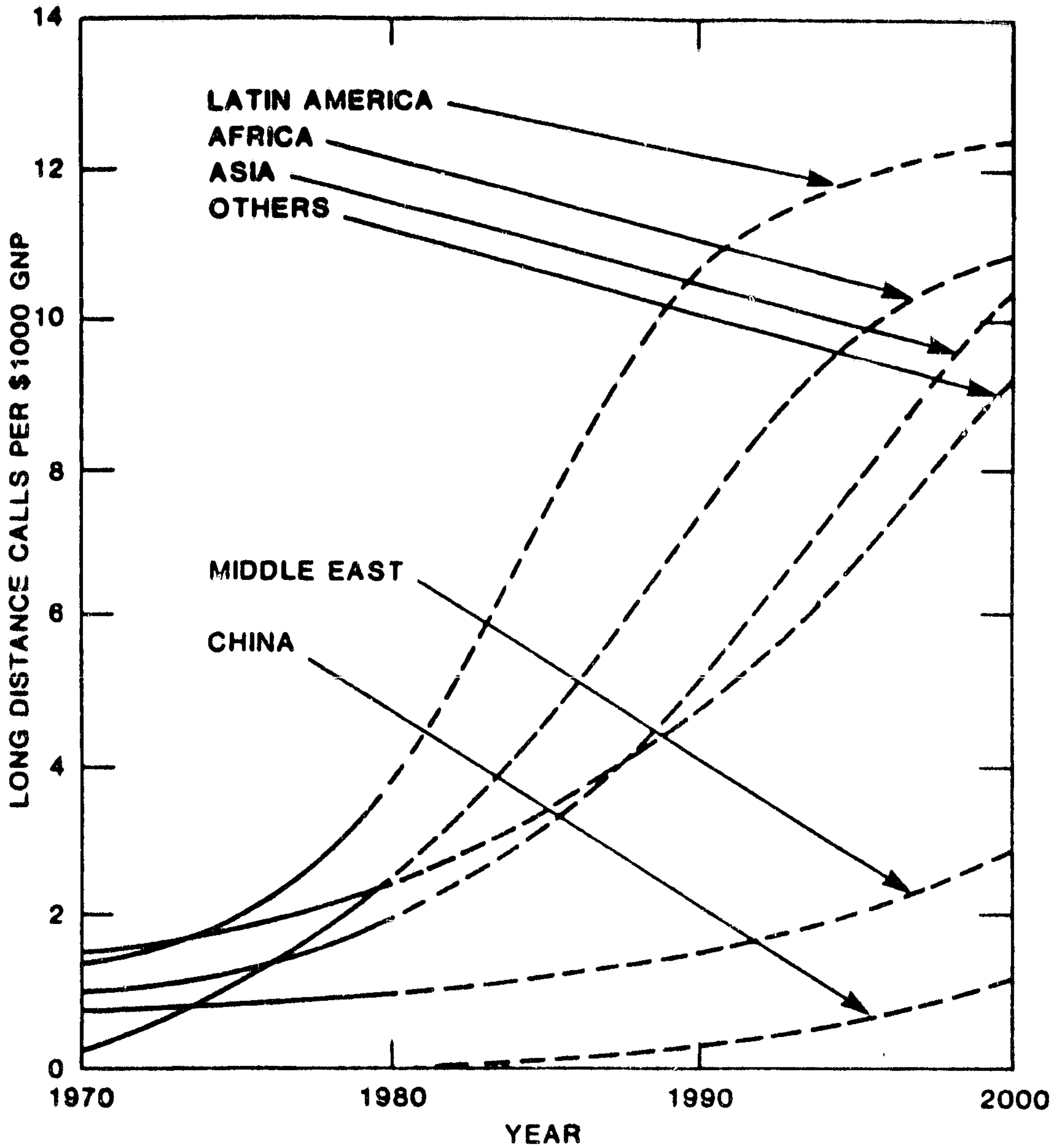


Figure 3-2

LONG-DISTANCE CALLS
PER $1000 OF GNP
GROUP 2 REGIONS

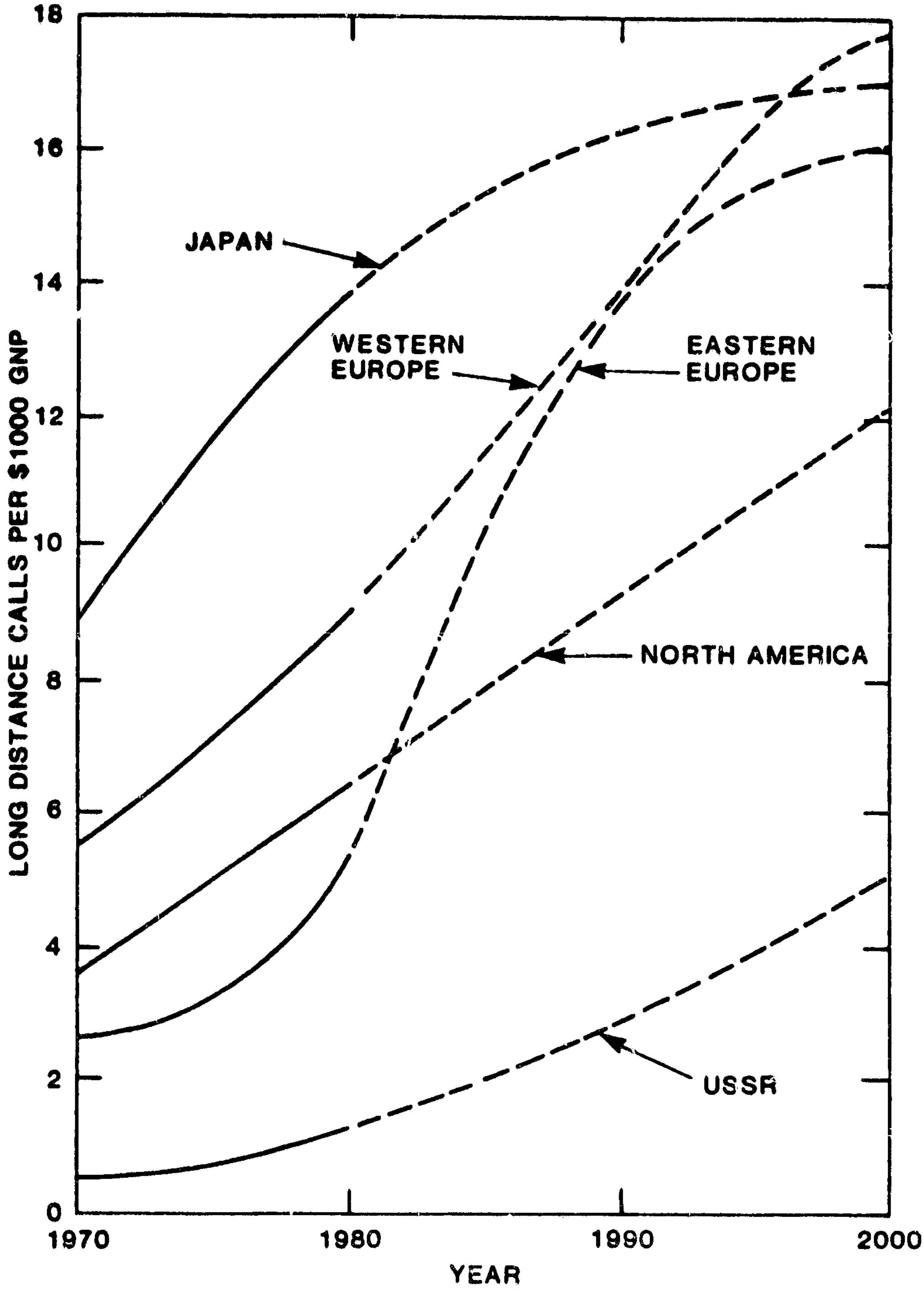


Figure 3-3

LONG-DISTANCE CALLS
PER $1000 OF GNP
GROUP 1 REGIONS

The present telephone density in the USA is about 70 telephones per 100 population. In some cities the density is already above 100. In our model the total number of telephones per 100 population for the developed countries in the year 2000 is 75, slightly higher than in the USA today. The total world average by the year 2000 is 20 telephones per 100 population, compared to about 10 today. This implies an annual growth of 4.7 percent for the world's telephones, while the world population will grow at an average rate of 1.6 percent per year.

Table 3-7 provides a cross-check on the correlation factors. It is found that the long distance calls per telephone range from 120 to 250 per year. This is quite reasonable, since the number of long distance calls per telephone for Sweden and Germany have already exceeded 200 per year in 1975.

The next step in generating transponder requirements consists of translating long distance calls into satellite call minutes. An average call duration of 9 minutes was used for this calculation, which was based on a summary of international statistics. Furthermore, it was assumed that from 5 to 25 percent of all long distance traffic by the year 2000 would be suitable for transmission via satellite. This percentage varies with the region and is dependent on the extent of the terrestrial transmission facilities presently existing.

At present the break-even distance for satellite and terrestrial communications in the USA is about 500 miles. In the USA at present, only about 5 percent of the total long distance traffic would be suitable for transmission via satellite. This follows from an FCC filing by AT&T of the distribution of route miles of leased lines. In the future, however, long distance transmission costs will continue to drop, and there will be a shift of long distance traffic to longer distances.

Table 3-7

Summary of Correlation Factors for Year 2000

(Figures are rounded)

Region	GNP Per Telephone $1,000	LD Calls Per Telephone Per Year	LD Calls Per $1,000 GNP
Group I			
North America	10	120	12
Western Europe	9	180	21
USSR	17	100	6
Eastern Europe	16	190	12
Japan	9	140	16
Total			13
Group II			
Latin America	11	190	17
Middle East*	20	40	2
China	25	50	2
Asia**	25	250	10
Africa***	19	310	16
Other	23	180	8
World Total	15	160	11

*Includes North Africa
**Excludes Japan and China
***Excludes South Africa and North Africa

Already today, the packet communications network of Telenet offers data communications with distance independent rates. A Washington to Los Angeles connection costs no more than a Washington to Baltimore connection. A similar trend will be experienced with telephony transmissions in the future. This will increase the portion of traffic which can best be carried by satellites.

In developing countries the expansion of the terrestrial network is more expensive than in Europe and the USA, because the repeater stations for the microwave links would be inaccessible and would be difficult to maintain. For these reasons, developing countries will opt to expand the transmission facilities with communications satellites to a greater extent than the already-developed countries. As the result of these considerations, we have selected the following percentages of total long distance traffic as being suitable for satellite transmission:

Western Europe	5%	Western Europe has a very well developed terrestrial network and the PTT's are in part opposed to domestic and regional satellite communications. Germany, for example, is said to be opposed to the satellite system because it would lose transit revenues for traffic that would otherwise be transmitted through the country.
Japan	6%	Japan also has a very well developed terrestrial system but has nevertheless already started to implement domestic satellite communications. One of the stated reasons for this system is the objective of technology advancement.
North America	8%	In spite of the well developed terrestrial system, there are already three domestic satellite systems in operation (not counting American Satellite Corporation, which leases transponders from Western Union), and a fourth system (SBS) will probably start construction in the near future.
Developing Countries	15-25%	For all developing countries we have assumed that up to 25% of the long distance traffic will be suitable for satellite communications.

As the final step, satellite call minutes are translated into transponder requirements as follows:

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, 1 billion call minutes per year requires 8,680 circuits.

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

The telephony forecast for the world model regions is developed in Tables 3-8 through 3-12.

Table 3-8

Long Distance Calls per $1000 GNP

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	6.42	7.58	8.74	9.90	11.06	12.22
Western Europe	8.96	10.80	12.92	15.32	17.99	20.94
U.S.S.R.	1.21	1.81	2.57	3.48	4.55	5.76
Eastern Europe	5.73	8.96	12.07	14.22	14.58	12.32
Japan	13.70	15.03	15.94	16.41	16.47	16.09
Latin America	3.86	6.45	9.52	12.65	15.40	17.37
Middle East	1.10	1.25	1.40	1.55	1.71	1.86
China	0.02	0.29	0.66	1.14	1.71	2.39
Asia	1.95	2.85	4.15	5.85	7.97	10.49
Africa	2.44	4.08	6.26	8.98	12.25	16.05
Others	2.45	3.19	4.13	5.27	6.60	8.13

Table 3-9

Total Long Distance Calls (Millions)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	18964	25573	33597	43317	55103	69446
Western Europe	32160	45031	62484	85815	116623	156865
U.S.S.R.	1547	2706	4476	7076	10786	15966
Eastern Europe	2932	5044	7476	9692	10933	10157
Japan	19260	25226	31887	39009	46155	52629
Total Group I	74863	103581	139920	184909	239600	305063
Latin America	2290	4945	9366	15867	24518	34936
Middle East	555	1040	1911	3448	6112	10629
China	12	206	576	1213	2244	3844
Asia	915	1857	3744	7273	13535	24204
Africa	365	624	976	1419	1948	2554
Total Group II	4137	8671	16572	29220	48357	76168
Others	698	975	1310	1684	2086	2526
Total	79697	113226	157801	215812	290042	383757

Table 3-10

Percent of Traffic Carried via Satellite

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	4.29	6.62	7.49	7.81	7.93	7.97
Western Europe	1.12	3.45	4.38	4.75	4.90	4.96
U.S.S.R.	4.41	6.38	7.27	7.67	7.85	7.93
Eastern Europe	0.00	2.64	5.59	6.92	7.51	7.78
Japan	1.54	3.54	4.38	4.74	4.89	4.95
Latin America	1.93	5.94	8.73	10.65	11.99	12.91
Middle East	3.00	6.96	9.22	10.50	11.23	11.65
China	0.00	5.09	9.40	11.84	13.21	13.99
Asia	11.61	13.02	13.85	14.33	14.61	14.77
Africa	11.07	15.08	17.29	18.51	19.18	19.55
Others	0.00	3.96	6.61	8.39	9.58	10.38

Table 3-11

Total Satellite Call-Minutes (Millions)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	7315	15237	22640	30446	39324	49837
Western Europe	3227	13973	24630	36703	51441	70031
U.S.S.R.	613	1555	2931	4887	7624	11401
Eastern Europe	0	1197	3761	6034	7393	7113
Japan	2664	8038	12583	16644	20315	23465
Total Group I	13820	40000	66545	94713	126097	161847
Latin America	397	2645	7355	15212	26453	40603
Middle East	150	651	1585	3259	6179	11144
China	0	94	487	1293	2669	4841
Asia	956	2176	4667	9379	17796	32180
Africa	364	847	1519	2364	3363	4493
Total Group II	1867	6414	15613	31507	56461	93262
Others	0	347	779	1271	1798	2359
Total	15687	46761	82936	127491	184355	257467

Table 3-12

Total Satellite Telephony Traffic
(In Thousands of Voice Channels or Transponders)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	127	265	394	530	684	867
Western Europe	56	243	429	639	895	1219
U.S.S.R.	11	27	51	85	133	198
Eastern Europe	0	21	65	105	129	124
Japan	46	140	219	290	353	408
Total Group I	240	696	1158	1648	2194	2816
Latin America	7	46	128	265	460	706
Middle East	3	11	28	57	108	194
China	0	2	8	22	46	84
Asia	17	38	81	163	310	560
Africa	6	15	26	41	59	78
Total Group II	32	112	272	548	982	1623
Others	0	6	14	22	31	41
Total	273	814	1443	2218	3208	4480

3.4 Data Traffic

To date, a significant amount of data traffic exists only in the United States and Europe. Our forecast for data transmission in areas of the world other than the U.S. is based on the U.S. forecast. The data are scaled by GNP. In addition, because the U.S. is more advanced in communications use, there will be a time delay factor. The growth curve for the U.S. is steeper, and the U.S. is further up the slope as well. Growth curves for the world model regions are shown later in this section. An explanation of the U.S. domestic traffic model is contained in Reference 1.

Data communications can be divided into the following categories:

Message Traffic

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

Computer Traffic

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

Narrowband Teleconferencing

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

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

For example, if a circuit-switched data channel is used for an interactive data communications application, the transmission efficiency may be only a fraction of a percent because of the low rate at which the human operator types in data and interprets results and because of the transmission idle periods when the time shared CPU performs its function. This low efficiency is one of the reasons for the introduction of packet data communications networks where virtual circuits are set up and where the transmission channel is shared by several virtual channels.

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

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

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

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

3.4.1 Estimate of Message Service Demand

Message service demand is divided into the following categories:

TWX/Telex Traffic
Conventional Facsimile Traffic
Advanced Electronic Mail

TWX/Telex Service Demand

The demand estimate for this service category is based upon estimates of the number of terminals in use. All estimates were converted into a number of messages per year based on the following conversion factors:

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

The various estimates are plotted in Figure 3-4. The estimated decline in demand past 1985 is based on the expectation that current TWX/Telex terminals will be retired in favor of more efficient message terminals in future years.

The number of messages is converted into a number of bits by assuming 120 words per message, six characters per word, and eight bits per character resulting in 5,760 bits per message. Annual traffic is then converted into peak busy hour traffic by assuming 250 business days per year, 24 hours per day, and a peak to average factor of four. On this basis one busy hour Mbps at 100 percent efficiency converts into 5.4 terabits per year. Transmission line efficency is assumed to range from 1 to 10 percent. The results are shown in Table 3-13.

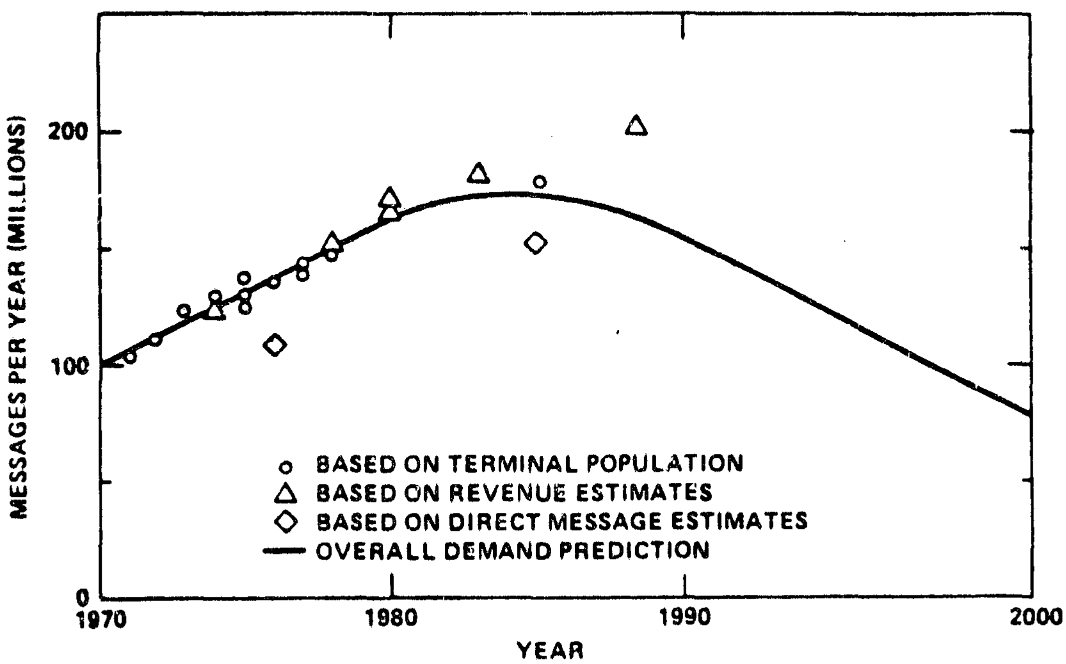
Table 3-13

Projected TWX/Telex Service Demand

(per Billion Dollars of GNP)

Year	Messages per Year (Millions)	Traffic in Terabits per Year	Transmission Efficiencies in Percent	Busy Hour Transmission Capacity in Mbps (one-way)
1980	6.02×10^{-5}	3.45×10^{-1}	1	6.4×10^{-12}
1985	6.01×10^{-5}	3.46×10^{-1}	2	3.2×10^{-12}
1990	4.53×10^{-5}	2.63×10^{-1}	5	9.7×10^{-13}
1995	3.31×10^{-5}	1.90×10^{-1}	10	3.6×10^{-13}

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



SOURCE: REFERENCE 16

Figure 3-4

TWX/TELEX MESSAGES PER YEAR
IN THE UNITED STATES

Conventional Facsimile Service Demand

Since the late 1960's, business use of facsimile has developed into a viable market. There is a wide diversion of estimates, but the assumed growth rates are uniform at about 18 percent per year. We have averaged these estimates and extrapolated them with a gradually dropping growth rate. The resulting service demand is shown in Table 3-14. The following conversion factors were used:

1,800 Pages per Year per Terminal

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

250 Days per Year

24 Hours per Day

Peak to Average Factor = 4

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

Table 3-14
Facsimile Service Demand Estimate
for Busy Hour Traffic
(per Billion Dollars of GNP)

Year	Number of Facsimile Terminals	Traffic in Terabits per Year	Transmission Efficiency (Percent)	One-Way Data Transmission Requirement Mbps
1980	1.04×10^{-4}	56.2	15.0	6.95×10^{-5}
1985	2.12×10^{-4}	114.5	17.5	1.21×10^{-4}
1990	3.59×10^{-4}	194.1	20.0	1.80×10^{-4}
1995	4.68×10^{-4}	252.9	22.5	2.08×10^{-4}

Advanced Electronic Mail Systems

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

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

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

Several estimates of advanced electronic mail service requirements for the U.S. have been made by A. D. Little, Frost & Sullivan, Xerox, George Washington University and others.

A composite of these estimates is translated into busy hour transmission capacity requirements in Table 3-15. Based on 250 days per year and a peaking factor of 4 at 100 percent transmission line efficiency one terabit per year corresponds to 0.185 Mbps.

Table 3-15

Advanced Electronic Mail

Service Demand Estimate

(per Billion Dollars of GNP)

	Year		
	1980	1990	2000
Terabits per Year per Billion Dollars GNP			
Image Mode	24.1	1687.5	1135.1
Character Mode	2.41	112.5	302.7
Total	26.51	1800.0	1437.8
Transmission Efficiency	30%	40%	50%
One-Way Data Transmission Requirement (Mbps)	1.6×10^{-11}	8.3×10^{-10}	5.3×10^{-10}

To permit interpolation to other years, advanced electronic mail service demand estimate has been plotted on Figure 3-5.

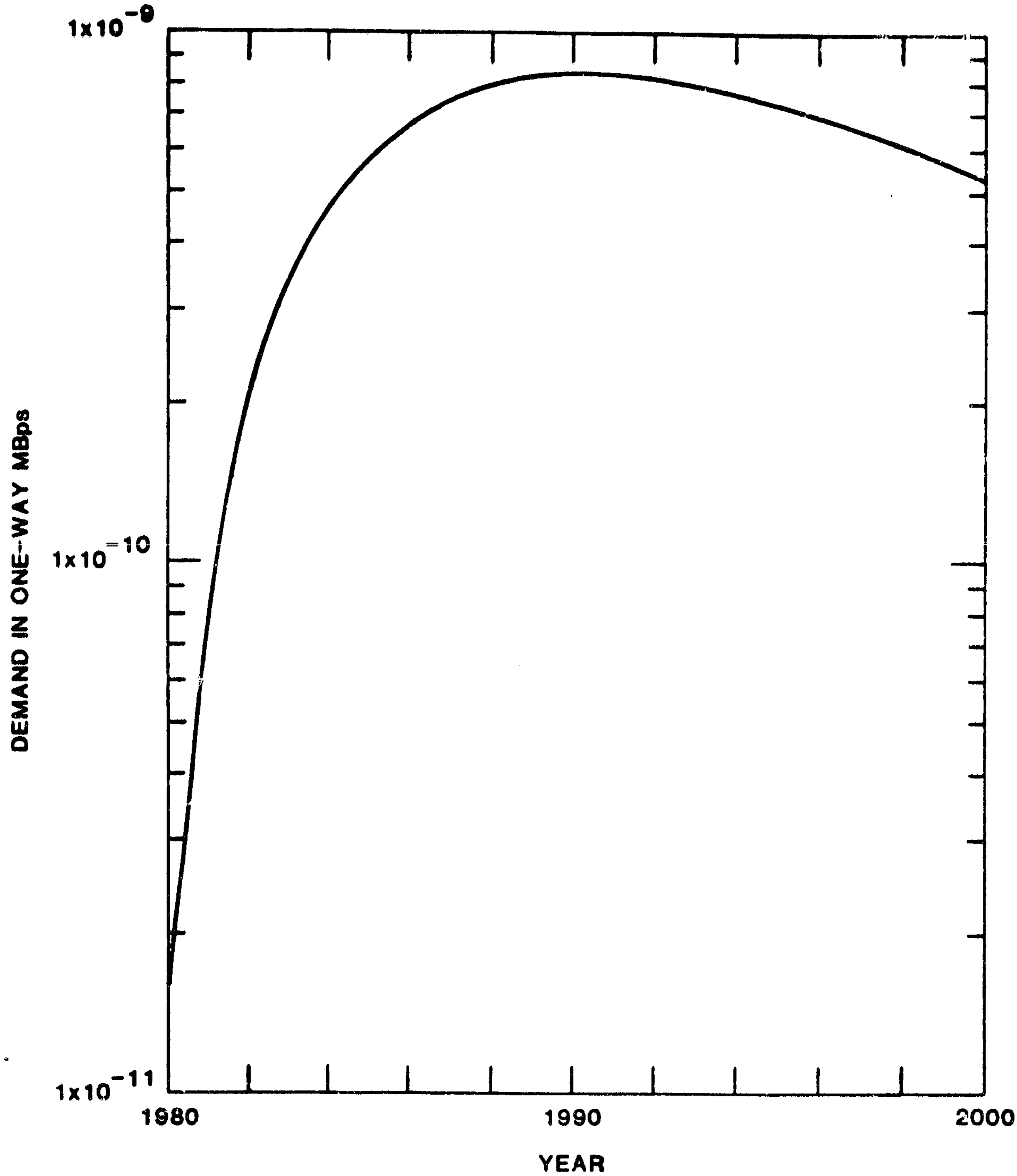


Figure 3-5

ADVANCED ELECTRONIC MAIL SERVICE
DEMAND PER $ BILLION GNP
(One-Way Mbps)

Total Message Service Demand

Table 3-16 lists the total message service demand in one-way Mbps.

Table 3-16

Total Message Service Demand

(One-Way Mbps per Billion Dollars of GNP)

Year	TWX/Telex	Conventional Facsimile	Advanced Electronic Mail	Total
1980	6.4×10^{-12}	7.0×10^{-11}	1.6×10^{-11}	9.25×10^{-11}
1985	3.2×10^{-12}	1.2×10^{-10}	2.2×10^{-10}	3.4×10^{-10}
1990	9.4×10^{-13}	1.8×10^{-10}	8.3×10^{-10}	1.0×10^{-9}
1995	3.6×10^{-13}	2.1×10^{-10}	8.1×10^{-10}	1.02×10^{-9}

3.4.2 Estimate of Computer Communication Service Demand

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

Computer to Terminal Communications

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

CPU to CPU Communications

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

Electronic Funds Transfer

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

Computer to Terminal Communications

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

In converting to the data rate requirements we have employed the following factors:

250 business days per year

24 hours per day

Peak factor of 4 (over 24 hours)

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

The resulting total transmission requirement is shown in Figure 3-6.

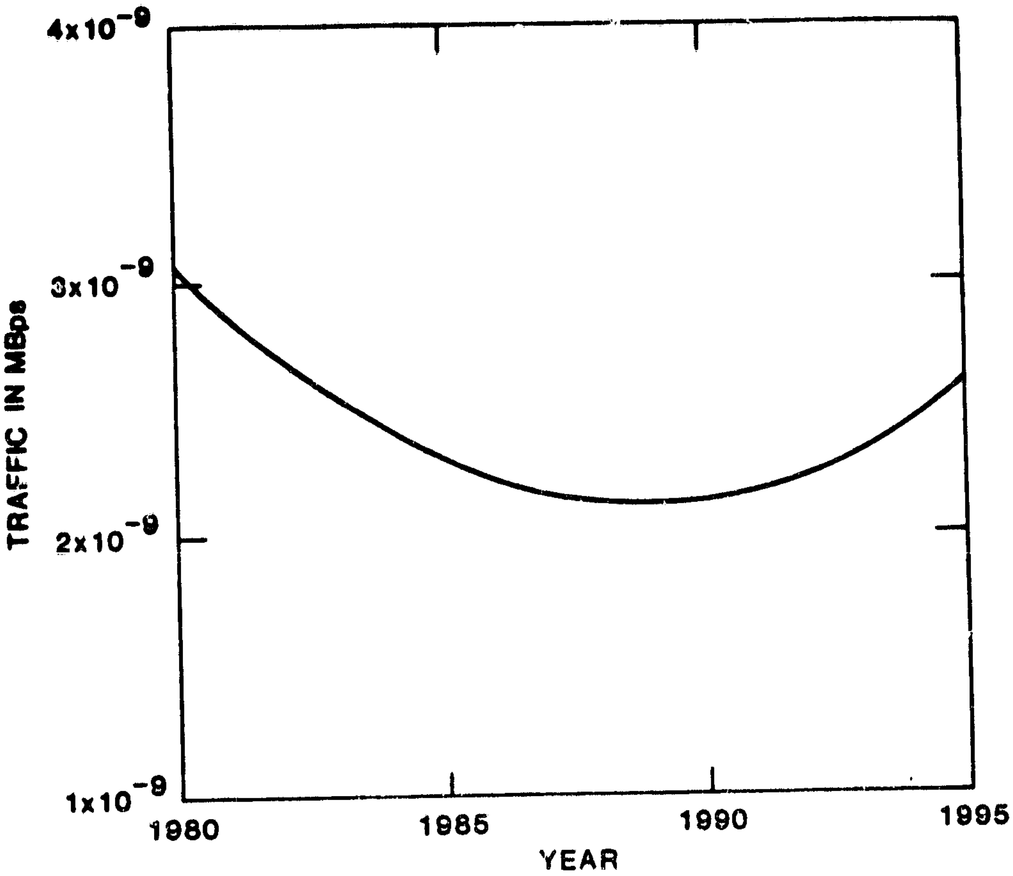


Figure 3-6

TERMINAL TO CPU TRAFFIC
(Per $ Billion GNP)

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

CPU to CPU Transmissions

This component of the data transmission market is quite difficult to estimate since there is very little of it in existence today. However, we have assumed that ultimately there will be a large fraction of the terminal to CPU traffic that will require data base access. In order to support this component, the data base contents must be transferred from one central computing facility to another. The transfers will be relatively less frequent than the accesses so the data traffic generated by the data base transfers will be smaller than the traffic generated by terminal to CPU communications.

Another source for this type of traffic is distributed processing. We have expressed this type of traffic as a fraction of the terminal to CPU traffic. Since this traffic is transferred without human intervention, the transmission efficiencies are higher than in the terminal to CPU case. Table 3-17 shows the resulting transmission requirement.

Table 3-17

CPU to CPU Traffic

(per Billion Dollars of GNP)

	Year			
	1980	1985	1990	1995
Terminal to CPU Traffic (Terabits per Year)	333.3	618.4	909.4	1424.2
Traffic Ratio	0.05	0.07	0.13	0.26
CPU to CPU Traffic (Terabits per Year)	16.5	43.5	118.8	369.2
Transmission Efficiency	4%	7%	10%	15%
One-Way Data Transmission Requirement (Mbps)	7.6×10^{-11}	1.2×10^{-10}	2.2×10^{-10}	4.6×10^{-10}

Electronic Funds Transfer (EFT)

This portion of the market will be concerned primarily with the clearinghouse function for check handling and the growing volume of credit card initiated funds transfers. Most of the growth in this service will come from the gradual conversion to this method of transaction handling, since there are strong indications that the volume of transactions is reaching a saturation region with rather slow growth. The forecast from Reference 13 has been converted to a data rate requirement as shown in Table 3-18. The transmission efficiency is assumed to range from 10 percent to 30 percent, since storage and data compression techniques can eliminate the inefficiencies caused by human interaction.

Table 3-18

Transmission Requirements for EFT

(per Billion Dollars of GNP)

	Year			
	1980	1985	1990	1995
Terabits per Year	1.6×10^{-12}	5.6×10^{-12}	9.4×10^{-12}	1.2×10^{-11}
Transmission Efficiency (Percent)	10	15	20	30
One-Way Data Transmission Requirement (Mbps)	2.8×10^{-12}	7.1×10^{-12}	8.8×10^{-12}	7.4×10^{-12}

Total Computer Communications Service Demand

Table 3-19 lists the estimate total computer communications service demand in one-way Mbps.

3.4.3 Narrowband Teleconferencing Service Demand

Narrowband teleconferencing includes all the features of a video conferencing facility except video:

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

Conferencing facilities of this type will be constructed with transmission bandwidth requirements ranging from 19.2 kbps to 112 kbps, two way.

Table 3-19

Total Computer Communications Service Demand

(One-Way Mbps per Billion Dollars of GNP)

Year	Terminal to CPU Traffic	CPU to CPU Traffic	EFT Traffic	Total Traffic
1980	3.1×10^{-9}	7.6×10^{-11}	2.3×10^{-12}	3.2×10^{-9}
1985	2.3×10^{-9}	1.1×10^{-10}	7.1×10^{-12}	2.4×10^{-9}
1990	2.2×10^{-9}	2.2×10^{-10}	8.8×10^{-12}	2.4×10^{-9}
1995	2.6×10^{-9}	4.5×10^{-10}	7.4×10^{-12}	3.1×10^{-9}

Transmission requirements for this type of traffic are presented in Table 3-20.

Table 3-20

Transmission Requirements for Narrowband Conferencing

(per Billion Dollars of GNP)

	Year			
	1980	1985	1990	1995
Terabits per Year				
Image Mode	.4	6.7	13.1	19.0
Character Mode	--	0.04	.06	0.3
Freeze Frame TV	3.2	47.7	100.0	152.9
Total	3.6	54.44	113.16	172.2
Transmission Efficiency (Percent)	10	12.5	15	20
Transmission Requirement (Mbps)	6.83×10^{-12}	8.06×10^{-11}	1.4×10^{-10}	1.59×10^{-10}

3.4.4 Data Forecast for World Model Regions

In order to convert the preceding forecasts of data communications traffic into specific forecasts for the various world model regions, we have postulated for each region a time varying conversion factor. This factor is a combination of the estimated fraction of the traffic which will be carried via satellite, and an estimated overall growth curve for this specific type of traffic. Each world model region has its own particular time varying factor.

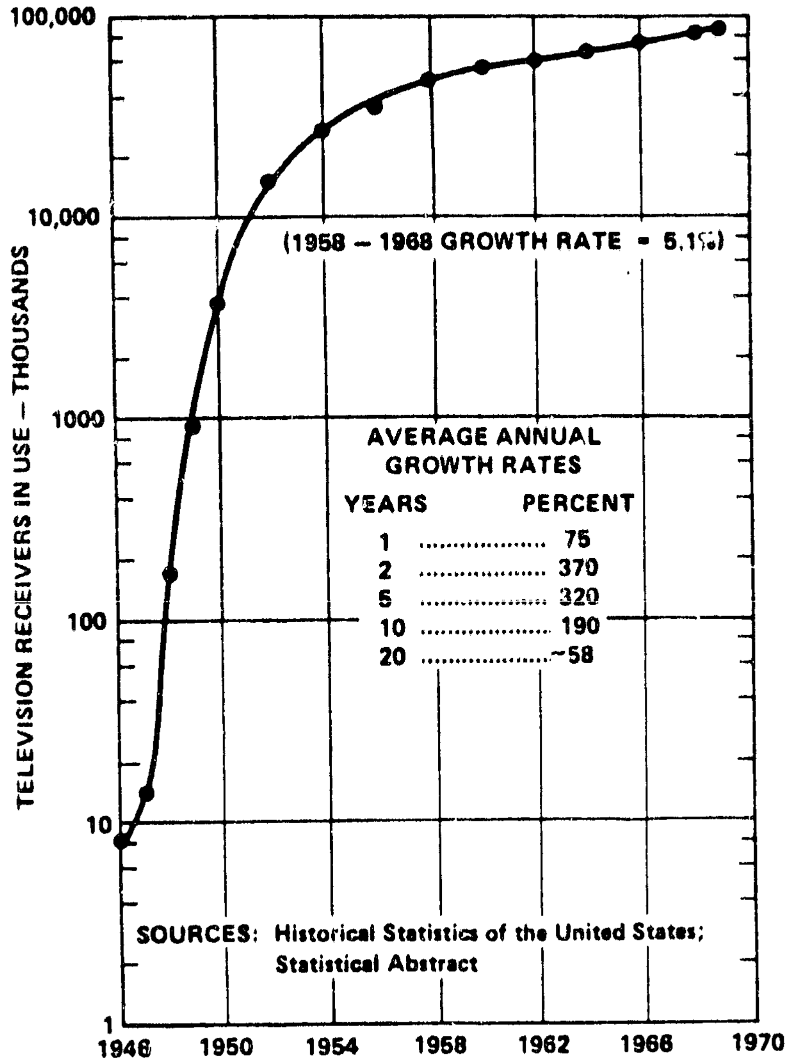
Satellite Capture

In any particular region the percentage of traffic which will be carried on the satellite system will depend greatly on how well developed the terrestrial radio network is. In the U.S. for example an efficient and complex terrestrial network is already in place. This results in a relatively low satellite capture ratio for services such as telephony and low speed data communications. Additionally, the terrestrial network in the United States is likely to undergo continuous improvement with the addition of facilities such as fiber optics links which will eventually capture a significant portion of even higher speed and wider bandwidth communications. A corresponding situation exists to a great extent in the developed countries such as the nations of Europe. However in many of the areas of the world climatic, geographical, or economic factors militate against the development of an efficient terrestrial network. In such areas, for instance most of Africa, communications are now relatively poor and the most rapid and economical improvement in communications quality will come from installation of satellite earth stations. In such areas the installation of advanced terrestrial communications systems such as long distance fiber optics links is highly unlikely for the foreseeable future. Therefore the percentage of traffic which will be carried via satellite will be quite high. In spite of this, we have remained conservative in our choice of the ultimate satellite capture ratio.

Growth of Communications Traffic

The market demand particularly for innovative services in a particular world model region will not depend solely on GNP. In many areas there will be delays often considerable in the introduction of some new services such as video conferencing or CPU to CPU data communications. This delay is more properly an illustration of the fact that introduction of new services is proportional to GNP per capita or GNP per square kilometer in a particular area rather than proportional to the total GNP. This is because these latter factors better reflect the actual state of development of a country and it is on this state of development that the introduction of advanced services depends. This relationship is not necessarily a linear one, nor need it be time invariant. The desire of a country or region to advance itself technologically and economically will be reflected to some extent in its pursuit of advanced communications methods. This stems in part from the fact that the most likely source of industrialization is nations that are already highly industrialized. Since these countries are likely to already be using advanced communications techniques, trade with them will be enhanced by the adoption of these communications methods.

No firm mathematical formulas tied directly to GNP or population figures are readily available for the two factors described above. However the evidence presented by the growth patterns of various unrelated systems and by the introduction of various products leads us to believe that this function combining satellite capture and the introduction of new services will have the form of the logistic or S-shaped curve. Such a growth history is shown in Figure 3-7. Accordingly we have estimated the parameters of such a curve for each world model region. As shown in Figure 3-8, the combination of these growth relationships with the data communications model proportional to GNP produces forecasts for the total satellite data communications requirements for the various world model zones. This composite forecast is shown in Table 3-21.



SOURCE: REFERENCE 23

Figure 3-7

GROWTH OF TELEVISION
IN THE UNITED STATES

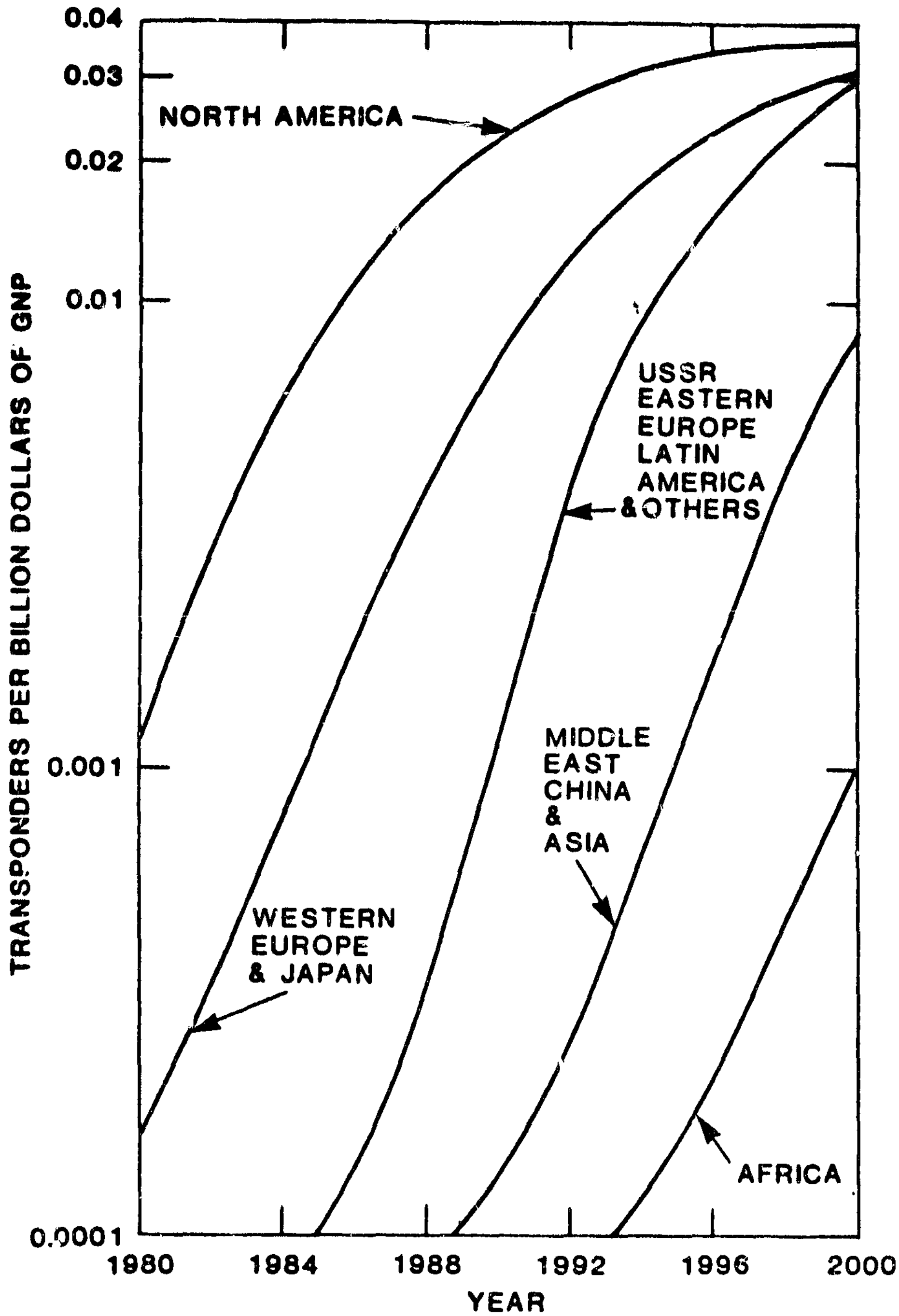


Figure 3-8

GROWTH OF DATA SERVICES

Table 3-21

New Data Transmission Requirements (Transponders)

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	3	19	64	123	174	216
Western Europe	0	2	42	164	246	297
U.S.S.R.	0	0	1	6	36	82
Eastern Europe	0	0	0	2	11	24
Japan	0	1	17	70	106	130
Total Group I	4	22	124	365	573	749
Latin America	0	0	0	4	24	60
Middle East	0	0	0	1	6	47
China	0	0	0	0	2	13
Asia	0	0	0	0	3	19
Africa	0	0	0	0	0	0
Total Group II	0	0	1	5	35	138
Others	0	0	0	1	5	9
Total	4	22	125	371	613	896

3.5 Video Conferencing

Background

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

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

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

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

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

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

Video conferencing demand for areas other than the U.S. was based on the U.S. forecast. Figure 3-9 shows the growth of video conferencing in the U.S. model in terms of transponders per billion dollars of GNP, over the period 1980 to 2000. Suitable delay factors were developed for the other world model regions. The variations in growth of video conferencing were estimated as also shown in Figure 3-9. Table 3-22 shows the forecast for all the world model regions.

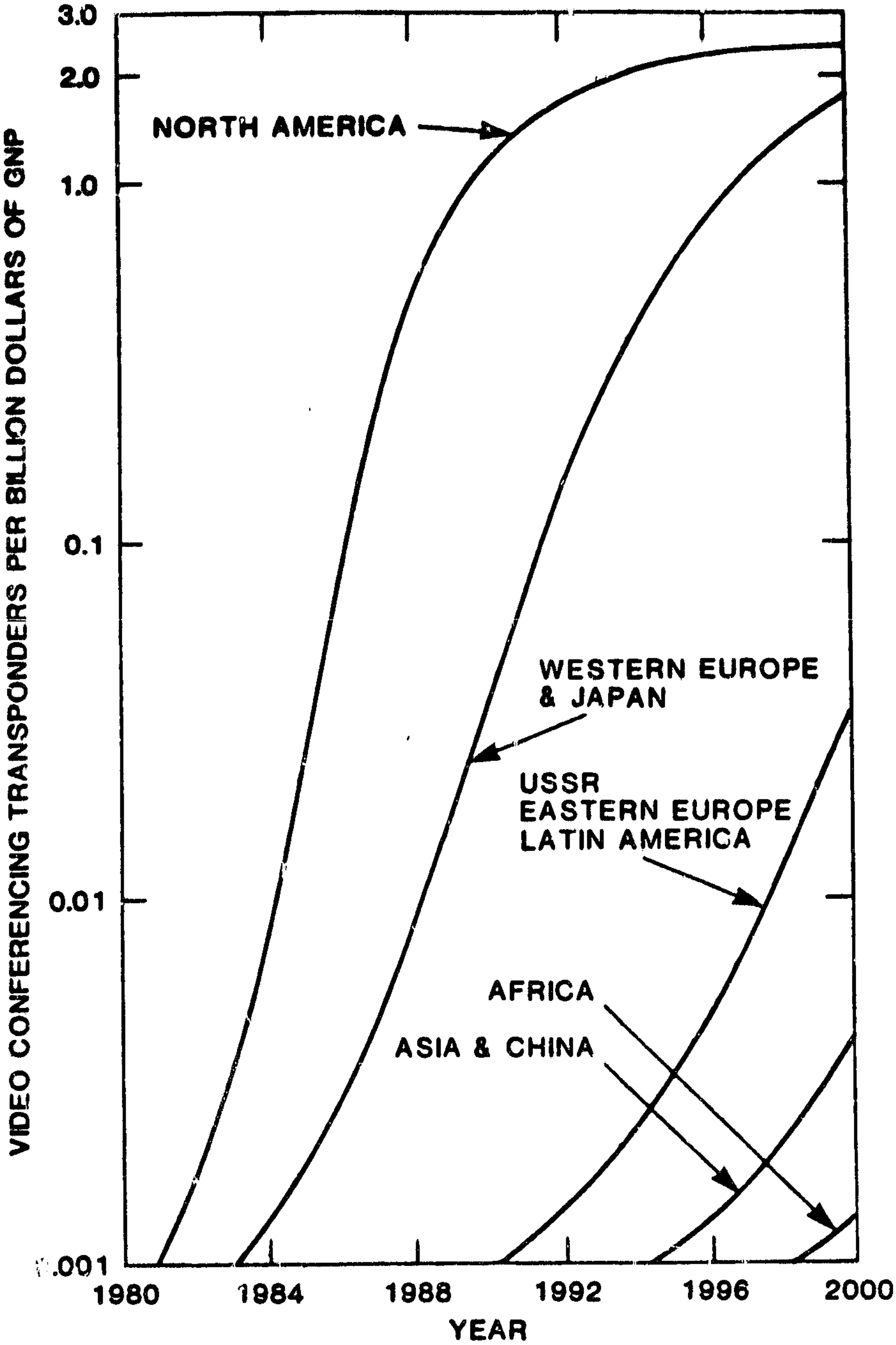


Figure 3-9

GROWTH OF VIDEO CONFERENCING

Table 3-22

Video Conferencing Requirements

Mid-Year:	1980	1984	1988	1992	1996	2000
North America	2	26	1497	8025	11970	14190
Western Europe	2	5	40	676	5201	13188
U.S.S.R.	1	1	1	3	12	88
Eastern Europe	0	0	0	1	4	26
Japan	1	2	17	287	2249	5759
Total Group I	6	34	1556	8991	19436	33250
Latin America	0	0	1	2	8	64
Middle East	0	0	1	3	18	181
China	0	0	0	1	2	7
Asia	0	0	0	1	2	10
Africa	0	0	0	0	0	0
Total Group II	1	1	3	7	30	261
Others	0	0	0	0	2	10
Total	7	36	1558	8998	19468	33521

3.6 INTELSAT Traffic Forecast

We have included a forecast for INTELSAT international traffic which is based on the history of INTELSAT and on the short range forecasts developed by the member nations of INTELSAT. INTELSAT provides primarily telephony services, and leased transponders and we expect this trend to continue, with more advanced services added slowly.

The historical and projected growth of international satellite traffic is shown in Figures 3-10 through 3-12. The growth rates are typical of those experienced by a new service - intially at a low level, then building to a peak, and later settling down to a moderate level as the system matures. This process is illustrated in Figure 3-13, for INTELSAT Atlantic traffic.

INTELSAT international traffic is now a mature service, with growth rates of approximately 15 to 17 percent per year. On this basis, we have extrapolated the historical data to yield the forecast shown in Table 3-23.

Table 3-23
Forecast of INTELSAT International Traffic
(Transponders)

Year	Atlantic Region	Indian Region	Pacific Region	Total
1980	30	11	5	46
1984	52	18	8	78
1988	81	27	12	120
1992	120	37	16	173
1996	173	49	22	244
2000	248	64	30	342

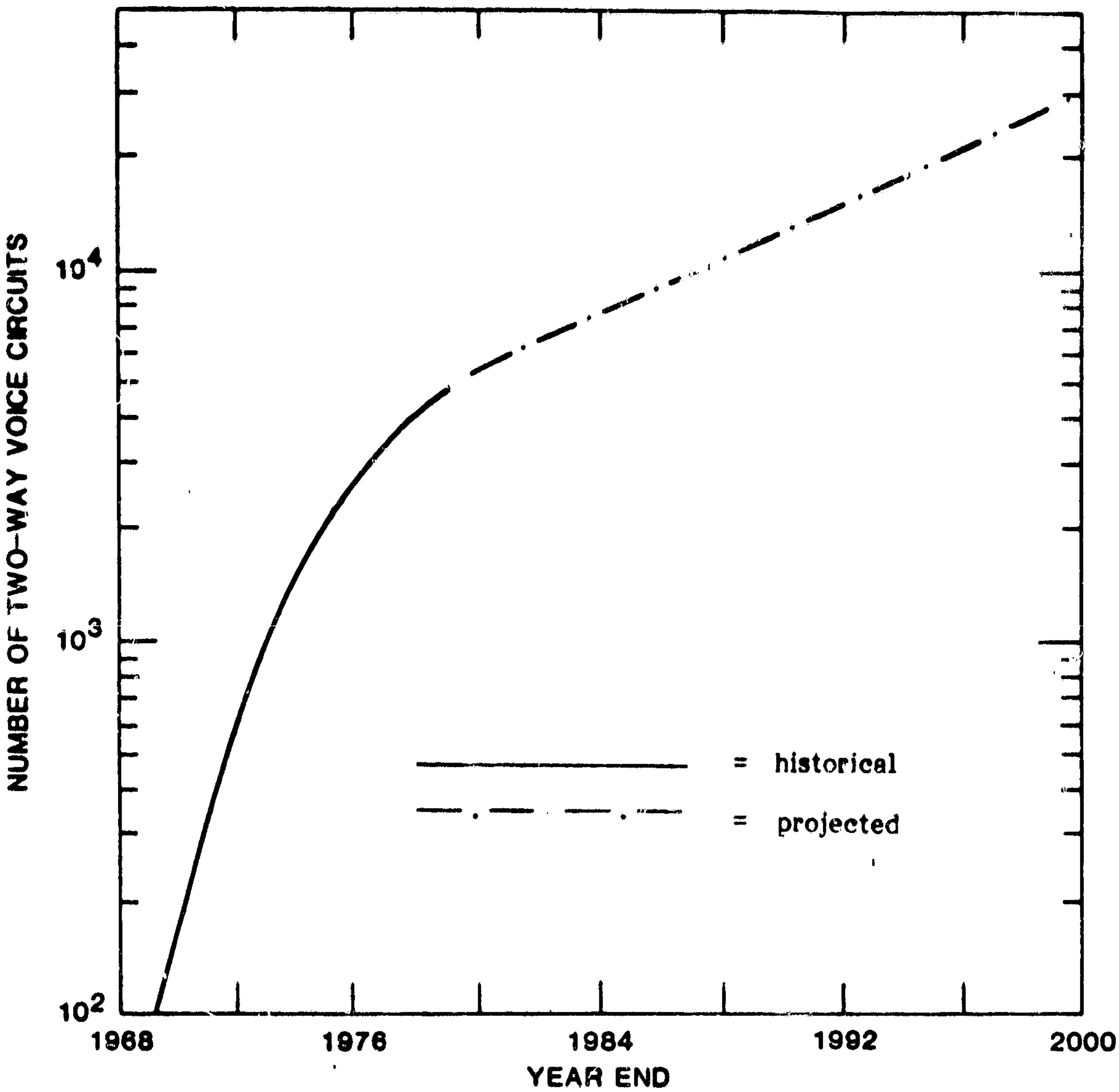


Figure 3-10

INDIAN OCEAN REGION
TRAFFIC FORECAST

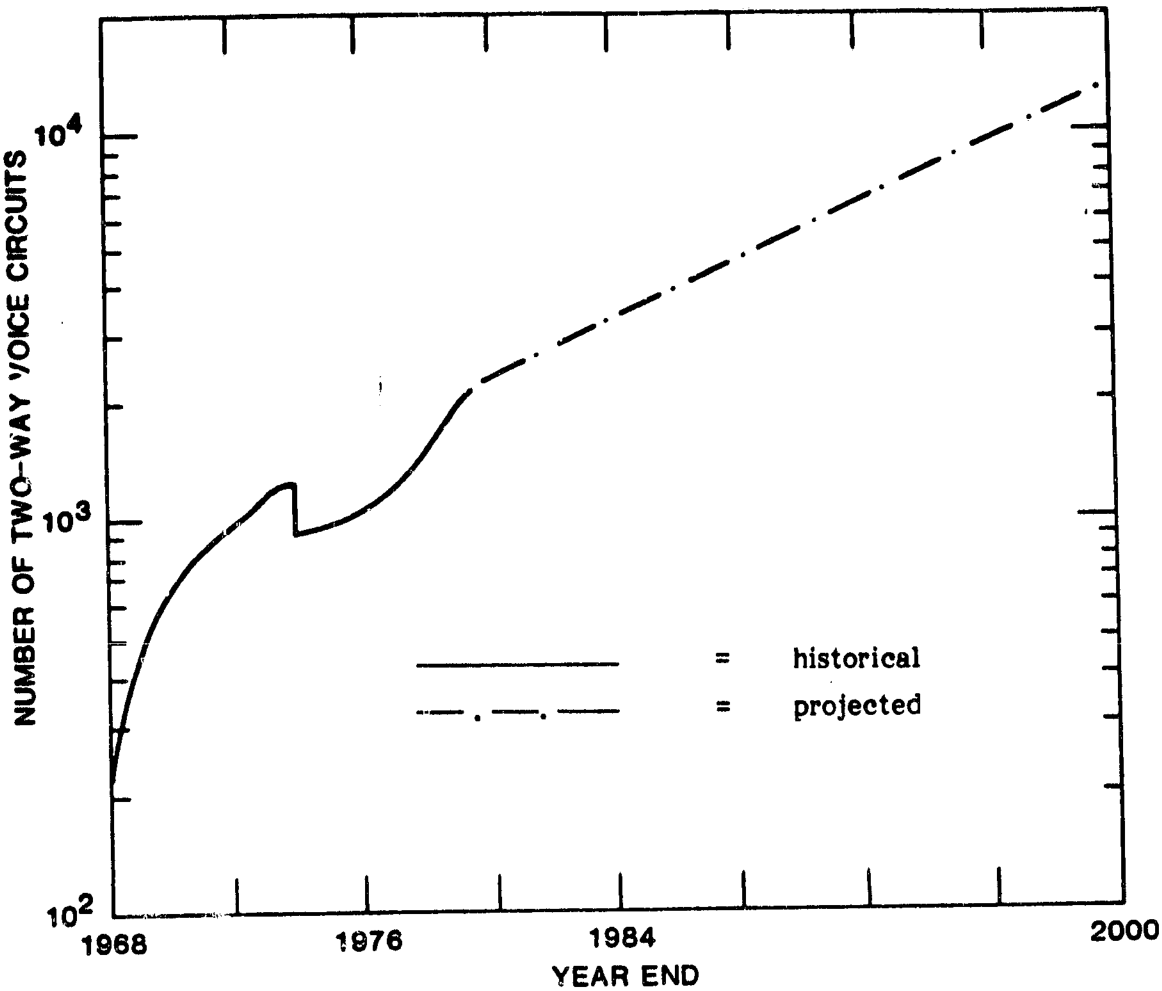


Figure 3-11

PACIFIC OCEAN REGION
TRAFFIC FORECAST

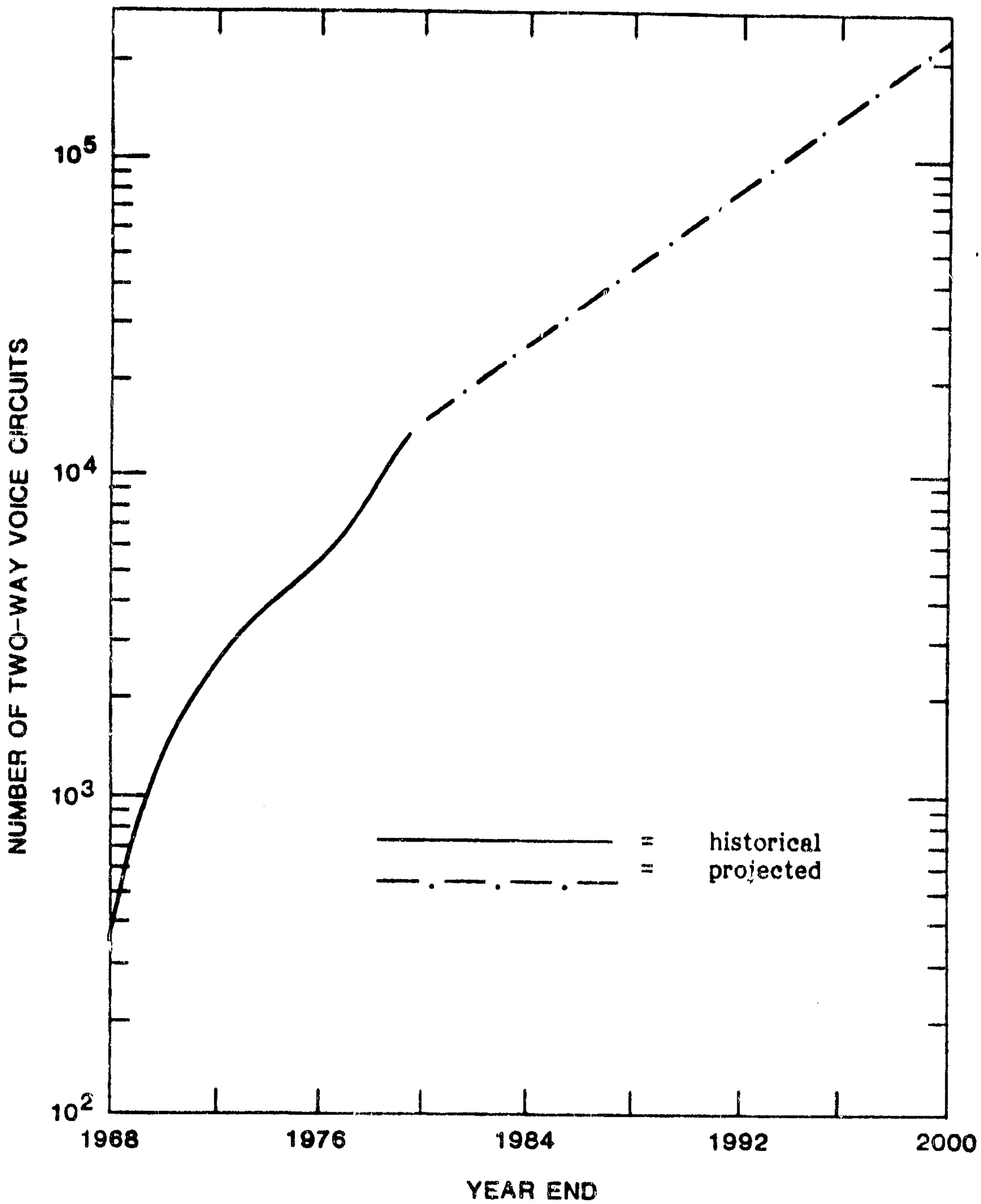
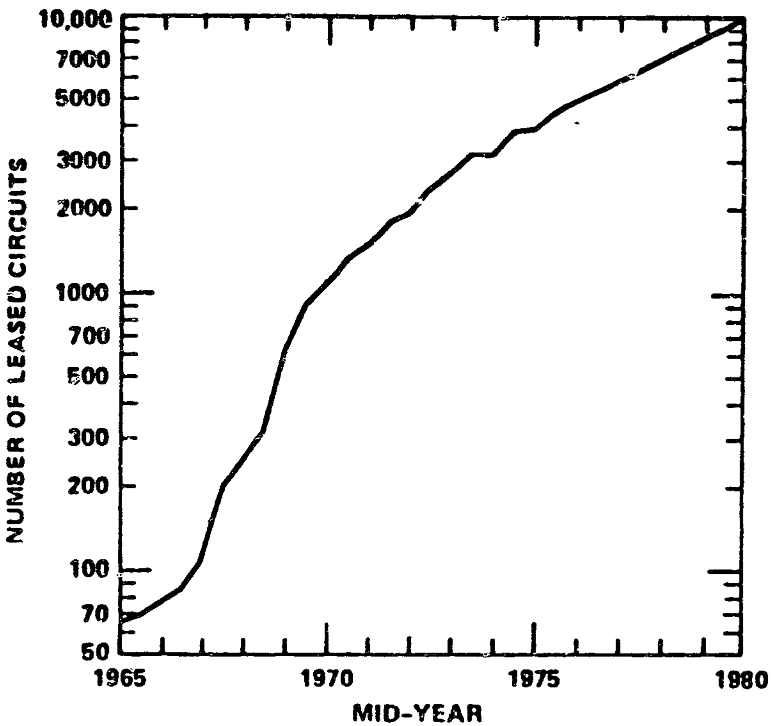


Figure 3-12

ATLANTIC OCEAN REGION
TRAFFIC FORECAST



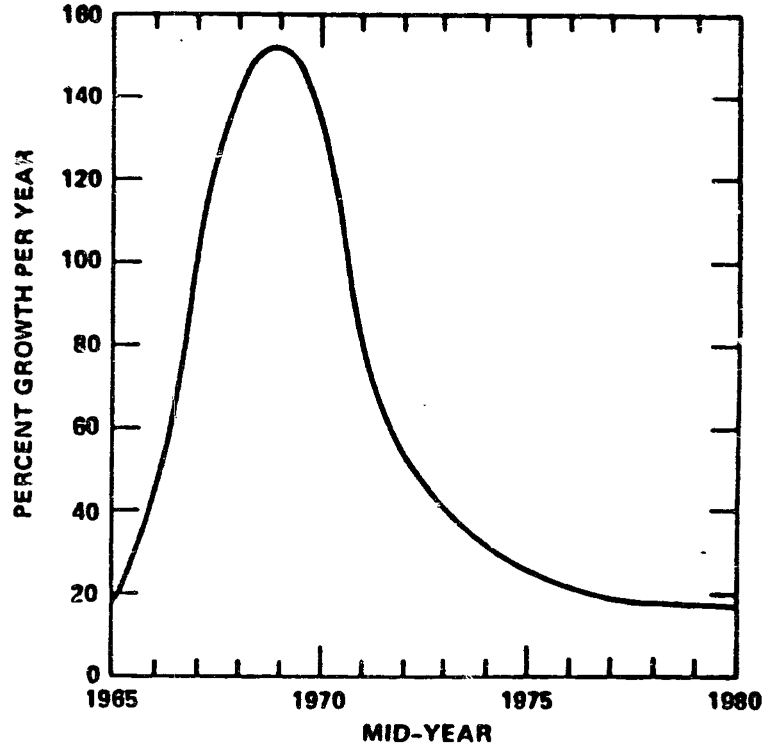


Figure 3-13

DYNAMICS OF SYSTEMS GROWTH FOR INTELSAT ATLANTIC OCEAN TRAFFIC

PERCENT GROWTH RATE PER YEAR FOR INTELSAT ATLANTIC OCEAN TRAFFIC

3.7 Total Requirements

Since there is still some uncertainty concerning the development of video teleconferencing systems, we have formulated two forecasts from the preceeding analysis. The low traffic model consists of the forecasts for telephony and data transmission. The high traffic model consists of the low traffic model with the video teleconferencing traffic added. Table 3-24 shows the total traffic for the low traffic model, by world model region. Table 3-25 shows the addition of the teleconferencing demand to produce the high traffic model.

Table 3-24
Total Requirements - Low Traffic Model
(Transponders)

Mid-Year	1980	1984	1988	1992	1996	2000
North America	131	284	458	653	858	1,063
Western Europe	56	245	470	803	1,141	1,515
U.S.S.R.	11	27	52	91	169	280
Eastern Europe	0	21	66	107	140	148
Japan	46	141	236	359	460	538
Total Group I	244	718	1,282	2,013	2,768	3,565
Latin America	7	46	128	269	485	766
Middle East	3	11	28	57	113	241
China	0	2	9	23	49	97
Asia	17	38	81	164	312	579
Africa	6	15	26	41	59	78
Total Group II	33	112	272	553	1,017	1,761
Others	0	6	14	24	36	50
Total	277	836	1,568	2,590	3,821	5,376

Table 3-25

High Traffic Model

	1980	1984	1988	1992	1996	2000
Regional Traffic	277	836	1,568	2,590	3,821	5,376
INTELSAT Traffic	46	78	120	173	244	342
Video Conferencing	7	36	1,558	8,998	19,468	33,521
Total	330	950	3,246	11,961	23,533	39,239

3.8 TV Distribution

Table 3-26 shows the estimates of capacity requirements for TV distribution in the U.S. Formulating such estimates for the other areas of the world is more difficult. This is due primarily to the fact that TV programming and distribution is a state-controlled monopoly in most of the world. Thus, the degree to which the latent demand for TV is satisfied depends on policy decisions rather than market forces as in the U.S. Some evidence that this service may be significant is available from INTELSAT transponder leases. In almost every case of a leased INTELSAT transponder, one of the first uses is for TV distribution. This indicates that the various administrations are interested in providing this type of service.

Table 3-26

TV Distribution Requirements

1980	50
1990	200
2000	500

We have not included these estimates in the totals because this type of service--point to multipoint—competes with the point to point services discussed previously for orbital locations.

SECTION 4
TRANSITION TO ADVANCED SYSTEMS

In organizing a forecast for future satellite systems, we find it helpful to indicate the likely course of transition from the systems of today. Even the most advanced of current and planned systems uses satellites of rather modest capacity. We have attempted in this section to outline the possible features that will characterize the growth from current systems to those using 30/20 GHz, on-board switching, and other technologies now under study.

4.1 Transition Scenario

Previous reports for NASA have stressed the use of highly-advanced technology for communications satellites. Such spacecraft are based on the use of multiple spot beams of about 1 to 2 degree diameter. The multiplicity of beams requires on-board switching. Considerable technology development would be required before such a satellite would be feasible. We found it desirable to formulate a somewhat less ambitious design concept for this study. Some general observations are in order before treating the actual design bounds.

First, we feel that U.S. manufacturers will likely set the pace for satellite communications in the next 20 years, because of several factors. The U.S. market is the most advanced and demanding one in the world today, and is likely to remain so for the near future. Thus, the U.S. satellites will adopt state-of-the-art measures to increase capacity. The U.S. manufacturers also employ an agressive sales force, and have a good track record of reliable spacecraft. In Europe, political considerations will probably prevail, but elsewhere, the U.S. has excellent chances, as witness ANIK, PALAPA, all INTELSAT satellites so far. U.S. companies also provide off-the-shelf satellite busses, which can reduce development costs considerably.

Second, current NASA programs and the availability of the Shuttle will encourage U.S. companies to employ present and near-term technology to develop a Shuttle-fitted spacecraft of increased capacity. An additional incentive to the use of higher frequencies is the lively market for CATV transponders at C-band. While we feel that current C-band point-to-point users will not allow themselves to be pushed out (due to the high value of their already frequency coordinated sites), the growth in demand will have to be mostly satisfied at the higher frequencies. Thus, we expect to see moderate use of multi-beam antennas, with perhaps four area beams covering the U.S. at C-band, and a number of spot beams at Ku-band for the major cities. Additional transmit power will be available, but no large and complex switching arrangements will be used in space, in the near term.

Third, based on NASA estimates, commercial Ka-band satellites will be available around 1991. We also estimate that a substantial advance in on-board switching will be feasible at this time. This will result in a step-function increase in available capacity, which will occur just about in time to alleviate a real shortage of transmission capacity.

Figure 4-1 illustrates the assumed transition scenario and its relationship to the historical development of satellite communications. A trend line has been drawn in, not to show a fitted curve, but rather to focus on the growth pattern and the scatter of the data points. Even now, with several forecasts of rapidly expanding demand published, we find plans being made for satellites of quite low capability.

Due in part to this factor, we have taken a somewhat conservative view of the growth of satellite capacity. This is shown in Figure 4-1, where we indicate that the average capacity will grow to about 100 transponders by the year 2000, if the use of Ka-band is precluded. Other assumptions of frequency availability are shown in Table 4-1.

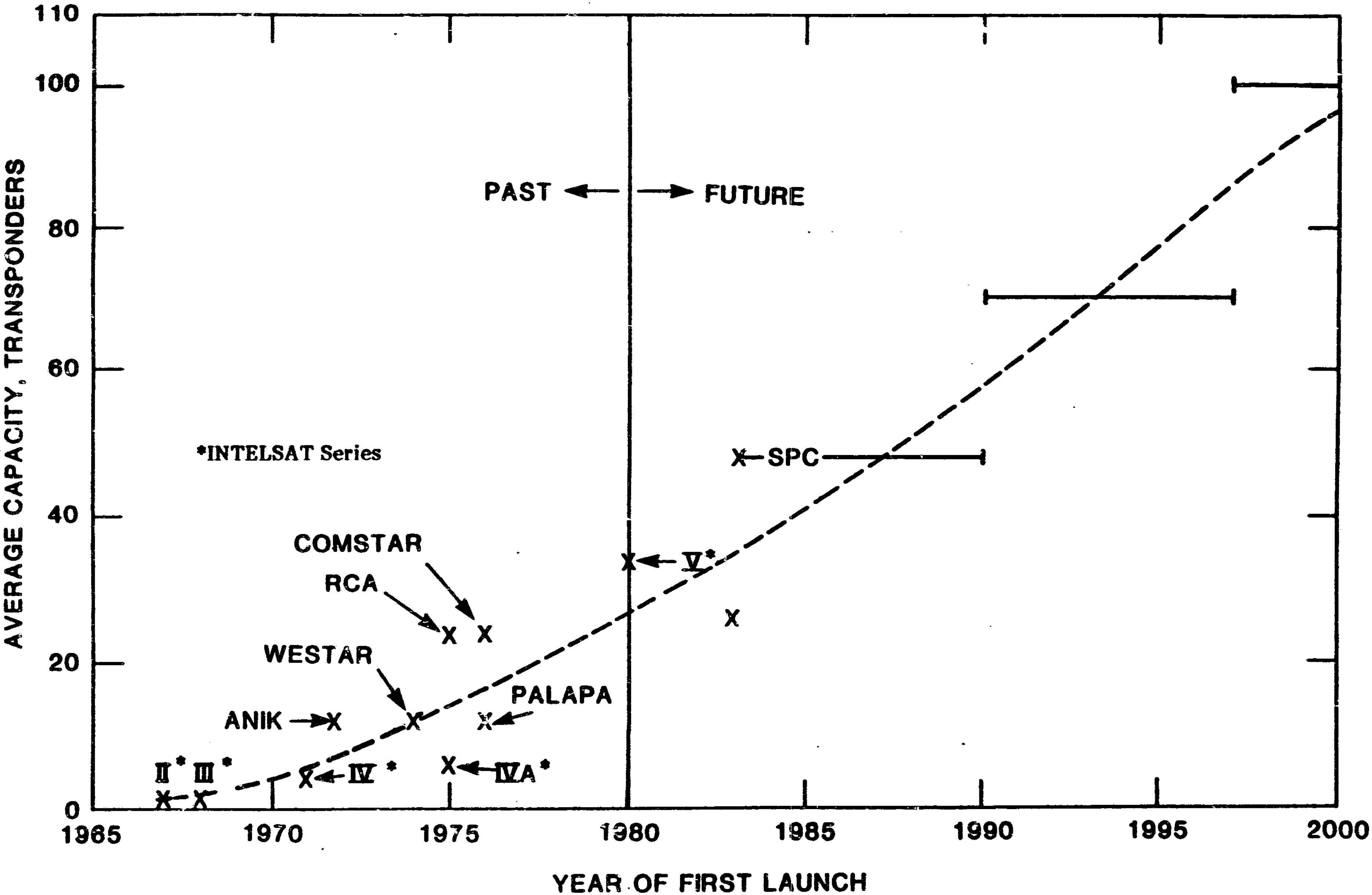


Figure 4-1

GROWTH AND TRANSITION OF SATELLITE CAPACITY (WITHOUT 30/20 GHZ)

Table 4-1

Frequency Band Assignments

Uplink Band MHz	Downlink Band MHz	Available Bandwidth MHz	Equivalent Number of Transponders
5,925-6,725	3,400-4,200	800/1,600*	20/40*
12,750-13,250 14,000-14,500	11,200-12,200	1,000/2,000*	24/48*
27,500-30,000	17,700-20,200	2,500	60
TOTAL		4,300	104

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

Table 4-2

Saturation at Lower Frequencies

(C-band and Ku-band)

Region	Saturation Dates	
	Low Traffic (No Video Conferencing)	High Traffic (Includes Video Conferencing
North America	*	1989
Western Europe	1999	1991
Japan	*	1994
Latin America	*	*
Middle East	*	*
China	*	*
Asia	*	*
Africa	*	*

* - after the year 2000.

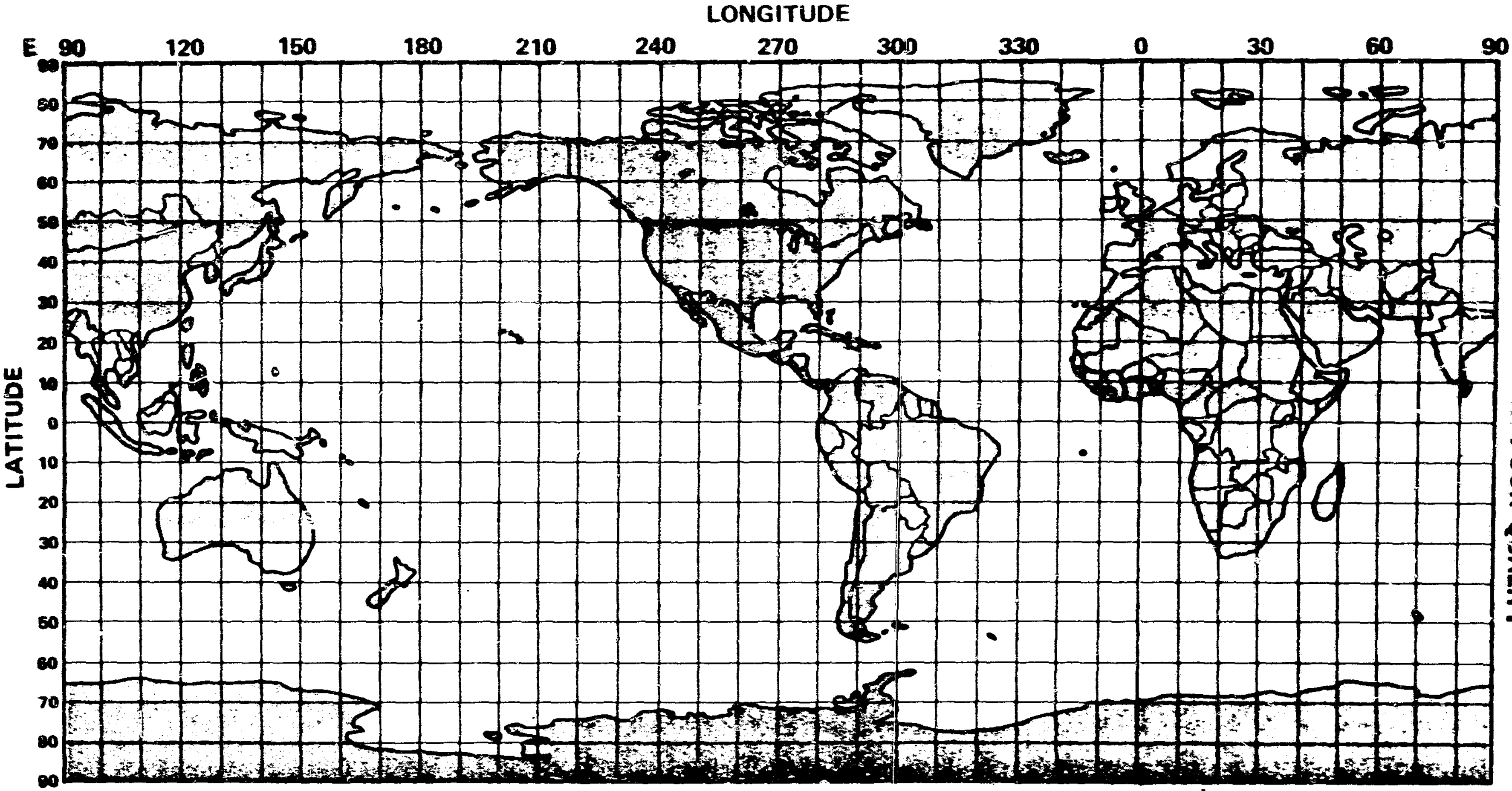
WARC 1979 set the allocation for the frequency band covering 10.7 GHz to 11.7 GHz as international use only. We have assumed that one-half of this, or 500 MHz, will become available for domestic use. At best, all 1000 MHz would be available, and there is a possibility that none will be allocated. We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

Based on the above scenario, Table 4-2 shows the probable time at which the lower frequency bands (4/6 and 12/14) would become saturated in each of the world model zones. This is the latest time that the use of 30/20 GHz and additional technology advances would be needed to satisfy demand. Due to the length of the planning/procurement cycle, and the life of satellites already in orbit, planning and construction of more advanced satellites should begin well before saturation is imminent.

4.2 Required Capacity Per Orbital Slot

In Section 3, we developed a traffic model for the period 1980-2000. This model results in total required capacity per world model region. The coverage arc of the various world model regions varies; in some cases there is some overlap, and some reuse of the orbit is available. The coverage arcs are shown in Figures 4-2 through 4-4. In Table 4-3 we have listed the estimated number of orbital slots available to each region; this is based on satellite spacing of 4 degrees, and the use of some slots for TV distribution. This latter service competes with point-to-point services for the use of the orbit, and hence reduces the number of slots available.

With the number of slots specified, and the traffic as a function of time, it is simple to determine the average required capacity per slot. This is shown in Figures 4-5 through 4-8. Several things are apparent from these figures.


LONGITUDE
E 90
120
150
180
210
240
270
300
330
0
30
60
90
LATITUDE
90
80
70
60
50
40
30
20
10
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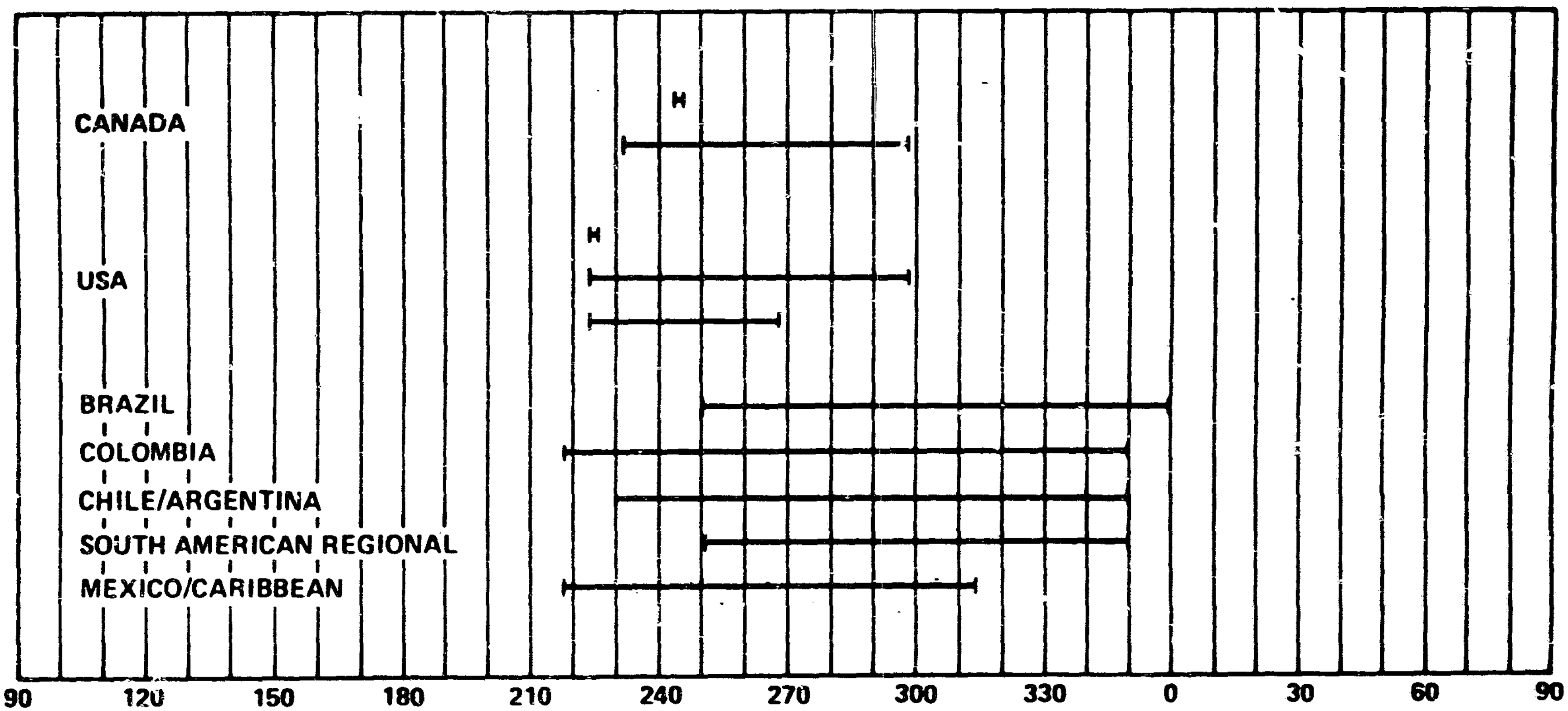
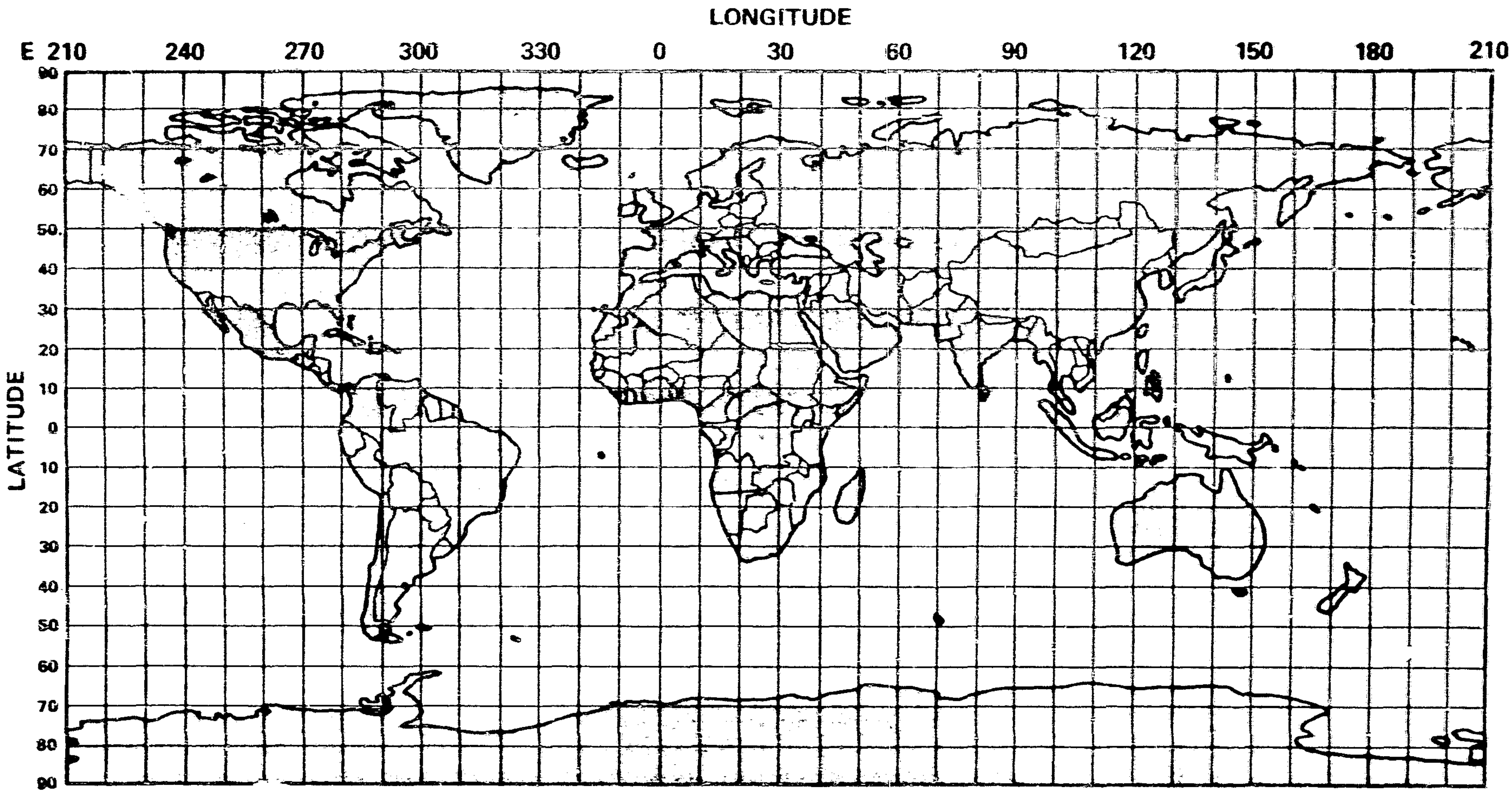


FIGURE 4-2

SERVICE ARC – NORTH/SOUTH AMERICA


LONGITUDE
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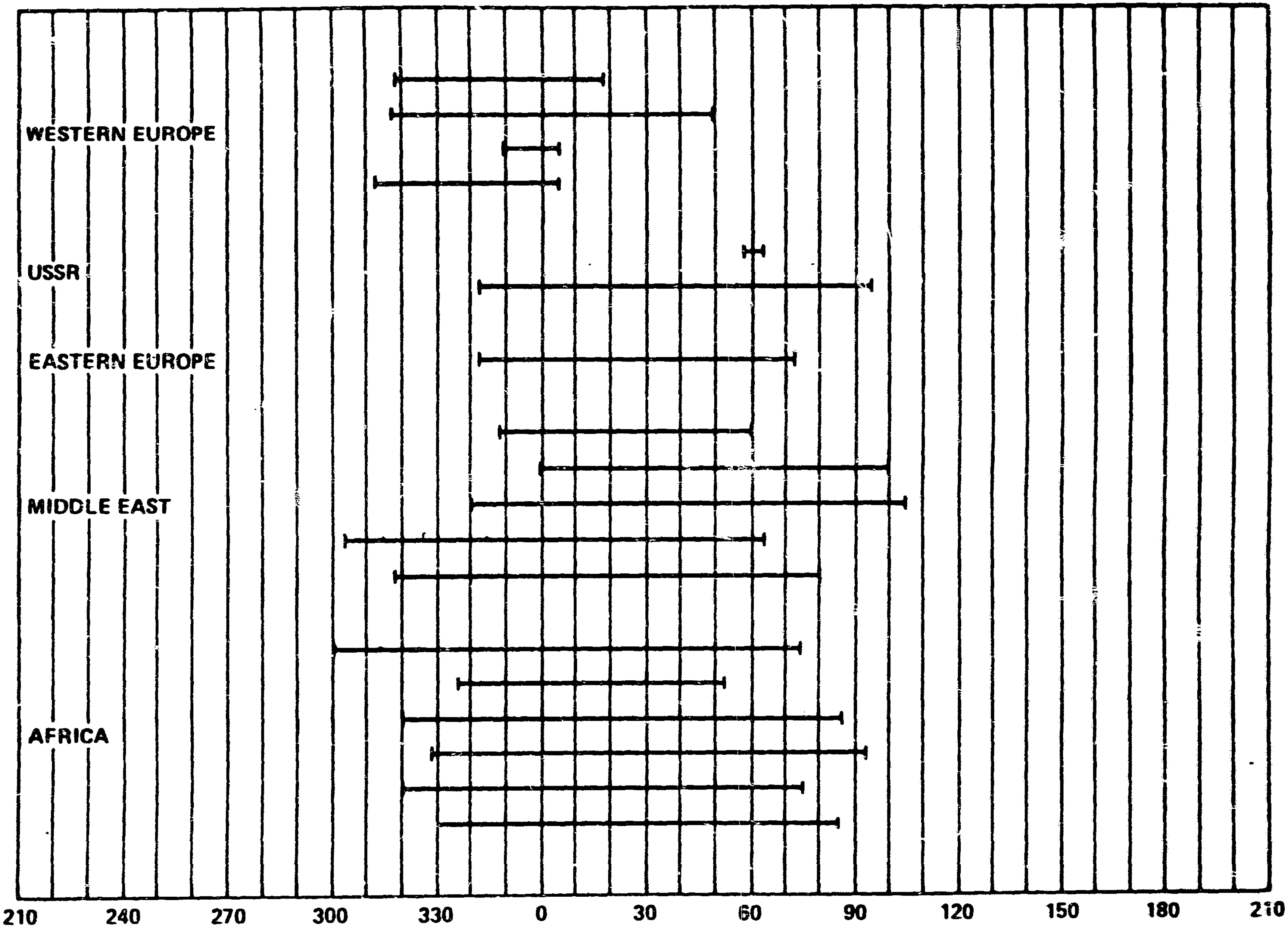
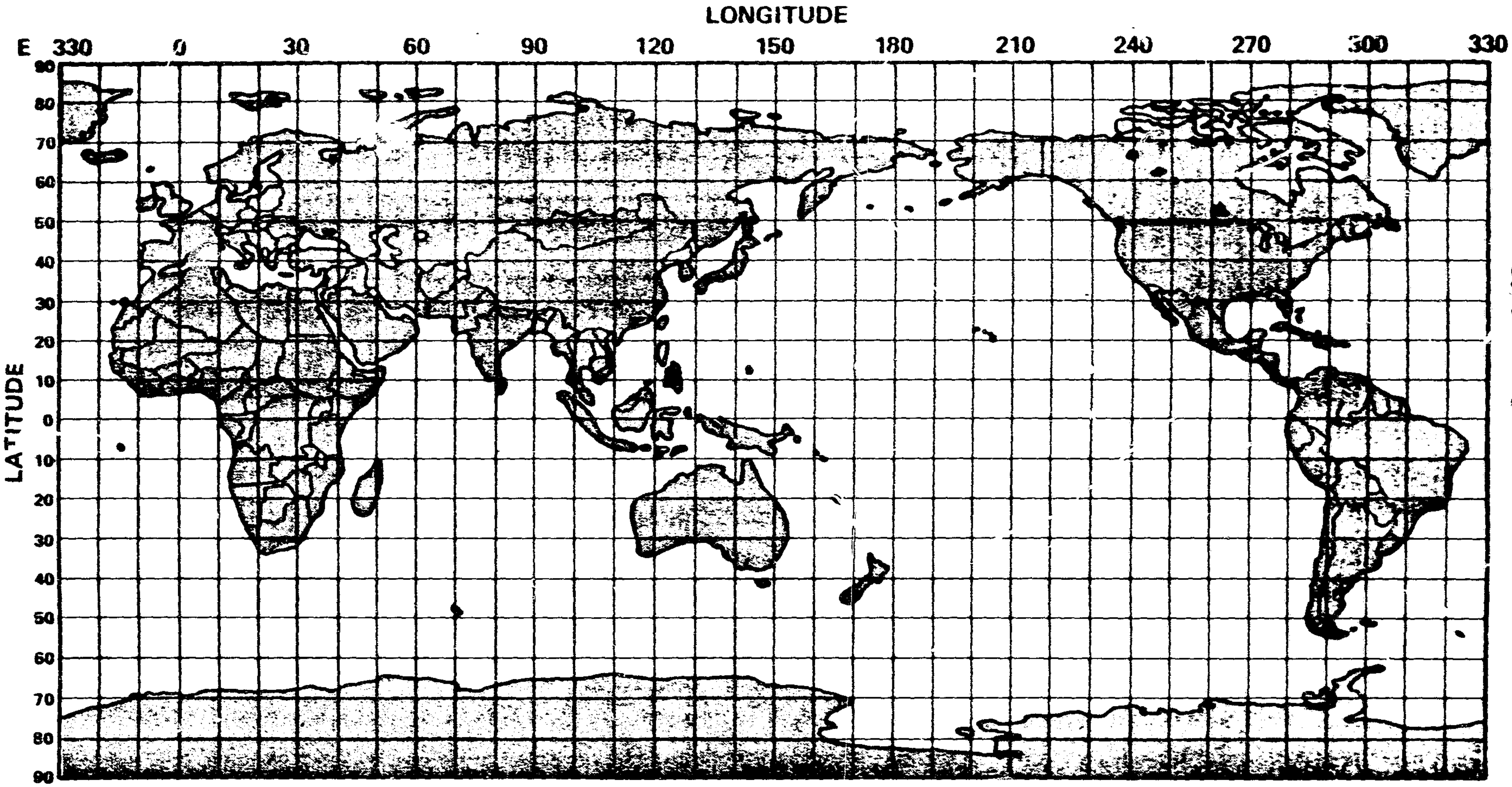


FIGURE 4-3

SERVICE ARC – EUROPE/AFRICA


LONGITUDE
E 330 0 30 60 90 120 150 180 210 240 270 300 330
LATITUDE
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90

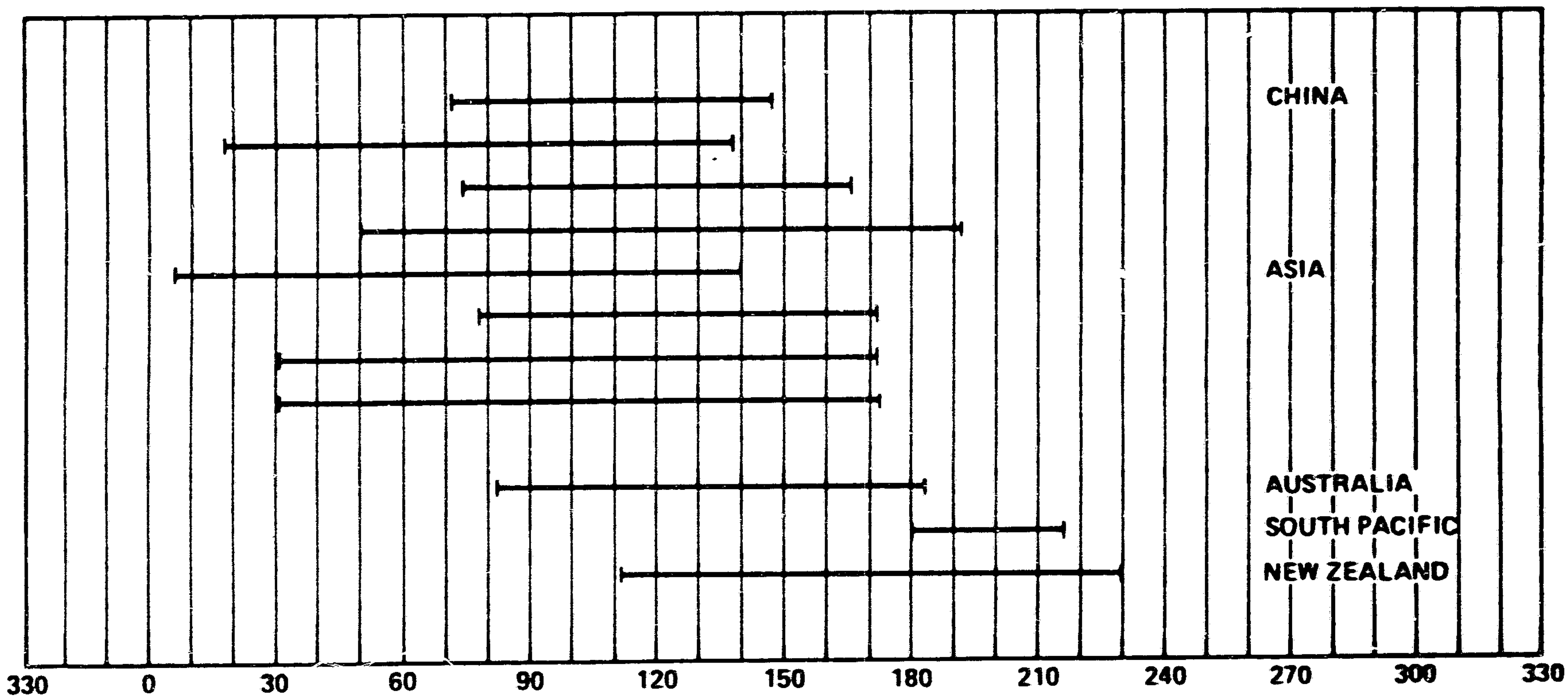


FIGURE 4-4

SERVICE ARC – ASIA/PACIFIC

Table 4-3

Number of Orbital Slots Available to Specific Regions

Region	Orbital Slots
North America	19
Latin America	32
West Europe	22
U.S.S.R.	27
East Europe	22
Middle East	40
Africa	37
China	18
Asia	45
Japan	23

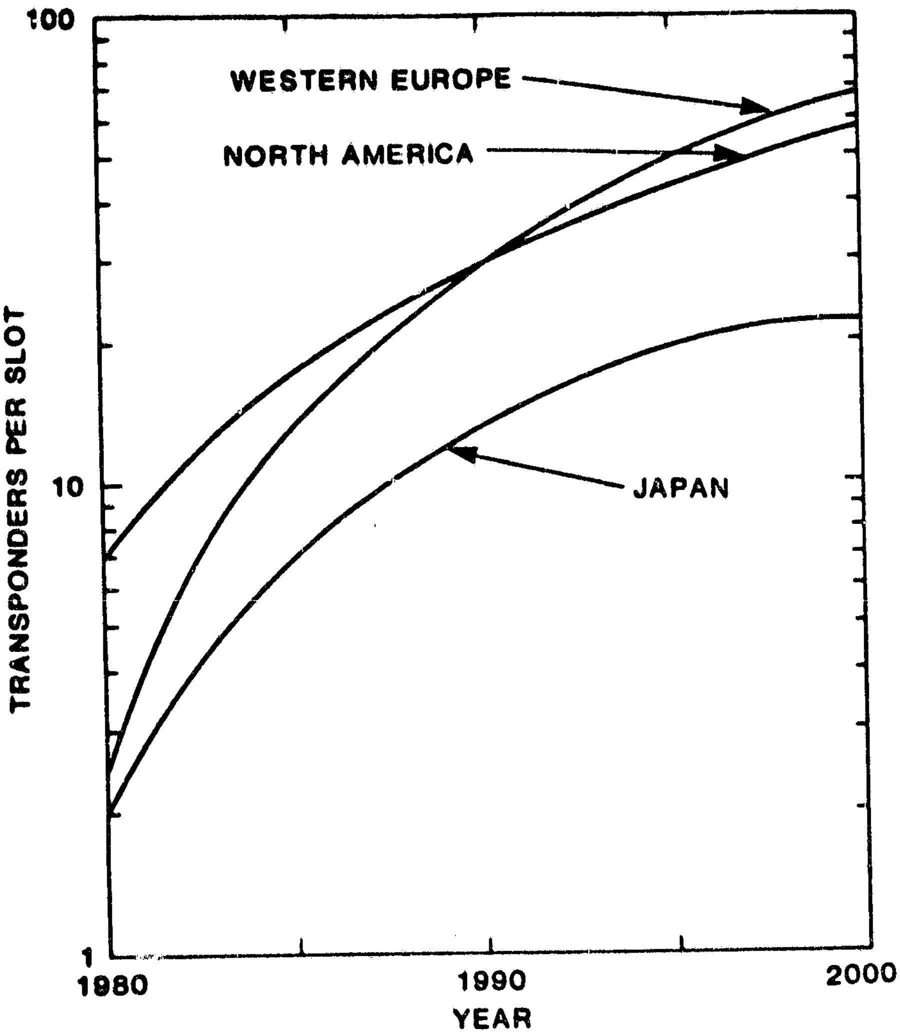


Figure 4-5

REQUIRED CAPACITY PER SLOT FOR GROUP 1 REGIONS
LOW TRAFFIC MODEL

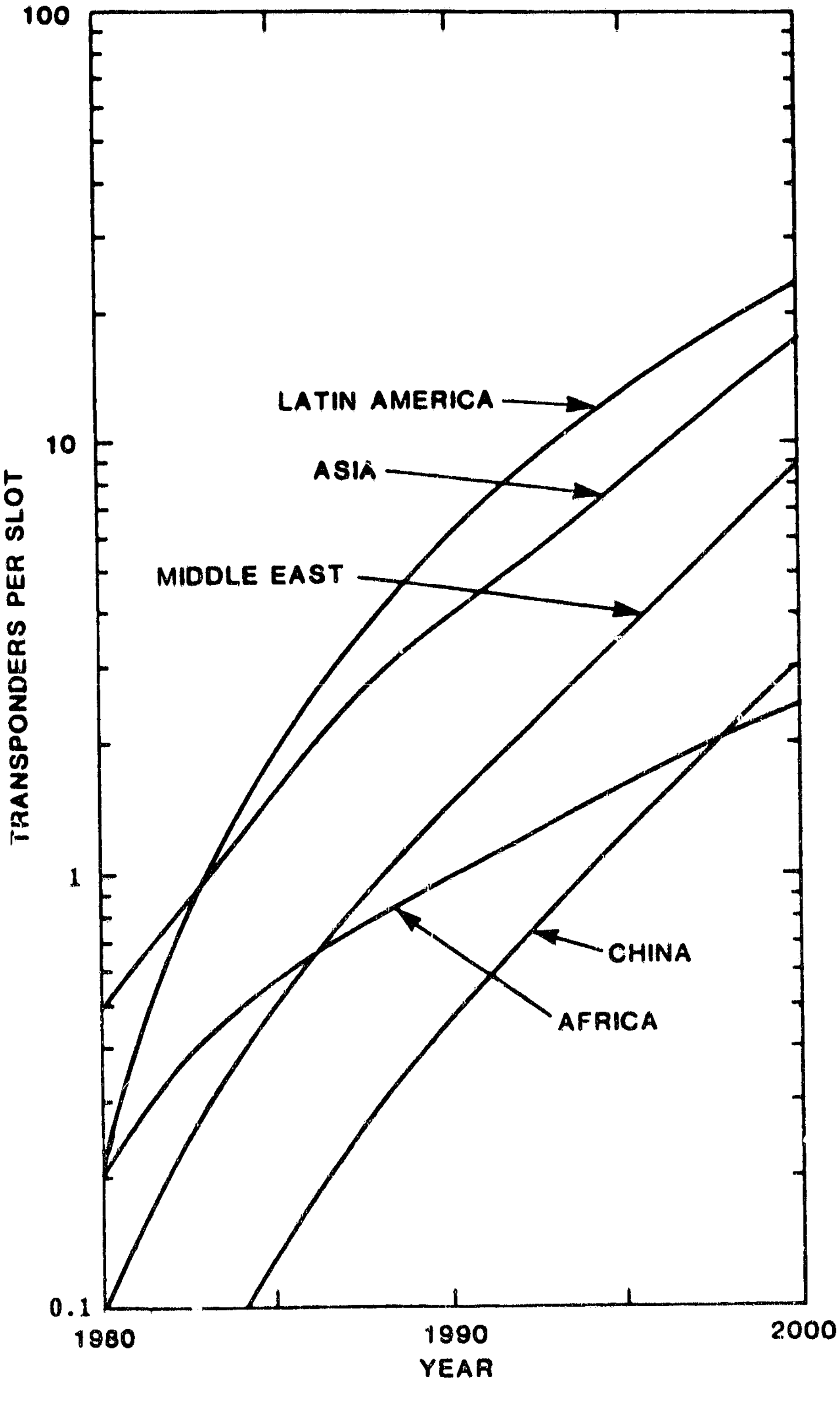


Figure 4-6

REQUIRED CAPACITY PER SLOT
FOR GROUP 2 REGIONS
LOW TRAFFIC MODEL

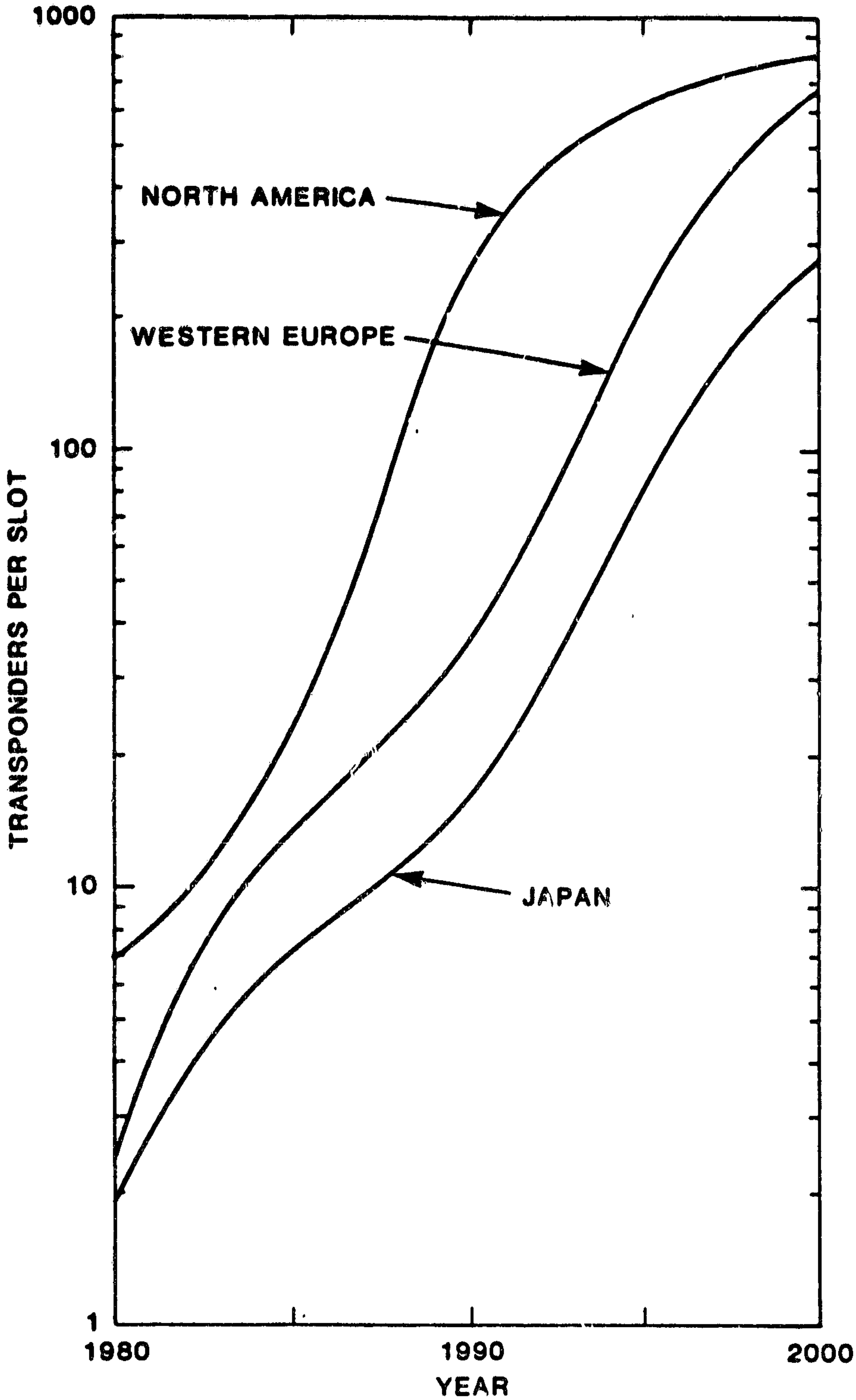


Figure 4-7

REQUIRED CAPACITY PER SLOT FOR GROUP 1 REGIONS
HIGH TRAFFIC MODEL

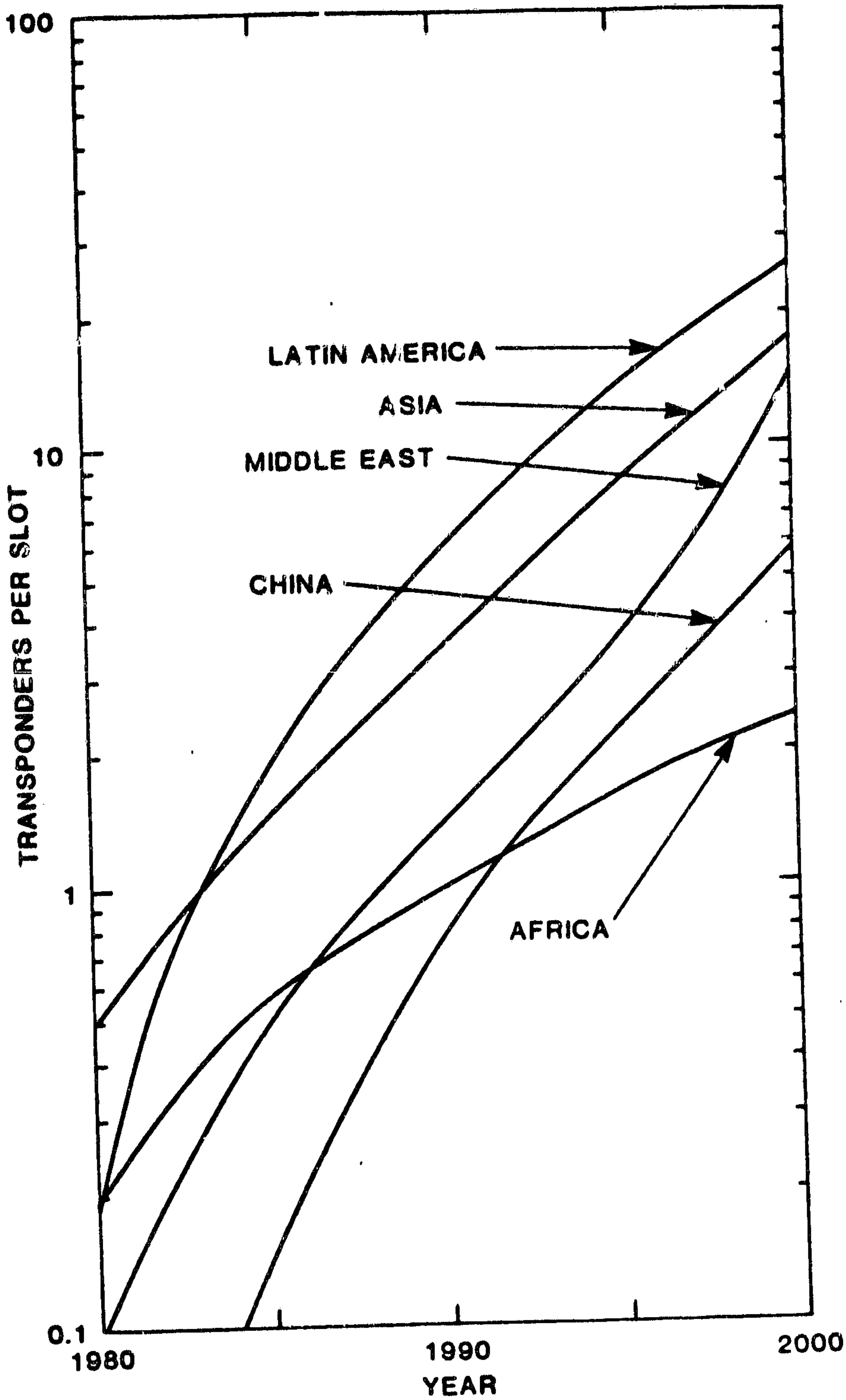


Figure 4-8

REQUIRED CAPACITY PER SLOT
FOR GROUP 2 REGIONS
HIGH TRAFFIC MODEL

1) For most of the world model regions, satellites of relatively modest capacity will do quite well.

2) All of the higher traffic areas also correspond to regions where geographical density of traffic is also quite high - for example, Europe, and Japan.

Generally speaking, the Equatorial regions, which have the most visible arc, also have the lowest traffic. Conversely, the developed nations, which have the higher levels of traffic, have the least visible arc by virtue of their more Northerly locations.

In formulating the traffic model, we made some conservative assumptions concerning the percent of total traffic which would be carried via satellite. In many instances, there are reasons to think that the actual figures will be higher. In the U.S., for example, we have used an 8% capture by satellite; in previous studies for NASA Lewis, figures as high as 12% were used for telephony.

In the less developed countries, we have used capture percentages of up to 25%. Because of the lack of terrestrial facilities and the relatively difficult installation problems that such links present, as much as 100% of long distance traffic could be carried on satellites in some developing nations. This is especially likely if low cost space segment and simple, inexpensive earth stations become widely available. In regions which consist mostly of islands, or where the population centers are separated by desert or jungle, satellite communications is certainly the best technique.

SECTION 5
SYSTEMS CONFIGURATIONS WITHOUT 30/20 GHZ

5.1 Background

In the previous section, the discussion of the transition scenario noted that the needed technology for high capacity satellites using 30/20 GHz would not be available until about 1990 or 1991, because of the dependence of such technology upon current and planned development programs at NASA. The technology will have to be demonstrated and then implemented commercially. Based on this assumption, we have postulated the use of conventional satellites until 1990, and at that point, have assumed the possible use of advanced multi-beam satellites with 30/20 GHz technology.

This section considers the design and analysis of systems which do not use 30/20 GHz. The development is as follows: first the needed capacity per orbital slot is determined from the traffic model. Next, satellites are configured to satisfy this traffic. A deployment schedule is postulated, and the efficiency of orbital utilization is determined. Lastly, the ground segment is treated, and overall system costs are estimated. This results in factors that can be conveniently compared with the results to be obtained in Section 6, Systems Configurations Using 30/20 GHz.

5.2 Space Segment Configurations Without 30/20 GHz

In this section, and also in Section 6, we essentially ignore the period before 1990. During this time, 30/20 GHz technology will not be commercially available, therefore, costs and scenarios for this time would be the same regardless of whether 30/20 GHz is eventually available or not.

5.2.1 General Spacecraft Constraints

During the period after 1990, we assume that the Space Shuttle will be available on a routine basis for launches of satellites worldwide. This implies that the current weight, power, and size constraints which hamper the development of spacecraft will be alleviated. We anticipate the advent of large satellites, using multiple spot beams for contiguous coverage, and having greatly improved transmission characteristics. Maximum size, weight, and power characteristics for these satellites are shown in Table 5-1.

Table 5-1
Size and Weight of
Advanced Satellites

Size Characteristics	
Fits in orbiter bay along with transfer vehicle	
Typical Length	9 meters
Typical Diameter	
undeployed	4.5 meters
deployed	25 meters
Mass	
Approx. 4,400 kg at BOL (maximum)	
Prime Power	
Up to 11 kw at EOL	

5.2.2 Implications of Capacity Requirements

The capacity requirements calculated previously have implications bearing on the satellite capacity which is planned. The satellite lifetime must also be taken into account. Typical satellites of the 1990's will have a design life of 10 years. The capacity of a spacecraft should be adequate to carry the required traffic at the end of life, and not merely at the beginning. This means that the capacity needed per slot in the year 2000 will dictate some of the characteristics of satellites launched as early as 1990.

5.2.3 Coverage Patterns and Capacity Estimates

The multiple-beam coverage pattern requires the frequency bands be divided into three parts. This ensures that adjacent beams do not use the same frequencies. We have based our calculations of the achievable capacity on the frequency bandwidths shown in Table 5-2. The 1979 WARC made some changes in allocations for fixed satellite services, among them the addition of 1,000 MHz at Ku-band. This addition has been earmarked for international service; we have assumed that pressures from the various administrations will make 500 MHz of this available for domestic and regional services.

Figures 5-1 through 5-3 show the coverage patterns we have postulated for the various world model regions. These coverages were based primarily on the estimates of needed capacity per slot, and were designed to provide at least that capacity, if possible. Naturally, the coverages shown here are only for the two lower frequency bands. In some areas, such as Western Europe, coverage at C-band was not considered possible due to the dense terrestrial microwave system. Table 5-3 shows the capacity per satellite for the given time frame.

5.2.4 Implementation Schedule

With the spacecraft characteristics determined, and the traffic specified, it is possible to develop an implementation schedule for the satellites. This will vary from region to region, according to the traffic growth.

Table 5-2

Frequency Band Assignment

Uplink Band MHz	Downlink Band MHz	Available Bandwidth MHz	Equivalent Number of Transponders
5,925-6,725	3,400-4,200	800/1,600*	20/40*
12,750-13,250 14,000-14,500	11,200-12,200	1,000/2,000*	24/48*
27,500-30,000	17,700-20,200	2,500	60
TOTAL		4,300	104

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

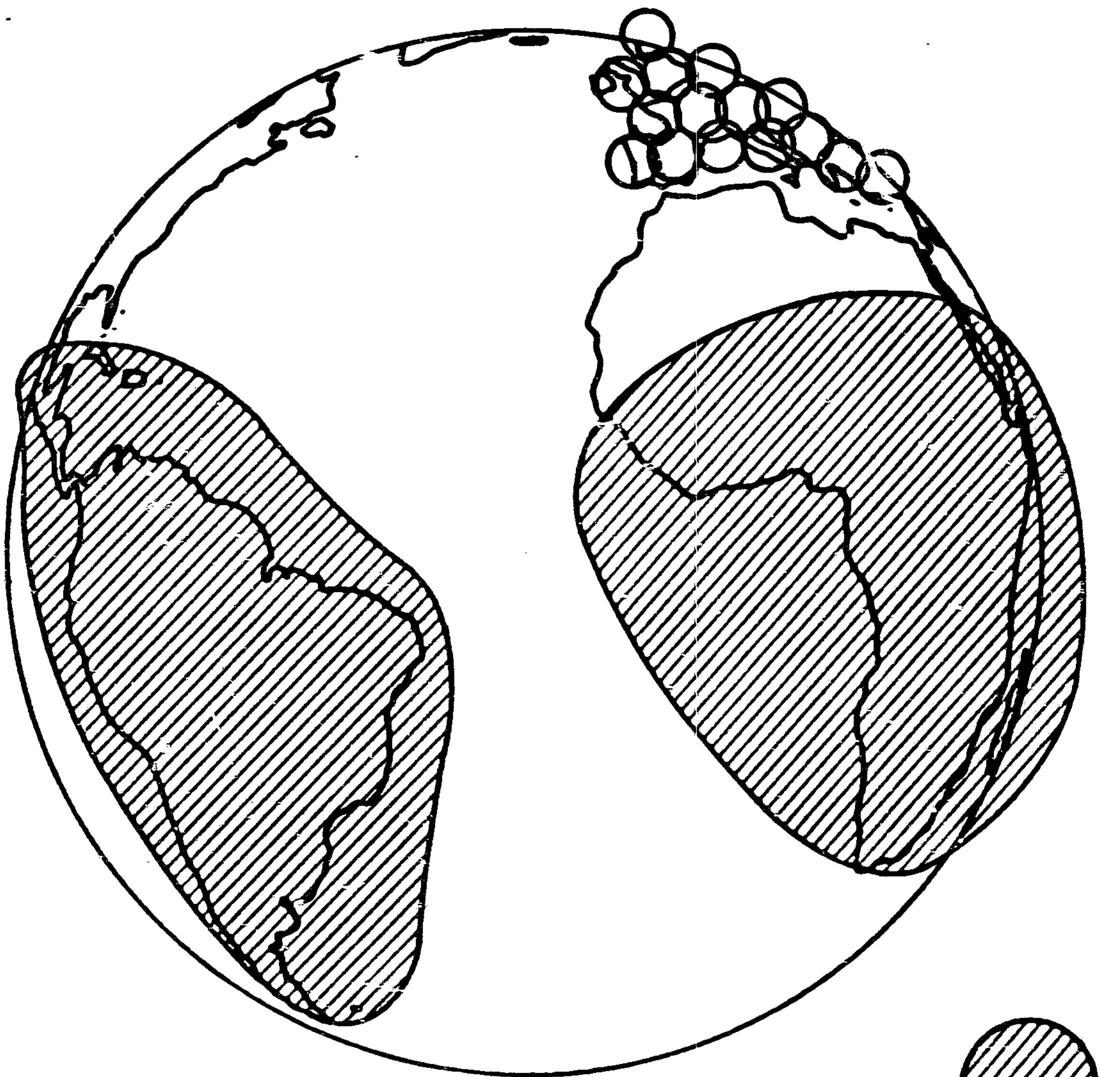
Table 5-3

Regional Satellite Capacities

Without Ka-band

(Transponders)

Region	1983-1989	1990-2000
Western Europe	24	120
Japan	64	160
Latin America	64	64
Middle East	64	64
Africa	64	64
China	64	64
Asia	64	64



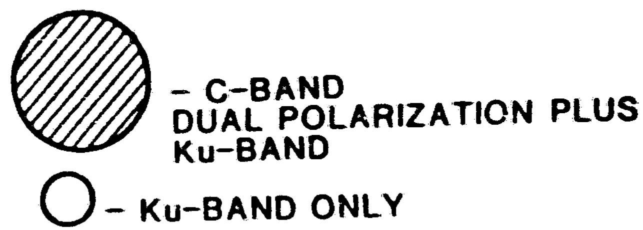


Figure 5-1

ATLANTIC OCEAN COVERAGE

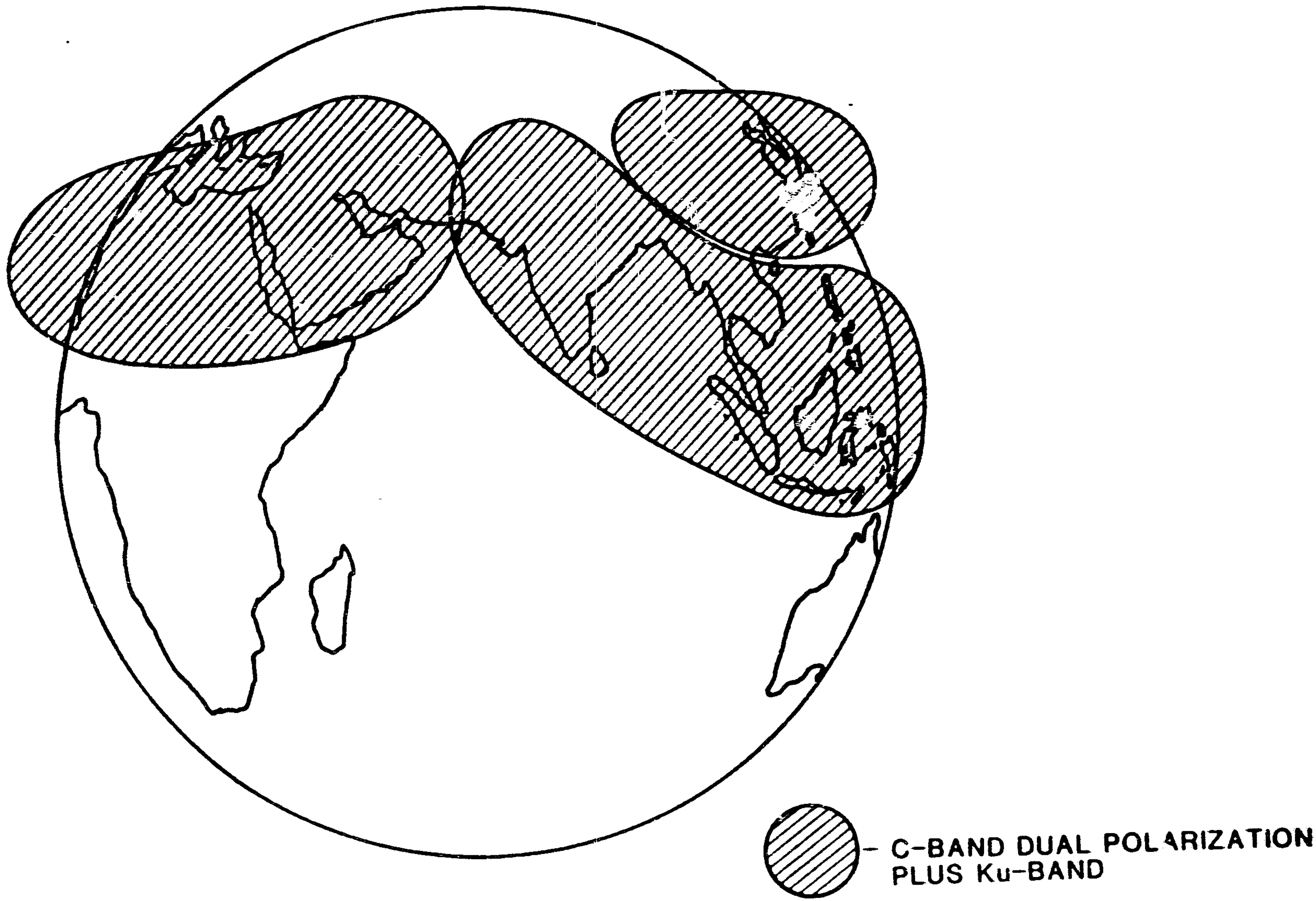


Figure 5-2

INDIAN OCEAN COVERAGE

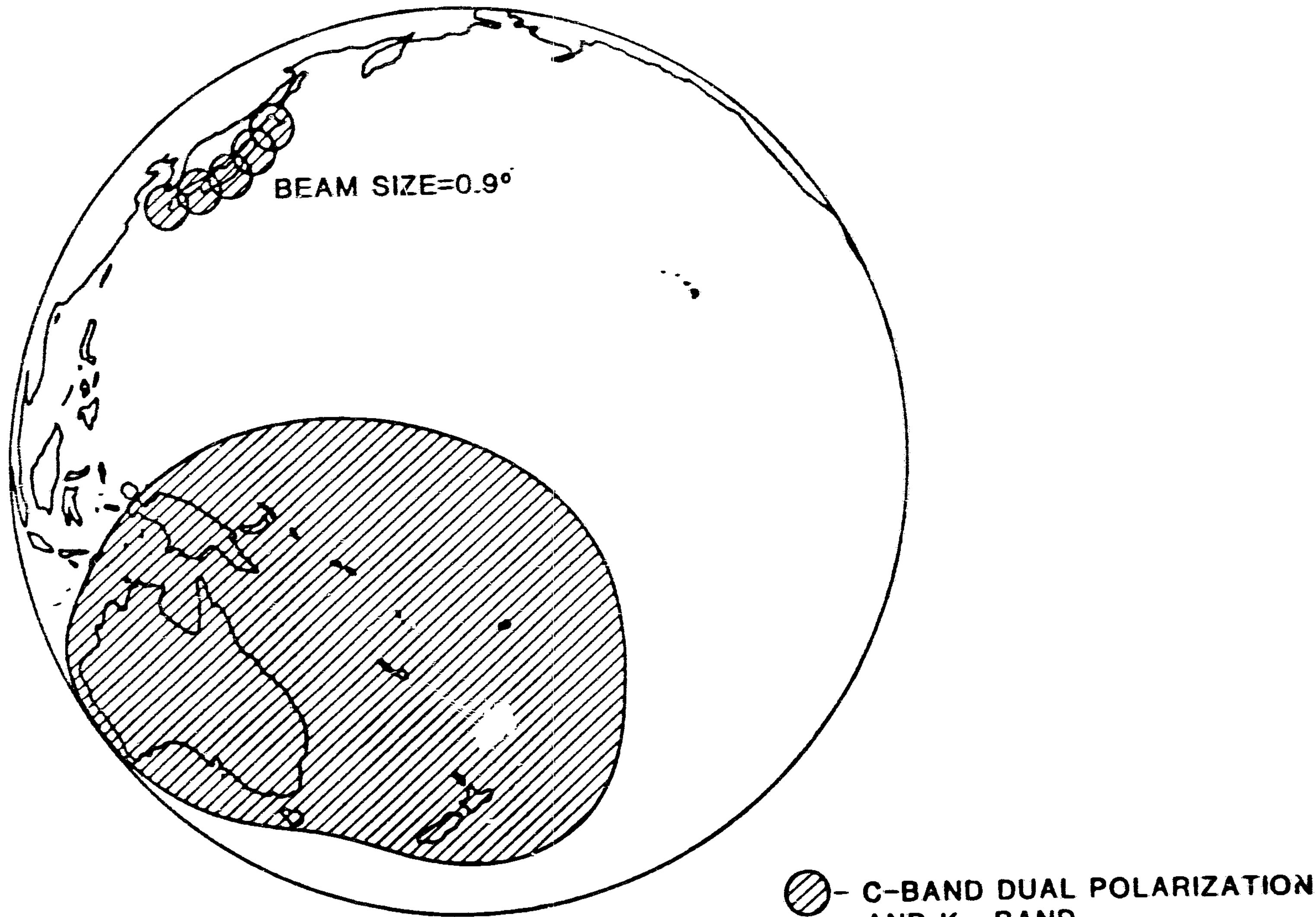


Figure 5-3

PACIFIC OCEAN COVERAGE

We have plotted the implementation schedules and the resulting capacity in orbit as a function of time for Western Europe, Japan, and Africa. These are shown in Figures 5-4 through 5-8. The first two regions are typical of high-traffic-density areas, while Africa is typical of the low-traffic areas. We used a computer system model, which attempts to satisfy the traffic demand by launching satellites as needed. Launches will occur six months before the traffic demand exceeds in-orbit capacity. The computer model also allows a number of satellites to be launched at once. The capacity per satellite is specified as an input; different satellites become available at various times. As long as there are enough orbital slots, the program will maintain the in-orbit capacity at a level equal to or greater than the traffic demand specified.

5.3 Orbit Utilization

The scenario just postulated for satellite systems growth is perhaps not the most efficient one from the orbit use standpoint, since the satellite sizing is done on the basis of filling the orbital slots available. There are obvious advantages to be gained from larger satellites. These will be considered later, when the question of system costs is addressed. At the moment, we will satisfy ourselves with the data in Tables 5-4 and 5-5 which show the effects of the postulated systems, and the effects of satellites of current capacity as well.

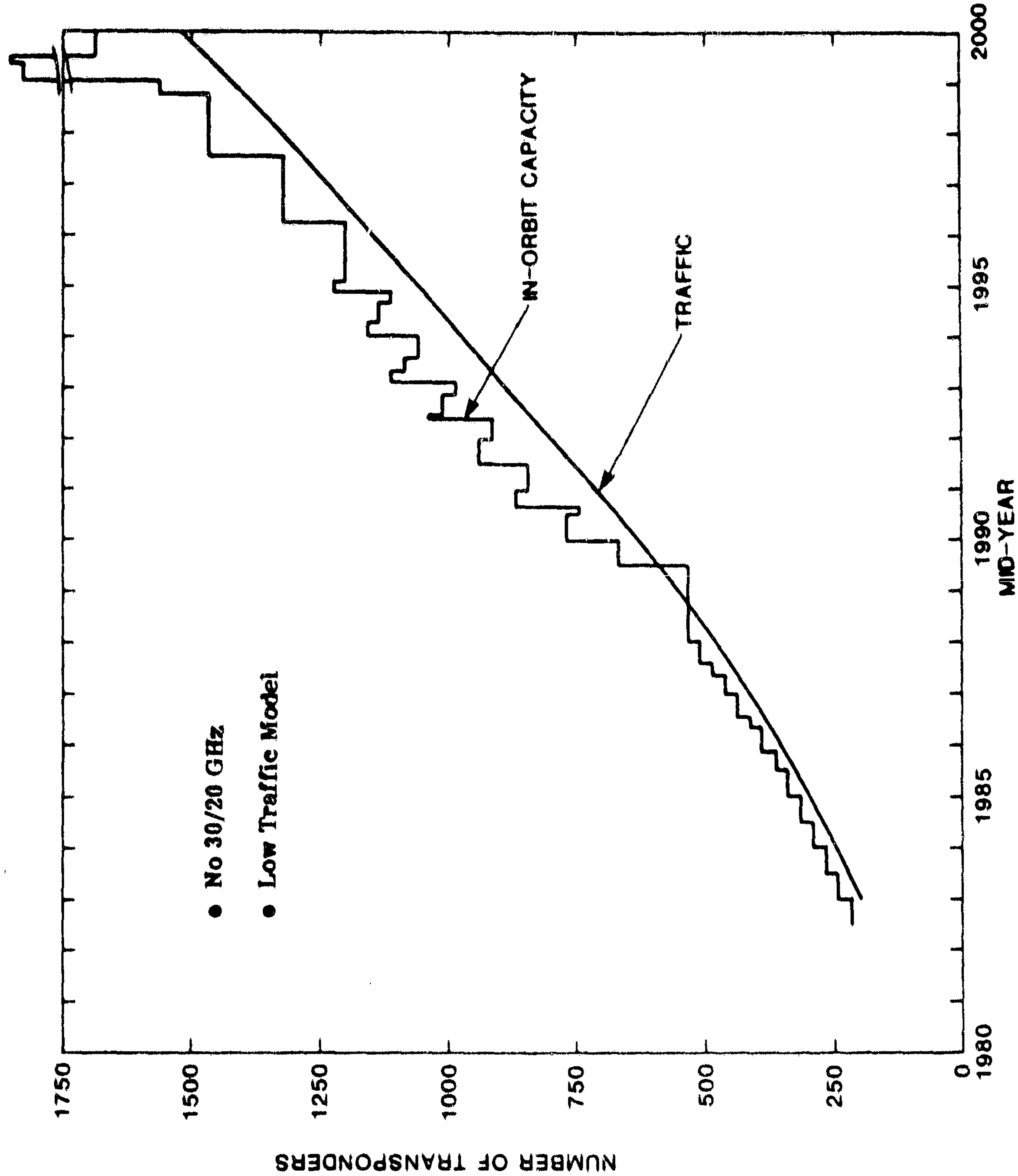


Figure 5-4

CAPACITY AND TRAFFIC FOR WESTERN EUROPE

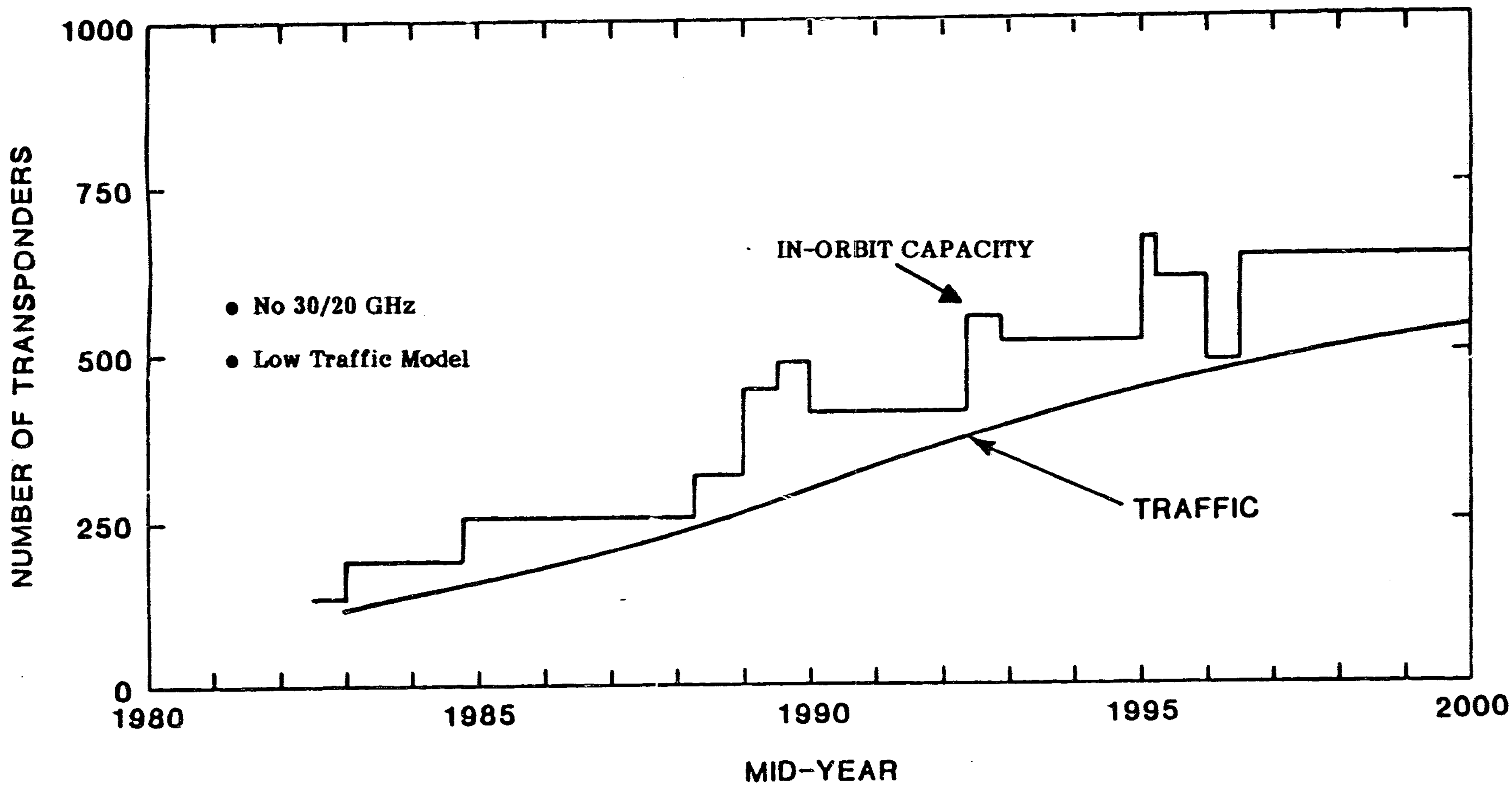


Figure 5-5

CAPACITY AND TRAFFIC FOR JAPAN

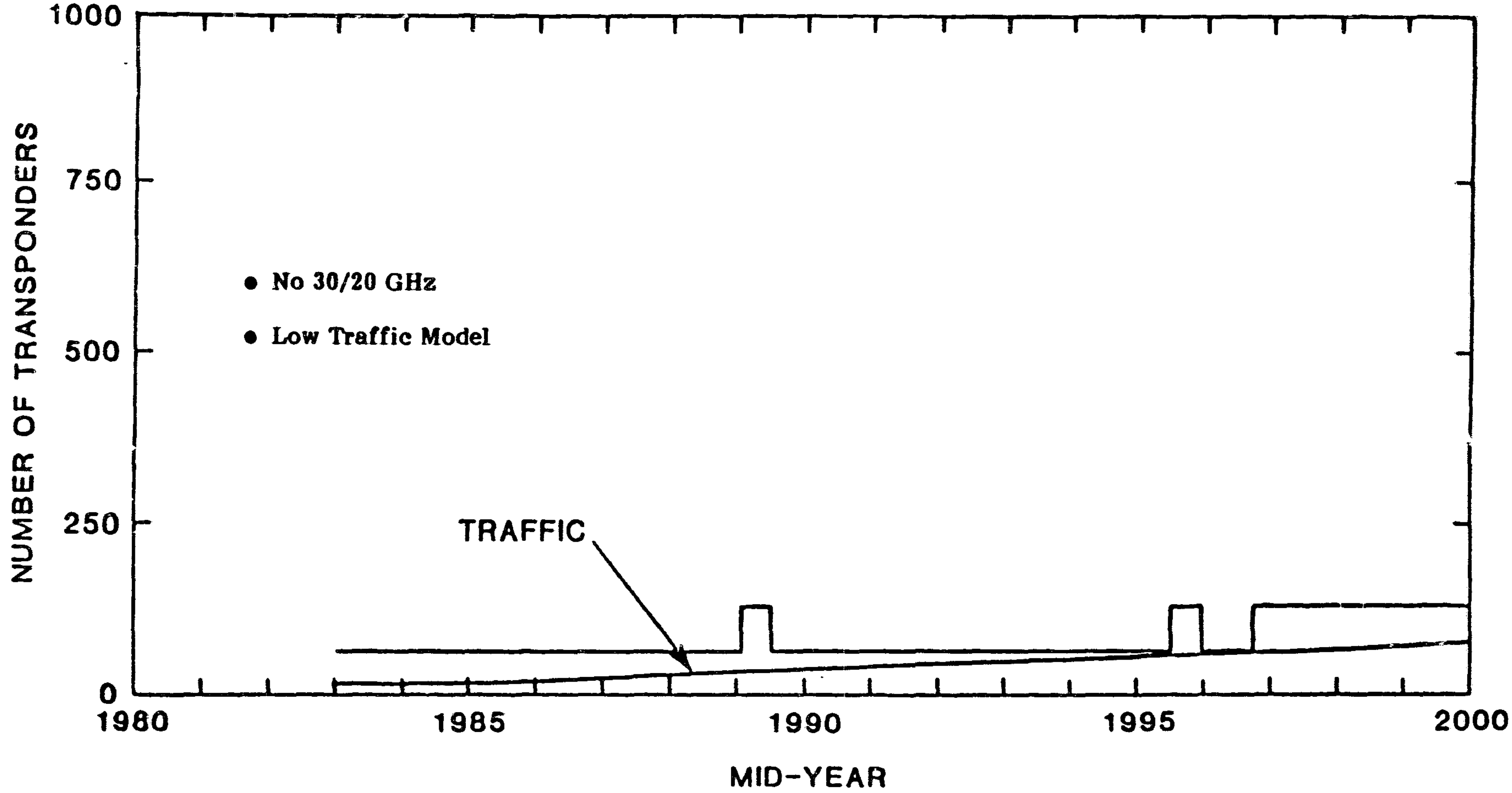


Figure 5-6

CAPACITY AND TRAFFIC FOR AFRICA

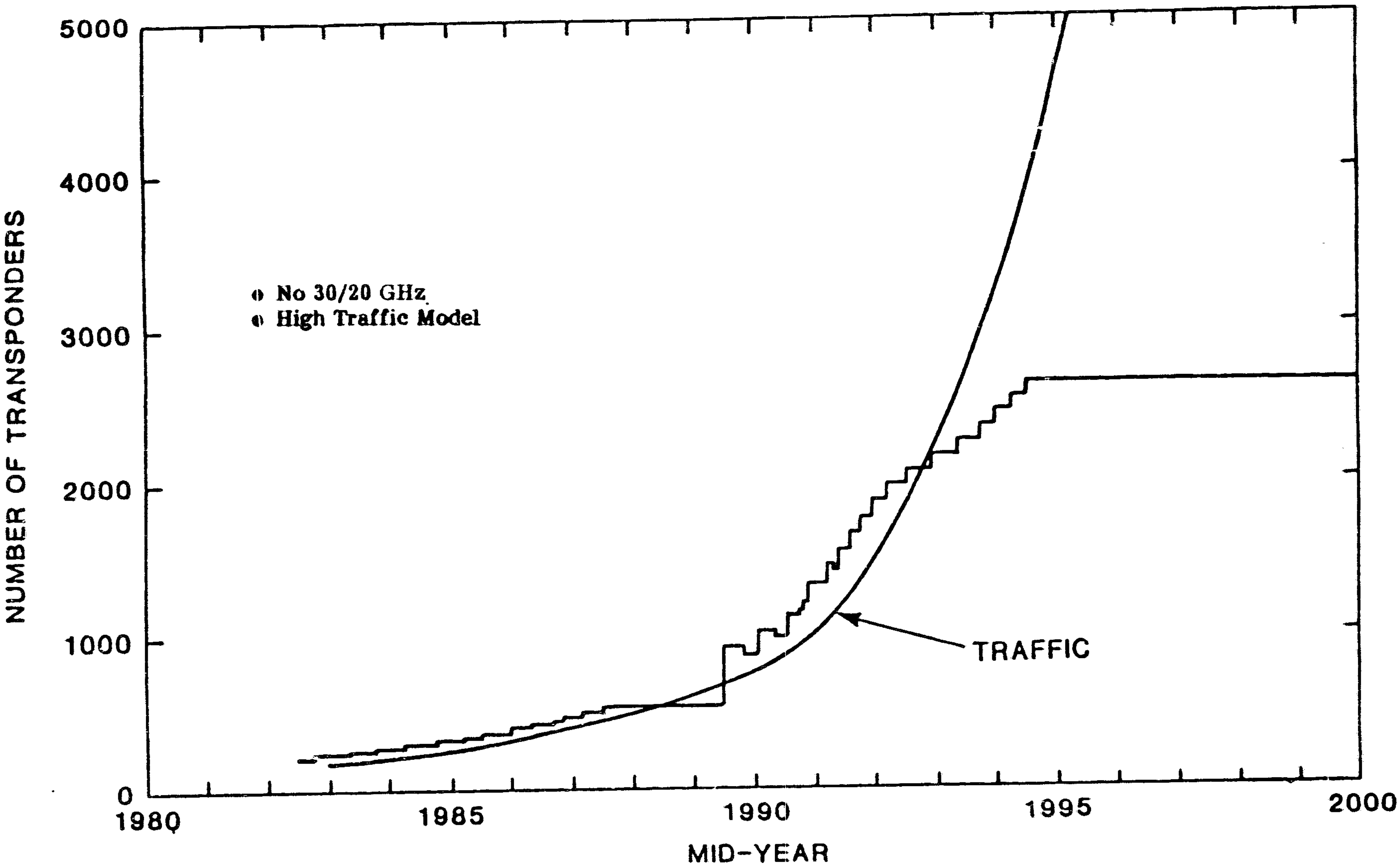


Figure 5-7

CAPACITY AND TRAFFIC FOR WESTERN EUROPE

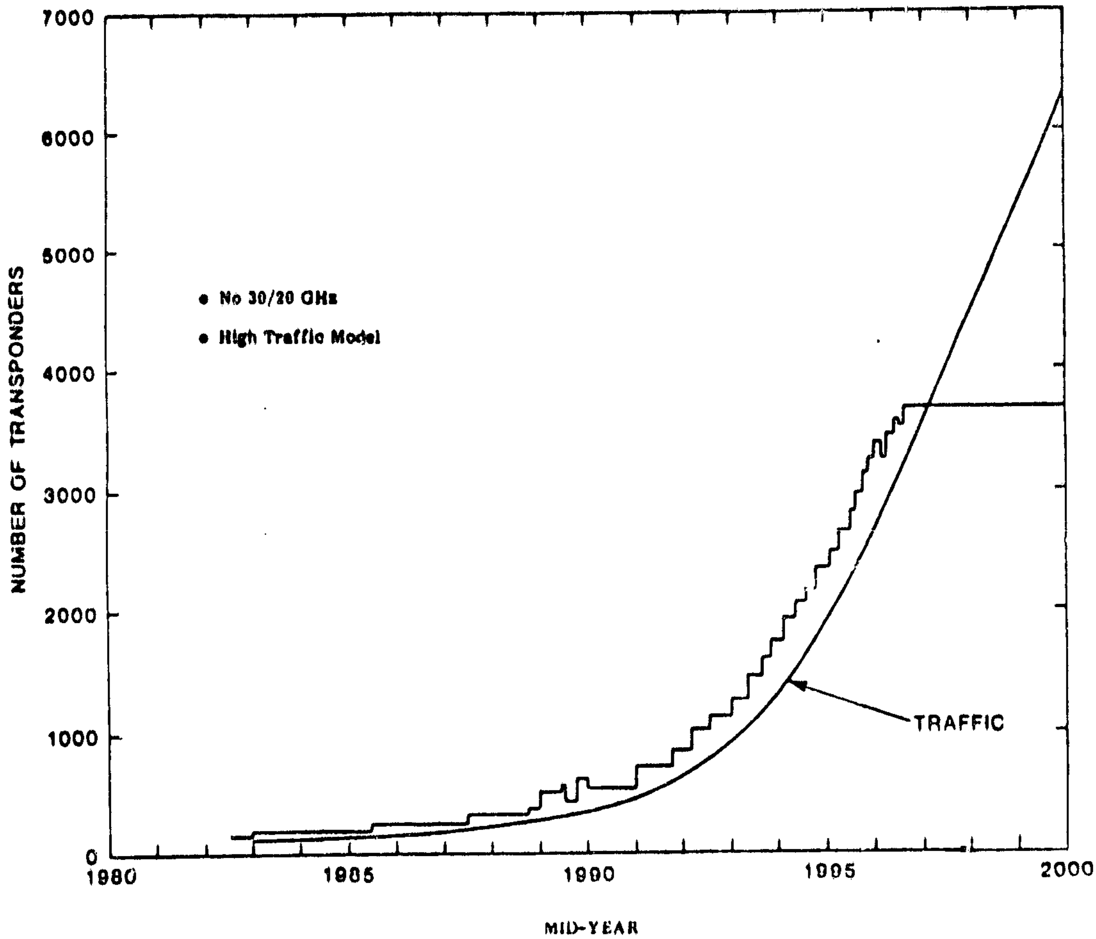


Figure 5-8

CAPACITY AND TRAFFIC FOR JAPAN

Table 5-4

Orbital Slot Fill Factors for Low

Traffic Scenarios Without Ka-band

(Percent)

Year	Western Europe	Japan	Latin America	Middle East	Africa	China	Asia
1983	45	13	3	3	3	6	2
1984	55	13	3	3	3	6	2
1985	64	13	6	3	3	6	2
1986	73	17	6	3	3	6	2
1987	82	17	6	3	3	6	4
1988	95	22	9	3	3	6	4
1989	100	30	9	3	5	6	4
1990	68	22	13	3	3	6	4
1991	68	22	13	3	3	6	7
1992	64	26	16	3	3	6	7
1993	59	22	19	5	3	6	11
1994	50	22	22	5	3	6	9
1995	45	22	25	5	3	6	11
1996	50	13	31	8	5	11	16
1997	50	13	31	8	5	6	16
1998	55	13	34	8	5	11	18
1999	73	13	38	10	5	11	20
2000	73	[illegible]	38	10	5	11	22

Table 5-5
Orbital Slot Fill Factors for
High Traffic Scenarios Without Ka-band
(Percent)

Year	Western Europe	Japan	Latin America	Middle East	Africa	China	Asia
1983	45	13	3	3	3	6	2
1984	55	13	3	3	3	6	2
1985	64	13	6	3	3	6	2
1986	77	17	6	3	3	6	2
1987	91	17	6	3	3	6	4
1988	100	22	9	3	3	6	4
1989	100	39	9	3	5	6	4
1990	77	30	13	3	3	6	4
1991	91	35	13	3	3	6	7
1992	100	43	16	5	3	6	7
1993	100	52	19	5	3	6	11
1994	100	70	22	5	3	6	9
1995	100	87	25	5	3	6	11
1996	100	100	31	10	5	11	16
1997	100	100	31	8	5	11	16
1998	100	100	34	10	5	11	18
1999	100	100	41	15	5	11	20
2000	100	100	41	18	5	11	22

5.4 Link Budgets

In order to estimate earth station costs, approximate link analysis is needed to size the power amplifier and determine the required G/T performance. We have used antenna diameters which we feel to be typical and noise performance at C- and Ku-band which can be supported from current technology.

Table 5-6 shows a noise budget for digital transmissions which we assume will carry the largest portion of the traffic. Tables 5-7 through 5-8 show typical link budgets for 120 Mbps and 6.3 Mbps. transmissions. Modulation in all cases is assumed to be 4-phase PSK. Rate 7/8 error coding is also used.

The transponder EIRP has been selected for successful multi-carrier operation, therefore, the link shows additional margin when used in the single-carrier mode.

Table 5-6

Noise Budget

(Without System Margin)

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

Table 5-7

Sample Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(Per Carrier)

Downlink

		Frequency Band, GHz	
		4/6	11/14
Transmit EIRP (Per Carrier)	dBW	30.5	41.5
Free space path loss at 30 degree elevation	dB	196	205
Transmission link margin	dB	3	10
Minimum flux density at the surface of the earth	dBW/m^2	-136	
Earth station antenna diameter	m	4.5	4.5
Earth station antenna gain	dB	43	52
Receive system noise temperature	^oK	155	385
Earth station G/T	$dB/^oK$	21	26
Receive noise bandwidth	MHz	4.1	4.1
Downlink carrier-to-noise ratio	dB	15	15

Table 5-7, (Continued)

Sample Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(Per Carrier)

Uplink

		Frequency Band, GHz	
		4/6	11/14
Earth station transmit power (per carrier)	Watts	40	160
	dBW	16	22
Line losses	dB	1.0	1.0
Antenna diameter	m	4.5	4.5
Antenna Gain	dB	46	54
Earth station transmit EIRP	dBW	61	75
Free space path loss 30 degree elevation	dB	200	207
Transmission link margin	dB	3	10
Flux density at the satellite	dBW/m^2	-105	-98
Satellite G/T	$dB/^oK$	0	0
Receive noise bandwidth	MHz	4.1	4.1
Uplink carrier-to-noise ratio	dB	20	20

Table 5-8

Sample Transmission Link Budgets for a 120 Mbps PSK Carrier

Downlink

		Frequency Band, GHz 4/6	11/14
Minimum transmit EIRP	dBW	45	56
Free space path loss at 30 degree elevation	dB	196	205
Transmission link margin	dB	5	12
Minimum flux density at the surface of the earth	dBW/m^2	-122	-118
Earth station antenna diameter	m	4.5	4.5
Earth station antenna gain	dB	43	52
Receive system noise temperature	K	155	385
Earth station G/T	dB/K	21	26
Receive noise bandwidth	MHz	72	72
Downlink carrier-to-noise ratio	dB	15	15

Table 5-8, (Continued)

Sample Transmission Link Budgets for a 120 Mbps PSK Carrier

Uplink

		Frequency Band, GHz 4/6	11/14
Earth station transmit RF power	Watts	630	2,500
	dBW	28	34
Line losses	dB	1.0	1.0
Antenna diameter	m	4.5	4.5
Antenna gain	dB	46	54
Earth station transmit EIRP	dBW	73	87
Free space path loss at 30 degree elevation	dB	200	207
Transmission link margin	dB	3	10
Flux density at the satellite	dBW/m^2	-93	-86
Satellite G/T	dB/K	0	0
Receive noise bandwidth	MHz	72	72
Uplink carrier-to-noise ratio	dB	20	20

5.5 Typical Satellite Weight and Power Budgets

In order to simplify the analysis somewhat, we have postulated two general satellite types: one which provides area coverage, with modest capacity per satellite, and a second, one which uses more advanced technology to provide multiple spot beams and service to high traffic density regions. The basic complexity of the spacecraft bus is quite different for the two designs. In order to avoid the question of specific design features, which are not readily predictable, we have included approximate allowances for antennas and communications electronics. The resulting weight and power budgets are shown in Table 5-9.

5.6 Space Segment Costs

Using the weight and power budgets developed previously, we have estimated costs for the spacecraft using the SAMSO model. This is a well-established model based on a curve-fit of a large number of satellite designs, with realistic cost figures. The main reservation involved in its use is the possible errors caused by satellite weight and power outside the range of the basic data. At present, no better model is available to us. The cost estimates are shown in Table 5-10 along with launch costs.

Table 5-9

Satellites Without 30/20 GHz

Item	Satellite Type 1	2	3
Coverage Type	Area	Area	Multiple Spot Beam
Approximate Capacity in 36 MHz Transponders	24	64	120-160
Design Life, years	7	7	10
Mass (kg)			
Communications System	100	270	650
TT&C	20	30	50
Electrical Power	150	300	450
Attitude Control	125	330	450
Structure/Thermal Control	150	400	500
Total	545	1,330	2,100
Power (Watts)			
EOL	1,150	2,000	3,000
BOL	1,450	2,500	4,200

Table 5-10
Costs for Satellites Without 30/20 GHz
(Costs in Millions of 1980 Dollars)

Item	Satellite Type 1	2	3
Fraction of STS Used	1/4	1/2	1
Upper Stage Used	IUS	IUS	IUS
Satellite			
Development Cost	40	60	82
Per-Unit Cost	15	32	53
Launch			
Shuttle Cost	10	20	30
Upper Stage Cost	14	16	18
Total per Satellite in Orbit	39	68	101

5.7 Earth Station Configurations

Satellites of the kind considered here will provide improvements in transmission parameters, thus enabling the average earth station size to be reduced. We expect that many of the newer earth stations installed in the future will be smaller than 7 meters antenna diameter. The power amplifiers required and the low noise amplifiers needed will both become less expensive.

Earth station baseband and switching equipment will not decrease in cost very much due to the limited interconnection capability of these satellites. Smaller earth stations carrying a limited amount of traffic can be expected to be of simple, inexpensive design, however.

In the developed nations, the use of C-band will be severely curtailed due to frequency coordination problems. C-band stations installed in Western Europe, for example, would be very difficult to clear, because the terrestrial network is so dense there. A similar situation exists in and around major cities in the U.S. although there are many rural areas where siting is not a problem.

The situation at Ku-band is less critical, although there are many Ku-band microwave links both in the U.S. and in Western Europe. In the less developed countries, both frequency bands are pretty much unused, and preference will be given to the use of C-band. This is mainly due to the lower margin needed and the more mature technology available.

5.7.1 Satellite-Switched TDMA Earth Stations

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

- Mux/demux
- Common control equipment
- QPSK modem

A functional block diagram for this type of station is shown in Figure 5-9 and a brief discussion of the terminal equipment subsections follows.

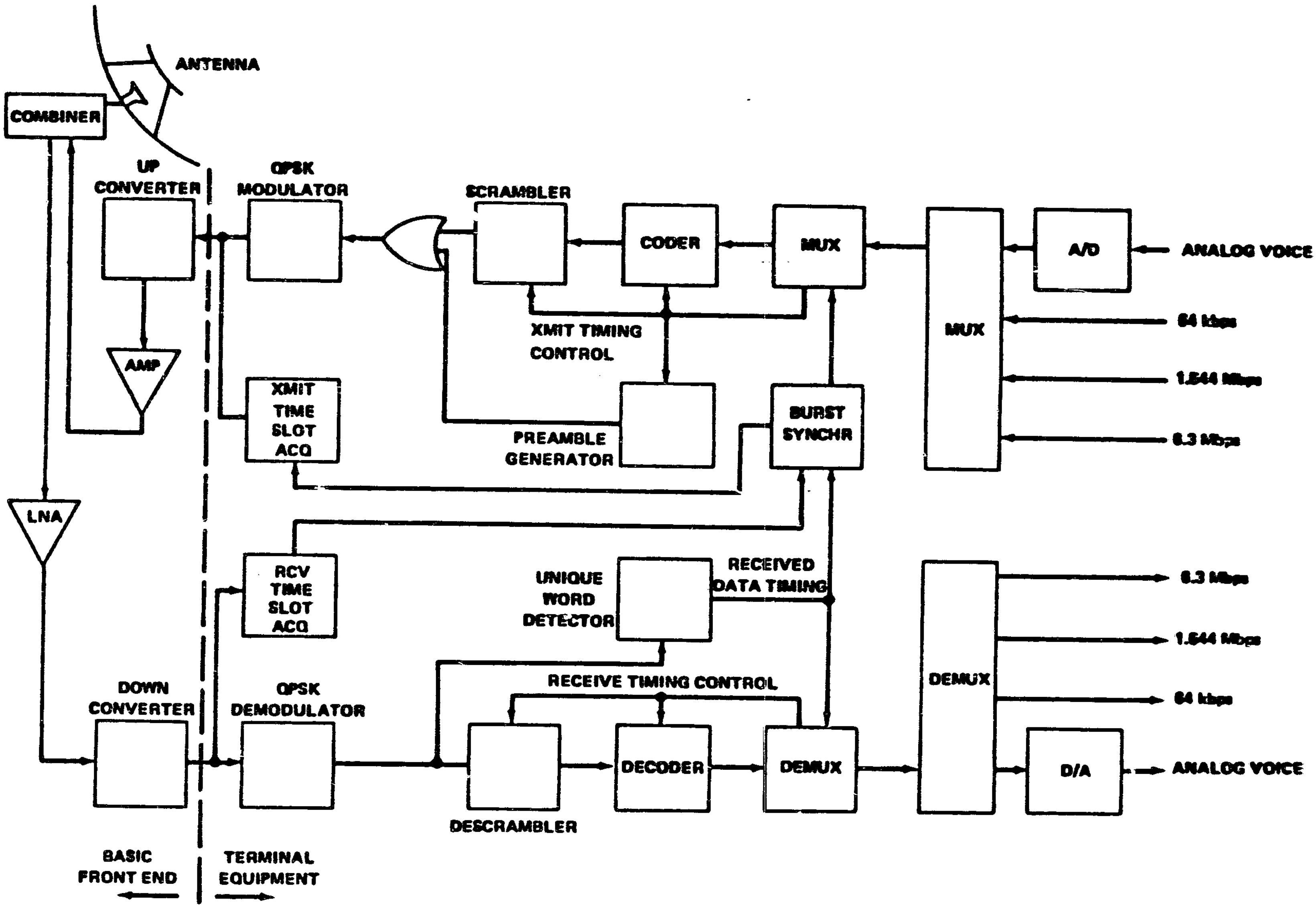


Figure 5-9

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

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

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

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

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

5.7.2 Multiple T-2 Carrier PSK Earth Stations

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

Mux/demux
Codec
QPSK modem
Carrier combiner and divider networks

A functional block diagram for this type of station is shown in Figure 5-10, 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.

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

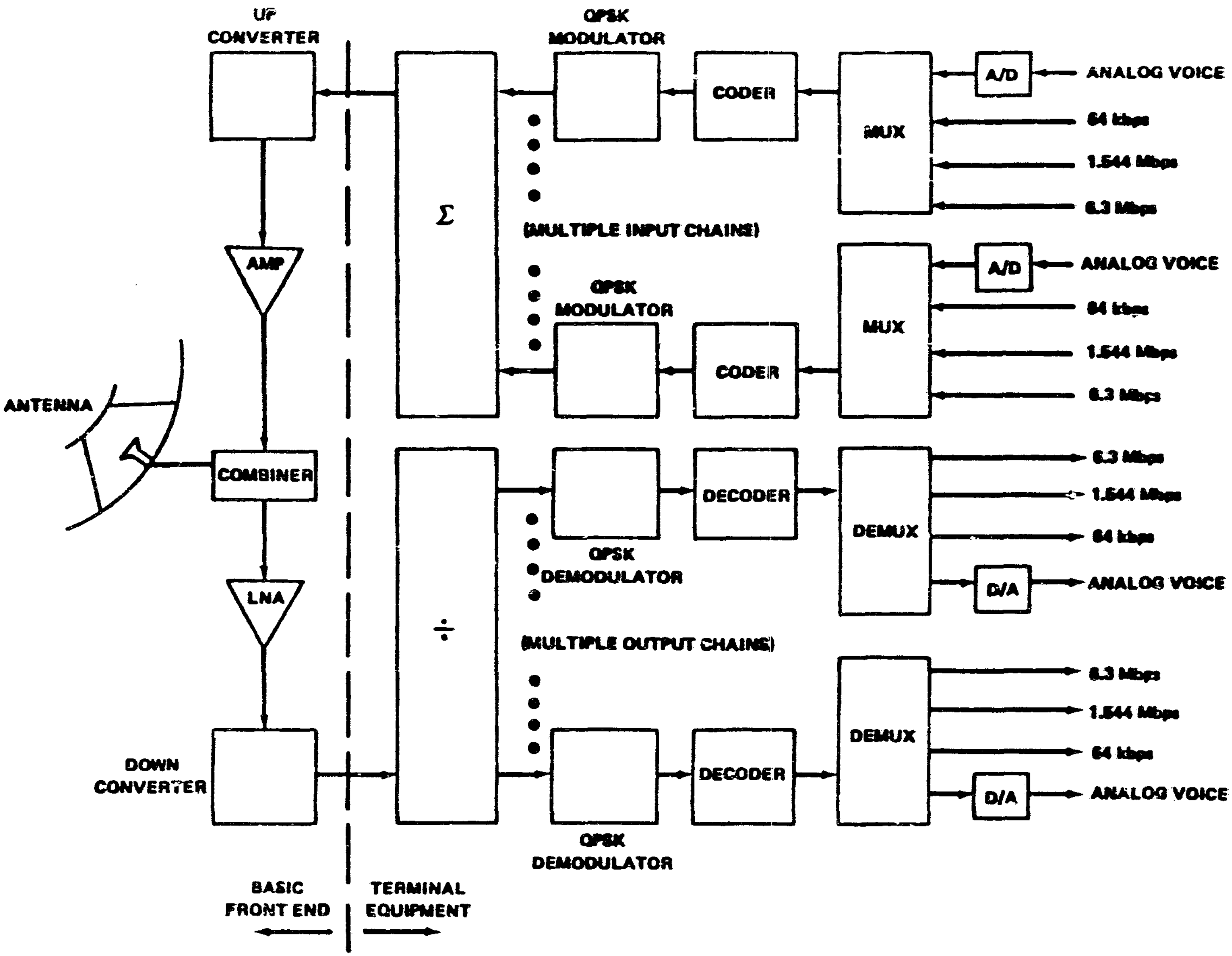


Figure 5-10

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

5.7.3 Thin-Route Earth Stations

Figures 5-11 and 5-12 show typical block diagrams of thin-route SCPC earth stations. Figure 5-11 shows a demand-assigned station, similar in concept to stations in the SPADE system. Such a system provides efficient utilization of the space segment. While this type of demand-assigned system was designed for global coverage use, complete connectivity with a multi-beam satellite could be achieved by sufficient frequency range to permit transponder hopping. In order to be efficient, a large pool of SCPC stations would need to access the system. In the diagram shown, the frequency assignment flexibility is provided in the channel units. Assignment control is generally by means of a separate signalling channel.

Figure 5-12 illustrates a simple bush-radio station. This would be used in an SCPC system using fixed assignment transmit frequencies, selectable receive frequencies.

5.8 Earth Station Cost Estimates

Typical earth station costs are shown in Table 5-11. 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.

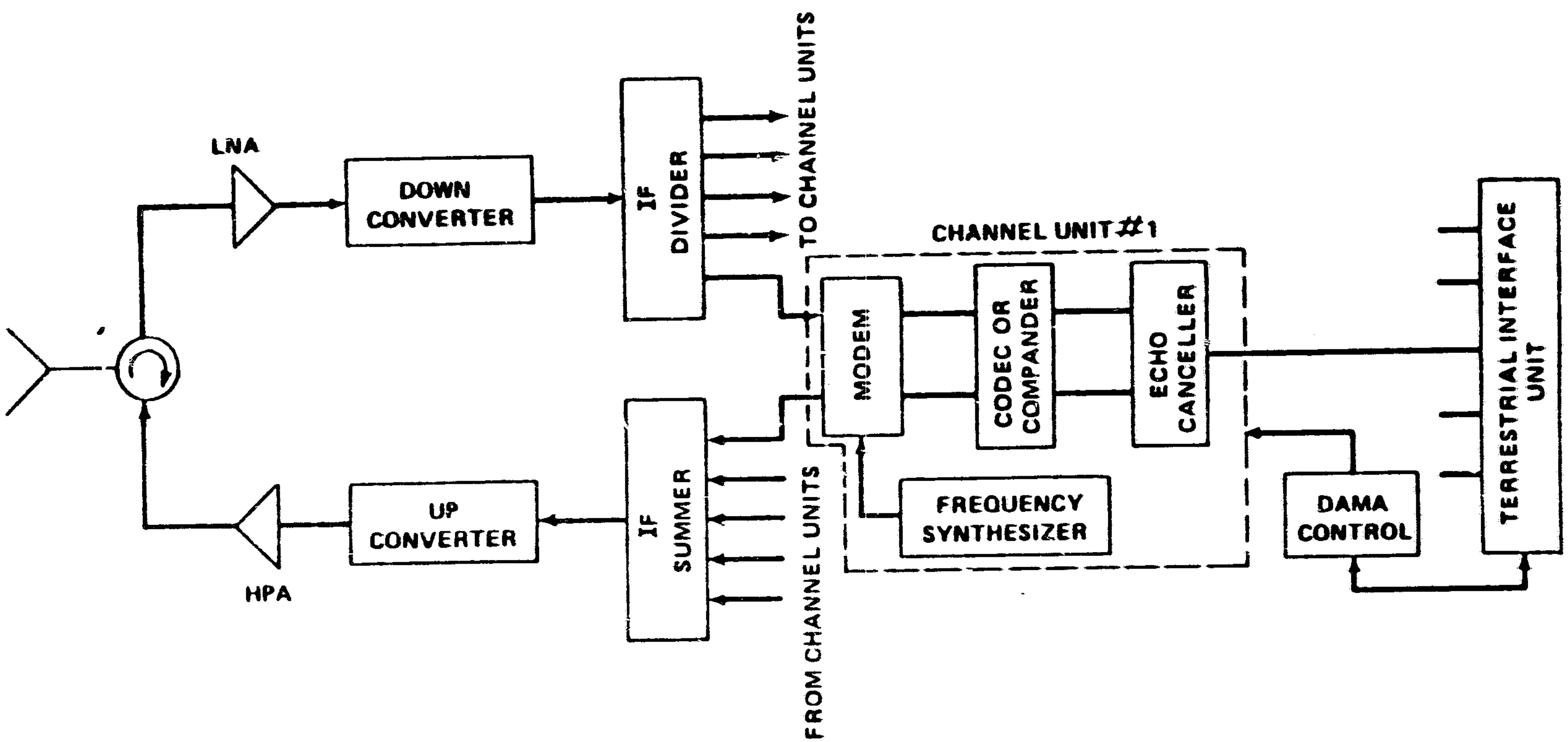


Figure 5-11

TYPICAL DEMAND-ASSIGNED SCPC EARTH STATION
(FUNCTIONAL BLOCK DIAGRAM)

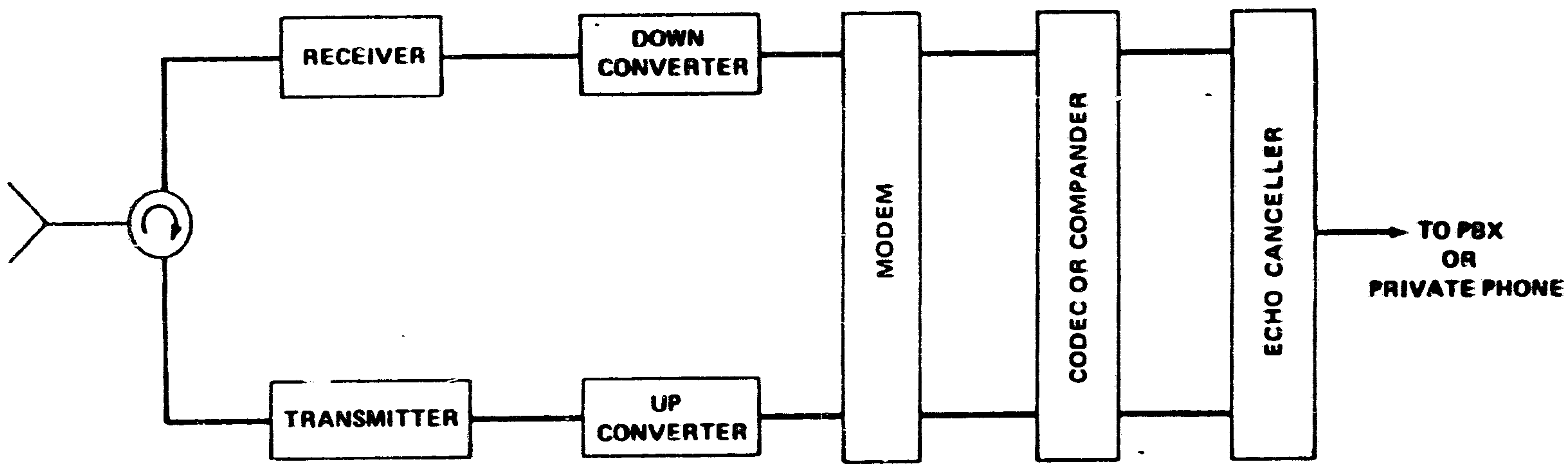


Figure 5-12

BUSH RADIO SCPC EARTH STATION
(FUNCTIONAL BLOCK DIAGRAM)

Table 5-11

Typical Earth Station Costs in 1990

(Thousands of 1980 Dollars)

(Moderate Quantity)

	Station Types			
Item	Bush Radio	SCPC/ DAMA	Multi-Carrier PSK	SS/TDMA
Front Ends				
Antenna System				
4/6 GHz	10	12	18	18
11/14 GHz	12	15	24	24
RF Equipment				
4/6 GHz	5	6	10	24
11/14 GHz	6	7	12	47
Terminal Equipment	3	6	30	59
Mux/Demux	—	3	18	4
Totals				
4/6 GHz	18	27	76	105
11/14 GHz	21	31	84	134

SECTION 6

SYSTEMS CONFIGURATIONS USING 30/20 GHZ

In the previous section, we considered various systems which did not make use of the 30/20 GHz frequency bands. In many of the world regions, the lower bands are adequate to fill the needs past the year 2000. In the developed regions, notably North America, Europe and Japan, however, the lower bands will become saturated before 2000 even with advanced multi-beam technology. This is perhaps the most imperative reason for the use of 30/20.

There are other considerations, however. In some regions, frequency coordination may not be available at C-band and possibly even at Ku-band, thus leading to a requirement for 30/20 GHz to serve these places. An economic analysis indicates that significant economies of scale are available with the use of higher capacity satellites; one simple method to expand capacity is the addition of 30/20 GHz.

Satellite systems utilizing 30/20 GHz will be commercially available by about 1990, judging from NASA schedules. We estimate that as a result of this and other programs, a major increase in spacecraft capacity will be available at that time. In formulating the system configurations in this section, we have assumed the use of this increased capacity where desirable.

6.1 Space Segment Configurations

The general spacecraft constraints in this section will be identical to those in the previous section. The largest satellite we consider will fit along with a transfer vehicle in the Shuttle orbiter cargo bay. Antennas up to 6 meters in diameter will be available. Multiple beam coverage and on-board switching will also be part of the technology base.

6.1.1 Coverage Patterns

Figures 6-1 through 6-3 show the postulated coverage patterns for the world model zones. The coverages have been kept similar to those of Section 5, but Ka-band has been added. Table 6-1 shows the capacity for each satellite.

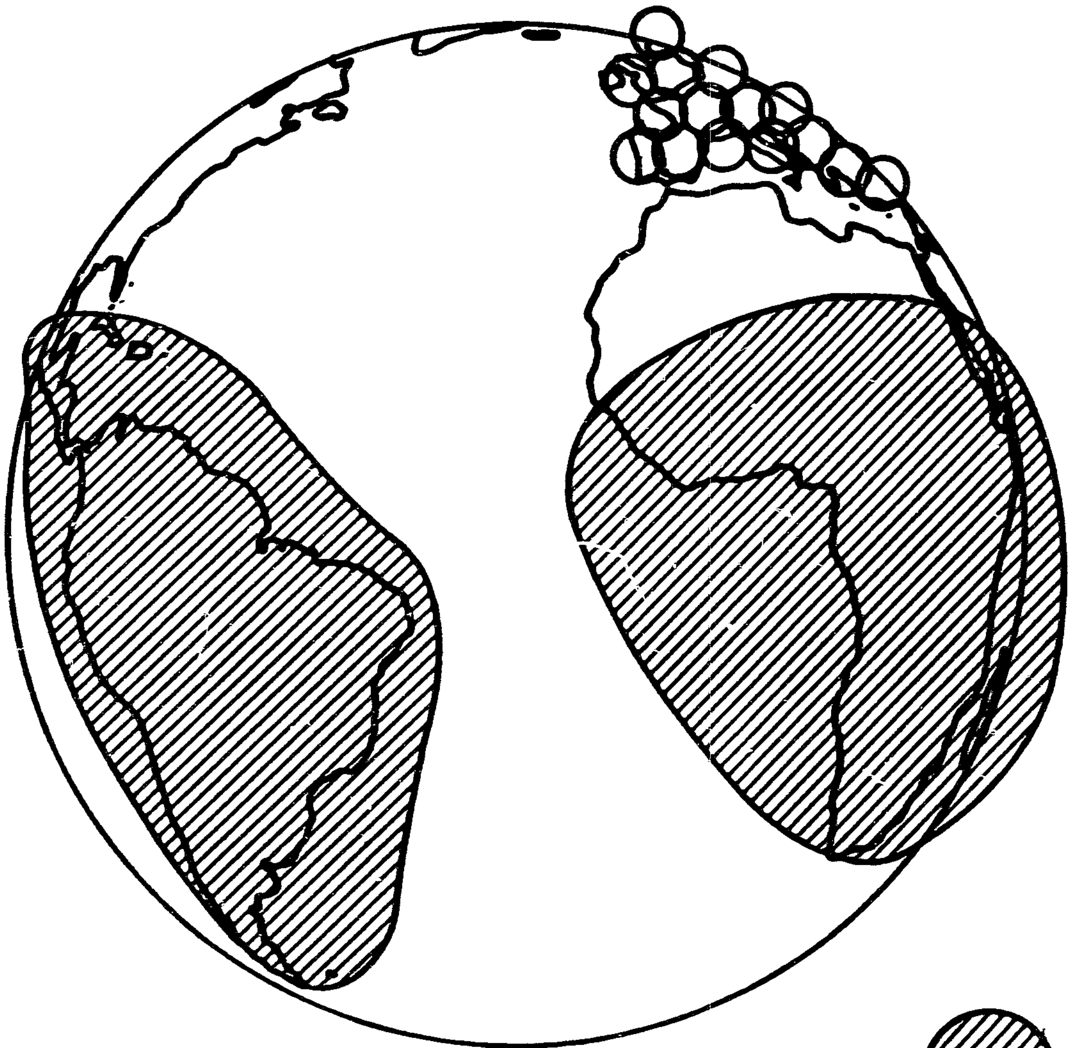
6.1.2 Implementation Schedule

Implementation schedules for three world regions are shown in Figures 6-4 through 6-8. In order to keep the system cost low, a fairly close match to the traffic requirements has been attempted. However, in the case of some of the lower traffic regions, larger satellites have been used to keep the number of launches down and gain some economy of scale.

Table 6-1
Regional Satellite Capacities With Ka-Band
(Transponders)

Region	1983-1989	1990-2000
Western Europe	24*	430*
Japan	64	315
Latin America	64	126
Middle East	64	126
Africa	64	126
China	64	126
Asia	64	126

*C-band assumed not available due to frequency coordination problems.



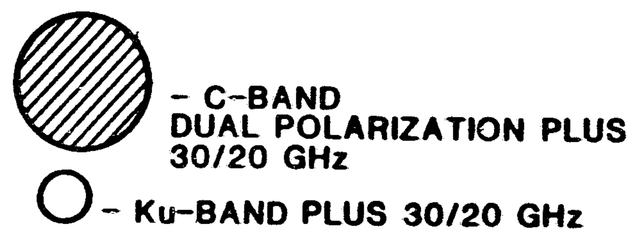


Figure 6-1

ATLANTIC OCEAN COVERAGE

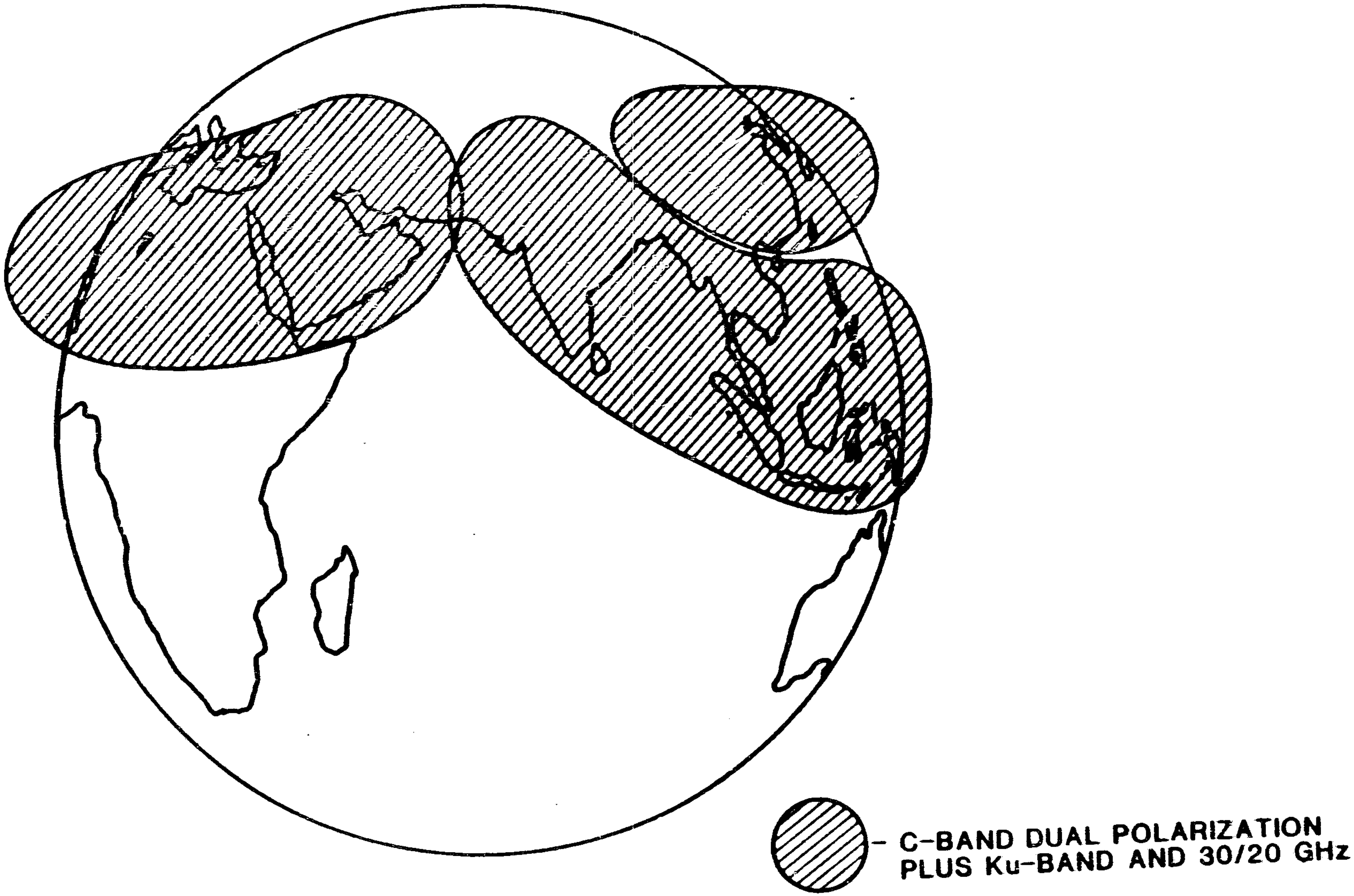


Figure 6-2

INDIAN OCEAN COVERAGE

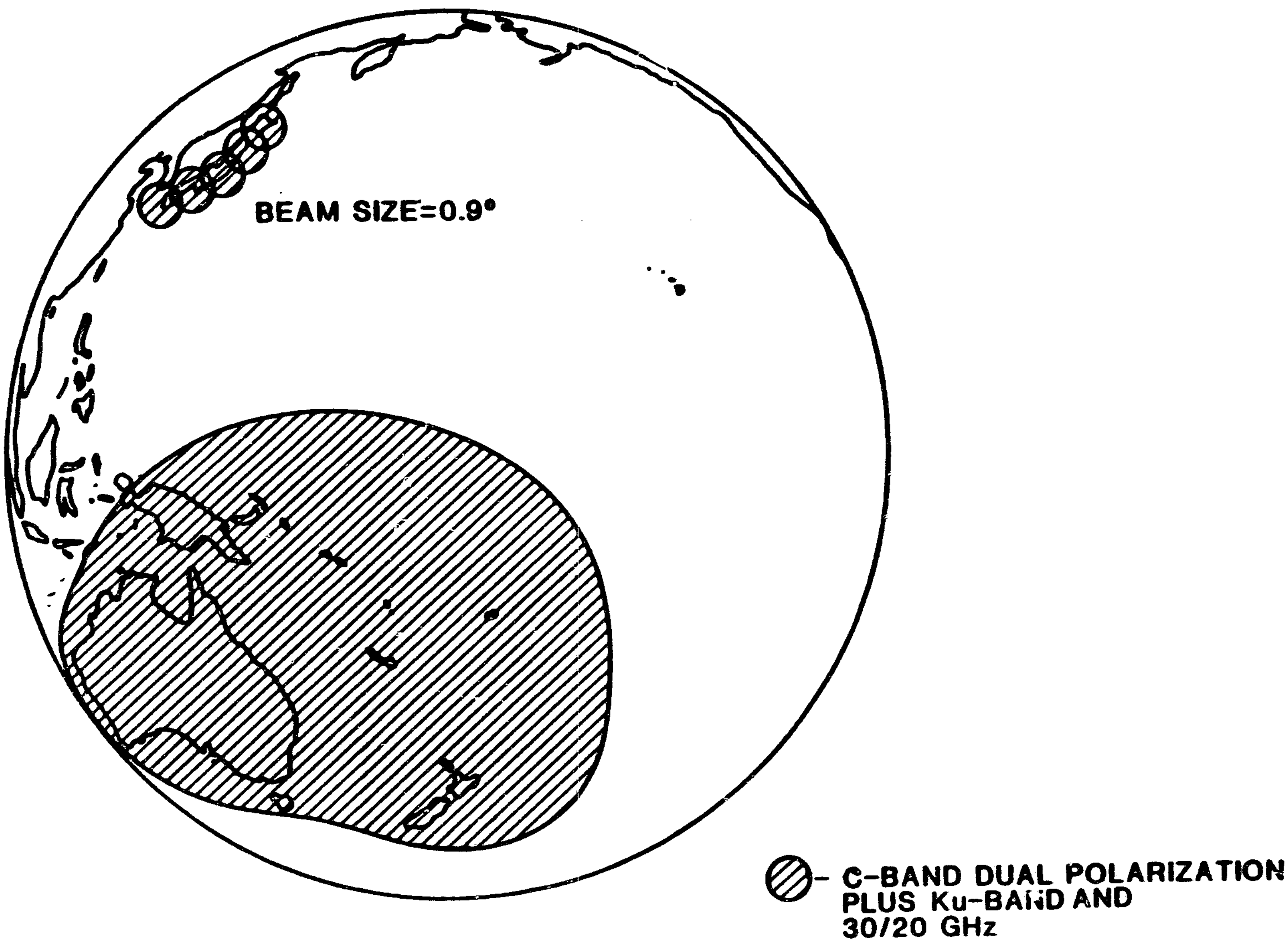


Figure 6-3

PACIFIC OCEAN COVERAGE

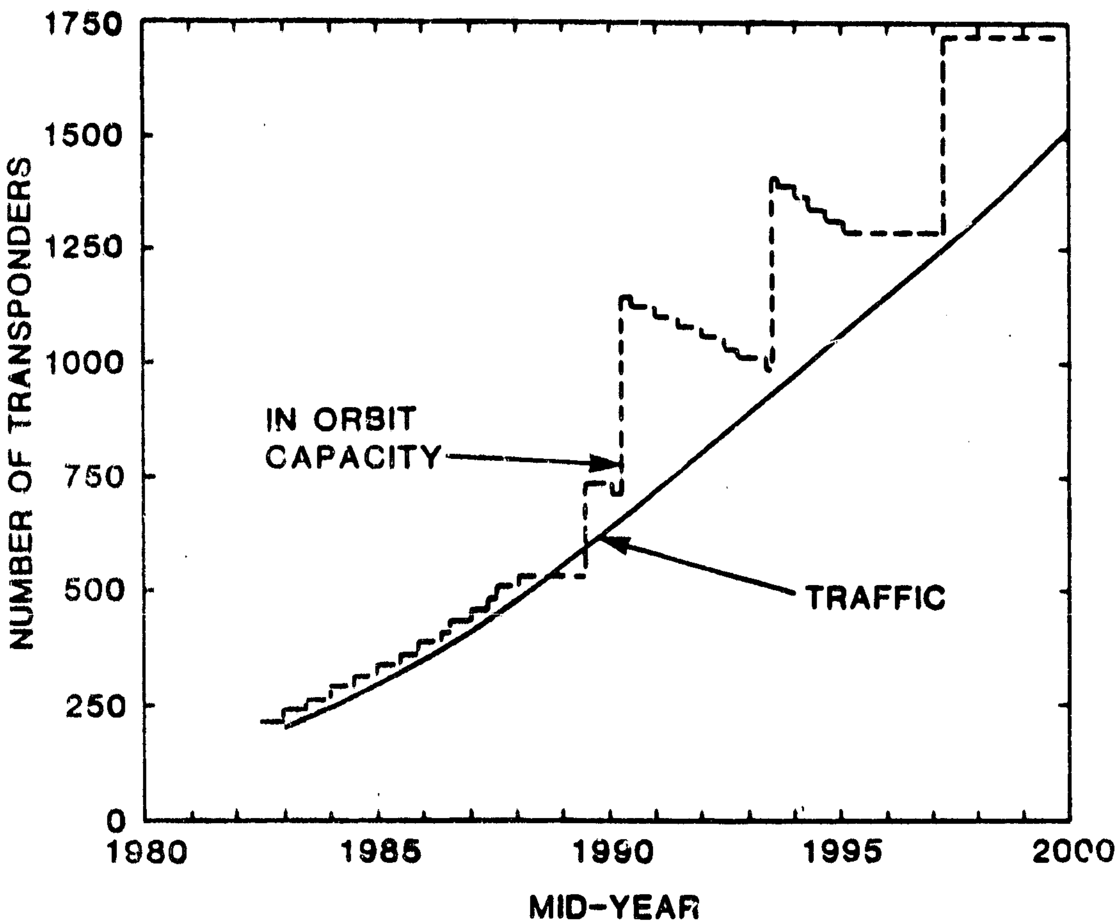


Figure 6-4

WESTERN EUROPE WITHOUT VIDEO CONFERENCING WITH KA-BAND

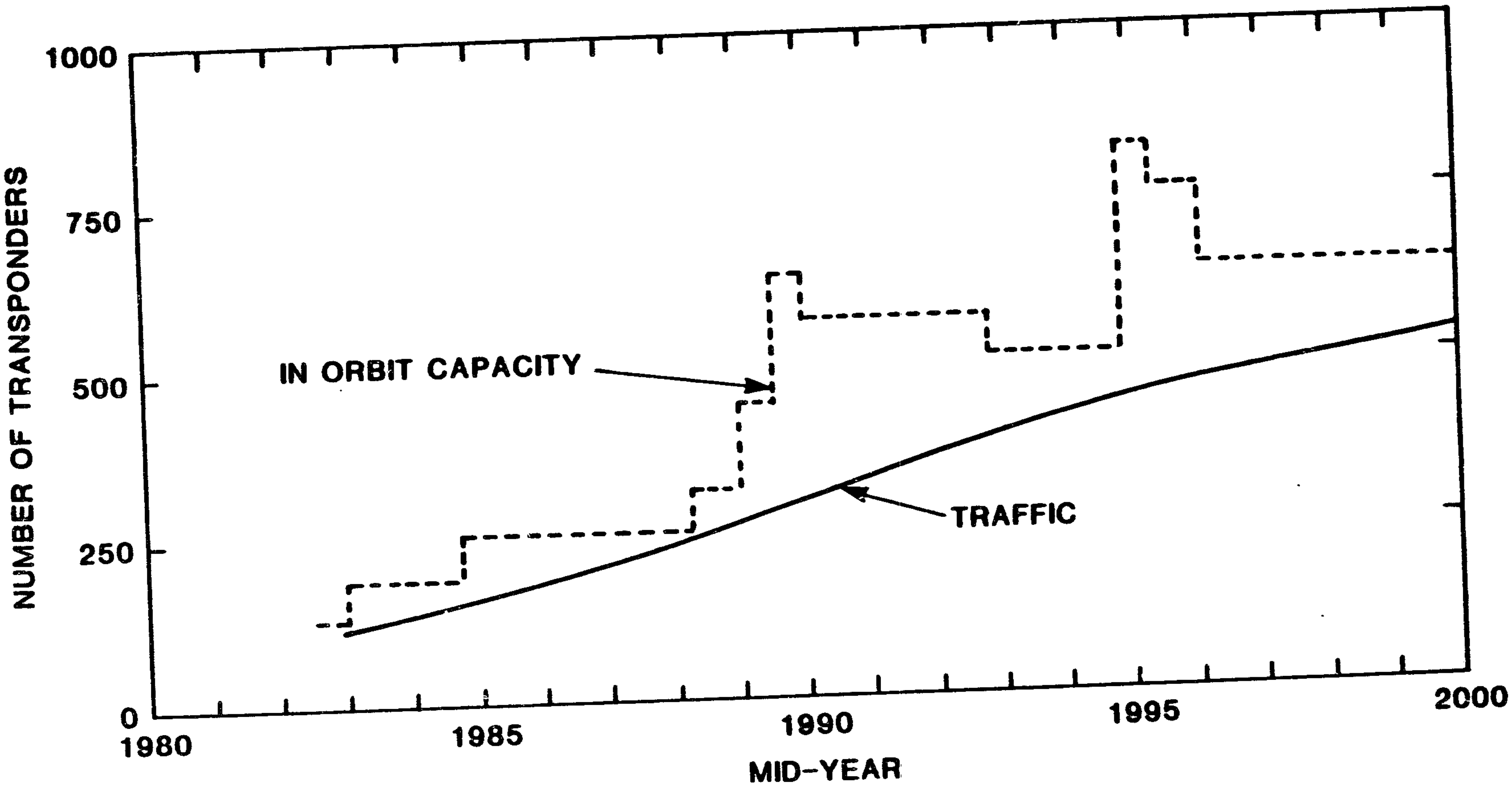


Figure 6-5

JAPAN WITHOUT VIDEO CONFERENCING WITH KA-BAND

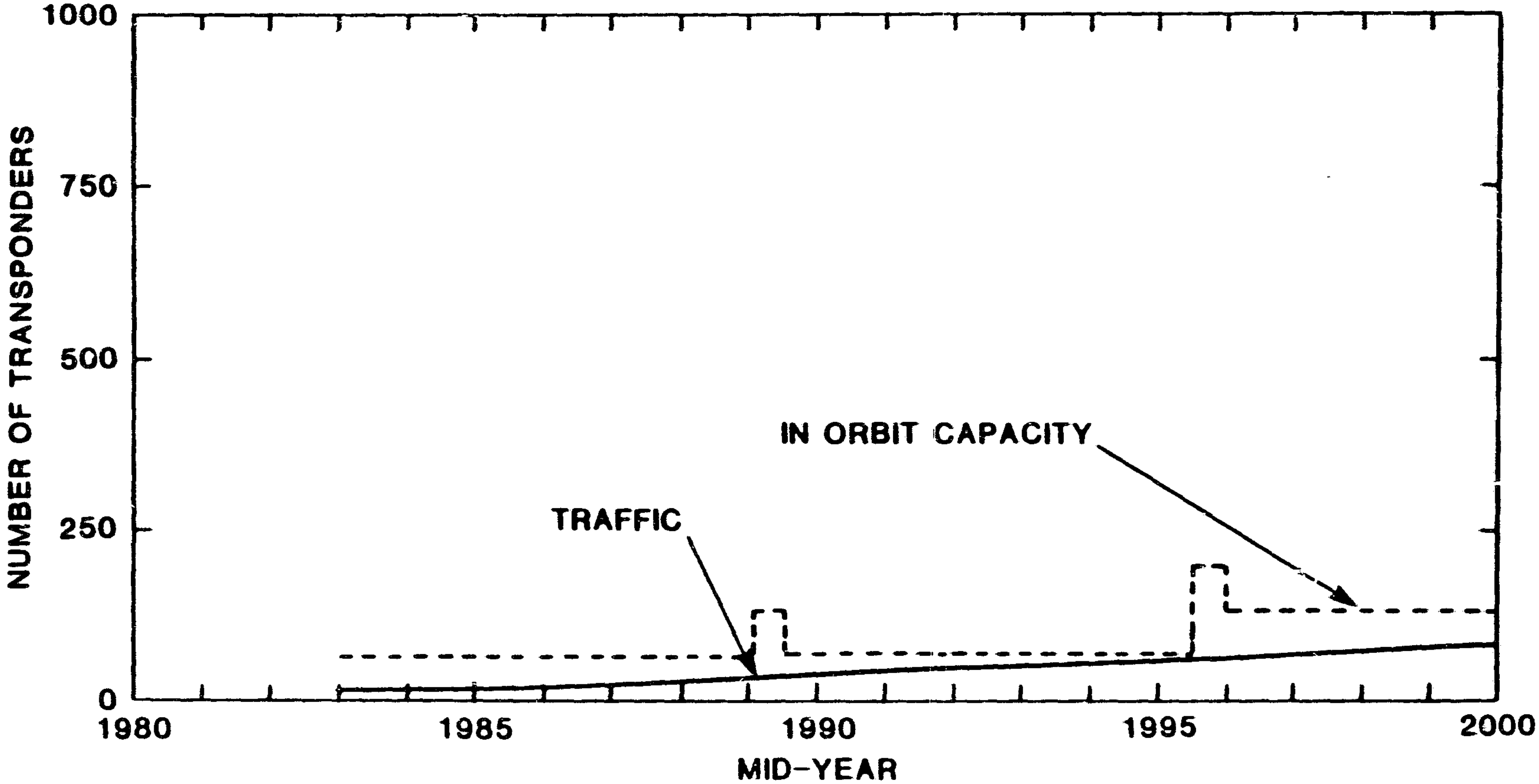


Figure 6-6

AFRICA WITHOUT VIDEO CONFERENCING WITH KA-BAND

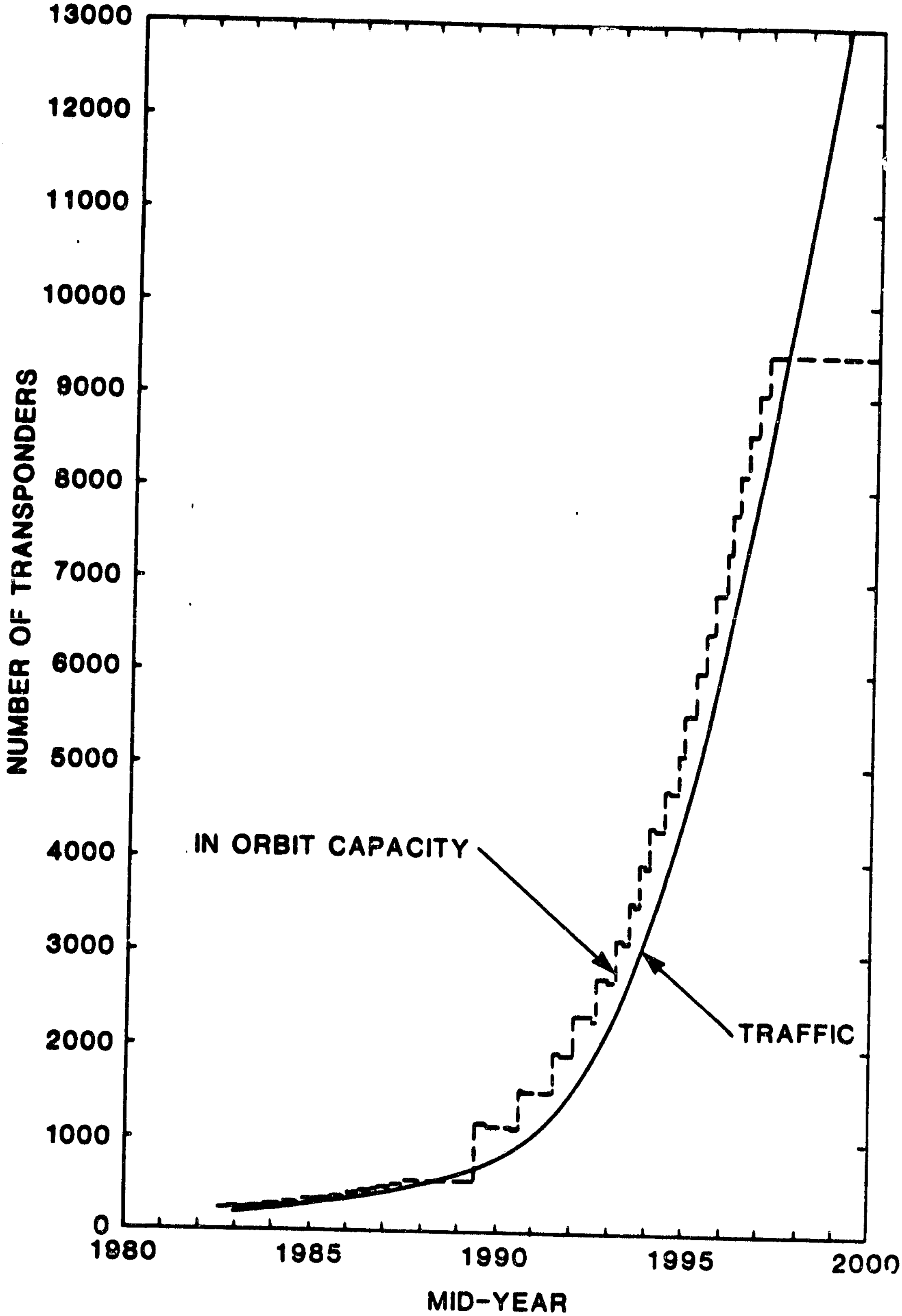


Figure 6-7

WESTERN EUROPE WITH VIDEO CONFERENCING WITH KA-BAND

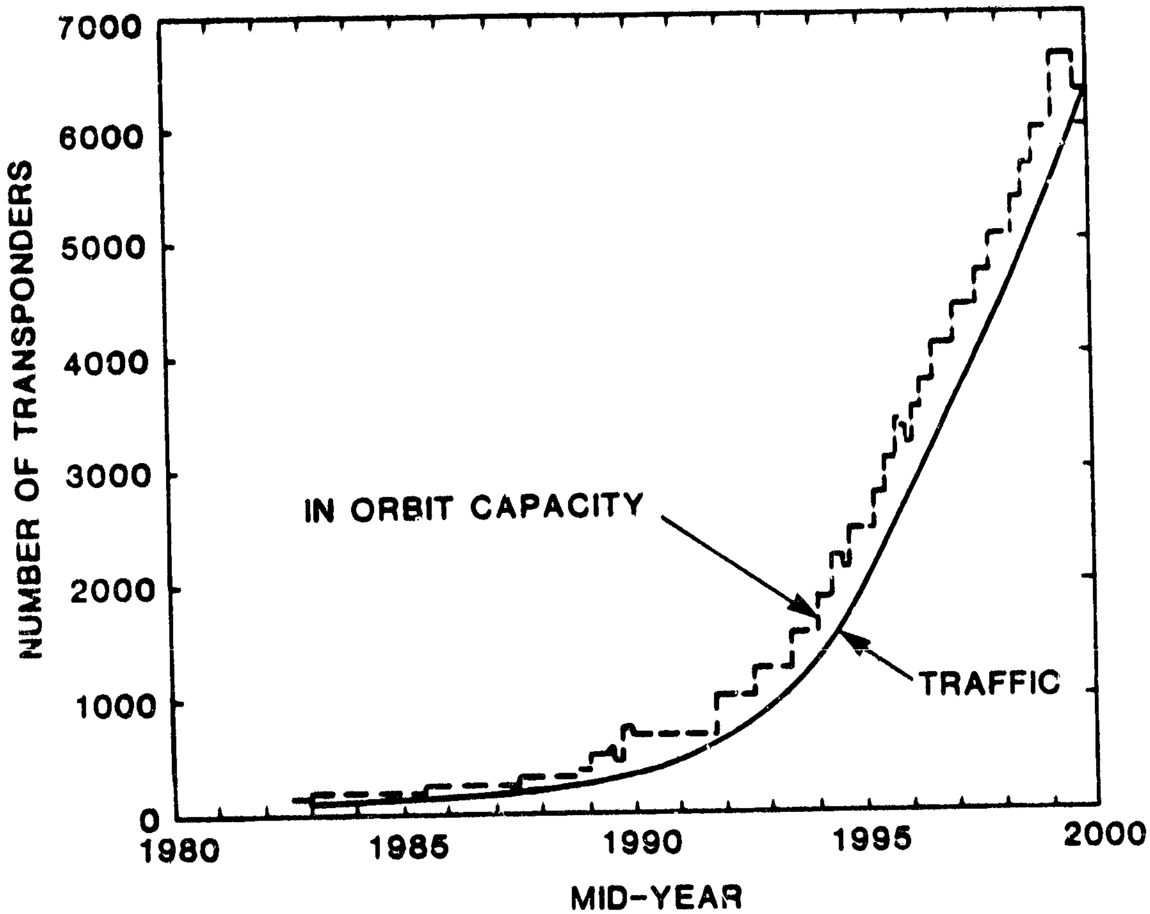


Figure 6-8

JAPAN WITH VIDEO CONFERENCING WITH KA-BAND

6.2 Orbit Utilization

Systems using the advanced technology and additional frequency space of Ka-band result in more efficient use of the orbital arc. Some problems arise with regions like Western Europe, where the high traffic density in a small geographical extent results in saturation of the arc if the high traffic model is used. Additional frequency re-uses are not possible without the use of yet smaller beams from the satellite; the technology is already pushed to its likely 1990 limit by the 0.9 degree beams shown in Figure 6-1.

This system achieves efficient use of the arc, since co-located satellites can serve both Europe and Africa. Further coordination of antenna coverages, with possible consolidation on a single spacecraft would make more capacity per satellite possible. Tables 6-2 and 6-3 show the percent of orbital arc utilization when using satellites with Ka-band in the 1990-2000 time frame.

6.3 Link Budgets

Link Budgets for the lower frequency bands will be the same as those presented in Section 5. For 30/20 GHz, the link budget margin must be increased to combat the additional rain attenuation. We have used a margin of 15 dB; this is quite large for a space link, and probably is close to the upper limit of reasonable margin. Additional data on the rain attenuation considerations appears later in this report. The 30/20 GHz link budgets are shown in Tables 6-4 and 6-5.

Table 6-2

Orbital Slot Fill Factors For

Low Traffic Scenarios With Ka-Band

(Percent)

Year	Western Europe	Japan	Latin America	Middle East	Africa	China	Asia
1983	45	9	3	3	3	6	2
1984	55	13	3	3	3	6	2
1985	64	13	6	3	3	6	2
1986	73	17	6	3	3	6	4
1987	82	17	6	3	3	6	4
1988	95	17	9	3	3	6	7
1989	100	22	9	3	3	6	7
1990	59	13	9	3	3	6	7
1991	50	13	13	3	3	6	7
1992	41	13	9	3	3	6	7
1993	36	9	9	5	3	6	7
1994	24	9	13	5	3	6	7
1995	14	9	13	5	3	6	7
1996	14	9	13	5	5	11	7
1997	14	9	13	5	3	11	9
1998	18	9	16	5	3	11	9
1999	18	9	22	5	3	11	11
2000	18	9	22	5	3	11	11

Table 6-3

Orbital Slot Fill Factors For

High Traffic Scenarios With Ka-Band

(Percent)

Year	Western Europe	Japan	Latin America	Middle East	Africa	China	Asia
1983	45	13	3	3	3	6	2
1984	55	13	3	3	3	6	2
1985	64	13	6	3	3	6	2
1986	77	17	6	3	3	6	4
1987	91	17	6	3	3	6	4
1988	100	22	9	3	3	6	4
1989	100	39	9	3	3	6	7
1990	59	30	9	3	3	6	7
1991	55	30	13	3	3	6	7
1992	55	35	9	5	3	6	7
1993	55	39	9	5	3	6	7
1994	55	48	13	5	3	6	7
1995	86	52	13	5	3	6	7
1996	91	52	13	8	5	11	7
1997	100	65	16	5	3	11	9
1998	100	74	16	5	3	11	9
1999	100	91	22	8	3	11	11
2000	100	100	22	10	3	11	11

Table 6-4

Sample 30/20 GHz Transmission Link Budgets for a 120 Mbps PSK Carrier

Downlink

Satellite transmit RF power	Watts	63
	dBW	18
Line losses	dB	0.5
Minimum satellite transmit EIRP	dBW	60.5
Free space path loss at 30 degree elevation	dB	209
Minimum flux density at the surface of the earth	dBW/m^2	-97.5
Earth station antenna diameter	m	4.5
Earth station antenna gain	dB	56.4
Receive system noise temperature	K	500
Earth station G/T	dB/K	29.4
Receive noise bandwidth	MHz	72
Downlink carrier-to-noise ratio	dB	30
Transmission link margin	dB	15

Table 6-4, Continued

Sample 30/20 GHz Transmission Link Budgets for a 120 Mbps PSK Carrier

Uplink

Earth station transmit RF power	Watts	1600
	dBW	32
Line losses	dB	1
Antenna diameter	m	4.5
Antenna gain	dB	61
Earth station transmit EIRP	dBW	92
Free space path loss at 30 degree elevation	dB	214
Flux density at the satellite	dBW/m^2	- 71
Satellite G/T	dB/K	+ 8
Receive noise bandwidth	MHz	72
Uplink carrier-to-noise ratio	dB	35
Transmission link margin	dB	15

Table 6-5

Sample 30/20 GHz Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(per carrier)

Downlink

Satellite transmit RF power (per carrier)	Watts	
	dBW	5
Line losses	dB	0.5
Minimum satellite transmit EIRP	dBW	47.5
Free space path loss at 30 degree elevation	dB	209
Minimum flux density at the surface of the earth	dBW/m^2	- 110
Earth station antenna diameter	m	4.5
Earth station antenna gain	dB	56.4
Receive system noise temperature	^oK	500
Earth station G/T	$dB/^oK$	29.4
Receive noise bandwidth	MHz	4.1
Downlink carrier-to-noise ratio	dB	30
Transmission link margin	dB	15

Table 6-5, Continued

Sample 30/20 GHz Transmission Link Budgets for a 6.3 Mbps PSK Carrier

(per carrier)

Uplink

Earth station transmit power (per carrier)	Watts	80
	dBW	19
Line losses	dB	1
Antenna diameter	m	4.5
Antenna gain	dB	61
Earth station transmit EIRP	dBW	79
Free space path loss at 30 degree elevation	dB	214
Flux density at the satellite	dBW/m^2	- 84
Satellite G/T	$dB/^oK$	8
Receive noise bandwidth	MHz	4.1
Uplink carrier-to-noise ratio	dB	35
Transmission link margin	dB	15

6.4 Typical Satellite Weight and Power Budgets

In a manner similar to that used in Section 5, we have postulated two somewhat different satellite types. Either satellite could use 30/20 GHz, however, the difficulty of providing the large power margin needed without the use of spot beams might limit 30/20 GHz to the larger, more complex spacecraft. In addition, the smaller satellites are used in areas where the traffic levels may not justify using 30/20 GHz. The resulting weight and power estimates are shown in Table 6-6.

Table 6-6
Satellites With 30/20 GHz

Item	Satellite Type 4	Satellite Type 5
Coverage type	area	multiple spot beam
Approximate capacity in 36 MHz transponders	130	300-450
Design life, years	10	10
Mass (kg)		
Communications System	650	1300
TT&C	50	100
Electrical Power	450	700
Attitude Control	450	900
Structure Thermal Control	500	1000
Total	2100	4000
Power (watts)		
EOL	3000	10kW
BOL	4200	14kW

6.5 Space Segment Costs

As was done previously, we have estimated costs for the spacecraft using the SAMSO model. The cost estimates are shown in Table 6-7, along with launch costs.

Table 6-7
Costs for Satellites with 30/20 GHz

Item	Satellite Type 4	Satellite Type 5
Fraction of STS used	1	1
Upper stage used	IUS	Centaur
Satellite		
Development cost	100	130
Per-unit cost	60	96
Launch		
Shuttle cost	30	30
Upper stage cost	18	20
Total per satellite in orbit	108	145

6.5 30/20 GHz Earth Station Costs

It is quite difficult to estimate the costs for 30/20 GHz equipment, due mainly to the rather low level of activity by manufacturers. During the course of their contract work, the systems contractors to NASA/Lewis developed estimates for 30/20 GHz earth stations. We have summarized these in Table 6-8. When sufficient interest is aroused to justify quantity production, costs will drop substantially, as we expect to occur at the lower frequency bands. Based on this assumption, we have performed our analysis using somewhat lower costs than those of the systems contractors; these costs are shown in Table 6-9.

Table 6-8

Summary of Costs Developed by Previous NASA/Lewis Contractors

(thousands of dollars)

	Contractor		
	FACC	Hughes	TRW
Diversity Trunking Station	6700 (FDMA) 6000 (TDMA)	7500 (TDMA)	--
DTU Station	518	227 (small) 611 (med.) 2167 (lg.)	293

Table 6-9

Typical 30/20 GHz Earth Station Costs in 1990

(thousands of 1980 dollars)

(moderate quantity)

Item	Bush Radio	SCPC/ DAMA	Multi-Carrier PSK	SS/TDMA
	Station Type			
Front Ends				
Antenna System	20	24	30	35
RF Equipment	30	55	80	160
Terminal Equipment	3	6	30	60
Mux/Demux	--	3	18	4
Totals	53	88	158	259

SECTION 7

COST COMPARISON OF SYSTEMS WITH AND WITHOUT 30/20 GHZ

7.1 Cost Model

Engineering cost calculations were made using the following cost model:

1. Revenue requirements were calculated for each of the 20 years of the study period, 1980 to 2000. Revenue requirements are the sum of depreciation, operation and maintenance costs, and return on investment.

2. Straight line depreciation based on satellite lifetimes of seven years (before 1990) and ten years (after 1990), and earth station useful lifetimes of ten years. This will result in conservative figures, since some earth station equipment will have longer life.

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

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

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

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

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

7.2 Investment and Operations and Maintenance (O&M) Schedule

The following assumptions were made regarding the investment and O&M schedule:

1. Shuttle Launch Costs

   The total launch costs were as follows: $30 million for the full Shuttle (1980 dollars), with lesser loads prorated as shown in Figure 7-1. Upper stages were assumed to be a modified Centaur or its equivalent for full Shuttle payloads; the transfer vehicle would occupy the cargo bay along with the satellite. This is at a cost of $20 million. For payloads which do not use the full cargo bay, the use of the IUS or similar upper stage, at a cost of $16 to $18 million.

2. Satellite Control Center and Tracking, Telemetry and Control (TT&C) Investment Costs

   In some regions, adequate TT&C facilities already exist. In other regions, they will have to be constructed. Since TT&C facilities are needed regardless of the use of 30/20 GHz, the cost will wash out in the comparison.

3. Earth Station Deployment and Costs

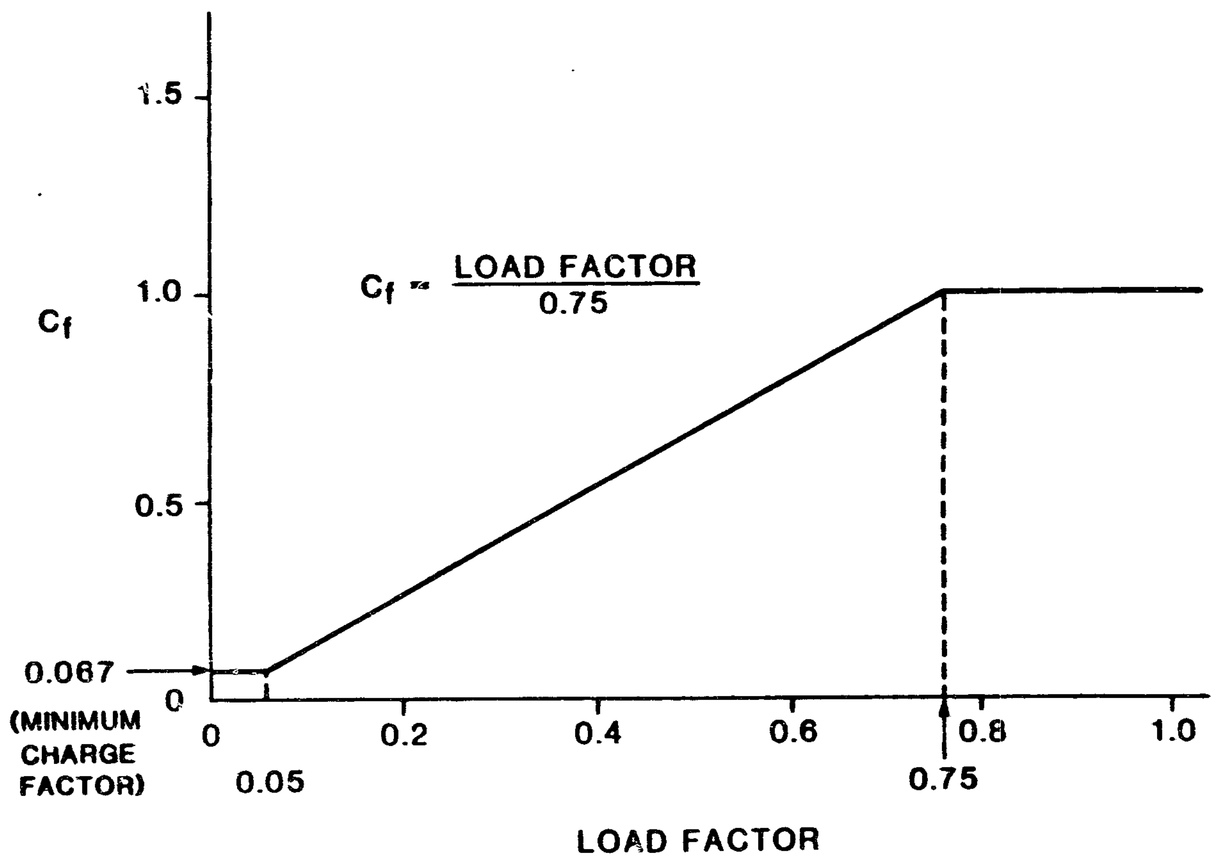
   In addition to the basic equipment cost, 40 percent was added to account for such costs as transportation, installation, integration, and spares.

7.3 Development and Deployment

Development costs for the first generation system were assessed in 1980, and for the second generation is 1990.

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

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



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

Source: NASA Headquarters

Figure 7-1

DETERMINATION OF CHARGE FACTOR (C_f) FOR 160 N.MI

7.4 TT&C and Operations

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

$0.5 N million

where

N is the number of spacecraft in orbit including spares.

7.5 Space Segment Cost Calculations

Based on the above model, and the costs for spacecraft calculated previously, we have computed the cost per transponder year for Europe, Japan, and Africa. Calculations were performed for the high traffic case as well as the low traffic, and for systems which did and didn't use 30/20 GHz. These cost calculations include the cost of in-orbit spares for each scenario. The resulting output from the computer program is shown in Tables 7-1 through 7-10.

Launch schedules for the above scenarios are shown in Table 7-11 through 7-20.

Table 7-1

Economic Model Forecast
Western Europe - Low Traffic Model - Without 30/20 GHz

Year	Net Invest	---------Annual-------- Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	504.0	82.0	7.0	50.4	139.4	199.00	.70	121.2
1984	488.9	93.1	8.0	48.9	150.0	245.00	.61	124.5
1985	496.0	109.9	9.5	49.6	169.0	293.00	.58	133.9
1986	453.0	121.0	10.5	45.3	176.8	344.00	.51	133.7
1987	465.7	143.3	12.5	46.6	202.4	403.00	.50	146.1
1988	389.3	154.4	13.5	38.9	206.9	470.00	.44	142.5
1989	234.9	154.4	13.5	23.5	191.4	528.00	.36	125.9
1990	686.7	135.1	16.0	68.7	219.8	631.00	.35	138.0
1991	744.5	144.2	17.0	74.5	235.6	717.00	.33	141.2
1992	708.0	137.6	17.5	70.8	225.9	803.00	.28	129.2
1993	767.3	142.6	18.5	76.7	237.9	888.00	.27	129.8
1994	737.9	130.4	19.0	73.8	223.2	971.00	.23	116.3
1995	709.5	129.4	19.5	70.9	219.9	1055.00	.21	109.3
1996	671.0	139.5	20.0	67.1	226.6	1141.00	.20	107.6
1997	531.5	139.5	20.0	53.1	212.7	1229.00	.17	96.4
1998	573.8	159.7	21.0	57.4	238.1	1320.00	.18	103.0
1999	959.5	220.3	24.0	95.9	340.2	1415.00	.24	140.5
2000	797.9	161.6	24.0	79.8	265.4	1515.00	.18	104.6

Total of Revenue Requirements = 3881.
Total Present Value of Revenue = 2244.
Average Cost per Xponder per Year = .27

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

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Table 7-2

Economic Model Forecast
Western Europe - Low Traffic Model - With 30/20 GHz

Year	Net Invest	Annual: Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	504.0	82.0	7.0	50.4	139.4	199.00	.70	121.2
1984	488.9	93.1	8.0	48.9	150.0	245.00	.61	124.5
1985	496.0	109.9	9.5	49.6	169.0	293.00	.58	133.9
1986	453.0	121.0	10.5	45.3	176.8	344.00	.51	133.7
1987	432.3	137.7	12.0	43.2	192.9	403.00	.48	139.3
1988	394.9	154.4	13.5	39.5	207.4	470.00	.44	142.9
1989	240.4	154.4	13.5	24.0	192.0	528.00	.36	126.2
1990	542.0	118.4	14.5	54.2	187.1	631.00	.30	117.5
1991	434.7	107.3	14.5	43.5	165.3	717.00	.23	99.0
1992	344.1	90.6	14.5	34.4	139.5	803.00	.17	79.8
1993	399.2	89.9	15.0	39.9	144.8	808.00	.16	79.1
1994	326.0	73.2	15.0	32.6	120.8	971.00	.12	62.9
1995	269.5	56.5	15.0	26.9	98.4	1055.00	.09	49.0
1996	213.0	56.5	15.0	21.3	92.8	1141.00	.08	44.1
1997	417.5	85.5	16.0	41.7	143.2	1229.00	.12	64.9
1998	332.0	85.5	16.0	33.2	134.7	1320.00	.10	58.3
1999	377.0	100.0	16.5	37.7	154.2	1415.00	.11	63.7
2000	319.0	58.0	16.5	31.9	106.4	1515.00	.07	41.9

Total of Revenue Requirements = 2715.
Total Present Value of Revenue = 1682.
Average Cost per Xponder per Year = .19

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-3

Economic Model Forecast
Western Europe - High Traffic Model - Without 30/20 GHz

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	504.0	82.0	7.0	50.4	139.4	203.00	.69	121.2
1984	488.9	93.1	8.0	48.9	150.0	250.00	.60	124.5
1985	496.0	109.9	9.5	49.6	169.0	301.00	.56	133.9
1986	486.4	126.6	11.0	48.6	186.2	356.00	.52	140.8
1987	493.6	148.9	13.0	49.4	211.2	424.00	.50	152.5
1988	378.1	154.4	13.5	37.8	205.7	510.00	.40	141.8
1989	223.7	154.4	13.5	22.4	190.3	528.00	.36	125.1
1990	948.3	165.4	17.5	94.8	277.8	796.00	.35	174.4
1991	1339.4	214.9	20.5	133.9	369.3	970.00	.38	221.3
1992	1595.7	248.7	23.0	159.6	431.2	1479.00	.29	246.6
1993	1731.4	268.4	25.0	173.1	465.5	2157.00	.22	254.6
1994	1758.0	276.4	26.5	175.8	478.7	2448.00	.20	249.4
1995	1669.0	291.0	27.5	166.9	485.4	2640.00	.18	241.4
1996	1378.0	291.0	27.5	137.8	456.3	2640.00	.17	216.6
1997	1087.0	291.0	27.5	108.7	427.2	2640.00	.16	193.6
1998	796.0	291.0	27.5	79.6	398.1	2640.00	.15	172.2
1999	505.0	291.0	27.5	50.5	369.0	2640.00	.14	152.3
2000	939.3	272.7	31.0	93.9	397.6	2640.00	.15	156.[illegible]

Total of Revenue Requirements = 5809.
Total Present Value of Revenue = 3219.
Average Cost per Xponder per Year = .22

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-4

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Economic Model Forecast
Western Europe - High Traffic Model - With 30/20 GHz

Year	Net Invest	Annual Dep +	O&M +	ROI =	Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	504.0	82.0	7.0	50.4	139.4	203.00	.69	121.2
1984	488.9	93.1	8.0	48.9	150.0	250.00	.60	124.5
1985	496.0	109.9	9.5	49.6	169.0	301.00	.56	133.9
1986	486.4	126.6	11.0	48.6	186.2	356.00	.52	140.8
1987	493.6	148.9	13.0	49.4	211.2	424.00	.50	152.5
1988	378.1	154.4	13.5	37.8	205.7	510.00	.40	141.8
1989	223.7	154.4	13.5	22.4	190.3	528.00	.36	125.1
1990	525.3	118.4	14.5	52.5	185.5	796.00	.23	116.4
1991	548.5	121.8	15.0	54.8	191.6	970.00	.20	114.8
1992	834.9	148.6	16.5	83.5	248.6	1479.00	.17	142.2
1993	1229.1	185.9	18.5	122.9	327.3	2157.00	.15	178.6
1994	1457.0	207.1	20.0	145.7	372.8	3179.00	.12	194.2
1995	1908.0	274.0	22.5	190.8	487.3	4582.00	.11	242.3
1996	2547.5	375.5	26.0	254.7	656.2	6342.00	.10	311.5
1997	2433.0	404.5	27.0	243.3	674.8	8420.00	.08	305.7
1998	2028.5	404.5	27.0	202.8	634.3	9460.00	.07	274.3
1999	1624.0	404.5	27.0	162.4	593.9	9460.00	.06	245.2
2000	1653.0	406.0	28.5	165.3	599.8	9460.00	.06	236.3

Total of Revenue Requirements = 6224.
Total Present Value of Revenue = 3302.
Average Cost per Xponder per Year = .11

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-5

Economic Model Forecast
Japan - Low Traffic Model - Without 30/20 GHz

Year	Net Invest	---------Annual--------- Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	228.9	35.1	1.5	22.9	59.5	118.00	.50	51.8
1984	193.7	35.1	1.5	19.4	56.0	141.00	.40	46.5
1985	158.6	35.1	1.5	15.9	52.5	162.00	.32	41.6
1986	240.0	54.6	2.5	24.0	81.1	185.00	.44	61.3
1987	185.4	54.6	2.5	18.5	75.6	209.00	.36	54.5
1988	189.1	64.3	3.0	18.9	86.2	236.00	.37	59.4
1989	241.4	83.7	4.0	24.1	111.9	266.00	.42	73.6
1990	442.5	83.0	5.0	44.2	132.2	298.00	.44	83.0
1991	359.5	83.0	5.0	35.9	123.9	329.00	.38	74.2
1992	367.4	93.1	5.5	36.7	135.3	359.00	.38	77.4
1993	299.8	67.6	5.5	30.0	103.1	387.00	.27	56.3
1994	232.1	67.6	5.5	23.2	96.4	413.00	.23	50.2
1995	265.1	68.0	6.0	26.5	100.5	437.00	.23	50.0
1996	216.5	48.6	6.0	21.6	76.2	460.00	.17	36.2
1997	258.8	58.7	6.5	25.9	91.1	481.00	.19	41.3
1998	200.1	58.7	6.5	20.0	85.2	501.00	.17	36.9
1999	323.2	78.9	7.5	32.3	118.7	420.00	.28	49.0
2000	272.7	50.5	7.5	27.3	85.3	538.00	.16	33.6

Total of Revenue Requirements = 1671.
Total Present Value of Revenue = 977.
Average Cost per Xponder per Year = .28

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

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Table 7-6

Economic Model Forecast
Japan - Low Traffic Model - With 30/20 GHz

Year	Net Invest	---------Annual-------- Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	228.9	35.1	1.5	22.9	59.5	118.00	.50	51.8
1984	193.7	35.1	1.5	19.4	56.0	141.00	.40	46.5
1985	158.6	35.1	1.5	15.9	52.5	162.00	.32	41.6
1986	240.0	54.6	2.5	24.0	81.1	185.00	.44	61.3
1987	185.4	54.6	2.5	18.5	75.6	209.00	.36	54.6
1988	189.1	64.3	3.0	18.9	86.2	236.00	.37	59.4
1989	241.4	83.7	4.0	24.1	111.9	266.00	.42	73.6
1990	564.9	96.6	5.0	56.5	158.1	298.00	.53	99.2
1991	468.3	96.6	5.0	46.8	148.4	329.00	.45	88.9
1992	371.7	96.6	5.0	37.2	138.7	359.00	.39	79.3
1993	300.6	71.1	5.0	30.1	106.2	387.00	.27	58.0
1994	229.4	71.1	5.0	22.9	99.1	413.00	.24	51.6
1995	298.5	75.9	5.5	29.8	111.3	437.00	.25	55.3
1996	242.0	56.5	5.5	24.2	86.2	460.00	.19	40.9
1997	185.5	56.5	5.5	18.5	80.5	481.00	.17	36.5
1998	129.0	56.5	5.5	12.9	74.9	501.00	.15	32.4
1999	203.0	71.0	6.0	20.3	97.3	420.00	.23	40.2
2000	174.0	29.0	6.0	17.4	52.4	538.00	.10	20.6

Total of Revenue Requirements = 1676.
Total Present Value of Revenue = 992.
Average Cost per Xponder per Year = .28

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-7

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Economic Model Forecast
Japan - High Traffic Model - Without 30/20 GHz

Year	Net Invest	Dep +	O&M +	ROI =	Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	228.9	35.1	1.5	22.9	59.5	120.00	.50	51.8
1984	193.7	35.1	1.5	19.4	56.0	143.00	.39	46.5
1985	158.6	35.1	1.5	15.9	52.5	165.00	.32	41.6
1986	240.0	54.6	2.5	24.0	81.1	190.00	.43	61.3
1987	185.4	54.6	2.5	18.5	75.6	218.00	.35	54.6
1988	189.1	64.3	3.0	18.9	86.2	253.00	.34	59.4
1989	416.3	112.9	5.5	41.6	160.0	299.00	.54	105.2
1990	497.3	102.0	6.0	49.7	157.7	367.00	.43	99.0
1991	486.2	112.1	6.5	48.6	167.2	472.00	.35	100.2
1992	646.7	142.4	8.0	64.7	215.1	646.00	.33	123.0
1993	893.4	157.4	10.0	89.3	256.7	928.00	.28	140.1
1994	1190.5	207.9	12.5	119.0	339.4	1358.00	.25	176.9
1995	1537.7	258.8	15.5	153.8	428.0	1956.00	.22	212.9
1996	1963.8	280.9	19.0	196.4	496.3	2709.00	.18	235.6
1997	1864.7	301.1	20.0	186.5	507.6	3574.00	.14	230.0
1998	1563.6	301.1	20.0	156.4	477.5	3680.00	.13	206.5
1999	1262.5	301.1	20.0	126.2	447.4	3680.00	.12	184.7
2000	1070.6	292.9	20.5	107.1	420.5	3680.00	.11	165.7

Total of Revenue Requirements = 4484.
Total Present Value of Revenue = 2295.
Average Cost per Xponder per Year = .18

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

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Table 7-8

Economic Model Forecast
Japan - High Traffic Model - With 30/20 GHz

Year	Net Invest	Dep +	O&M +	ROI =	Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
		----------Annual--------						
1983	228.9	35.1	1.5	22.9	59.5	120.00	.50	51.8
1984	193.7	35.1	1.5	19.4	56.0	143.00	.39	46.5
1985	158.6	35.1	1.5	15.9	52.5	165.00	.32	41.6
1986	240.0	54.6	2.5	24.0	81.1	190.00	.43	61.3
1987	185.4	54.6	2.5	18.5	75.6	218.00	.35	54.6
1988	189.1	64.3	3.0	18.9	86.2	253.00	.34	59.4
1989	416.3	112.9	5.5	41.6	160.0	299.00	.54	105.2
1990	580.1	111.2	6.0	58.0	175.2	367.00	.48	110.0
1991	468.9	111.2	6.0	46.9	164.1	472.00	.35	98.3
1992	488.1	125.7	6.5	48.8	181.0	646.00	.28	103.5
1993	779.4	143.8	8.0	77.9	229.7	928.00	.25	125.4
1994	896.6	172.8	9.0	89.7	271.4	1358.00	.20	141.4
1995	1125.0	206.6	10.5	112.5	329.6	1956.00	.17	163.9
1996	1619.5	230.5	13.0	161.9	405.5	2709.00	.15	192.5
1997	1780.5	274.0	14.5	178.1	466.6	3574.00	.13	211.4
1998	1898.0	317.5	16.0	189.8	523.3	4495.00	.12	226.3
1999	2233.0	390.0	18.5	223.3	631.8	5416.00	.12	260.8
2000	1870.5	362.5	18.5	187.1	568.0	6297.00	.09	223.8

Total of Revenue Requirements = 4517.
Total Present Value of Revenue = 2278.
Average Cost per Xponder per Year = .15

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-9

Economic Model Forecast
Africa - Low Traffic Model - Without 30/20 GHz

Year	Net Invest	---------Annual-------- Dep +	O&M +	ROI =	Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	112.3	15.7	.5	11.2	27.4	12.00	2.29	23.9
1984	96.6	15.7	.5	9.7	25.9	15.00	1.72	21.5
1985	80.9	15.7	.5	8.1	24.3	17.00	1.43	19.3
1986	65.1	15.7	.5	6.5	22.7	20.00	1.14	17.2
1987	49.4	15.7	.5	4.9	21.2	23.00	.92	15.3
1988	33.7	15.7	.5	3.4	19.6	26.00	.75	13.5
1989	134.6	35.1	1.5	13.5	50.1	30.00	1.67	32.9
1990	109.1	25.4	1.5	10.9	37.8	33.00	1.15	23.8
1991	83.7	25.4	1.5	8.4	35.3	37.00	.95	21.1
1992	58.3	25.4	1.5	5.8	32.8	41.00	.80	18.7
1993	38.9	19.4	1.5	3.9	24.8	45.00	.55	13.5
1994	19.4	19.4	1.5	1.9	22.9	50.00	.46	11.9
1995	0.0	19.4	1.5	0.0	20.9	54.00	.39	10.4
1996	115.2	12.8	2.0	11.5	26.3	59.00	.45	12.5
1997	224.8	26.4	3.0	22.5	51.9	63.00	.82	23.5
1998	198.4	26.4	3.0	19.8	49.2	68.00	.72	21.3
1999	172.0	26.4	3.0	17.2	46.6	73.00	.64	19.2
2000	145.6	26.4	3.0	14.6	44.0	78.00	.56	17.3

Total of Revenue Requirements = 584.
Total Present Value of Revenue = 337.
Average Cost per Xponder per Year = .78

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

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Table 7-10

Economic Model Forecast
Africa - Low Traffic Model - With 30/20 GHz

Year	Net Invest	Annual Dep	+ O&M	+ ROI	= Revenu	Traffic	Cost per Xponder	PV of Annual Revenue
1983	112.3	15.7	.5	11.2	27.4	12.00	2.29	23.9
1984	96.6	15.7	.5	9.7	25.9	15.00	1.72	21.5
1985	80.9	15.7	.5	8.1	24.3	17.00	1.43	19.3
1986	65.1	15.7	.5	6.5	22.7	20.00	1.14	17.2
1987	49.4	15.7	.5	4.9	21.2	23.00	.92	15.3
1988	33.7	15.7	.5	3.4	19.6	26.00	.75	13.5
1989	134.6	35.1	1.5	13.5	50.1	30.00	1.67	32.9
1990	109.1	25.4	1.5	10.9	37.8	33.00	1.15	23.8
1991	83.7	25.4	1.5	8.4	35.3	37.00	.95	21.1
1992	58.3	25.4	1.5	5.8	32.8	41.00	.80	18.7
1993	38.9	19.4	1.5	3.9	24.8	45.00	.55	13.5
1994	19.4	19.4	1.5	1.9	22.9	50.00	.46	11.9
1995	0.0	19.4	1.5	0.0	20.9	54.00	.39	10.4
1996	187.2	20.8	2.0	18.7	41.5	59.00	.70	19.7
1997	166.4	20.8	2.0	16.6	39.4	63.00	.63	17.9
1998	145.6	20.8	2.0	14.6	37.4	68.00	.55	16.2
1999	124.8	20.8	2.0	12.5	35.3	73.00	.48	14.6
2000	104.0	20.8	2.0	10.4	33.2	78.00	.43	13.1

Total of Revenue Requirements = 553.
Total Present Value of Revenue = 324.
Average Cost per Xponder per Year = .74

Note: Traffic is in Xponder
Cost is $millions per Xponder per Year

Table 7-11

Launch Schedule for Western Europe

Low Traffic Model, Without 30/20 GHz

Year	Launches
1983	14
84	2
85	3
86	2
87	4
88	2
89	0
1990	5
91	2
92	1
93	2
94	1
95	1
96	1
97	0
98	2
99	6
2000	0

Table 7-12

Launch Schedule for Western Europe

Low Traffic Model With 30/20 GHz

Year	Launches
1983	14
84	2
85	3
86	2
87	4
88	2
89	0
1990	2
91	0
92	0
93	1
94	0
95	0
96	0
97	2
98	0
99	1
2000	0

Table 7-13

Launch Schedule for Western Europe

High Traffic Model Without 30/20 GHz

Year	Launches
1983	14
84	2
85	3
86	3
87	4
88	1
89	0
1990	8
91	6
92	5
93	4
94	3
95	2
96	0
97	0
98	0
99	0
2000	7

Table 7-14

Launch Schedule for Western Europe

High Traffic Model With 30/20 GHz

Year	Launch
1983	14
84	2
85	3
86	3
87	4
88	1
89	0
1990	2
91	1
92	3
93	4
94	3
95	5
96	7
97	2
98	0
99	0
2000	3

Table 7-15

Launch Schedule for Japan

Low Traffic Model Without 30/20 GHz

Year	Launches
1983	3
84	0
85	0
86	2
87	0
88	1
89	2
1990	2
91	0
92	1
93	0
94	0
95	1
96	0
97	1
98	0
99	2
2000	0

Table 7-16

Launch Schedule for Japan

Low Traffic Model With 30/20 GHz

Year	Launches
1983	3
84	0
85	0
86	2
87	0
88	1
89	2
1990	2
91	0
92	0
93	0
94	0
95	1
96	0
97	0
98	0
99	1
2000	0

Table 7-17

Launch Schedule for Japan

High Traffic Model Without 30/20 GHz

Year	Launches
1983	3
84	0
85	0
86	2
87	0
88	1
89	5
1990	1
91	1
92	3
93	4
94	5
95	6
96	7
97	2
98	0
99	0
2000	1

Table 7-18

Launch Schedule for Japan

High Traffic Model With 30/20 GHz

Year	Launches
1983	3
84	0
85	0
86	2
87	0
88	1
89	5
1990	1
91	0
92	1
93	3
94	2
95	3
96	5
97	3
98	3
99	5
2000	0

Table 7-19

Launch Schedule for Africa

Without 30/20 GHz

Year	Launches
1983	1
84	0
85	0
86	0
87	0
88	0
89	2
1990	0
91	0
92	0
93	0
94	0
95	0
96	1
97	2
98	0
99	0
2000	0

Table 7-20

Launch Schedule for Africa

With 30/20 GHz

Year	Launches
1983	1
84	0
85	0
86	0
87	0
88	0
89	2
1990	0
91	0
92	0
93	0
94	0
95	0
96	1
97	0
98	0
99	0
2000	0

7.6 Earth Segment Costs

Annual costs per channel for the earth segment have been calculated based on several assumptions. The basic earth station costs were used as developed in Sections 5 and 6. In the case of systems without 30/20 GHz, the lower capacity per orbital slot will require more satellites in orbit. We estimate that each earth station will need to access the same capacity, regardless of the use or not of 30/20 GHz. Thus, in the systems without 30/20 GHz, larger earth stations will have a need to access more satellites. We have accordingly increased the costs for antennas and RF equipment for these stations, by the factor that the capacity per satellite is lower.

In order to calculate costs per channel-year, we have assigned a certain capacity to each class of earth station, as shown below:

	Station Type			
	Bush	SCPC	Multi-Carrier PSK	SS/TDMA
Capacity in Voice Circuits	2	10	50	500

Further, we have estimated the annual cost per earth station as a function of the total investment cost. The factor used includes allowances for cost of money, return on investment, depreciation, and operations and maintenance. Based on our past experience, we have found that the annual cost taking these items into account is about 40 percent of the investment cost.

The resulting costs per channel-year are shown in Table 7-21.

7.7 Total Costs

In order to develop total cost figures for comparison purposes, we much add the space segment cost per channel to the earth segment cost per channel. For convenience, the space segment cost per channel is summarized in Table 7-22. Table 7-23 shows the resulting total costs, for both low traffic (without video conferencing) and high traffic (with video conferencing) models. The costs for systems which include 30/20 GHz are higher for the low capacity stations, and lower for the higher capacity stations. The primary reason for this is that the low capacity stations generally access only one satellite, and thus do not benefit as much from the increased capacity per orbital slot which is available when 30/20 GHz is used. The higher density stations derive a significant advantage from this increase of per-slot capacity.

Table 7-21

Average Annual Earth Station Costs

(Thousands of 1980 Dollars)

		Without 30/20 GHz		With 30/20 GHz	
		Annual	Per Circuit	Annual	Per Circuit
Western Europe	Bush	8.4	4.2	17.2	8.6
	SCPC/DAMA	12.4	1.2	28.4	2.8
	Multi-Carrier	81.2	1.6	54.4	1.1
	SS/TDMA	192.8	0.4	[illegible]	0.2
Japan	Bush	8.0	4.0	15.2	7.6
	SCPC	11.6	1.2	24.8	2.5
	Multi-Carrier	45.2	0.9	49.2	1.0
	SS/TDMA	71.6	0.2	78.8	0.2
Africa	Bush	8.0	4.0	15.2	7.6
	SCPC/DAMA	11.6	1.2	24.8	2.5
	Multi-Carrier	45.2	0.9	49.2	1.0
	SS/TDMA	71.6	0.2	78.8	0.2

Table 7-22

Summary of Space Segment Costs

Per Circuit-Year in 1980 Dollars

		Region		
		Western Europe	Japan	Africa
Low Traffic	W/O 30/20	540	560	1,560
	with 30/20	380	560	1,480
High Traffic	W/O 30/20	440	360	—
	with 30/20	220	300	—

Table 7-23

Average Annual Cost Per Voice Circuit

(In Thousands of 1980 Dollars)

Region	Earth Station Type	Low Traffic: Without 30/20	Low Traffic: With 30/20	High Traffic: Without 30/20	High Traffic: With 30/20
Western Europe	Bush Radio	8.9	17.6	8.8	17.4
	SCPC/DAMA	2.9	6.0	2.8	5.8
	Multi-Carrier PSK	3.7	2.6	3.6	2.4
	SS/TDMA	1.3	0.8	1.2	0.6
Japan	Bush Radio	8.6	15.8	8.4	15.5
	SCPC/DAMA	3.0	5.6	2.8	5.3
	Multi-Carrier PSK	2.4	2.6	2.2	2.3
	SS/TDMA	1.0	1.0	0.6	0.5
Africa	Bush Radio	9.6	16.8	—	—
	SCPC/DAMA	4.0	6.5	—	—
	Multi-Carrier PSK	3.4	3.5	—	—
	SS/TDMA	2.0	1.9	—	—

7.8 Summary of Cost Analysis

This section has presented an analysis of the costs associated with two types of systems: one using only the C- and Ku-bands and another which also includes 30/20 GHz. Launch schedules for satellites were developed, costs assigned to the launches, and a time-phased analysis performed. This calculation included depreciation, operation and maintenance, and return on investment. Costs were also developed for earth stations, and the results were combined to yield total costs per voice-channel-year.

The basic conclusion from this analysis is that while some cost reductions are possible due to the addition of 30/20 GHz, the decrease is not large. In the case of smaller capacity stations, overall costs may increase.

Caution should be exercised in using this conclusion, however. Other factors will assume more prominence since the economic difference is small. Some other considerations are:

1. Some regions may require 30/20 for frequency coordination reasons--Western Europe is a good example.
2. In some cases, the total demand, especially for direct-to-the-user services and video conferencing, could not be satisfied in any event without the use of 30/20 GHz.
3. Technical considerations such as the desire for smaller antenna diameters will provide an impetus to use 30/20 GHz.

SECTION 8
MARKET ANALYSIS

This section presents an analysis of the potential market for 30/20 equipment that will be available to U.S. industry. We have made estimates of the percentage of the various world markets which will be serviced by U.S. companies. These estimates are necessarily somewhat uncertain, due to the many political considerations involved. However, we have attempted to explain the environment which exists in these world regions, and thence to proceed to the capture estimates in a logical fashion.

First, we examine the overall market universe, then the potential sales of spacecraft and ground equipment are considered separately.

8.1 Overall Market Environment

8.1.1 Canada

The Canadian domestic satellite system owned and operated by Telesat Canada has been providing satellite services via its Anik satellite since early in 1973. Television and message services are provided using a network of over 100 earth stations of varying sizes. Both FM and digital modulations have been used, and for the most part the ground segment has been operating unmanned. Earth stations vary in size from 30-meter heavy-route stations to 3.7-meter thin-route SCPC transportable stations. As early as 1977, there were over 30 SCPC stations operating in the Anik system.

The Canadians have endeavored to provide telecommunications services to all citizens. The introduction of the Anik C satellites should ensure adequate satellite capacity well into the 1980's and an expansion of services already provided. Canada, however, has also been committed strongly to sovereignty. Despite the fact that satellites have been procured outside of Canada, there is a definite policy of "buy Canadian" and a commitment to develop a communications industry to service Canadian requirements.

Due to this policy, direct sales to the Canadian Government or to government controlled corporations would not be practical. Sales in Canada would require affiliation with a local manufacturer or a local subsidiary, which would then lead to a significant Cana   n content.

8.1.2 Europe

France

France is planning a domestic satellite communications system operating at Ku-band with the primary purpose of providing data communications services throughout France. This network is intended to operate with a TDMA system and will have 100 to 200 earth stations. In addition, the French domestic system could provide C-band coverage to many geographical areas, such as the province of Quebec, other French speaking countries in Africa and to the West Indies islands such as Martinique and Guadaloupe. These latter applications will take the form of a regional telecommunications system, and some of these applications may be provided by means of thin-route SCPC stations.

The OTS/ECS System

OTS stands for Orbital Test Satellite. This satellite is presently in operation and provides communications services at Ku-band. It will be followed by ECS, the European Communications Satellite System, which will use wideband TDMA at Ku-band and TV distribution. Most of the European PTTs do not see a requirement for satellite communications for their internal traffic, and they have only reluctantly gone along with political pressures to participate in the ECS system, but their intent is to participate at a minimum level of only one station per country. By the very nature of such a network, the single station will serve as a gateway station providing relatively heavy gateway traffic to other European countries. One of the problems associated with this type of system is the extensive use of even Ku-band for terrestrial microwave links. For example, the German

Bundepost states that in Germany it may be possible to clear only one location for Ku-band earth station operation. This is a location outside of Frankfurt which is being used for OTS/ECS.

Other European Opportunities

There is a likelihood that Italy may proceed with the implementation of a domestic system operating at Ka-band. This system would use approximately 22 stations providing high density trunk traffic.

Western Europe has a much greater density of population and GNP per square kilometer than other regions, as shown in Table 8-1.

In a general sense, satellite communications will be most advantageous relative to terrestrial communications in those cases where population density and especially GNP density is low. High GNP density permits the cost-effective installation of terrestrial communications facilities. Spain, Scandinavia, and some of the other European countries have lower CNP densities and are even better prospects for domestic and regional satellite communications.

Some European countries have strict policies concerning national content in telecommunica.ions procurement which is government controlled. This applies specifically to France and Italy. Where there is no viable local source, imports are considered.

8.1.3 Latin America

Argentina

Argentina has indicated interest in a lease of INTELSAT transponder for the implementation in 1981-1982 to provide 78 circuits (48 circuits on primary routes and 30 circuits on thin-routes) initially and to grow thereafter at the rate of 10 to 15 percent per year. Also included would be one TV channel for an occasional use. Earth stations presently planned would be constrained by the relatively low EIRP available from current INTELSAT satellites; that is, 22 dBW on global beam transponders and 26 dBW on hemispheric beam transponders. Accordingly, earth

Table 8-1

Typical Population and GNP Densities

Country	Population* (Millions)	GNP** ($ Billions)	Area (Sq. km) (Thousands)	Pop. Density (Pop./km^2)	GNP Density ($k of GNP/$km^2$)
Canada	24.1	259.8	9,976.1	2.4	26.0
United States	222.2	2,700.7	9,363.1	23.7	288.4
France	53.8	675.4	547.0	98.4	1,234.7
Germany, F.R.	61.3	919.2	248.6	246.6	3,697.5
Sweden	8.3	115.7	450.0	18.4	257.1
Spain	37.6	168.6	504.8	74.5	334.0
Japan	117.5	1,406.0	372.3	315.6	3,776.6
Brazil	122.0	227.4	8,512.0	14.3	26.7
Argentina	27.1	34.5	2,776.9	9.8	12.4
Saudi Arabia	8.1	102.9	2,149.7	3.8	47.9
Algeria	19.3	36.9	2,381.7	8.1	15.5
China	985.9	577.8	9,596.9	102.7	60.2
Nigeria	77.2	45.4	923.8	83.6	49.1
Zaire	29.6	5.0	2,345.4	12.6	2.1

*mid-1980 population in millions

**mid-1980 GNP in billions of 1980 dollars stations will be in the 5- to 13-meter diameter category. Present plans in Argentina would be an initial number of fifteen 5-meter stations in 1981-1982, growing to twenty-five 5-meter stations by 1989. Stations as small as 3-meter diameter are also considered.

Bolivia

Bolivia is considering the use of an INTELSAT transponder for domestic communications. Their tentative plans consist of the use of 1/4 of the transponder with an 11-meter central station and with two to three 8-meter remote stations. These are very initial plans, and once the system is implemented it is certain that the number of earth stations will be increased.

Brazil

Brazil is presently leasing two global beam transponders and 1/2 of a hemispheric beam transponder. Brazil is planning to expand its system in the future. The system is presently exclusively FDM/FM telephony and FM television but expansion to SCPC is very likely.

In 1975 and 1976 when Brazil still actively planned its own dedicated space segment, it was expected the initial system would consist of approximately 12 backbone earth stations operating in a trunk traffic mode with FM or TDMA carriers and an additional 30 to 40 earth stations operating in an SCPC mode. All earth stations were to use 10-meter diameter antennas because of a prototype design of this type of antenna that had been developed by the Brazilian state company Avibras.

Chile

At present, Chile leases 1/4 of an INTELSAT transponder with two operating stations. For additional antennas and additional applications, SCPC will be the most promising technique since link requirements will generally be small.

Chile's main motivation is to provide domestic satellite services to the province of Magallanes in the south. The remainder of the country is served by a fairly extensive microwave backbone network which stretches from Arica in the north to Castro in the south. This 3,200 kilometer backbone provides services such as telephone and television.

The southern part of Chile is extremely rugged and extends about 1,200 kilometers from Castro to Cape Horn. The region contains many islands, mountains, and ice fields. The province has approximately 100,000 inhabitants primarily in the population centers of Punta Arenas, Puerto Natales, and Porvenir. Satellite techniques are ideally suited to this region since extending the terrestrial microwave system further south would require numerous microwave hops from island to island which would be expensive to install and nearly impossible to maintain.

Besides the presently planned stations, we expect the satellite network to grow as experience is gained and other cities will eventually be brought into the network. Because of the mature terrestrial network existing today we expect the earth station growth to be moderate.

Colombia

Colombia at present leases space segment from INTELSAT. There are three earth stations with 30-meter diameter. By 1982, a total of 8 trunking high capacity stations and 15 SCPC stations of less than 10-meters in size are planned.

The topography of Columbia can be divided into two categories. The west, where the vast majority of the population (98 percent) lives, is characterized by mountains. Much of the remaining portion of the country, to the east of the Andes is very sparsely populated. The eastern region is characterized by plains, virgin forests, and the river basins of the Amazon and Orinoco Rivers. Most transportation in the east is by air since the road network is not extensive and hard to maintain.

Provision of telecommunication services to the eastern region via microwave is not feasible because of the vast distances between the existing microwave facilities and the major eastern population centers. The present microwave system provides service among the western cities.

The Colombian government has been exploring the possibility of launching its own satellite. Such a development will likely affect the growth of earth stations dramatically. The satellite system designated SATCOL has an orbital arc position applied for and its introduction will likely encourage satellite systems on a regional basis.

In this regard, an Andean regional system has long been planned and it would include the Andean nations of Bolivia, Ecuador, Peru, and Venezuela in addition to Columbia. The SATCOL system could well be a predecessor to the Andean system if Columbia chooses to lease spare transponders and if SATCOL provides reasonable coverage to any of the Andean nations.

Mexico

Mexico has recently announced plans for satellites for domestic communications. Mexico is not sufficiently covered by any of the INTELSAT satellites, the Mexicans are therefore leasing space through INTELSAT on a U.S. satellite. When space segment is made available that provides adequate coverage to all of Mexico, we expect that Mexico will become one of the major users of domestic satellite communications.

There are numerous cities in Mexico with large populations. Mexico could be properly covered as early as 1983 by various satellite systems. Chief among these are a specialized INTELSAT satellite which provides capacity for domestic use and perhaps a U.S. domestic satellite with a spot coverage of Mexico. In later years a Latin American regional satellite could cover Mexico. Because of the uncertainty of adequate coverage of Mexico, this market may not develop very quickly.

Peru

Peru has four Standard B domestic stations with a total of 188 circuits. TV transmission is also used. Peru has not announced any plans for immediate expansion. Peru's relatively large physical extent, low population density, and rugged terrain make it ideally suitable for the later introduction of a large number of earth stations.

The present telecommunications network in Peru provides coverage primarily of the coastal region. This arid and sandy region is separated for the remaining population centers of the jungle by the Andes Mountains. The eastern region of this country consists of dense tropical forests and lowlands surrounding the Amazon basin. The eastern region is characterized by high humidity and abundant rain of over 3 meters per year in some areas.

Venezuela

At this time Venezuela has not announced any plans to use satellites to meet its communications needs. Venezuela is an extensive country of nearly 1 million square kilometers and wide ranging topology. Primarily because of the oil fields located near Maracaibo the GNP per capita has been steadily rising. Like many tropical countries access to interior areas is difficult and although a microwave communications system exists, satellite communications would allow rapid expansion of facilities at reasonable cost.

8.1.4 Africa

Since 1975 when domestic service via INTELSAT was inaugurated with the lease of spare transponder capacity to Algeria, Nigeria, Sudan, Zaire and Uganda have leased a total of six transponders from INTELSAT for use with over 50 earth stations. Use of INTELSAT space segment has allowed expansion of existing facilities for very low initial outlays, and Africa will continue to demand satellite services as experience grows with these already operating systems.

Nigeria

Nigeria is presently leasing three transponders from INTELSAT, and continues to be interested in a separate domestic and regional satellite system for itself and West Africa. Systems planning at this time considers 16 additional earth stations, in addition to the 19 earth stations now used in the Nigerian lease with INTELSAT. The service provided would be 100 voice and data SCPC shannels in 1982 and would rise to 300 channels in 1988 plus two TV channels throughout this period.

Sudan

Sudan is presently leasing capacity from INTELSAT for its domestic applications. One full global beam transponder is being used for TV transmission and for SCPC. The system is designed to carry TV, telephony, Telex and telegraphy traffic among 13 remote stations and a master station at Sudan's capitol Khartoum. Single channel per carrier companded FM is used for telephony. Initially the Sudosat system will provide SCPC in a star network, and eventually the network will operate as a mesh network in the demand-assignment multiple access mode. There are 14 earth stations presently operating in Sudosat.

Zaire

Zaire provides domestic satellite communications by means of INTELSAT transponder lease. A global beam transponder is being used to carry TV, video FM broadcast, SCPC companded FM and Telex transmissions. The system is designed for 84 SCPC shannels. Thirteen earth stations are being used. They have a G/T of 44.3 dB/K, and the antennas have 14.5-meter diameters.

Other African Opportunities

Besides the African nations already listed, there are many other countries which are candidates for satellite communications. Because of the low population density in most of Africa and the wide range of topologies of most nations, small earth stations will, in many cases, satisfy their needs. In addition, the costs of terrestrial microwave systems are often prohibitive, while satellite systems which lease space segment are much more cost-effective in most instances. All of these factors are likely to influence the growth of earth station markets in Africa.

8.1.5 Middle East

The Middle East is seeing an era of rapid economic growth spurred on by the oil reserves in many of its nations. Generally speaking the Middle East can be considered to comprise the Arab speaking countries. Two of these countries were covered under Africa, i.e., Mauritania and Sudan. The League of Arab States is actively planning a regional satellite system to become operational before the mid-1980's. The Arabsat system may contain over 2,000 channels initially distributed among the major Arab cities. An initial complement of 40 earth stations of the Standard B type (G/T = 31.7 dB/K) is probably conservative and many smaller earth stations designed for community TV reception at 2.5 GHz are envisioned. Although the Arabsat system has been described as a regional system to be used for communications between Arab states, it is not inconceivable that domestic services will one day be provided via Arabsat if capacity permits.

Four of the Arab states are presently leasing INTELSAT space segment for domestic communications: Algeria, Sudan, Saudi Arabia, and Oman; two are undergoing approval by INTELSAT to space segment lease: Egypt and Iraq; and two have made inquiries concerning space segment lease: Mauritania and Morocco. It is clear then that satellite communications are favorably regarded in the Middle East.

Algeria

Algeria was the first country to lease space capacity from INTELSAT for domestic communications. Since the l 'e began in late 1974 the system has grown to 15 earth stations accessing one transponder. SCPC/FM is used throughout with about 140 channels total. Demand assignment is not presently utilized, but as the system grows it will likely become a necessity. The 15 earth stations presently operating cover cities scattered over the whole of Algeria. The system allows desert cities to communicate with the coastal population centers and growth beyond the present configuration is likely to be encouraged by the Arabsat system.

Egypt

Egypt's lease with INTELSAT began early in 1980. It is rather unique in that it serves a communications network between Cairo and Egypt's embassies around the world.

Although there are no plans for a more conventional domestic system at this time there may be some opportunities for expansion of this private network to other embassies in the future and we expect that expansion to cover Egyptian population centers not now adequately covered by microwave is inevitable.

Saudi Arabia

Saudi Arabia presently leases 2 1/4 transponders from INTELSAT to link 15 earth stations distributed throughout the country. Based on Saudi Arabia's major participation in Arabsat and its high GNP/capita and GNP/capita growth, it can be expected to be a major user of satellite communications in the Middle East. Large expenditures have been made recently to develop a more extensive microwave system within Saudi Arabia. Ground transportation is still poor between the large cities and as economic growth continues communications between these cities will be increasingly important.

Riyadh is experiencing a period of rapid growth at this time while communications are poor. As many corporations set up offices within Saudi Arabia the demand for better communications will be crucial to continued economic growth. The easiest way to improve this situation, especially where a domestic satellite system already exists is to provide thin-route stations at many points throughout the cities perhaps as roof top stations and we therefore see a proliferation of such stations in Saudi Arabia.

Arabsat

As mentioned previously, Arabsat will serve some 21 Arab states. Initial plans call for 2,000 SCPC channels among 40 stations linking the major Arab cities. These stations will be of the Standard B variety and will also handle trunking traffic probably FM and network TV.

8.1.6 Asian Opportunities

India

India has implemented a domestic satellite network linking five remote areas to the national network at New Delhi and Madras. All the remote stations have poor communication facilities at present. In the case of Leh, located in an isolated valley in the Himalayas, there was no connection with the national network prior to initiating satellite services.

There are many areas of this type within India and an Indian domestic satellite system, Insat, is due to become operational in 1982. This system will link the country with thin-route communications facilities at C-band and TV network operating at 2.5 GHz.

Indonesia

Since mid-1976 Indonesia has been providing domestic satellite communications to its many islands via the Hughes Aircraft Company—built Palapa satellite. The system consists of two in-orbit satellites, (one is a spare), each with 12 transponders at C-band. There are presently 40 operating earth stations: a master control station, 18 main traffic stations and 21 light traffic stations. In addition, there are ten 5-meter stations linking remote towns to the system.

At this time, a follow-on system is being planned, designated Palapa B, and it is a cooperative venture of the Asean countries of Indonesia, Malaysia, The Philippines, Singapore, and Thailand. The Palapa B will most likely become operational around 1983. Based on the present expansion within Indonesia and its

C-3

commitment to satellite communications, we expect the network to continue growing through the lifetime of the current Palapa satellite series and into the Palapa B era.

Peoples Republic of China

The Peoples Republic of China has recently been discussing plans to implement a domestic satellite system. Under proposals being discussed, COMSAT would provide technical assistance to China in building a network of satellites and earth stations. Under such an arrangement between the U.S. and the Chinese government, it is expected that a great deal of equipment would be purchased in the United States. Some technology transfer and perhaps local manufacture may be required. In any case the market is bound to be large considering the population and the wide range of topology of China.

In addition, China has made inquiries of INTELSAT concerning leased satellite capacity. Two systems are being discussed, one for a TV distribution system to remote areas and one which will link remote areas to Peking by thin-route SCPC telephony using a total of 200 channels. Peking would have a 15-meter station with 10 remote stations of 5-meter diameter initially.

Pakistan

Pakistan has recently announced plans that it intends to lease INTELSAT space segment beginning around 1985 for telephony, Telex, data and TV distribution. The non-TV services would require about 240 channels initially and are projected to grow at a 14 percent annual rate thereafter. The earth station network would initially be six stations expanding to 20 in 1989.

Philippines

The Philippines, like Indonesia, consist of several large islands which are well suited to satellite service. The Filipinos have been leasing capacity on Palapa, and are involved in the Palapa B system.

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Thailand

Thailand is involved with Palapa B discussions. Unlike Indonesia and the Philippines, Thailand does not consist of many islands but nevertheless covers some 500,000 km^2, nearly twice that of the Philippines.

8.1.7 Other Areas

Australia

Australia has contracted with COMSAT for the design of a domestic system. There will be up to 50 receive-only terminals. Australia has conducted extensive studies concerning its domestic satellite communication system and the plans are now before the government. It is very probable that Australia may implement a domestic system, to some extent for political reasons, to provide communications services to the scattered population throughout the interior of the country where terrestrial communications do not exist and are not practical. Such communications would be entirely thin-route bush type SCPC stations. Hundreds of terminals are foreseen.

It is probable that Australia will initiate a pilot system for SCPC transmission before going ahead with its own dedicated satellite system. These SCPC stations would be of the simple, low-cost nonexpandable type. When and if an Australian satellite system is procured, it is possible that service may also be provided to New Zealand.

New Zealand

The entry of New Zealand into the satellite earth station market will probably revolve around Australia's decisions. The most likely scenario for New Zealand is sharing of space capacity with Australia.

South Africa

As of now, South Africa has not announced plans to use satellites for domestic communications' purposes. It could be served by an INTELSAT lease or perhaps an African regional system. South Africa is different from other African nations in that its GNP/capita is significantly higher and to a large extent is more developed.

Based on our model of telecommunications demand, the total number of earth stations projected for South Africa is nearly 100 in 1990. However, based on the current state of politics in South Africa, it is unlikely that there will be much interest in satellite communications. Even if there were to be an orderly transition of government, it seems unlikely that a satellite system could develop in the near future and certainly not within the next five years. Accordingly, we do not foresee a viable market in South Africa. If South Africa could have control over its space segment either through individual or joint ownership, it is conceivable that the market could develop before 1990. However, the leasing of space segment may not be considered viable since just as sanctions have been imposed on South Africa, access to space segment can be denied.

Oceania (South Pacific Islands)

Oceania is the collection of South Pacific islands including Fiji, Samoa, and French Polynesia. We have forecast very little demand for telecommunications' services in this area based on the traffic model.

The widespread geography of this area makes the use of satellites ideal especially in light of the now minimal communications' facilities. Some traffic to U.S. installations of the Department of the Interior has used the ATS satellite. This could develop into a market for small earth stations, but its size is difficult to estimate at this time.

Table 8-2

Major Small Pacific Islands and

Traffic Forecast (36 MHz Transponders)

	Area (km^2)	1980 Population (Thousands)	1980 GNP in Millions of 1980 U.S. Dollars	1980 GNP/Capita	1980 GNP Density (10^3) U.S. $/$km^2$)
American Samoa	197	33	320	9,830	1,624.4
Fiji	18,272	621	1,140	1,840	62.4
French Polynesia	3,999	158	1,020	6,480	255.1
Guam	549	97	910	9,350	1,657.6
Kiribati	886	58	50	920	56.4
New Caledonia	19,058	160	890	5,580	46.7
New Hebrides	14,763	109	70	670	4.7
Solomon Islands	28,446	228	120	530	4.2
Tonga	699	97	50	520	71.5
Trust Terr. of the Pacific Islands	1,779	141	212	1,500	119.2
Western Samoa	2,842	161	100	590	35.2
			Traffic Requirements		
Year	1985	1990	1995	2000	2005
Total Number of Transponders	0.6	1.2	1.8	2.4	3.0

8.2 Estimate of the Potential Spacecraft Market

We have based the estimate of the potential spacecraft market on the systems scenarios developed earlier in this report. This implies that the total spacecraft market can be easily deduced from the launch schedules shown previously. The overall market developed in this manner is shown in Table 8-3. Year-by-year values are not shown to avoid the impression of unwarranted precision.

Given the total market, it is then necessary to estimate that portion which will be "captured" by U.S. industry. In so doing, we have relied on our qualitative analysis of the market environment in the various world regions, as presented earlier in this section. The estimated "capture percentages" are shown in Table 8-4. The exact figures are, of course, open to argument, and depending on one's point of view, some of them would be adjusted upward or downward. We have used our best judgment, but have included the earlier discussions in order to allow some insight into the judgment process.

Table 8-3
Total 30/20 Transponder Market
Low Traffic Model

	1990	1992	1996	2000
Canada	27	37	50	63
Western Europe	450	574	815	1,082
Japan	173	209	267	313
Latin America	110	156	282	445
Middle East	23	33	66	140
China	9	13	28	56
Asia	67	95	181	337
Africa	19	24	34	45
Others	10	13	21	29

Table 8-4

Capture Percentages for

30/20 Space Segment

North America	90% (including U.S.A.)
Canada	90
Western Europe	0
Japan	0
Latin America	70
Middle East	70
China	70
Asia	50
Africa	70
Others	90

Based on the capture percentages shown above, we have computed the number of 30/20 GHz transponders that will be furnished by U.S. industry during the period 1990 to 2000. This is shown in Table 8-5. Using the spacecraft costs developed in Section 6, the total value of this market is approximately 450 million 1980 dollars.

Table 8-5

Transponders Sold By U.S. Industry

Low Traffic Model

	1990-1992	1992-1996	1996-2000
Canada	33	12	12
Western Europe	0	0	0
Japan	0	0	0
Latin America	109	88	114
Middle East	23	23	52
China	9	11	20
Asia	48	43	78
Africa	17	7	8
Others	12	7	2
Total	251	191	291

8.3 Estimates of the Potential Earth Station Market

The amount of traffic handled by an earth station can vary over a wide range. We have examined data for some existing systems, and probable values for planned systems, and have concluded that the most readily applicable method of sizing the earth station market is to base the number of earth stations on the traffic volume, using some fixed proportional factor. Different correlation factors have been developed for Japan and Western Europe and for North America. These factors are lower than those used for the remaining regions because:

1. The existence of mature terrestrial communications facilities in these regions makes satellite communications less necessary. Furthermore, regions with heavy terrestrial networks cannot as easily tolerate a proliferation of earth stations due to interference consideration. A good example of this is West Germany, where earth station sites have been limited due to interference conditions.

2. Regions with high GNP density, i.e., GNP per km^2, have more need for short communications links and hence are more likely to use terrestrial communications and to continue to expand on existing facilities.

The following correlation factors are averages over the 20-year study period. No attempt has been made to approximate a function of time to the correlation.

Earth Station Correlation Factors (earth stations per transponder)

Japan and Western Europe	9.0
North America	16.0
All Others	19.0

These correlations factors represent system averages. A larger number of earth stations per transponder would result from a pure data transmission system, but the number of transponders required would be relatively small. On the other extreme, a high capacity trunking system for telephony transmission will require fewer earth stations per transponder than those estimated for the systems average.

Using these correlation factors and the data produced by the traffic model, we have calculated the total market for 30/20 GHz earth stations, including multifrequency stations. This is shown in Table 8-6.

Next, in a manner similar to that used for the spacecraft market, we have estimated the capture percentages for U.S. industry for the earth station market. These are generally lower than for the spacecraft market, primarily because the earth station components are already manufactured by a large number of firms worldwide. The capture percentages are shown in Table 8-7. Using these, we have derived the market which is likely to be sold by U.S. industry; this is shown in Table 8-8. Total dollar value is difficult to estimate due to the varying types and capacities of the earth stations, and the use of multi-frequency stations, but could be in the range of 450 to 2,700 millions of 1980 dollars.

Table 8-6

Total 30/20 Earth Station Market

Low Traffic Model

	1990	1992	1996	2000
Canada	432	592	800	1,008
Western Europe	4,050	5,166	7,335	9,738
Japan	1,557	1,881	2,403	2,817
Latin America	2,090	2,964	5,358	8,455
Middle East	437	627	1,254	2,660
China	171	247	532	1,064
Asia	1,273	1,805	3,439	6,403
Africa	361	456	646	855
Others	190	247	399	551

Table 8-7

U.S. Industry Capture Percentage for 30/20 Earth Stations

North America	70% (including U.S.)
Canada	20
Western Europe	20
Japan	5
Latin America	50
Middle East	50
China	25
Asia	30
Africa	50
Others	30

Table 8-8

30/20 Earth Stations Sold By U.S. Industry

Low Traffic Model

	1990-1992	1992-1996	1996-2000
Canada	120	40	40
Western Europe	1,030	435	480
Japan	95	25	20
Latin America	1,480	1,200	1,550
Middle East	315	315	700
China	60	70	135
Asia	540	490	890
Africa	230	95	105
Others	75	45	45

8.4 Market Estimates-High Traffic Model

In an exactly corresponding manner to that used for the preceding computations, we have estimated the markets for the high traffic model. The figures are naturally substantially higher. The space segment markets are shown in Tables 8-9 and 8-10. Capture percentages were assumed to be the same as for the low traffic model. The market is about 900 million 1980 dollars for U.S. industry.

Tables 8-11 and 8-12 present the data for the earth segment markets The total U.S. industry share will range from about 1.7 billion to 8.4 billion 1980 dollars, depending on the mix of ground equipment and earth station sizes.

Table 8-9
Total Market for 30/20 GHz Transponders
High Traffic Model

	1990	1992	1996	2000
North America	3,016	4,630	6,649	7,704
Western Europe	569	1,056	4,530	10,502
Japan	213	376	1,575	3,661
Latin America	111	158	287	483
Middle East	24	35	76	245
China	9	14	30	60
Asia	68	96	183	342
Africa	19	24	34	45
Others	10	13	22	35

Table 8-10

Transponders Furnished By U.S. Industry

High Traffic Model

	1990	1991-1992	1993-1996	1997-2000
Canada	270	145	180	95
Latin America	75	30	90	140
Middle East	15	8	25	120
China	6	3	10	20
Asia	35	15	40	80
Africa	13	3	7	8
Others	7	2	6	9

Table 8-11

Total 30/20 GHz Earth Station Market

High Traffic Model

(Numbers of Earth Stations)

	1990-1992	1993-1996	1997-2000
Canada	7,400	3,200	1,700
Western Europe	9,500	31,000	53,000
Japan	3,300	10,000	18,000
Latin America	3,000	2,400	3,700
Middle East	650	780	3,200
China	270	300	570
Asia	1,800	1,600	3,000
Africa	450	190	200
Others	250	170	250

Table 8-12

30/20 Earth Stations Furnished by U.S. Industry

High Traffic Model

	1990-1992	1993-1996	1997-2000
Canada	1,400	640	340
Western Europe	1,900	6,200	10,600
Japan	160	500	900
Latin America	1,500	1,200	1,850
Middle East	300	390	1,600
China	70	75	140
Asia	540	480	900
Africa	220	100	100
Others	75	50	75

8.5 Market Summary

Based on our judgment of the market potential, the total U.S. opportunity for 30/20 GHz equipment for 1990 to 2000 is as shown in Table 8-13. Significant markets exist for U.S. industry in Europe and Latin America.

Market estimates of this type are subject to considerable variability due to the newness of the 30/20 GHz service and the political uncertainties involved with sales to foreign telecommunications operators.

Table 8-13

Market Summary for 30/20 GHz Systems

		High Traffic	Low Traffic
Total Space Segment			
Sales -	Transponders	1,450	730
	1980 Dollars	$900 Million	$450 Million
Total Earth Segment			
Sales -	Earth Stations	32,000	10,600
	1980 Dollars	$1.7 - $8.4 Billion	$0.6 - $2.7 Billion
Total Market for U.S. Industry			
	1980 Dollars	$2.6 - $9.3 Billion	$1.0 - $3.1 Billion

SECTION 9

LAUNCH REQUIREMENTS FOR 30/20 GHz SATELLITES

Based on our assessment of advanced 30/20 GHz satellites, we have concluded that the majority of them will be too large to be conveniently accomodated on conventional launchers. This implies that they are all prime candidates for the STS (Shuttle). On this assumption, Table 9-1 shows the number of full Shuttle launches needed to place these satellites in orbit. Each of the advanced satellites was assumed to occupy the Shuttle bay along with its transfer vehicle, and to fill the bay completely.

We have not included the effects of the market capture in estimating the Shuttle requirements. The main reason for this is the absence of a competing transportation system. Thus, even satellites constructed wholly or partially in another country are considered to require the US built Shuttle.

Table 9-1

Shuttle Requirements

Year	Low Traffic	High Traffic
1990	5	7
1991	2	3
1992	1	6
1993	2	7
1994	1	7
1995	2	10
1996	6	16
1997	2	8
1998	1	3
1999	5	10
2000	0	2
TOTAL	27	79

SECTION 10
IMPLICATIONS OF SYSTEM AVAILABILITY

One of the factors affecting user acceptance of a service offering is the availability associated with the service. To some extent, a decrease in availability can be offset by a decrease in price; how large a decrease in price is a subject for much discussion. However, there will also be some services for which the reduced availability is unacceptable at any price. This section considers the implications of the availability of 30/20 GHz satellite links on the market acceptance of those links.

10.1 Link Margin Considerations

It is well known that rain attenuation is a severe problem at 30/20 GHz. Depending on the model used, attenuations of over 100 dB are predicted for 0.01 percent of the time for some climates. By contrast, the maximum reasonable margin in a satellite link is about 20 dB. It is usual to propose that either space diversity or frequency diversity be used to combat these excessive fades. Both these approaches involve considerable extra expense.

In order to select regions of the world where the use of 30/20 GHz will not encounter too much rain attenuation, we have made use of the climate map developed for the CCIR. (International Radio Consultative Committee) This map is shown in Figure 10-1, taken from Reference 11. Using the techniques developed in Reference 11, we have computed estimates of the link margins needed at 30 and 20 GHz. These margins are shown in Tables 10-1 and 10-2.

Using a 20 dB maximum margin as a guideline, we see that only Zones E, G, and H are unsuitable for availabilities of 99.9 percent. However, no zone is suitable, without diversity, for availabilities of 99.99 percent. Thus, only the highest traffic reliability would be excluded if a 20 dB margin were used.

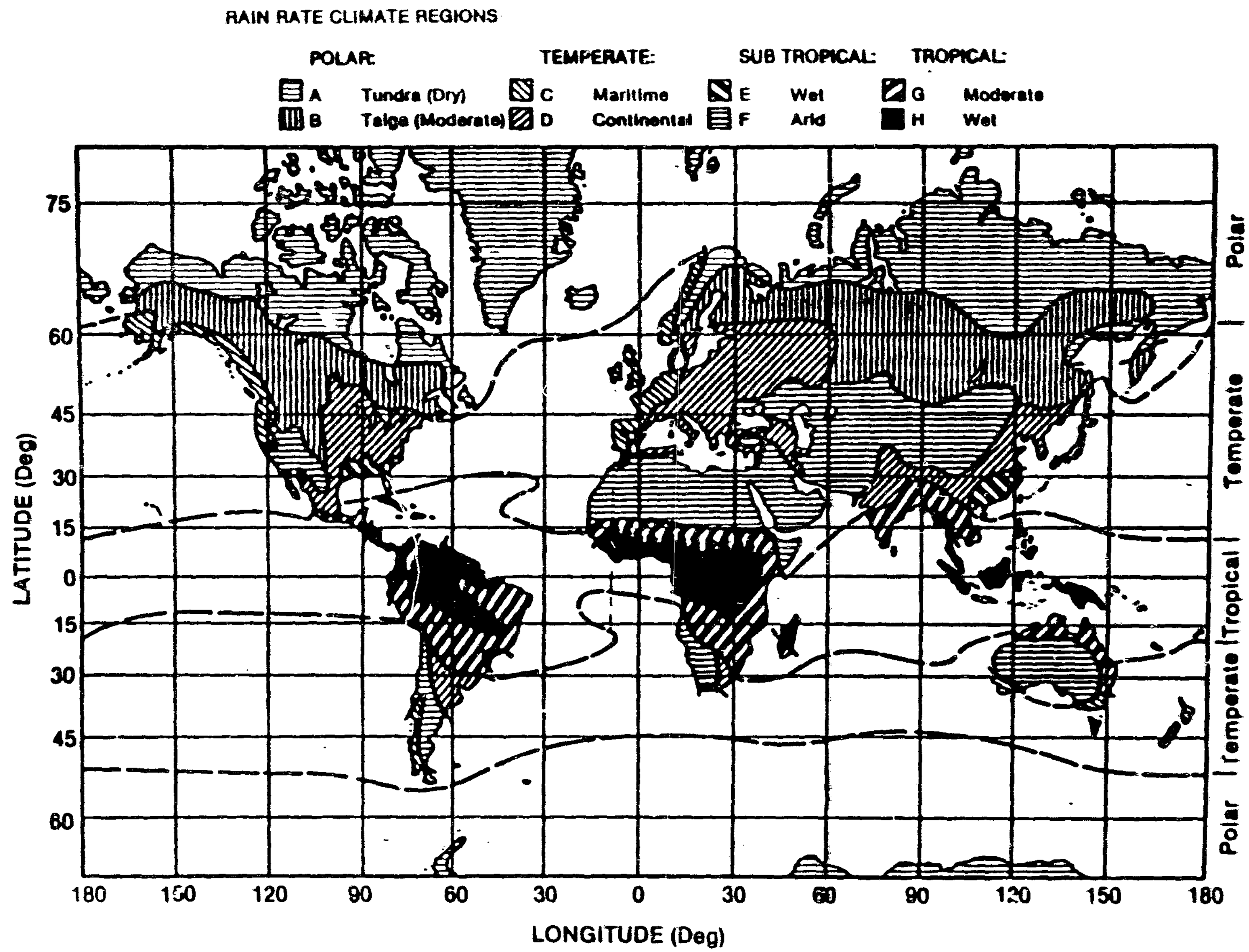


Figure 10-1

GLOBAL RAIN RATE CLIMATE REGIONS FOR THE CONTINENTAL AREAS

Table 10-1

Precipitation Margins at 20 GHz

(dB)

Climate Zone	Outages 0.01%	0.05%	0.1%	0.5%	1.0%
A	7	3	2	0	0
B	13	5	3	1	0
C	20	8	5	1	1
D	32	14	9	3	1
E	72	42	30	9	5
F	22	9	6	3	2
G	53	29	21	8	4
H	99	58	41	13	7

Table 10-2

Precipitation Margins at 30 GHz

(dB)

Climate Zone	Outages 0.01%	0.05%	0.1%	0.5%	1.0%
A	16	6	4	1	0
B	28	12	8	2	1
C	45	17	11	3	2
D	71	31	21	6	3
E	157	92	66	20	11
F	49	20	14	7	5
G	118	65	46	18	10
H	215	127	91	29	16

10.2 Space Diversity

Space diversity has been used for a number of years in terrestrial microwave systems. In such systems it is generally used to combat degradations due to ducting, multipath, and other phenomena characteristic of paths near and parallel to the earth's surface. The use of space (or "separation") diversity with satellite links is primarily intended to combat high attenuation due to intense precipitation. The basis on which the method rests is the observation that regions of intense rainfall are generally limited in geographic extent. This is true for temperate climates. The physical separation of the satellite earth stations then serves to reduce the correlation of such heavy rainfall at the sites. Some simple means of choosing the better of the sites at any instant then completes the diversity system.

A useful tool in the study of diversity systems is the concept of "diversity gain", as developed by D. Hodge of Ohio State University. The derivation of diversity gain is best illustrated by a figure. In Figure 10-2 the two curves to the right are the individual cumulative time distributions of attenuation for the two sites operating individually. The single curve to the left is the cumulative time distribution for diversity operation; that is, the better of the two stations at any instant. As shown, the distance between the curves for the same percentage time is the diversity gain in decibels.

Hodge of Ohio State University has determined an empirical relationship between the separation distance, fade depth and diversity gain based on measurements made using ATS-5. These measurements were taken at 15.3 GHz. This relation is as follows:

$$G = a(1-e^{-bD})$$

where

G	=	Diversity gain in dB
D	=	The site separation distance in km
a	=	$A-3.6(1-e^{-0.24A})$
A	=	The single site attenuation in dB
b	=	$0.46(1-e^{-0.26A})$

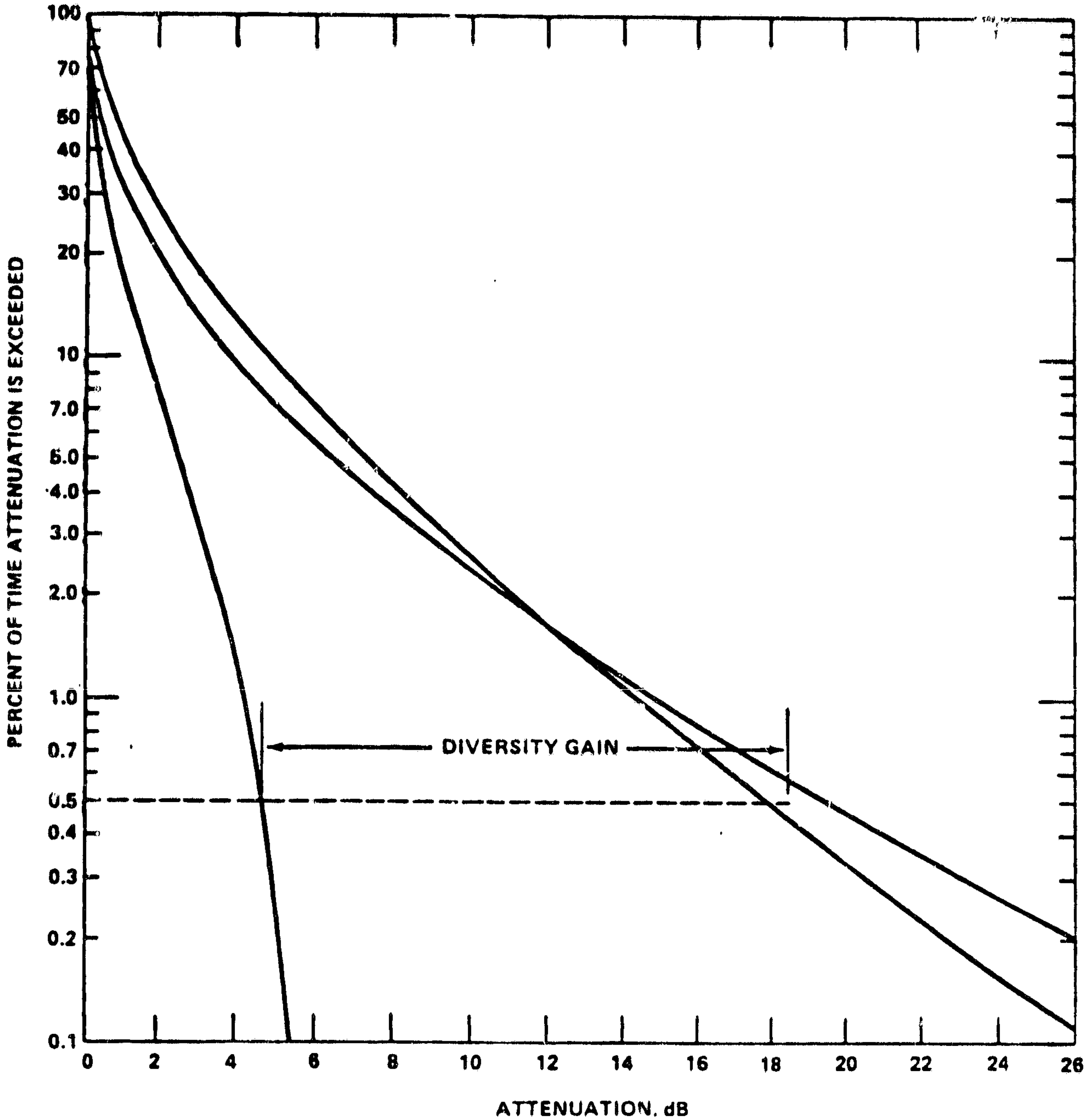


Figure 10-2

DIVERSITY GAIN CALCULATION

Data taken using ATS-6 indicated that the diversity gain was not strongly dependent on frequency. The optimum separation for the diversity sites seems to be about 8 to 10 km. This function is shown in Figure 10-3.

10.3 Fade Duration and Annual Distribution

The duration of typical fades (outages) and their distribution throughout the year have an impact on the acceptability of the communications link. Typical data available from experiments indicate that fade durations of 10 minutes are not uncommon in the continental climates, for fades of 10 dB at 30 GHz. It is quite difficult to typify the data; therefore, representative experimental results are shown in Figures 10-4 through 10-7. At the 10 dB level at 30 GHz, the majority of fades are less than five minutes in duration.

Another consideration is the distribution of outages throughout the year. The worst month can easily be five to ten times as bad as the annual average. Data from Reference 13 are shown in Figure 10-8. The original data were collected at 11.7 GHz using CTS. Distributions of monthly rainfall data are shown in Figures 10-9 and 10-10. These also illustrate the yearly variation, but the situation with peak rain rates is worse. This is due to the high incidence of thunderstorms during the summer months. It is these intense storms that produce the maximum rainfall rates.

10.4 Selection of Regions for 30/20 GHz Systems

One use for the availability criteria is to select likely areas for applications of 30/20 GHz systems. Using the world zone map and Tables 10-1 and 10-2, it is possible to determine regions which will yield a given availability with a given margin. For some regions, however, other factors may apply. For example, regions which currently do not enjoy good telecommunications may be more willing to accept lower availability than the developed nations, which are generally accustomed to a very good grade of service.

In some of the tropical areas, the occurrence of intense rainfall over a significant portion of the year will tend to produce very poor availability during

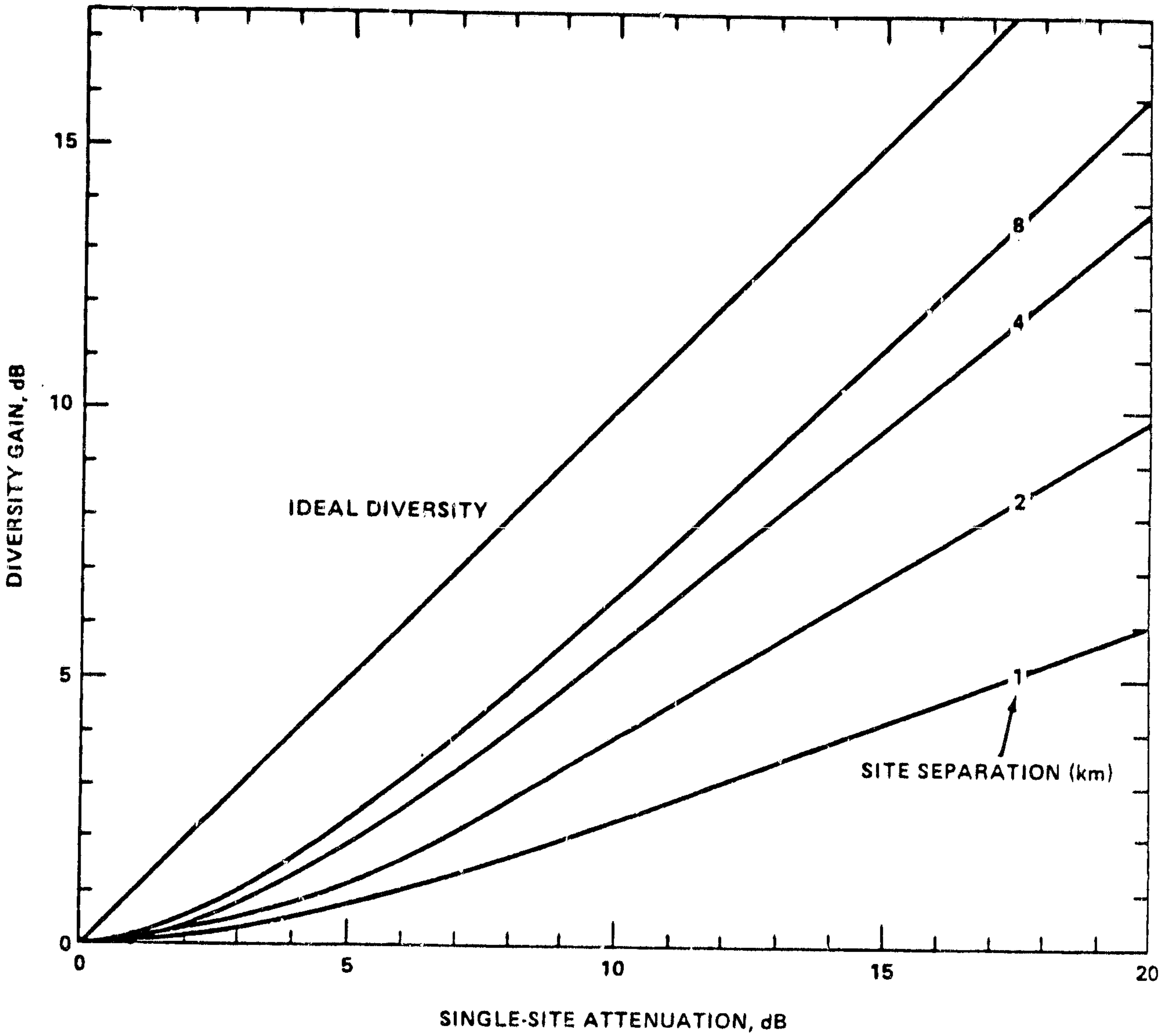


Figure 10-3

DIVERSITY GAIN FOR VARIOUS SEPARATIONS
(Hodge, 1976)

18.5 GHZ ATTENUATION MEASUREMENTS

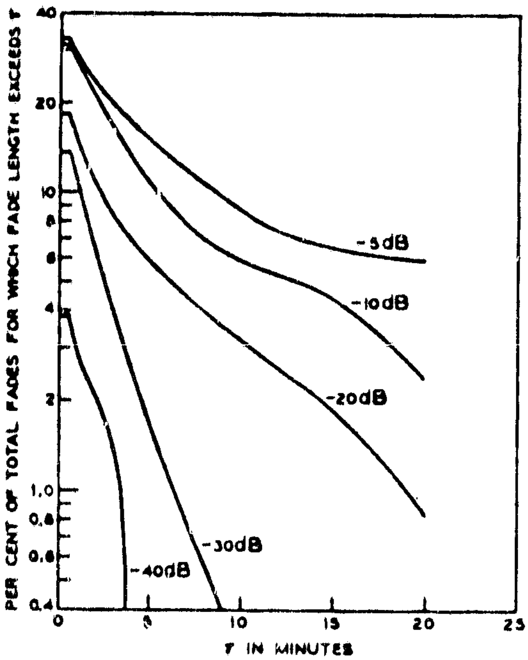


Figure 10-4

PERCENT OF TOTAL NUMBER OF FADES FOR WHICH LENGTH EXCEEDS THE ABSCISSA. BASED ON 17.8 HOURS OF RAIN DATA AND A TOTAL OF 182 FADES

Source: Reference 14

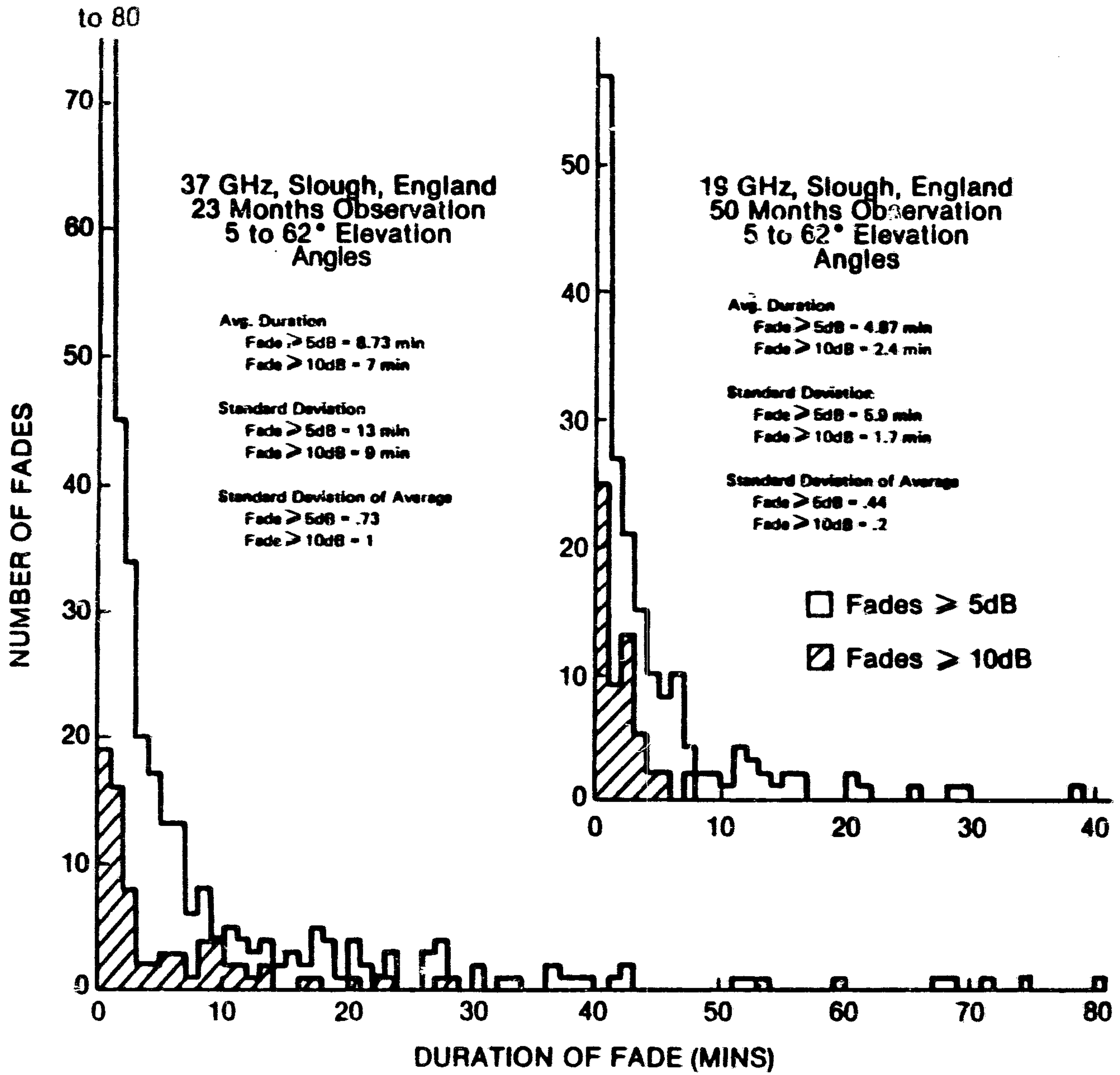


Figure 10-5

HISTOGRAMS OF FADES GREATER THAN 5 AND 10 dB AT 19 AND 37 GHZ

Source: Reference 11

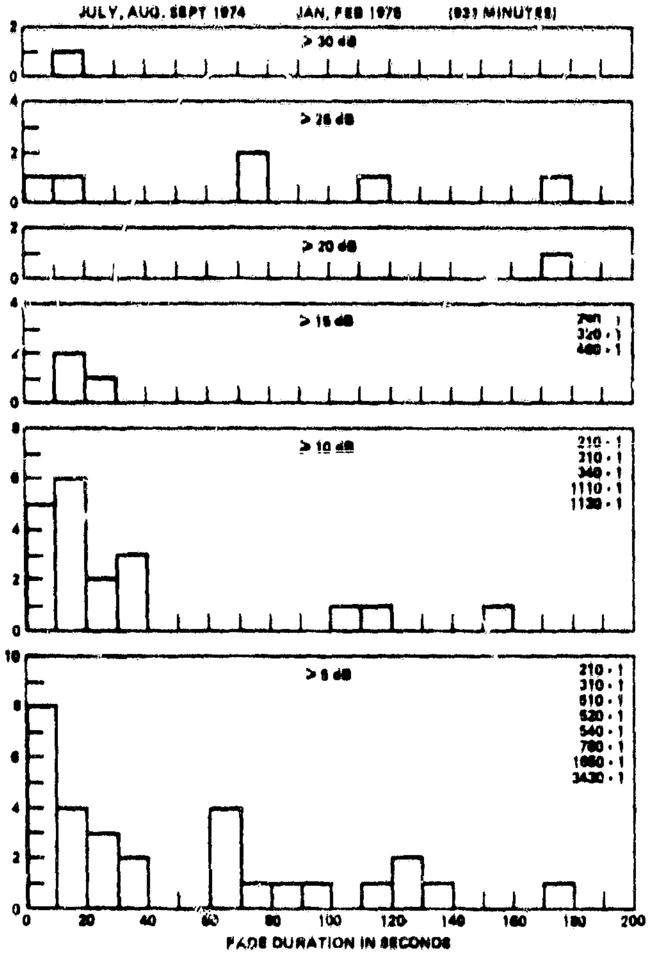


Figure 10-6

FADE DURATION HISTOGRAM FOR 30 GHZ AT ROSMAN, NORTH CAROLINA

Source: Reference 15

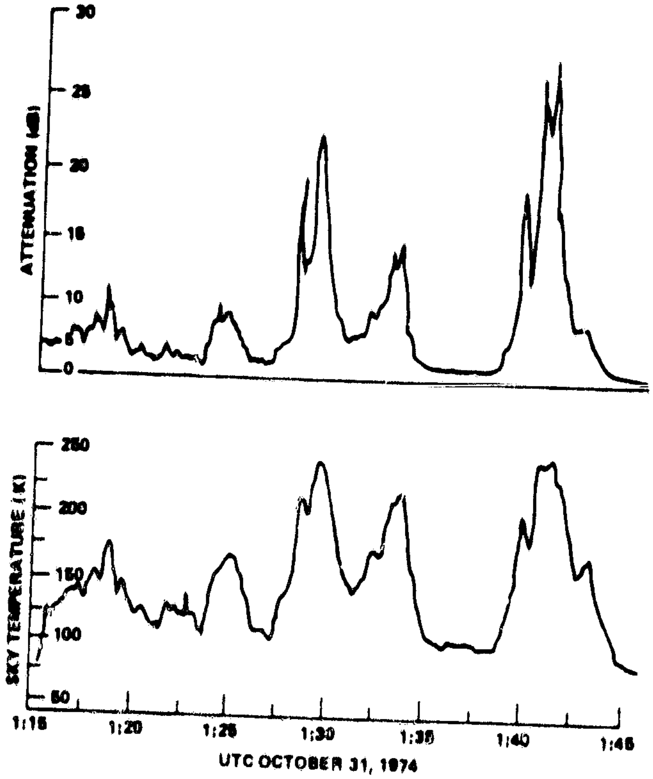
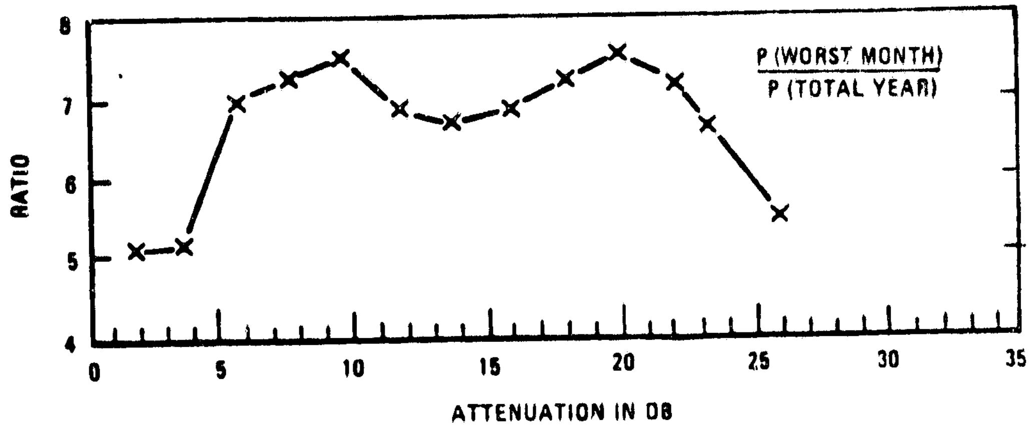


Figure 10-7

30 GHZ ATTENUATION AND 20 GHZ SKY TEMPERATURE

Source: Reference 15



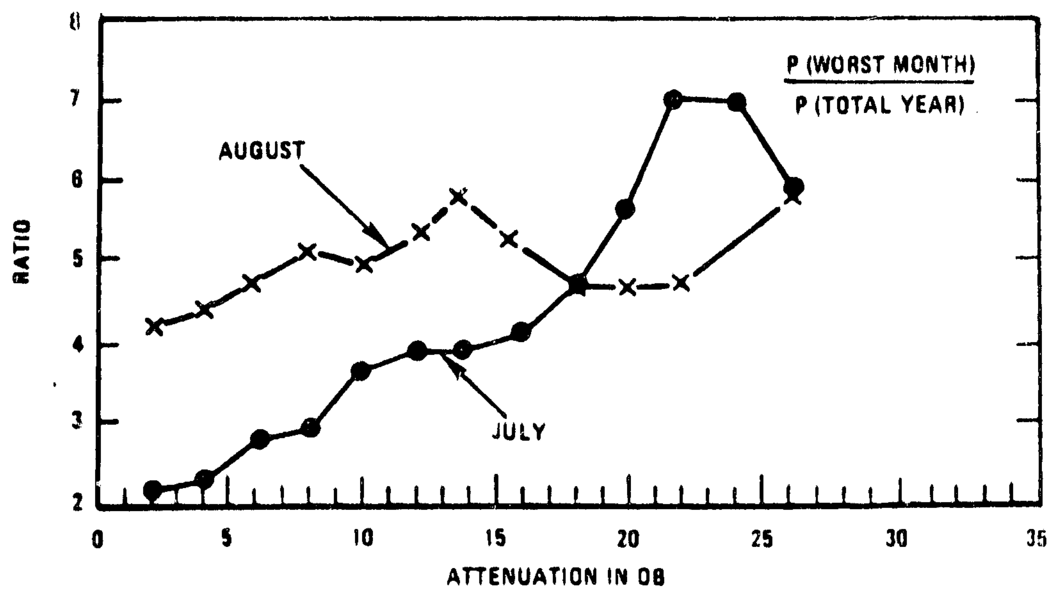


Figure 10-8

COMPARISON OF WORST MONTH AND
ANNUAL ATTENUATION STATISTICS FOR 1977

Source: Reference 13

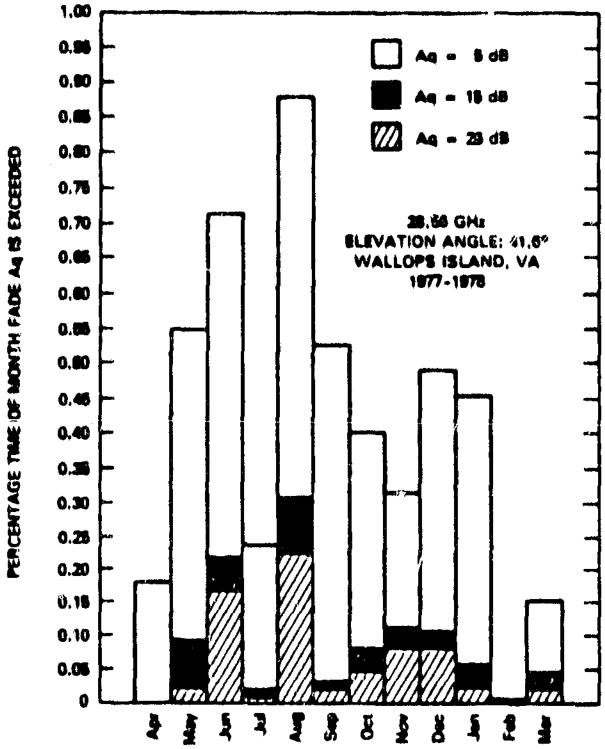
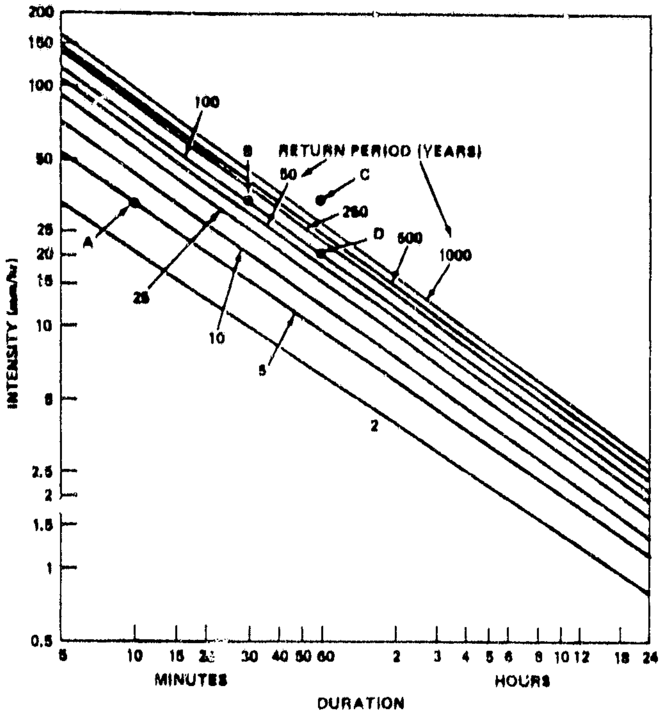


Figure 10-9

HISTOGRAM DENOTING PERCENTAGE TIMES FOR VARIOUS MONTHS THE FADES OF 5, 15, and 25 dB WERE EXCEEDED

Source: Reference 11



Note: Return period is the statistical interval between occurrences (rainfall) of a given value (intensity).

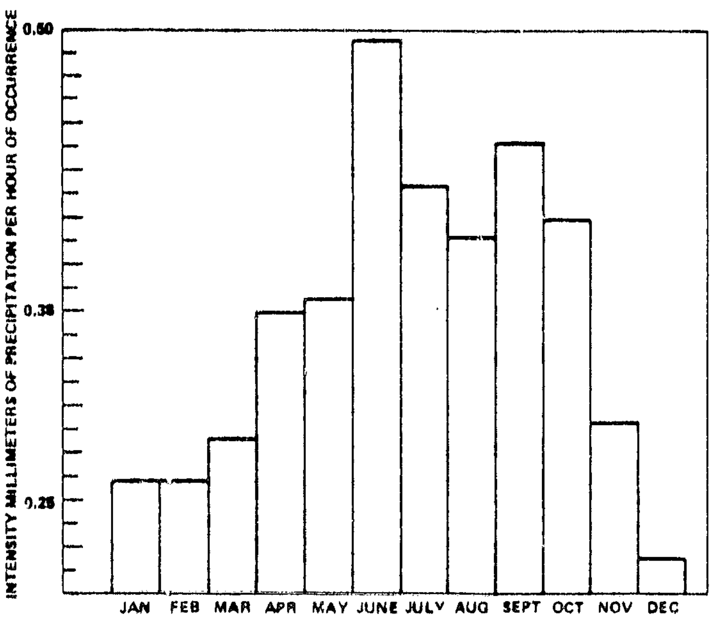


Figure 10-10

AVERAGE MONTHLY PRECIPITATION INTENSITY FACTORS BASED ON THE PERIOD FROM 1946 to 1970

Source: Reference 15

that season, if an annual weighted availability target is used for system design. Based on this premise, it is desirable to use a "worst-month" design in regions which experience monsoon type rainfall.

SECTION 11
SUMMARY AND CONCLUSIONS

This report has examined the interaction between foreign satellite communications and NASA's 30/20 GHz program. Several opportunities for US industry have been identified, and the benefits from these have been examined. In this section, we summarize the key results of previous sections and identify the conclusions to be drawn.

11.1 Demand Forecast

The demand for satellite communications capacity will continue to be strong, especially in the developed areas of the world. Total demand for the developed nations will reach 2800 transponders for telephony, 750 transponders for data communications, and 33000 transponders for video teleconferencing by the year 2000. This will account for 90 to 95 percent of the total world requirements at that time.

In the developing nations, satellite communications will play an increasingly important role as the embryonic communications systems of these countries expand. Due to the lack of an existing terrestrial network, satellites will capture a large portion of the total long distance traffic in the less developed countries.

11.2 Transition to Advanced Systems

In order to satisfy the rapidly increasing demand, satellite systems will have to evolve. Current systems make limited use of the available frequency space, and EIRP and antenna gains of the spacecraft are low. The continuation of systems with current capability will fail by a large margin to fulfill the requirements. We see the early 1990's as a watershed in this evolutionary process, with 30/20 GHz technology being used, augmented by advanced antenna designs, frequency re-use, and on-board switching to provide a large step increase in the capacity per satellite.

11.3 Systems Configurations

A variety of satellite systems were configured to satisfy the traffic demand forecast of three world model regions: Europe, Japan, and Africa. The number of systems considered was limited in order to maintain the task at a tractable level. Europe and Japan are fairly typical of the developed regions, and are difficult to cover due to the high traffic density. Africa was chosen as typical of the less developed areas.

Essentially, systems with and without 30/20 GHz were considered in the following way: the period before 1990 was assumed to be identical in both scenarios, due to the unavailability of 30/20 GHz spacecraft and earth stations. During this period, traffic was satisfied to the extent possible with the use of C-band and Ku-band frequencies. In Europe, these bands are not adequate to carry the projected traffic. Spacecraft launched in 1990 or later were assumed to have 30/20 GHz available. In the scenario without 30/20 GHz, this capability was, of course, unused. A series of satellites with some advanced features was postulated, and the traffic was satisfied to the extent possible.

The other scenario employed the 30/20 GHz bands, and a different series of satellites, with higher capacity, was used to handle the traffic.

Earth stations were also configured for the various frequency bands used. Costs for satellites, launches, and ground equipment were estimated using available models and data.

11.4 Economic Comparison

Based on the costs developed in the systems configurations, an economic analysis of the two competing approaches was performed. This analysis used a time-phased launch schedule, and appropriate costs to estimate the space-segment cost per channel-year. Earth station costs per channel-year were also estimated. Total system costs on a per channel-year basis were then compared.

Several results came from this analysis. The space segment cost using 30/20 GHz was lower in most cases. This is done primarily to the economies of scale available with greater capacity per satellite.

Earth segment costs for high capacity stations, for example heavy-route trunking stations, were also lower with the use of 30/20 GHz. The primary reason for this is the need for connectivity. With higher capacity satellites, an earth station will need fewer antennas to provide the same degree of connectivity. This is most important to the larger stations, which generally serve a larger access community.

By contrast, the costs for the low capacity stations reflected the basic higher cost of 30/20 GHz hardware. This is due to the less stringent connectivity requirements for such stations, and their typical use in multicarrier per transponder modes with demand assigned capacity.

11.5 Market Analysis

Based in part on the economic analysis, and in part on available information concerning the plans and policies of the countries involved, we have examined the market potential for 30/20 GHz spacecraft and earth stations. We anticipate that US industry will have good opportunities for sales to foreign systems and to INTELSAT. Many nations do have local content requirements, however, which may require the use of a local subsidiary, licensee, or partner.

Since a number of countries are now operating or considering systems which employ 30/20 GHz, the US share of the total market will depend strongly on a firm commitment by the US industry to a 30/20 GHz development program. Effort needs to be applied to earth station equipment as well as spacecraft development. If this work is undertaken, then the excellent US experience with many operating satellites will produce a substantial advantage.

11.6 Systems Availability Aspects

The quality of telecommunications services depends notably on the circuit quality of the basic link, but also on the degree to which that quality is available. At the 30/20 GHz frequencies, the primary cause of system unavailability is attenuation due to rainfall. From the standpoint of the user, the degradation is most objectionable when it occures suddenly and effectively inactivates the link. This is one of the characteristics of the deep fades that would be experienced at 30/20 GHz.

Basic conclusions of this analysis are that for services such as video conferencing, which virtually require the direct-to-user type of service that 30/20 GHz will provide, acceptable system available (on the order of 99.9%) can be provided. This would be accomplished by means of a dual-bit rate scheme, whereby the transmission bit rate (and bandwidth) would be reduced from 6.3 MBps to 64kBps during rain fades. This would provide an additional 20 dB margin, and would allow the conference to continue using voice and ancillary features.

Services such as trunking transmission, which are less flexible and less outage-tolerant, would require a higher basic systems margin, and possible use of site diversity, to achieve the required availability.

11.7 Overall Conclusions

This report indicates a substantial market outside the US for 30/20 GHz equipment, both satellites and ground equipment. This market is partly available to US industry, due to the experience and success rate of US-built satellites and earth stations. However, this market will be available only under certain conditions:

1) US industry must take the lead in developing and proving technology for the 30/20 GHz bands.

2) US firms must make arrangements for the satisfaction of local manufacturer/local content requirements.

3) Incooperation with NASA, US manufacturers should begin parallel incorporation of results from NASA's 30/20 GHz development program, so as to reduce the lag between NASA demonstrations of practicality and actual use in commercial satellites.

ANNEX A
RAIN ATTENUATION MODEL

NOTE: Portions of this Annex have been extracted verbatim from Reference 11. Acknowledgement is hereby given to NASA and Operations Research Inc. for this material. This extracted text is single-spaced within the Annex.

ANNEX A
RAIN ATTENUATION MODEL

It has long been known that the occurance of rainfall along a microwave transmission path attenuates the signal. Due to the non-homogeneous nature of rainfall, and its extreme variability with time, a statistical model of this process is needed for system availability calculations. A relationship between the statistical rainfall parameters and the attenuation to be expected, is also needed.

This Annex contains descriptions of the rain model, known as the Global Model, and the attenuation model. This particular unifide treatment is extracted from Reference 11, "A Propagation Effects Handbook for Satellite Systems Design", however, the models are the results of work by many experimenters and propagation experts. Reference 11 should be consulted for further details.

The Global Model

The Global Model has been developed in two forms. Both of these forms utilize cumulative rain rate data to develop cumulative attenuation statistics. The first form, called the Global Prediction Model (CCIR-1978a, Doc. P/105-E, 6 June), employs a path averaging parameter "r" to relate the point rain rate to the average rain rate along the path from the ground station to the point where the hydrometeors exist in the form of ice crystals. The later form of the model includes path averaging implicitly, and adjusts the isotherm heights for various percentages of time to account for the types of rain structures which dominate the cumulative statistics for the respective percentages of time.

Rain Model

The rain model employed in both forms of the attenuation model is used for the estimation of the annual attenuation distribution to be expected on a specific propagation link. It differs from most other rain models in that it is based entirely on meterological observations, not attenuation measurements. The rain model, combined with the attenuation estimation, was tested by comparison with attenuation measurements. This procedure was used to circumvent the requirement for attenuation observations over a span of many years. The total attenuation model is based upon the use of independent, meteorologically derived estimates for the cumulative distributions of point rainfall rate, horizontal path averaged rainfall rate, the vertical distribution of rain intensity, and a theoretically derived relationship between specific attenuation and rain rate obtained using median observed drop size distributions at a number of rain rates.

The first step in application of the model is the estimation of the instantaneous point rain rate (R_p) distribution. The Global Prediction Model provides median distribution estimates for broad geographical regions; eight climate regions A through H are designated to classify regions covering the entire globe. Figure A-1 shows the geographic rain climate regions for the continental areas of the earth.

The climate regions depicted by the Global Model are very broad. The upper and lower rain rate bounds provided by the nearest adjacent region have a ratio of 3.5 at 0.01 percent of the year for the proposed CCIR climate region D, for example, producing an attendant ratio of upper-to-lower bound attenuation values of 4.3 dB at 12 GHz. This uncertainty in the estimated attenuation value can be reduced by using rain rate distributions tailored to a particular area if long term statistics are available.

The values of R_p may be obtained from the rain rate distribution curves of Figure A-2, which shows the curves for the eight global climate regions designated A through H for one minute averaged surface rain rate as a function the percent of year that rain rate is exceeded. Numerical values for R_p are provided in Table A-1.

Description of the Rain Attenuation Region

A path averaged rainfall rate $R = rR_p$, where r is defined as the effective path average factor, is useful for the estimation of attenuation for a line-of-sight radio relay system but, for the estimation of attenuation on a slant path to a satellite, account must be taken of the variation of specific attenuation with height. The atmospheric temperature decreases with height and, above some height, the precipitation particles must all be ice particles. Ice or snow do not produce significant attenuation; only regions with liquid water precipitation particles are of interest in the estimation of attenuation. The size and number of rain drops per unit volume may vary with height. Measurements made using weather radars show that the reflectivity of a rain volume may vary with height but, on average, the reflectivity is roughly constant with height to the height of the $0^\circ C$ isotherm and decreases above that height. The rain rate may be assumed to be constant to the height of the $0^\circ C$ isotherm at low rates and this height may be used to define the upper boundary of the attenuating region. A high correlation between the $0^\circ C$ height and the height to which liquid rain drops exist in the atmosphere should not be expected for the higher rain rates because large liquid water droplets are carried aloft above the $0^\circ C$ height in the strong updraft cores of intense rain cells. It is necessary to estimate the rain layer height appropriate to the path in question before proceeding to the total attenuation computation since even the $0^\circ C$ isotherm height depends on latitude and general rain conditions.

As a model for the prediction of attenuation, the average height of the $0^\circ C$ isotherm for days with rain was taken to correspond to the height to be expected one percent of the year. The highest height observed with rain was taken to correspond to the value to be expected 0.001 percent of the year, the average summer height of the $-5^\circ C$ isotherm. The latitude dependences of the heights to be expected for surface point rain rates exceeded one percent of the year and 0.001

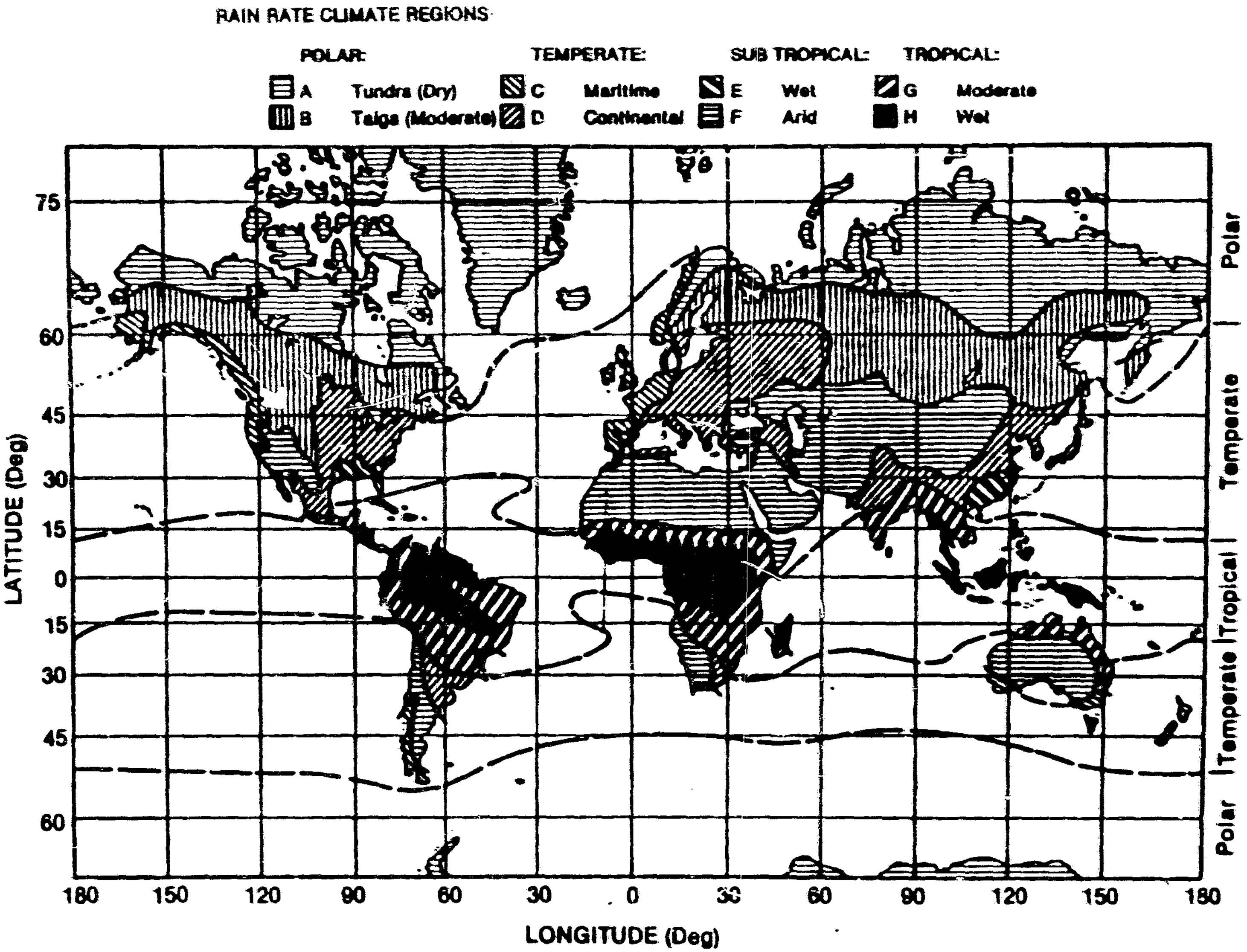


Figure A-1

GLOBAL RAIN RATE CLIMATE REGIONS

FOR THE CONTINENTAL AREAS

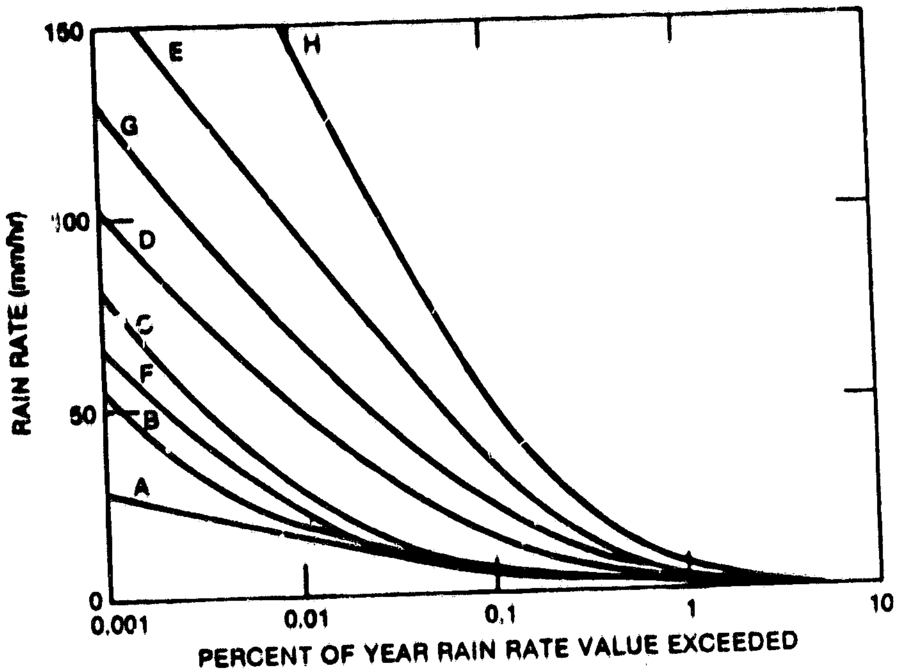


Figure A-2
RAIN RATE DISTRIBUTIONS FOR
GLOBAL PREDICTION MODEL REGIONS

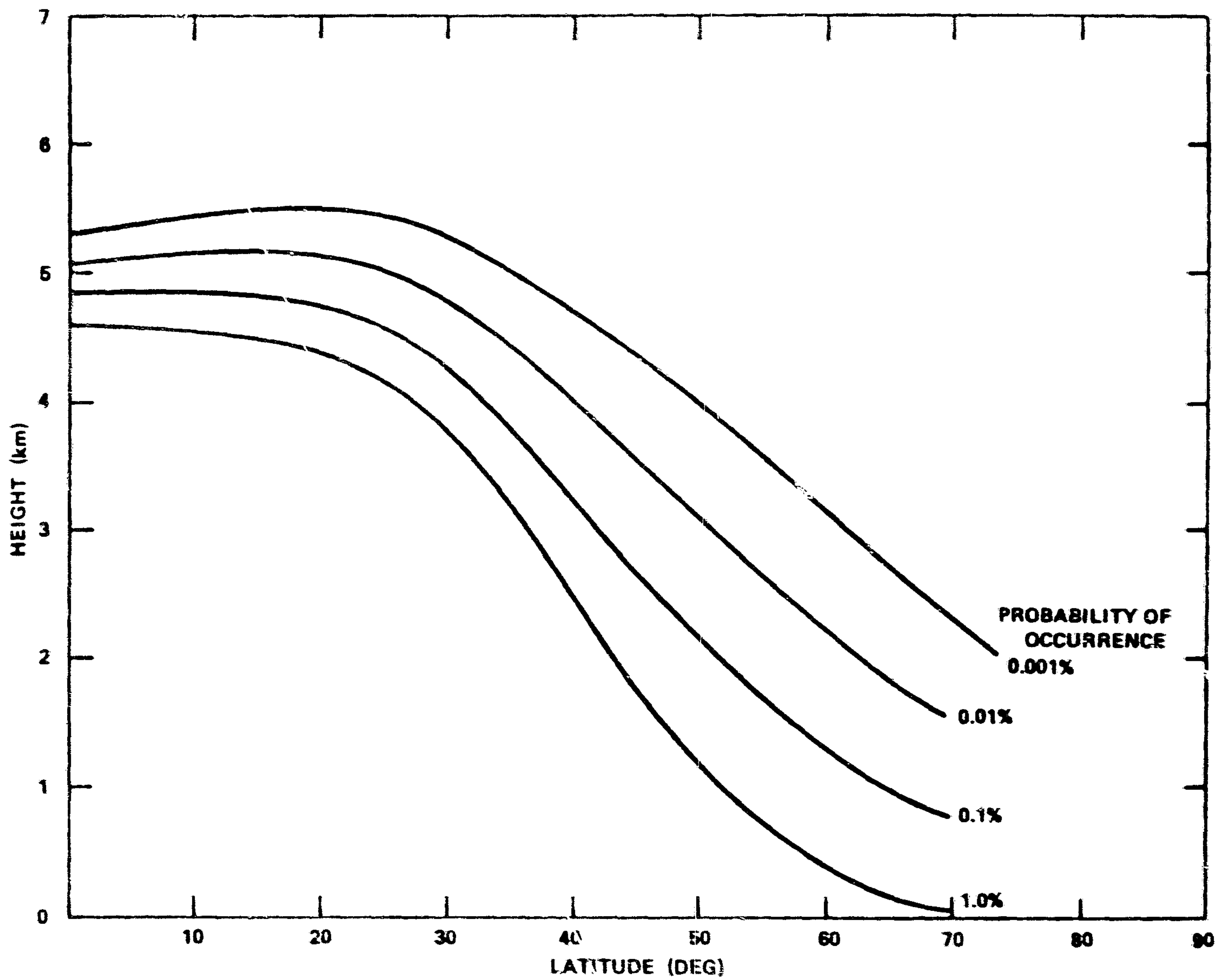


Figure A-3

LATITUDE DEPENDENCE OF THE RAIN LAYER 0°C ISOTHERM HEIGHT (H) AS A FUNCTION OF PROBABILITY OF OCCURRENCE

Table A-1

Point Rain Rate Distribution Values (mm/hr)

Versus Percent of Year Rain Rate is Exceeded

Percent of Year	A	B	C	Rain Climate Region: D	E	F	G	H	Minutes per Year	Hours per Year
0.001	28.0	54.0	80.0	102.0	164.0	66.0	129.0	251.0	5.3	0.09
0.002	24.0	40.0	62.0	86.0	144.0	51.0	109.0	220.0	10.5	0.18
0.005	19.0	26.0	41.0	64.0	117.0	34.0	85.0	178.0	26.3	0.44
0.010	15.0	19.0	28.0	49.0	98.0	23.0	67.0	147.0	53.0	0.88
0.020	12.0	14.0	18.0	35.0	77.0	14.0	51.0	115.0	105.0	1.75
0.050	8.0	9.5	11.0	22.0	52.0	8.0	33.0	77.0	263.0	4.38
0.100	6.5	6.8	7.2	15.0	35.0	5.5	22.0	51.0	526.0	8.77
0.200	4.0	4.8	4.8	9.5	21.0	3.8	14.0	31.0	1052.0	17.50
0.500	2.5	2.7	2.8	5.2	8.5	2.4	7.0	13.0	2630.0	43.80
1.000	1.7	1.8	1.9	3.0	4.0	1.7	3.7	6.4	5260.0	87.66
2.000	1.1	1.2	1.2	1.8	2.0	1.1	1.6	2.8	10520.0	175.30

percent of the year were obtained from the latitude dependences provided by Oort and Rasmussen (1971). The resultant curves are presented in Figure A-3. For the estimation of model uncertainty, the seasonal rms uncertainty in the 0^oC isotherm height was 500 m or roughly 13 percent of the average estimated height. The value of 13 percent is used to estimate the expected uncertainties to be associated with Figure A-3.

The correspondence between the 0^oC isotherm height values and the excessive precipitation events showed a tendency toward a linear relationship between R_p and the 0^oC isotherm height H_o for high values of R_p. Since, at high rain rates, the rain rate distribution function displays a nearly linear relationship between R_p and log P (P is probability of occurrence), the interpolation model used for the estimation of H_o for P between 0.001 and one percent is assumed to have the form, $H_o = a + b \log P$. The relationship was used to provide the intermediate values displayed in Figure A-3.

Attenuation Model

The complete model for the estimation of attenuation on an earth-space path starts with the determination of the vertical distance between the height of the earth station and the 0^oC isotherm height ($H_o - H_g$ where H_g is the ground station height) for the percentage of the year (or R_p) of interest. The path horizontal projection distance (D) can then be obtained by:

$$D = (H_o - H_g)/\tan\theta \qquad \theta \geq 10^o$$

where

H_o = height of 0^oC isotherm

H_g = height of ground terminal

θ = path elevation angle

The specific attenuation may be calculated for an ensemble of rain drops if their size and shape number densities are known. Experience has shown that adequate results may be obtained if the Laws and Parsons (1943) number density model is used for the attenuation calculations and a power law relationship is fit to calculated values to express the dependence of specific attenuation on rain rate. The parameters a and b of the power law relationship:

$$\alpha = aR_p^{\ b}$$

where α = specific attenuation (dB/km)

R_p = point rain rate (mm/hour)

are both a function of operating frequency. The appropriate a and b parameters may be obtained from Table A-2 and used in computing the total attenuation from the model.

Table A-2

Regression Calculations for a and b in aR^b (dB/km) as a Function of Frequency

(Source: Olsen, Rogers and Hodge - 1978)

FREQ. (GHz)	a		b	
	LP_L	LP_H	LP_L	LP_H
10	1.17×10^{-2}	1.14×10^{-2}	1.178	1.189
11	1.50×10^{-2}	1.52×10^{-2}	1.171	1.167
12	1.86×10^{-2}	1.96×10^{-2}	1.162	1.150
15	3.21×10^{-2}	3.47×10^{-2}	1.142	1.119
20	6.26×10^{-2}	7.09×10^{-2}	1.119	1.083
25	0.105	0.132	1.094	1.029
30	0.162	0.226	1.061	0.964
35	0.232	0.345	1.022	0.907
40	0.313	0.467	0.981	0.864
50	0.489	0.669	0.907	0.815
60	0.658	0.796	0.850	0.794
70	0.801	0.869	0.809	0.784
80	0.924	0.913	0.778	0.780
90	1.02	0.945	0.756	0.776
100	1.08	0.966	0.742	0.774

Variable Isotherm Height Technique

The variable isotherm height technique uses the fact that the effective height of the attenuating medium changes depending on the type of rainfall event. Also, various types of rainfall events selectively influence various percentages of time throughout the annual rainfall cycle. Therefore, a relation exists between the effective isotherm height and the percentage of time that the rain event occurs. This relation has been shown earlier. Again the total attenuation is obtained by integrating the specific attenuation along the path. The resulting equation to be used for the estimation of slant path attenuation is:

$$A = \frac{a\, R_p^{\,b}}{\cos\theta}\left[\frac{e^{UZb}-1}{Ub} - \frac{X^b e^{YZb}}{Yb} + \frac{X^b e^{YDb}}{Yb}\right];\ \theta \geqslant 10^\circ$$

where U, X, Y and Z are empirical constants that depend on the point rain rate. These constants are:

$$U = \frac{1}{Z}\left(e^{YZ} \ln X\right)$$

$$X = 2.3\, R_p^{-0.17}$$

$$Y = 0.026 - 0.03 \ln R_p$$

$$Z = 3.8 - 0.6 \ln R_p$$

The following steps apply the variable isotherm height rain attenuation model to a general Earth-to-space path:

Step 1

At the Earth terminal's geographic latitude and longitude, obtain the appropriate climate region: A to H (1 of 8 regions). If long term rain rate statistics are available for the location of the ground terminal, they should be used instead of the model distribution functions.

Step 2

Select probabilities of occurrence (P) covering the range of interest in terms of the percent of time rain rate is exceeded (e.g., .01, .1 or 1 percent).

Step 3

Obtain the terminal point rain rate R_p (mm/hour) using Figure A-2, or Table A-1 or long term measured values if available of rain rate versus the percent of year rain rate is exceeded at the climate region and probabilities of occurrence (Step 2).

Step 4

For an Earth-to-space link through the entire atmosphere, obtain the rain layer height from the height of the 0° isotherm (melting layer) H_o at the path latitude (Figure A-3). The heights will vary correspondingly with the probabilities of occurrence (Step 2). To interpolate, plot H_o (P) vs Log P and use a straight line to relate H_o to P.

Step 5

Obtain the horizontal path projection D of the oblique path through the rain volume:

$$D = \frac{H_o - H_g}{\tan\theta};\ \theta \geq 10^{\circ}$$

H_o = H_o (P) = height (km) of isotherm for probability P

H_g = height of ground terminal (km)

Θ = path elevation angle

Step 6

Test $D \leq 22.5$ km; if true, proceed to the next step. If $D \geq 22.5$ km, the path is assumed to have the same attenuation value as for a 22.5 km path but the probability of occurrence is adjusted by the ratio of 22.5 km to the path length:

$$\text{new probability of occurrence, } P' = P\left(\frac{22.5\text{ km}}{D}\right)$$

where D = path length projected on surface (>22.5 km).

Step 7

Obtain the parameters a(f) and b(f), relating the specific attenuation to rain rate, from Table A-2, or equivalent observed data.

Step 8

Compute the total attenuation due to rain using R_p, a, b,Θ, D

$$A = \frac{a R_p^{\,b}}{\cos\theta}\left[\frac{e^{UZb}-1}{Ub} - \frac{X^b e^{YZb}}{Yb} + \frac{X^b e^{YDb}}{Yb}\right];\ \theta \geq 10^{\circ}$$

where A = total path attenuation due to rain (db)

a, b = parameters relating the specific attenuation to rain rate (from Step 7), = $aR_p^{\,b}$ = specific attenuation

R_p = point rain rate (Step 3)

θ = elevation angle of path

D = horizontal path distance (from Step 5)

$Z \leq D \leq 22.5$ km

or alternatively, if $D < Z$,

$$A = \frac{a R_p^b}{\cos \theta} \left[\frac{e^{UbD} - 1}{Ub} \right]$$

or if $D = O$, $\theta = 90^o$,

$$A = (H - H_g)(a R_p^b)$$

Noise Temperature Increase Due To Rain Attenuation

The satellite receiving antenna always points at the hot earth, representing a mean temperature of about 290 K. Increased path attenuation due to rain attenuation does not cause a significant variation of this temperature. Contrary to this, the earth station antenna normally points at space with a very low temperature, governed primarily by clear sky atmospheric absorption and to a lesser extent by cosmic radiation. (In addition, the effect of the hot earth is introduced through antenna sidelobes.) For a small percentage of the time the noise temperature as seen by the earth station receive antenna is increased greatly as the result of pointing at the sun and by a smaller amount as the result of pointing at the moon. However, during periods of rain the rain attenuation increases the noise temperature of the receive antenna.

This increase has, in fact, been exploited to provide indirect measurements of precipitation attenuation without the use of an orbiting beacon. The relationship between the sky noise and the attenuation is given by the following approximation, valid for antennas with narrow beamwidths:

$$T = \left[1 - 10^{-A/10}\right] T_r$$

where

T_r is the physical temperature of the sky seen by the antenna, generally about 273 K

A is the attenuation in dB

T is the apparent temperature increase of the sky, including the effects of precipitation

This increase in noise temperature must be added to the temperature of the receiving system and the clear-weather sky temperature. This produces a degradation in the receive gain-to-noise temperature ratio or G/T. The decrease is dependent on the initial system G/T. Systems having a low noise antenna and amplifier are affected more than those with a higher receive noise temperature.

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