FUTURE COMMUNICATIONS SYSTEMS

VIA SATELLITES UTILIZING LOW COST EARTH STATIONS

JULY, 1968

Prepared By

An Ad Hoc Group

of

The Engineering Committee

Satellite Telecommunications Subdivision

Industrial Electronics Division

Electronic Industries Association

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PREFACE

The Industrial Electronics Division of the Electronic Industries Association, based on the interest shown at its 1967 seminar on Communications Satellite Development, established a Satellite Telecommunications Subdivision to consider matters associated with Satellite Telecommunications Systems. Since satellite systems are becoming prominent in telecommunications and policies concerning these systems are being formulated, it was appropriate that industry consider its position and relationship to this field. The subdivision has three committees which deal with the various areas of Satellite Telecommunications Systems; namely, (1) Engineering (2) Policy, and (3) International. Ad hoc groups are established to undertake specific tasks.

The Engineering Committee considers engineering aspects of space telecommunications systems. This includes transmitters, receivers, antennas, spacecraft, and associated equipment, both as to the space and earth segments. It also includes multiple access and the interface with other systems, as well as radiation phenomena, the characteristics of propagation, and all data transmission which is an integral part of the space systems.

The Policy Committee is concerned with policy, economic, social, legal, and organizational matters affecting the development, growth, and diversification of space telecommunications systems. This committee draws together the views of industry and provides advice to telecommunications entities, executive and regulatory agencies of the Government, and the Congress of the United States for the purpose of encouraging the exploitation of space telecommunications.

The International Committee handles questions pertaining to international matters that arise out of the activities of the other committees in EIA. This committee concerns itself with international developments, financing, trade, and trade restrictions, as well as the international use of telecommunications satellites.

Among the matters under consideration by the Satellite Telecommunications Subdivision is the need to promote the development and use of telecommunications satellites and to substantiate their advantages. In this connection, the subdivision, on 25 April 1968, took the policy position that a domestic telecommunications satellite system should be aggressively pursued and implementation should be effected at the earliest possible date. The resolution reads:

" RESOLVED:

The Satellite Telecommunications Subdivision of Electronic Industries Association (EIA) hereby calls for the aggressive pursuit of a domestic telecommunications satellite system with implementation to be effected at the earliest possible date. We urge that all appropriate responsible governmental, legislative, and industrial activities vigorously work toward this end without further delay. Problems of ownership, financing, frequency allocation, etc., must be resolved in a positive manner, but without unduly comprising the United States' worldwide leadership position. It is in the national interest to resolve the terrestrial satellite interface and interference problems as rapidly as possible by an early implementation of a U.S. domestic communications satellite project. The recently approved Canadian and Soviet National Satellite Telecommunications Systems are positive proof that other communities are proceeding to assume a lead role in the implementation of national satellite telecommunications. The Satellite Telecommunications Subdivision of EIA feels that the United States can ill afford to be pre-empted."

At the same time, the subdivision established an ad hoc group to prepare a report in accordance with this policy position. This report represents the subdivision's major contribution to the President's Telecommunications Task Force.

It is to be noted that the positions taken in this report have been arrived at by members of industry, in an attempt to represent the best interest of the public. The positions must be considered as consensus positions in which not every member and associate member of this subdivision concurs on all points. Furthermore, the information in this report is purposely presented with a wide range of cost figures which can be used, hopefully, to gauge the magnitude of the project and cost trends, but cannot be used or construed as a basis for accurately gauging the costs of any specific project in the future.

SECTION 1

SUMMARY

1.1 GENERAL

Considerable attention and controversy has been evidenced in the past year as to the direction and extent of using satellites for telecommunications. Systems are being proposed having national and international characteristics. A basic economic competition between this new technology (e.g., satellite telecommunications) and conventional systems has arisen. Claims as to the cost effectiveness of each system are being made, and each proponent is claiming his system as the most cost effective. As is usually true in controversies of this nature, each case has merit when viewed within a limited scope.

The importance of this matter has been evidenced, for example, by the fact that the President established a Task Force on Communications Policy. Furthermore, the Satellite Telecommunications Subdivision sponsored the preparation of this report, the object of which was to develop informed engineering/economic judgments on future satellite telecommunications systems.

In order to develop these judgments, significant system parameters were evaluated for their economic impact, and models were developed to illustrate, in some detail, these engineering and economic effects. The key to increased usage of satellites is to reduce the per-unit cost to the user. The per-unit cost at the present time is primarily established by the expense associated with the terrestrial communications equipment, a major portion of which is the satellite earth station. This report, therefore, concentrates on this aspect of the communications satellite system. A second reason is that studies have shown a much greater demand for domestic communications traffic as contrasted to the longer distance point-to-point traffic. Therefore, in order for communications satellite systems to become an economic alternative to conventional terrestrial means, especially for developing nations, costs must be lowered.

The most costly area in today's commercial earth station is the antenna subsystem and associated low-noise receiver. Specifically, the need for large, steerable antennas with automatic tracking plus cryogenically cooled parametric amplifiers must be eliminated. This can be accomplished by reducing the required sensitivity of the earth station and by correspondingly increasing the satellite effective radiated power. The reduction of earth station sensitivity can be accomplished by using uncooled low-noise preamplifiers and smaller-diameter antennas. It is recognized that the use of smaller-diameter antennas leads to a reduction in theoretical orbital channel capacity; however, it has been demonstrated that there is also a significant reduction in earth station cost when using smaller-diameter antennas.

In preparing this report, higher satellite effective radiated power capability was evaluated and found feasible during the early 1970's. Furthermore, it was determined that the cost of an earth station can be significantly reduced by removing the need for large steerable antennas and cryogenically cooled amplifiers. These actions will result in sufficient cost reductions to warrant implementing low-cost earth stations as a possible economic alternative to conventional terrestrial communications systems.

Existing earth stations utilizing large antenna subsystems are fundamentally compatible with the proposed systems utilizing low cost earth stations. Modulation techniques considered are consistent with existing practice, only the modulation index has been reduced. This planned compatibility will permit existing earth stations to be phased into an over-all satellite network utilizing low cost earth stations and higher power satellites.

1.2 CONCLUSIONS

- Satellites radiating relatively high output power, coupled with low-cost earth stations, will lead to a significant reduction in overall user costs. There are no technological limitations that prevent the immediate fabrication of low-cost earth stations. Satellites radiating relatively high power are feasible and will be available for system implementation in the early 1970's.

- The dominant cost components in current standard earth stations have been the large steerable antennas with automatic tracking facilities and cryogenically cooled parametric amplifiers. The use of smaller nontracking antennas and uncooled low noise receivers results in the multiplex equipment becoming the dominant cost factor, especially for high-voice channel capacity stations.

- Earth stations utilizing smaller antennas lead to significant savings in installation and operational costs, e.g. real estate purchase, site preparation, maintenance, etc.

- There is an essentially linear reduction in maximum orbital channel capacity as the diameter of earth station antennas is reduced.

- There is a significant cost reduction in the earth station as the diameter of the earth station antenna is reduced.

- The extensive use of frequencies in excess of 10 GHz appears promising under certain circumstances or conditions, e.g. point coverage, high arrival angles, geographic diversity, etc. as with a future "domestic" system. Millimeter waves cannot, however, be considered as a substitute for the more desirable frequency bands below 10 GHz for area coverage.

1.3 TECHNICAL SUMMARY

1.3.1 Scope

Satellite Communications Systems must be developed to provide multi-point TV and two-way Communications service to continue to compete economically with the more conventional terrestrial means (e.g., microwave, cables, etc.). Typical low-cost earth station models have been developed and are described in this report.

Current satellites have low effective isotropic radiated power (EIRP)*. For example, the INTELSAT III satellites, which are scheduled for launch beginning in August 1968, have multiple access capability through a linear transponder which furnishes only +22 dBW EIRP over 225 MHz of usable bandwidth. Two independent transponders cover the 500 MHz allocated frequency band.

The earth stations that complement the INTELSAT III satellites, 70 of which are currently envisioned, require G/T** ratios of 40.7 dB/$^{\circ}$K and a top voice channel signal-to-noise ratio of 52 dB; these are typical specifications for existing earth stations. To accomplish this, 85- to 105-foot diameter antennas, cryogenically cooled parametric amplifiers, and threshold extension demodulators (for message traffic) are used. Automatic tracking for the antennas is usually employed and highly recommended; however, it is not a requirement.

The relationship between Satellite EIRP and G/T ratio, expressed in dB, is a simple one (refer to Paragraph 2.1.2.1d for the derivation):

$$\text{EIRP} = (K - G/T) \text{ dBW} \tag{1-1}$$

where

EIRP = Satellite Effective Isotropic Radiated Power in dBW.

---

* This is also called equivalent isotropic(ally) radiated power.

** The figure of merit of the earth terminal is stated as the ratio of antenna gain (G in dB) to the receiver system noise temperature (T in dB = 10 log t, t in degrees Kelvin).

G/T = The figure of merit of the earth station, where G is the antenna gain in dB, and T is the equivalent system noise temperature.

K = A parameter dependent upon the frequency of operation, the path length, and the performance grade or service, expressed in dB. When these parameters are established, K becomes fixed.

Once K is determined, the economic and performance trade-off between EIRP and the G/T ratio can be determined. Thus, applying Equation (1-1) to current satellite communications systems, which are EIRP limited, establishes the need for high G/T ratio.

As the satellite EIRP is raised, the earth station antenna size and installation costs can be reduced, and cooled front ends can be eliminated, thus effecting cost economies in both the installation and operation of the earth stations. These two subsystems plus installation comprise a major portion of the current earth station costs, as shown in Section 2.3. The increase in EIRP will be achieved using greater satellite antenna gain coupled with increased transponder output power. By 1980, satellite EIRP's of up to +70 dBW will be feasible. As satellites with these higher EIRP's become operational, the utilization of low-cost earth stations can be realized.

The primary assumptions used in the model developments and system calculations are:

a. Only geo-stationary satellites have been considered.

b. The required EIRP has been achieved by increased satellite antenna gain coupled with increased transponder power.

c. Current CCIR Flux Density limitations are not exceeded. *

d. Earth station antennas of 30-foot diameter or less with mechanical positioning are considered.

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* This limitation applies to the 1-10 GHz frequency band (CCIR Recommendation 358, OSLO, 1966).

e. Present commercial satellite frequencies are assumed (receive** 3.7 to 4.2 GHz and transmit** 5.925 to 6.425 GHz), except for systems using vestigial sideband amplitude modulation.

f. Modulation techniques considered are:

(1) Frequency Modulation (FM)

(2) Vestigial Sideband Amplitude Modulation (VSAM)

The modulation techniques used in the models are consistent with existing practice and the modulation index has been reduced to correspond to existing CCIR terrestrial link standards. It is recognized, however, that there will be a continual increase in digital traffic, leading to an increased use of digital modulation techniques during the 1970-1980 time frame. Investigations to date indicate that costs associated with the use of digital techniques will not markedly differ from the data in this report; in fact, the integrated use of digital techniques is expected to lead to further economies.

g. Only uncooled low-noise preamplifiers are used.

h. Threshold extension demodulators are not necessary.

i. Total usable satellite bandwidths of 500 MHz are assumed, except for systems using vestigial sideband modulation.

The system calculations in Section 2 have been developed to show system feasibility. The calculations are not intended to be used in establishing actual specifications or standards for a specific system.

1.3.2 System Models

The system models considered are:

** These terms refer to the earth station. "Receive" corresponds to down-links, and "transmit" corresponds to up-link.

a. Color TV Service

(1) Vestigial sideband amplitude modulation (VSAM)

(2) Frequency Modulation (FM)

b. Communication Service

(1) Preassigned

(a) Multi-Destination Carrier System (FDM/FM)*

(b) Single Destination Carrier System (FDM/FM)*

(2) Demand-Assigned (SCC/FM)**

For conceptual clarity and model simplicity, the preassigned and demand-assigned systems have been considered separately, as if they were to use separate satellites and earth stations. One recognizes that a single satellite could accommodate both services simultaneously by using separate parts of the frequency band. Preassigned service is primarily intended for heavily used routes, i.e., continuously or nearly continuously used message channels, whereas demand-assigned service can be used advantageously for light routes (low message channel usage).

Models for earth stations which handle TV or two-way communications are detailed in Section 2.2.

1.3.2.1 Color TV Service

Figure 1-1 shows a possible one-way multichannel TV distribution system providing continental coverage and serving upwards of 250 (perhaps as high as 1000) commercial receiver earth stations. Separate earth stations are used for transmission and reception. Both regional and national reception and transmission stations are depicted. The difference between the two is the number of RF carriers that the station can handle simultaneously. Regional stations can be tuned to any of the twelve TV channels, but can receive or transmit only one RF carrier, while national stations can handle up to five.

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* Frequency Division Multiplex/Frequency Modulation

** Single Channel Carrier/Frequency Modulation

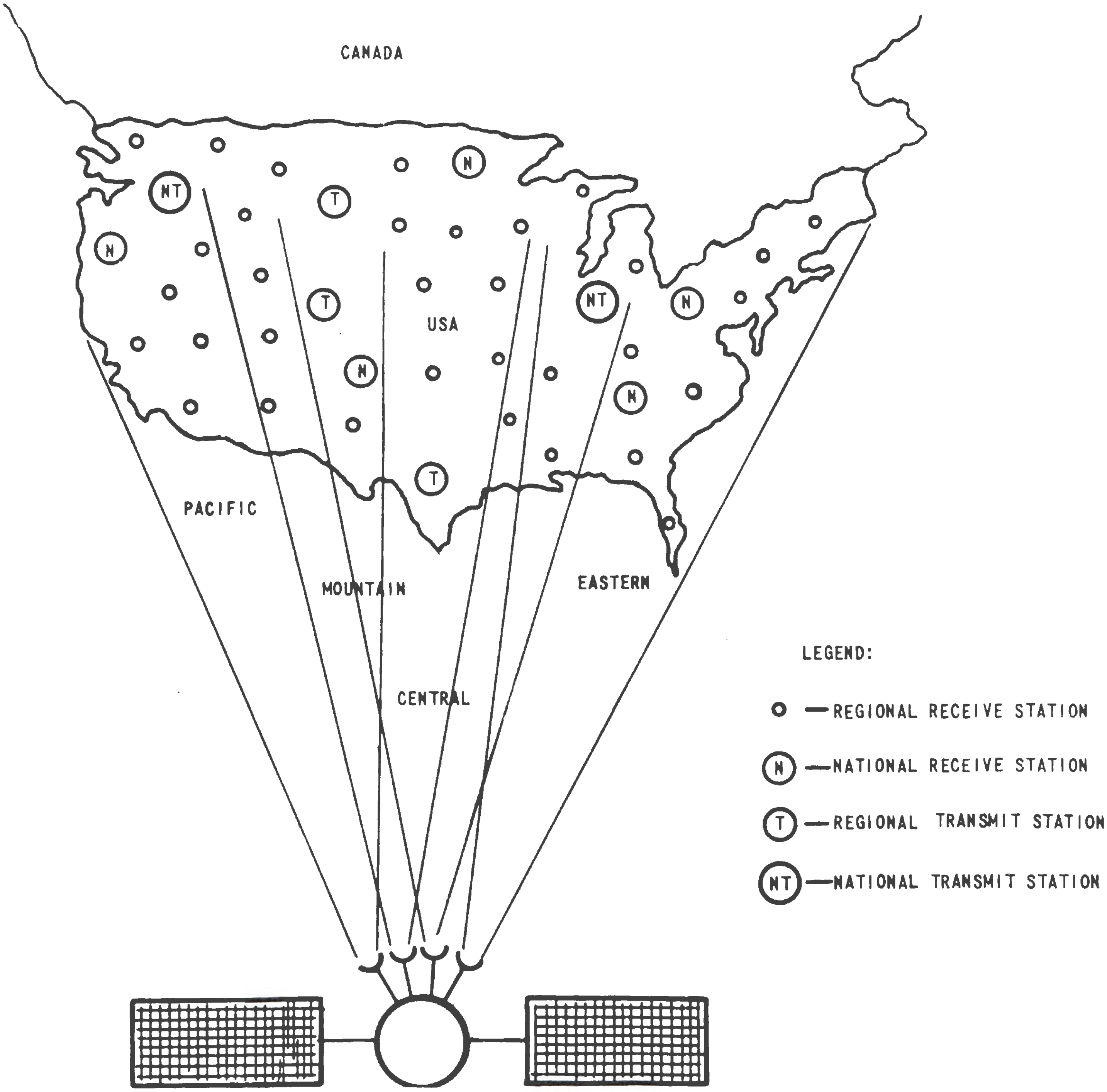

Figure 1-1. Domestic One-Way Multichannel TV Distribution System Showing National and Regional Stations

Table 1-1 shows TASO* TV performance characteristics for Service Grades 1 through 6. The table is based upon subjective evaluation by viewers of a TV monitor.

Table 1-1. TASO TV Performance Characteristics**

Grade	Median Observer Signal-to-Interference Ratio (dB)	Impairment	Quality
1	44.5	NONE	Excellent
2	34	Perceptible	Fine
3	27	Not Objectionable	Passable
4	23	Somewhat Objectionable	Marginal
5	17	Definitely Objectionable	Inferior
6	—	—	Unusable

For reception to cable heads (CATV) or interfacing with terrestrial microwave links for TV distribution, a peak-to-peak signal-to-rms noise ratio $(S/N)_o$ of 53 dB has been selected as a representative value. This value allows for noise degradation by the terrestrial equipment, thus making it possible for the ultimate viewer to receive a Grade 1 TV picture.

For reception directly to the home, a peak-to-peak signal-to-rms noise ratio $(S/N)_o$ of 33 dB has been selected as a representative value, thereby making possible Grade 3 or better TV service to the home.

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* Television Allocations Study Organization

** G. L. Fredendall and W. L. Behrend, "Picture Quality-Procedures for Evaluating Subjective Effects of Interference," Proc. IRE, Vol. 48, pp. 1030-1034; June, 1960. Also, C.E. Dean, "Measurements of the Subjective Effects of Interference in Television Reception," Proc. IRE, Vol. 48, pp. 1035-1049; June, 1960.

The modulation techniques used are frequency modulation operating in the Commercial Satellite frequency bands (receive 3.7 to 4.2 GHz and transmit 5.925 to 6.425 GHz), and vestigial sideband amplitude modulation operating in the UHF band (receive 818 to 890 MHz and transmit 1.5 to 1.572 GHz*).

To achieve the necessary Satellite EIRP for TV receive time zone coverage, 3 degree beamwidth is assumed. Four beams will provide separate time-zone coverage of the continental United States. Since a 7.5 degree beamwidth can cover the continental United States, three 3° beamwidths can be used to provide coverage when two time zones are combined as in standard broadcast practice.

1.3.2.1.1 Vestigial Sideband Amplitude Modulation (VSAM) - A single RF carrier has been assumed for the transmission of both the TV video and TV audio information, the latter being sent on an FM subcarrier. The RF bandwidth required for reception is approximately 6 MHz.

a. Down-Link Considerations (818-890 MHz)

The equations relating Satellite EIRP to the G/T ratio for $(S/N)_o$ = 53 dB and 33 dB are as follows:

$$EIRP = (72.6 - G/T) \text{ dBW } ((S/N)_o = 53 \text{ dB}) \quad (1\text{-}2)$$

$$EIRP = (52.6 - G/T) \text{ dBW } ((S/N)_o = 33 \text{ dB}) \quad (1\text{-}3)$$

For national or regional receive station models, a G/T ratio of 13.5 dB/$^{\circ}$K at 850 MHz has been assumed; this corresponds to a 30-foot diameter antenna using an uncooled paramp. The EIRP requirement thus becomes 59.1 dBW per TV channel. A satellite antenna with a 3° beamwidth will yield a gain of 34.6 dB (55 percent efficiency is assumed); thus the required actual satellite power is 24.5 dBW, or approximately 300 watts per channel.

A similar analysis can be performed in the case of direct service to the home (see Figure 1-2). In the model considered the equipment used is a 5-foot diameter antenna, an RF amplifier, and a current consumer television receiver.

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* This frequency band has been selected only as a frame of reference. It is recognized that other services plan to use part or all of this band, e.g., the F.A.A. aircraft-to-ground communications via satellite relay, which plan to use the band 1.54 - 1.66 GHz. Therefore, in actual practice another available frequency band may be selected.

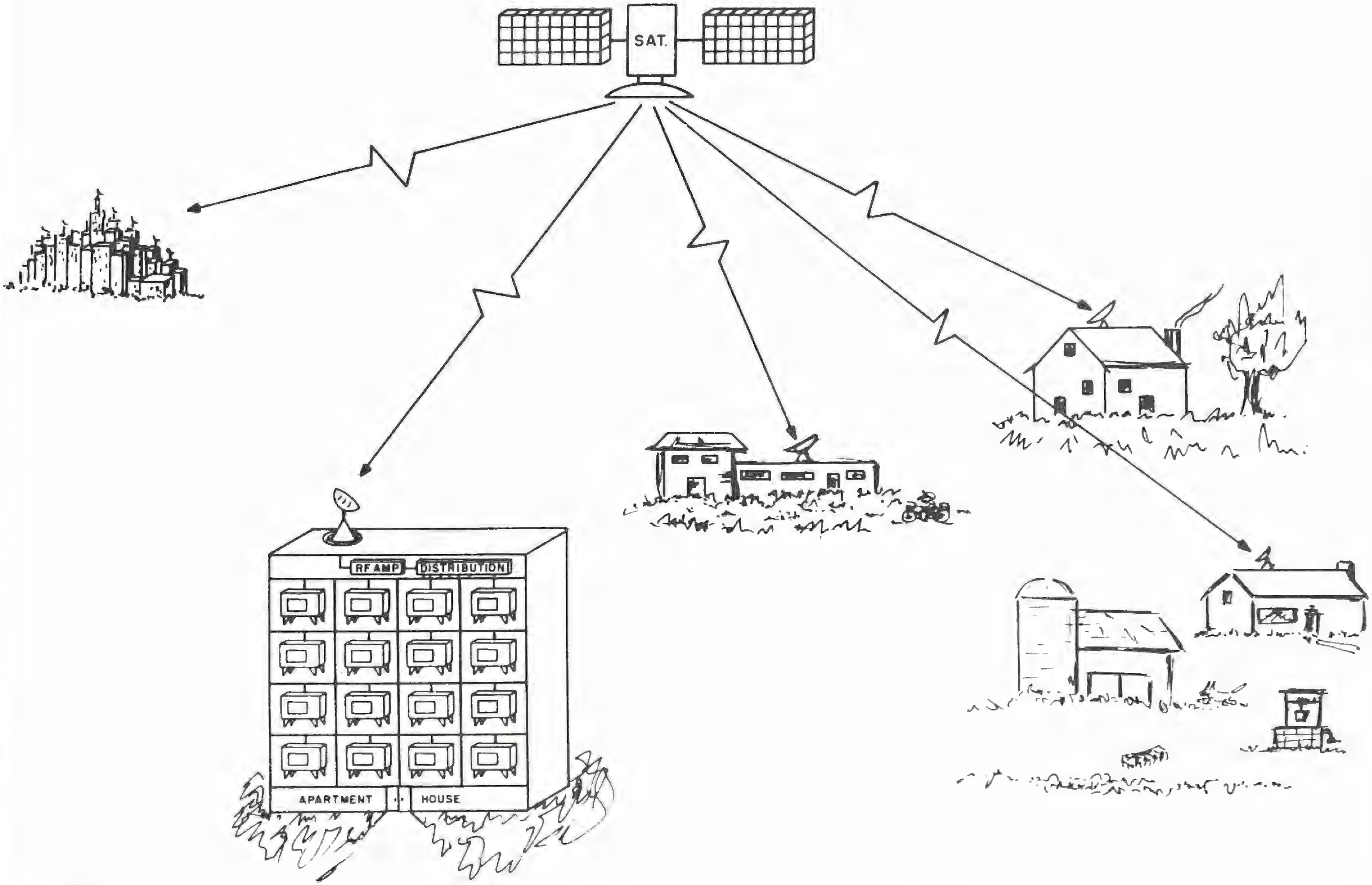

Figure 1-2. TV Service Directly to the Home

A G/T ratio of -7.0 dB/$^{\circ}$K has been assumed, yielding an EIRP requirement of 59.6 dBW. This value of EIRP is very close to that required by CATV, broadcasters, and other commercial users. Therefore, the same satellite can serve both users. Obviously, improved home performance can be obtained by using larger antennas at the home or increasing Satellite EIRP.

The required EIRP for both cases is realizable in the time frame allotted (1970's).

b. Up-Link Considerations (1.5 to 1.572 GHz)

The equation relating the power required at the earth station as a function of the system antenna gains is expressed as follows:

$$P_{tg} = \left[117.4 - (G + G_t)\right] \quad \text{dBW}, \qquad (1\text{-}4)$$

where

P_{tg} = earth station high power amplifier (HPA) output

G = earth station antenna gain in dB

G_t = satellite antenna gain in dB

In the model (Subsection 2.2), we have assumed an earth station antenna with a diameter of 30 feet and an efficiency of 68 percent. For this discussion we have assumed a more average-quality antenna (55 percent efficiency), G becomes approximately 41 dB at 1.5 GHz. Assuming a 1.7° satellite antenna coverage, $G_t \approx 39$ dB. This complements the 3° beam coverage used in the receive-only earth stations, which operates at a lower frequency.

Therefore,

$$(G + G_t) = 80 \text{ dB, and}$$

$$P_{tg} = 37.4 \text{ dBW} \approx 5.5 \text{ kW}.$$

High Power Amplifiers (HPA's) of this capability are available, and have been used in the model earth station transmitter.

It should be noted at this point that, since VSAM is susceptible to amplitude distortion, a separate HPA is used for each carrier.

1.3.2.1.2 Frequency Modulation (FM) - Separate RF carriers are used for TV video and TV audio information. This technique is consistent with current earth station practices.

The RF bandwidths required for TV video and TV audio information are, respectively, 40 MHz and 3 MHz. The video requirements predominate the audio requirements; hence, the latter will not be considered. The peak deviation used for TV video information is 15.2 MHz.

a. Down-Link Considerations (3.7 to 4.2 GHz)

The equation relating satellite EIRP to the G/T ratio for $(S/N)_o = 53$ dB is:

$$\text{EIRP} \simeq (60.6 - G/T) \text{ dBW} \tag{1-5}$$

For national or regional receive station models, a G/T ratio of 21.0 dB/^{o}K at 4 GHz has been assumed; this corresponds to a 15-foot diameter antenna, using an uncooled paramp. The EIRP requirement thus becomes 39.6 dBW/TV video carrier.

A satellite antenna with a beamwidth of 3 degrees will yield a gain of 34.6 dB (55 percent efficiency is assumed). Thus, the required actual satellite power is 5.0 dBW, or approximately 3 watts per channel. Since this power is readily available, the possibility of using a satellite antenna with a wider beamwidth arises. If we assume a beamwidth of 7.5^{o}, which would provide U.S. continental coverage, we have an antenna gain of approximately 26.5 dB. The actual satellite power requirement per channel is 13.1 dBW, or approximately 20 watts, which again will be readily achievable. The required EIRP for FM is easily realizable in the time frame allotted in the 1970's.

b. Up-Link Considerations (5.925 to 6.425 GHz)

The equation relating the power required at the earth station as a function of the system antenna gain is expressed as follows:

$$P_{tg} = \left[103.6 - (G + G_t)\right] \text{ dBW} \tag{1-6}$$

where

P_{tg} = earth station high-power amplifier (HPA) output,

G = earth station antenna gain in dB,

G_t = satellite antenna gain in dB.

In the transmit earth station models, we have used a 30-foot and a 15-foot diameter antenna for the national and regional earth station respectively. The 30-foot diameter antenna allows up to 6 dB backoff for the common HPA used in the national stations. In the discussion that follows the regional station with the 15-foot diameter antenna will be used.

Assuming a 15-foot diameter antenna and an efficiency of 55 percent, we have an antenna gain G of 46.5 dB at 6 GHz. If the satellite antenna beamwidth is 2 degrees, the antenna gain is $G_t \approx 38$ dB. This complements the 3-degree time zone coverage used in the receive-only stations which operate at lower frequencies.

Therefore,

$$(G + G_t) = 84.5 \text{ dB, and}$$

$$P_{tg} = 19.1 \text{ dBW} \approx 80 \text{ watts.}$$

If we assume a satellite antenna beamwidth of 5.2°, this beamwidth complements the national coverage given to the receive-only earth stations.

$$G_t \approx 30 \text{ dB (satellite antenna efficiency of 55 percent)}$$

Therefore

$$(G + G_t) = 76.5 \text{ dB and}$$

$$P_{tg} = 27.1 \text{ dBW} \approx 520 \text{ watts.}$$

In both cases HPA's of this capability are available. An HPA with a 1 kW capacity has been postulated in the earth station model.

1.3.2.2 Communications Services

The communications services have duplex capability (two-way service) as opposed to TV service, which is one-way. Multi-access satellite operation is assumed. The system models considered are preassigned (multi- and single-destination carrier) and demand-assigned. Any of these services can be accommodated by a multiplicity of satellites or a common satellite.

The preassigned models use FDM/FM with a message (voice) channel capacity of 24, 60, 132, 300, and 600 voice channels per RF carrier. In addition, for the multi-destination carrier (MDC), TV operation has been considered. The per-channel test tone deviations complement current CCIR terrestrial line-of-sight (LOS) microwave standards. With the exception of 24 voice channels, which use a deviation of 140 kHz rms, all voice channel loadings use a deviation of 200 kHz rms. The output signal-to-noise ratio assumed is toll quality (52 to 53 dB psophometrically weighted).

The demand-assigned model is a modified version of the "STAR" system*. The demand-assigned technique used is SCC/FM. An RF spectrum of 100 kHz has been allotted to each demand-assigned (message) channel. The output signal-to-noise ratio will be of toll quality.

1.3.2.2.1 Preassigned Models -

a. Multi-Destination Carrier System (MDC)

The Multi-Destination Carrier System makes use of the broadband satellite transponder by using multi-destination carriers, which results in each earth station transmitting fewer RF carriers than it receives. The transmitted carrier from a particular earth station in a network is sent to the other earth stations in that network. Each earth station in the network receives as many carriers as there are other stations within the network; each carrier is demodulated and the preassigned channels for that particular station are extracted. Figure 1-3 shows such a communications system being used for both inter- and intracontinental communications.

The Multi-Destination Carrier (MDC) system provides a moderately high capacity for communications among earth stations and can be used for intra- and intercontinental links, thereby allowing various key cities to be incorporated within a given network.

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* M. Morita, T. Fukami, and S. Yamato, "Project STAR," Telecommunications, Volume 1, No. 2, pp. T22-T25; October, 1967. Also, M. Morita, et. al., "STAR System," NEC Research and Development, No. 8, pp. 1-66, October, 1966.

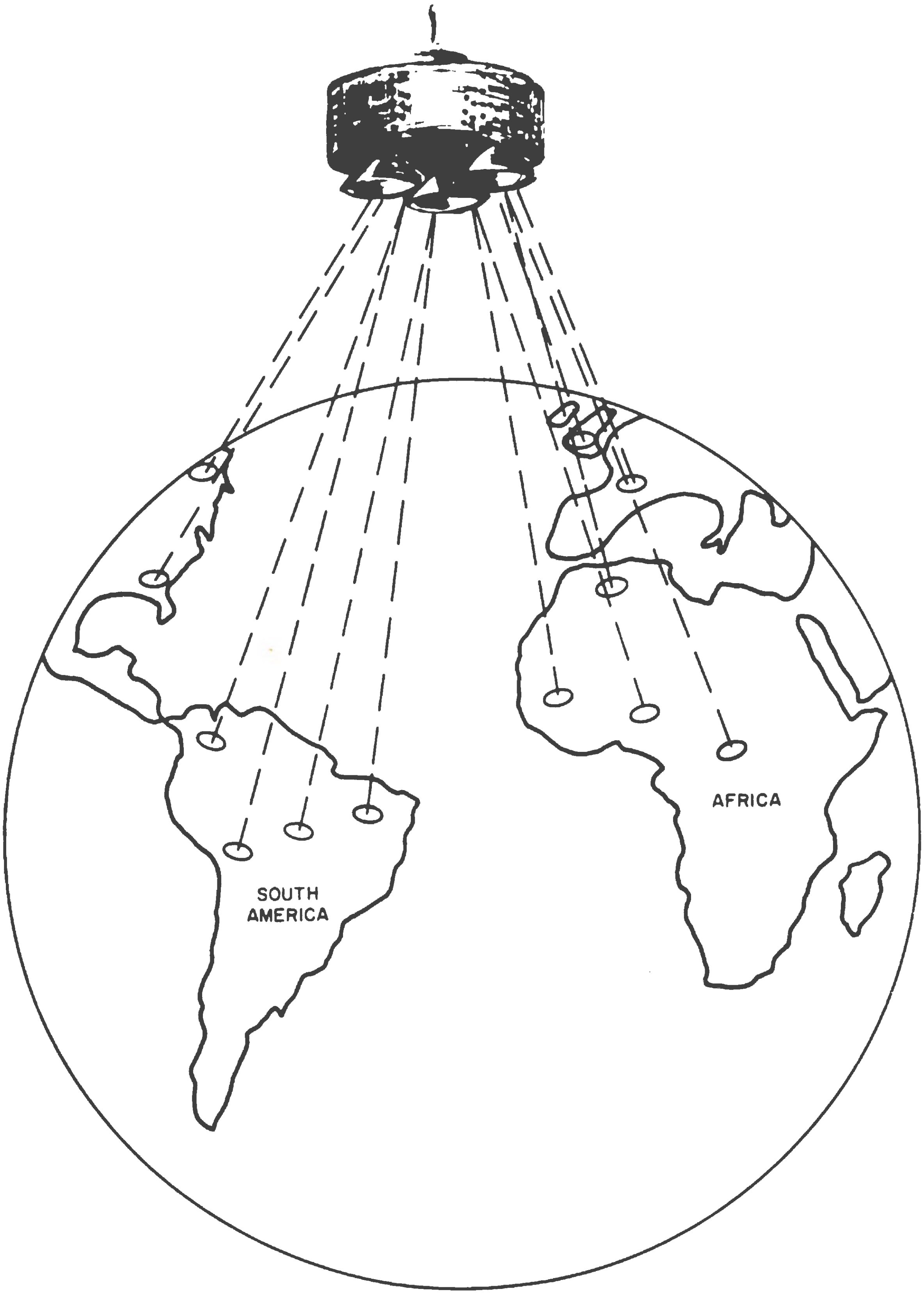

Figure 1-3. Preassigned Multi-Destination Satellite Communications Systems Used for Both Inter-and Intracontinental Communications

The satellite can be considered as a pool of 500 MHz which can be shared by a number of networks; the exact number of networks accommodated by the satellite is a function of the number of multi-destination carriers within each network and the bandwidth required per network. The bandwidth, in turn, is a function of the number of voice channels required (see Table 1-2).

This system as described does not preclude the possibility of inter-network communications by the use of additional carriers. In fact, there is no reason (other than cost and inefficient use of circuits) why each of the stations which use a particular satellite could not communicate with one another.

Table 1-2. IF Bandwidth as a Function of Voice Channel Loading, Using CCIR Loading Standards*

Carrier Capacity Voice Channels	24	60	132	300	600
B_{if} in MHz Nominal	3.0	5.0	7.0	10.0	15.0

The earth station model developed in Section 2 has the capability of transmitting one and receiving five RF carriers**; in addition, provision is made for transmitting and receiving TV video and audio (program) information. The requirements of TV transmission and reception have been discussed previously and will not be included in this discussion. The TV receive-only stations discussed in the previous section are compatible with this system.

In the system described above, a network consists of six earth stations, each transmitting 300 voice channels. Thus, the transmit capacity of the network is 1800 voice channels.

The bandwidth B_{if} required for 300 voice channels is 10 MHz, and the satellite bandwidth is 500 MHz. Thus the maximum theoretical satellite capacity is 15,000 voice channels.

The earth station model developed has a figure of merit (G/T ratio) of 27.0 dB/^{o}K at 4 GHz. This is achieved by using a 30-foot diameter antenna and an uncooled parametric amplifier. The satellite EIRP requirements for 300

* CCIR Recommendation 353-1, Volume IV, Oslo, 1966.

** Each transmit RF carrier accommodates 300 voice channels; the bandwidth required is 10 MHz.

voice channels[1] and the TV program traffic[2] are, respectively 38.6 dBW/carrier and 21.6 dBW/carrier. The requirement for TV video is 33.6 dBW per carrier. This value is 6 dB less than that of the TV receive-only case discussed previously, and results from the increase in the antenna diameter from 15 feet to 30 feet.

The power amplifier used in the earth station model has a capacity of 2 kW (33 dBW) and a bandwidth of 500 MHz. If we assume U.S. continental coverage, the satellite antenna gain is 26.5[3] dB at 6 GHz added to the earth station antenna gain of 53.5 dB, the approximate powers required per carrier on the ground are as follows:

TV Video	23.6 dBW, or 235 Watts[4]
TV Program	11.4 dBW, or 13.8 Watts[5]
Telephony	28.6 dBW, or 720 Watts[6]

The HPA used in the earth station model has sufficient reserve power capability, allowing for back-off to minimize the intermodulation problems.

b. <u>Single-Destination Carrier System (SDC)</u>

This type of communications system is a special case of the MDC system, primarily intended for use in heavy-loaded point-to-point systems covering large distances, e.g., an east coast location (Washington, D.C.) to Western Europe (Paris) or the west coast (San Francisco). Figure 1-4 depicts such a system.

An 1800 voice channel FDM/FM capacity is assumed per earth station. This capacity is accomplished via three RF carriers. Each carrier handles 600 voice channels. The IF bandwidth required to accommodate 600 voice channels is approximately 15 MHz (see Table 1-2); therefore, the spectrum utilized by each terminal is 45 MHz. Consequently, the satellite can handle 10 stations, or a total theoretical maximum capacity of 18,000 voice channels.

---

(1) EIRP = (65.6 - G/T) dBW for 300 voice channels.

(2) EIRP = (48.6 - G/T) dBW for TV program (audio).

(3) 7.5 degree antenna beamwidth, (antenna efficiency of 55 percent is assumed).

(4) $P_{tg} = [103.6 - (G + G_t)]$ dBW for TV Video.

(5) $P_{tg} = [91.4 - (G + G_t)]$ dBW for TV Program (Audio).

(6) $P_{tg} = [108.6 - (G + G_t)]$ dBW for 300 Voice Channels.

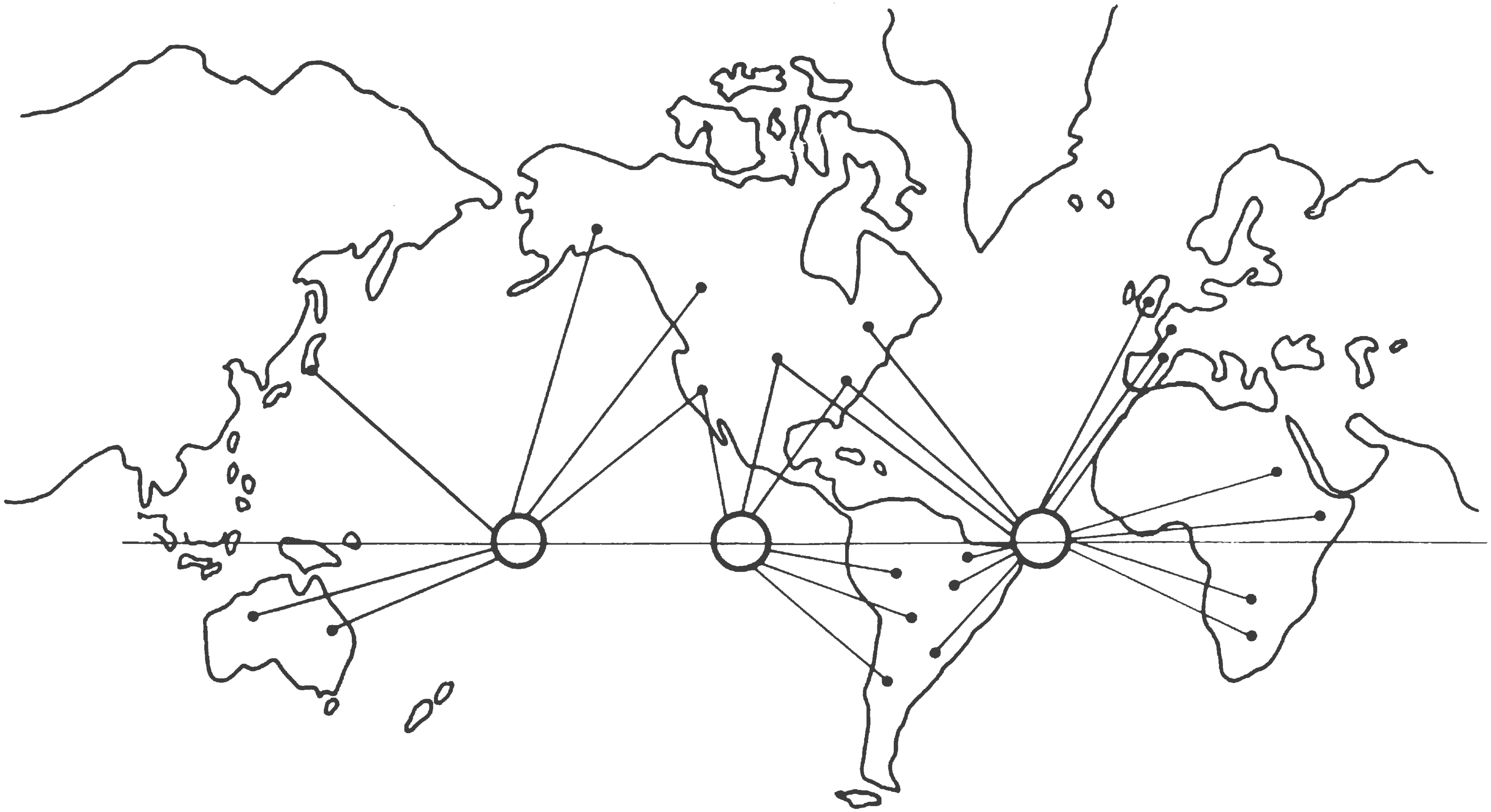

Figure 1-4. Preassigned Single Destination Satellite Communications System Used for Both Inter- and Intracontinental Communications

Under most circumstances, the earth stations will handle different numbers of voice channels, resulting in different voice channel loading in the satellite, depending upon its usage. From Table 1-2 it can be seen that the IF bandwidth does not vary linearly with the voice channel loading; consequently, the greater the voice channel loading per RF carrier, the greater the capacity of the satellite.

The figure of merit (G/T ratio) of the earth stations considered is 27.0 dB/^{o}K at 4 GHz which results from using a 30-foot diameter antenna and an uncooled paramp. The EIRP required per 600 voice channel RF carrier is 45.1 dBW*.

The high-power amplifier (HPA) used in the model station has a capacity of 2 kW (33 dBW) over a bandwidth of 500 MHz. If we assume a satellite antenna gain $\approx$ 34.6 dB at 6 GHz, which corresponds to time zone coverage (3-degree beamwidth), and add the earth station antenna gain of 53.5 dB to this value, the approximate power required on the ground is 410 watts (26.2 dBW) per carrier (each carrier transmits 600 FDM/FM voice channels). **

1.3.2.2.2 Demand-Assigned Model - The model uses a form of SCC/FM. Each voice channel frequency modulates one carrier, and the carriers are arranged within the transmission bandwidth of the satellite.

The channel capacity of the system is limited not only by the bandwidth of the satellite but also by its output power and the performance of each earth station which is linked to the others by means of the common satellite.

Voice channels through the satellite are not assigned to each earth station, but are assigned on a demand basis. This on-demand assignment is the so-called automatic routing operation.

In an operating voice channel, the carrier is not continuously transmitted; that is, a technique in which the wave is emitted only for the time in which a voice is present, and in which the wave (signal) is cut off for the period during which no voice is presented, is the so-called "Start-Stop" function. Using this approach, the number of usable channels is increased by utilizing the limited output power of a satellite most effectively, and the interference to other channels is minimized by cutting off the unmodulated waves.

---

* EIRP = (72.1 - G/T) dBW for 600 Voice Channels.

** $P_{tg} = \left[114.3 - (G + G_t)\right]$ dBW for 600 Voice Channels.

The earth stations are always connected through the routing center by means of data transmission links for channel assignment. Time-division multiplex is used for the data link. However, the voice channels are transmitted using frequency modulation. Thus, each earth station has an analog system for voice channel transmission, and digital system for voice channel demand assignments.

This system for developed and developing nations is described. The essential difference between the two is the earth station channel capacity and the application of the "Stop-Start" function. Thus, conversion from developing to developed nation earth terminals is readily accomplished.

Each demand channel has been allocated a 100 kHz spectrum. Thus, a channel can accommodate a single voice channel.

The satellite has a bandwidth of 500 MHz; therefore, a theoretical maximum capacity of 5000 voice channels can be accommodated. The number of earth stations that can be accommodated by the satellite is a function of the expected traffic (data, voice, etc.), the allowable delays, etc. and is a traffic engineering problem.

Many earth stations can use the satellite. The applications of the "Start-Stop" further decrease the activity factor, thereby reducing the average power required in the satellite transponder.

The demand-assigned system offers flexibility in the use of satellite transponder bandwidth, and allows many earth stations of low traffic capacity to tie into the satellite. A useful application of the demand-assigned system would be in the case of many topographically separated communities which lack adequate terrestrial links but desire to communicate among themselves and with the centers of commerce. Figure 1-5 is a pictorial application of the demand-assigned principle.

The capacities of the earth stations for developing and developed nations have been assumed as 12 and 85 channels respectively.

The demand-assigned earth station includes a 15-foot diameter antenna and an uncooled parametric amplifier, yielding a G/T ratio of approximately 21.0 dB/^{o}K at 4 GHz. Therefore, a satellite EIRP of 13.6 dBW per carrier is required.*

---

* EIRP = (34.6 - G/T) dBW per voice channel.

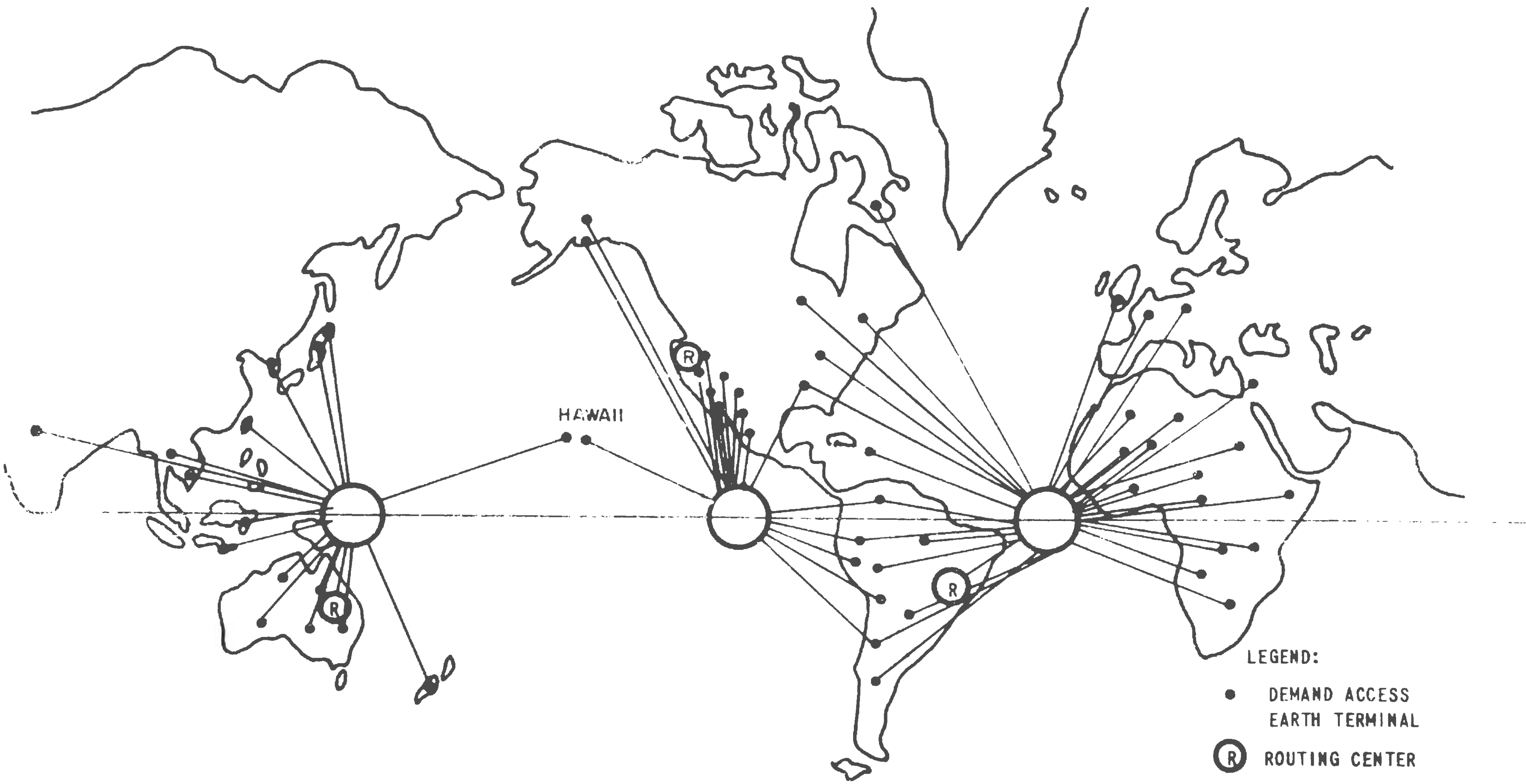

Figure 1-5. Demand-Assigned Satellite Communications System for use in Developing and Developed Nations

The high-power amplifier (HPA) associated with the earth station model is 1 kW and has a bandwidth of approximately 500 MHz. If we assume global (hemispheric) coverage, 18-degree beamwidth, the satellite antenna gain is 19 dB at 6 GHz (antenna efficiency of 55 percent); adding the earth station gain of 47.5 dB, the approximate power required per carrier at the earth station is 13 watts.* The HPA postulated for employment has more than sufficient reserve power capabilities to be used by developing and developed nations.

An analysis similar to that presented above can be performed for the Routing Center. The G/T ratio of the station is 21.0 dB/$^{\circ}$K. Correspondingly, the EIRP required for the data channel is 24 dBW. The HPA associated with the Routing Center is 20-watt power amplifier with a bandwidth requirement of only 5 MHz.

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* $Ptg = \left[77.6 - (G + G_t)\right]$ per voice channel

1.3.3 Cost Comparisons

The model used for cost comparison is a standard station* that complements the INTELSAT-III-type satellite. This station has typical characteristics as follows:

Transmit:	3 RF Carriers:	one TV Video
		one TV Audio (Program)
		one redundant telephony** (132-voice-channel capability)
Receive:	7 RF Carriers:	five telephony (132 voice channels per RF carrier)
		one TV Video
		one TV Audio (Program)
		one spare; provides 1:7 backup

The total cost of this standard station ranges from $2.65 to $5.173 million, with a mean cost of approximately $4 million. Details are given in Subsection 2.3.

Tables 1-6 and 1-7 shown at end of this section give a comparison of the mean costs of the standard or existing earth station and the models projected for the 1972-1980 time frame. The models are discussed in more detail in Subsection 2.2. In addition, the cost of the antennas and multiplex equipment, where applicable, is expressed as a percentage of the particular earth station cost.

a. <u>Per-Channel Cost Comparison (Initial Investment)</u>

In order to determine the economic impact of low-cost earth stations and higher-power satellites on initial investment, the cost per channel for an existing INTELSAT-type system is compared to projected systems utilizing low-cost (MDC) earth stations. The quality of message service is equivalent for all models.

---

* $G/T = 40.7 dB/^{o}K$

** One of the redundant telephony carriers can be used as a spare for TV video or audio backup.

The total cost per channel is the sum of the earth station transmit per-channel cost and the satellite per-channel cost. This relationship is expressed as follows:

$$\frac{\text{Total earth station cost}}{\text{Number of transmit channels}} + \frac{\text{Total Satellite cost}}{\text{Total Satellite channel capacity}} = \text{Total per-channel cost}$$

(1) Earth Station Per-Channel Cost

The standard earth station has a message transmit capability of 132 channels.* The cost of the earth station is approximately \$4 million; therefore, the per-channel cost is given by the following relationship:

$$\frac{\text{Total earth station cost}}{\text{Number of transmit channels}} = \text{Cost per channel}$$

Therefore, by applying this relationship to the standard earth station we obtain:

$$\frac{\$4M}{132} = \$30,000 \text{ per channel}$$

The low-cost earth station with comparable message channel transmission capacity costs approximately \$400k; therefore, the per-channel cost is:

$$\frac{\$400k}{132} = \$3000 \text{ per channel,}$$

or 1/10 the cost of the standard earth station.

---

*All earth station models compared include single TV video and audio (program) channels. It has been determined that the costs associated with this TV capability do not exceed 10 percent of the total station cost, and therefore, to simplify comparison, these TV channel costs have been distributed across the message (voice) channels.

The MDC low-cost earth station model postulated (see Table 1-6, Item 1) has a 300-channel transmit capability and costs $480k; therefore, the per-channel cost is:

$$\frac{\$480k}{300} = \$1600 \text{ per channel}$$

(2) Satellite Per-Channel Cost

The INTELSAT III (low satellite EIRP type), which complements the standard earth station, costs approximately $10 million including launch. Its capacity is 2400 channels. The per-channel cost in the satellite is given by the following relationship:

$$\frac{\text{Total satellite cost}}{\text{Total satellite channel capacity}} = \text{Cost per channel}$$

Therefore, by applying this relationship to the INTELSAT III satellite, the cost per channel is:

$$\frac{\$10M}{2400} \approx \$4200 \text{ per channel}$$

The high EIRP satellite that complements the low-cost earth stations has a cost of approximately $30 million. Its total channel capacity is a function of the number of channels transmitted per RF carrier (see Table 1-2). Conservatively speaking, the total channel capacity is 6000 and 10,000 for an RF transmit carrier capacity of 132 and 300 channels respectively. Therefore, by applying the satellite per-channel relationship previously developed, the cost per channel is $5000 and $3000 respectively.

Table 1-3 summarizes these comparative costs on a per-channel basis. The results are quite dramatic and show the cost advantage of the high-EIRP satellite system coupled with the low-cost earth stations.

Table 1-3. Comparative Per-Channel Cost*

(Initial Investment)

	Existing	1970's Projected	
Earth Station transmit capacity*	132	132	300
Earth Station cost	\$4M	\$400k	\$480k
Earth Station per-channel cost	$\frac{\$4M}{132}$ = \$30,000	$\frac{\$400k}{132}$ = \$3000	$\frac{\$480k}{300}$ = \$1600
Satellite channel capacity	2400	6000	10,000
Total Satellite cost	\$10M	\$30M	\$30M
Satellite per-channel cost	$\frac{\$10M}{2400}$ ≈ \$4200	$\frac{\$30M}{6000}$ = \$5000	$\frac{\$30M}{10,000}$ = \$3000
Total per-channel cost	\$34,200	\$8000	\$4600

where k = thousand

M = million.

---

*See previous footnote.

b. Total System Cost Comparison (Initial Investment)

In order to determine the economic impact of low-cost earth stations and higher-power satellites on total system cost, the subsystem costs for an existing INTELSAT-type system were compared to those of a projected system utilizing low-cost (MDC) earth stations. Also included in the comparison is a projected system utilizing lower-power satellites, such as INTELSAT-III, which require present-day G/T ratios ($40.7\ dB/^{o}K$) at the earth station. In this last case, however, we have economic improvements due to technological advances in both the earth station and the satellite which will have occurred by this time.

To simplify the comparison, a system having 4 satellites and 70 earth stations was used for both time frames. The estimated average subsystem costs are shown in Table 1-4. It can be seen from this table that the cost for the existing INTELSAT-type system is about \$320 million, while the cost for the projected high-EIRP system is about \$155 million. The difference is \$165 million, which is substantial, especially when coupled with the increased message channel capacity. A future high-EIRP system can accommodate up to 300 or 600 duplex voice channels with a relatively small increase in cost for the additional multiplex equipment. Furthermore, if projected future requirements for telecommunications using 6 or more satellites with up to 700 earth stations are considered, total system cost saving by using high-EIRP satellites becomes even more substantial. See Table 1-5.

Table 1-4. Comparative System Costs - 4 Satellites, 70 Earth Stations

(Initial Investment)

Subsystem	Existing	1970's Projected	
		High-EIRP Satellite	Low-EIRP Satellite
Satellite (incl. launch cost)	\$10M	\$ 30M	\$ 7M
Earth Station	\$ 4M	\$ 0.5M	\$ 3M
Total System Cost	\$320M	\$155M	\$238M

Table 1-5. Comparative System Cost - 6 Satellites, 700 Earth Stations

(Initial Investment)

Subsystem	Existing	High-EIRP Satellite System
Satellite (including launch cost)	$ 10M	$30M
Earth Station	$ 4M	$0.5M
Total System Cost	$2860M	$530M

The significance of these projected systems utilizing higher EIRP satellites and low-cost earth stations is that, for a given investment, a network with greater capacity and more flexibility can be established. In other words, the per-unit cost to the user will be greatly reduced and will provide more than adequate channel capacity for developing nations and the smaller user. This will, in effect, accelerate the development of a large market, in that communications services can be provided at much lower installation and operational costs.

Table 1-6. Cost Analysis of Communications Service Earth Stations

Description	Block Diagram Figures	Grade of Service	Equip. List Table No.	Capacity	User	Cost* Comparison	Antenna Cost Normalized	Multiplex Cost Normalized
A. Preassigned								
1. Multi-Destination Carrier (FDM/FM Station)	2-13	TV-No. 1 Message-Toll quality (S/N=52dB)	2-41	Ties in with a network of five ground stations-300 voice capacity plus one TV channel	Developed or Developing *** Nations	12%	7%	30%
2. Single Destination Carrier (FDM/FM Station)	2-14	Message-Toll quality (S/N=52dB)	2-42	1800 voice channels point-to-point	Developed Nations (e.g. USA to Europe)	30%	3%	72%
B. Demand Access								
1. SCC/FM System **	2-16	Toll quality	2-43	85 demand access voice channels		15%	3%	60%
2. SCC/FM System **	2-16	Toll quality	2-44	12 demand access voice channels		6%	8%	30%

* Ratio of the particular earth station to the Cost Model in percent.
** The cost of the routing earth station is counted with the cost of the satellite.
*** Could reduce cost by having a multiplex of lower capacity, e.g., 132 voice channels.

Table 1-7. Cost Analysis of Color TV Service Earth Stations

Description	Block Diagram Figures	Grade of Service	Equip. List Table No.	Capacity	User	Cost**	Antenna Cost Normalized
A. Reception Regional (VSAM) $850 MHz	2-6	No. 1	2-33	One channel	Commercial*	2.0%	40%
National (VSAM) @850 MHz	2-7	No. 1	2-34	Five channels simultaneously	Commercial*	5.0%	20%
Home (VSAM) @ 850 MHz	2-8	No. 3.5	2-35	1 channel	Home	.01%	10%
Regional (FM) @ 4 GHz	2-10	No. 1	2-37	One channel	Commercial*	2.0%	14%
National (FM) @ 4 GHz	2-11	No. 1	2-38	Five channels simultaneously	Commercial*	5.0%	6%
B. Transmission Regional (VSAM) @ 1.5 GHz	2-9	No. 1	2-36	One channel	Commercial*	5.0%	20%
National (VSAM) @ 1.5 GHz	---	No. 1	2-36	Transmits three channels simultaneously	Commercial*	13%	7%
Regional FM @ 6 GHz	2-12	No. 1	2-39	One channel	Commercial*	3.0%	10%
National FM @ 6 GHz	---	No. 1	2-40	Transmits three channels simultaneously	Commercial*	5.0%	20%

* Cable head or interfaces with terrestrial microwave for distribution by TV stations.
** The ratio of the particular earth station to the COST MODEL expressed in percent.

1.3.4 Millimeter Waves

Table 1-8, below, summarizes the link loss factors which are sensitive to frequency. The first of these factors is free space loss. The additional loss factors are system noise, temperature, and propagation loss due to absorption through the atmosphere (rain, clouds, oxygen, and water vapor).

Table 1-8. Link Loss Factors ***

Frequency	4GHz	16GHz	35GHz
Satellite Antenna Gain	constant (constant beamwidth required for coverage)		
Free Space Loss $\left(\frac{\lambda}{4 \pi R}\right)^2$ (dB)	197	208.5	215.8
Ground Antenna Gain (dB)			
15-Foot	43	54.5	61.8
30-Foot	49	60.5	67.8
System Noise Temperature (dB)	28 TDA	28 TDA	32 Uncooled Paramp
Propagation Loss Maring (dB)	0.2	3.4	14.3*
Link Availability - 97% (weather only)	0.2	3.4	14.3*
Link Availability - 99%	0.4	10.9**	44.2**

* Due mainly to cloud cover attenuation. These may be reduced when better data on cloud density and coverage statistics is available.

** Use of geographic diversity at ground stations may significantly reduce these values. See Subsection 2.5.

*** These frequencies selected lie in the low propagation attenuation regions between water vapor and oxygen absorption frequencies.

The first of these factors, free space loss, increases with the square of the wave length. If the size of the earth station antenna remains constant, the increased gain exactly cancels the increase in free space loss. However, comparative antenna costs indicate, for example, that a 15-foot antenna operating at 35 GHz doubles the price of the same size antenna designed for 4 GHz, thus placing an increased economic burden on the earth station. The additional loss factors, system noise, temperature, and propagation loss, can be offset by increasing the gain of the satellite antenna. This action, however, will result in a much narrower beam, thereby sacrificing area coverage. Another consideration toward offsetting these loss factors is to restrict the utilization of millimeter waves to high angles of arrival, thus reducing the effects of the earth's atmosphere.

In brief, extensive use of frequencies above 10 GHz appears promising under certain circumstances, i.e., point coverage, high arrival angles, and possibly geographic diversity. In any event, millimeter waves cannot be considered as a substitute for the better frequency bands below 10 GHz.

SECTION 2

TECHNICAL DISCUSSION

2.1 SYSTEM PARAMETERS

2.1.1 System Assumptions

In the analysis that follows, the up-link (transmit) and down-link (receive) system trade-off parameters for TV and Communications Services (message operation) will be derived.

The developed equations, tables, and figures will then be utilized as a guide in establishing the engineering and economic design judgements for the various earth station models.

The assumptions used in the calculations are enumerated as required within each appropriate subsection of the analysis. However, some of the salient assumptions are:

a. Only synchronous geo-stationary satellites are considered. The Satellite transponder has an RF bandwidth exeeding 500 MHz, the exception being the color TV service system using Vestigial Sideband Amplitude Modulation (VSAM).

b. The frequencies used in the calculations are primarily the Comsat frequencies (Receive 3700 to 4200 MHz and Transmit 5925 to 6425 MHz). For the case of Vestigial Sideband Amplitude Modulation (TV service), the frequencies used are: receive 818-890 MHz, and transmit 1.5-1.572 GHz. These frequencies have been selected for modeling only; other frequencies in the 0.8 to 10 GHz band are not precluded.

c. All receivers will use either uncooled parametric amplifiers, TDA's, or other RF low-noise amplifiers.

d. The calculations for Preassigned Operation (multi-destination carrier or single destination carrier) use FDM/FM. The modulation technique used for Demand-Assigned Operation (one channel per RF Carrier) and TV broadcast operating in the commerical satellite frequency bands is SCC/FM.

e. Only conventional demodulators (limiter-discriminator) are used for FM demodulation. No Threshold Extension Demodulators are used for FM demodulation, since higher satellite effective isotropic radiated power (EIRP)* is postulated.

*This is also called equivalent isotropic(ally) radiated power.

2.1.2 System Parameter Calculations

2.1.2.1 General System Calculations

The discussion which follows is general and applies to all of the earth station models.

a. <u>Path Loss</u>

The classical communications equation* may be used to describe the up-link (the ground transmitter to the satellite) and down-link (the satellite to the ground receiver) path losses. The equation is:

$$\alpha = [36.6 + 20 \log f + 20 \log d] \text{ dB} \quad (2\text{-}1)$$

where

α = free space loss (dB)

d = distance between transmission points (e.g., transmitter and receiver) in miles

f = operating frequency in MHz

Only synchronous quasi-stationary satellite orbits are considered.

Therefore:

d = distance to satellite = 25,500 miles at a 5° slant angle at each end of the path (synchronous quasi-stationary orbit)

The RF frequencies considered and the corresponding path losses are listed in Table 2-1.

b. <u>Antenna Gain</u>

The gain of a parabolic dish is a function of diameter and frequency and is given by

$$G = \eta \, 10^{-5} \, D^2 \, f^2 \quad (2\text{-}2)$$

---

*<u>Reference Data for Radio Engineers,</u> International Telephone and Telegraph Corporation, New York, 1956, p. 751.

Table 2-1. Operating Frequency and Path Loss

Band	RF Frequencies	Path Loss
UHF - TV Reception VSAM Only (Last 12 channels)	818 - 890 MHz	183 dB @ 850 MHz
UHF - TV Transmission VSAM Only 12 channel	1.5 - 1.572 GHz*	188 dB @ 1.54 GHz
Comsat Receive Band FM - TV, Voice etc.	3.7 to 4.2 GHz	197 dB @ 4 GHz
Comsat Transmit Band FM - TV, Voice etc.	5.925 to 6.425 GHz	200 dB @ 6 GHz

*This frequency band has been selected as a frame of reference for model development. This does not preclude the use of other frequency bands in actual practice.

where

G = antenna gain

D = diameter in feet

f = operating frequency in MHz

η = antenna efficiency which is a function of surface tolerance, frequency of operation, aperture blockage, spillover, feedline losses, etc. The antenna efficiency varies from greater than 70 percent for large apertures (85 ft.) to less than 44 percent for smaller diameters (5 ft.). For the analysis that follows, an efficiency of 68 percent will be assumed as a frame of reference (68 percent is achievable for 30-foot dishes or greater).

In terms of dB, Equation (2-2) becomes:

$$G\ (\mathrm{dB}) = 10 \log G = [-51.6\ \mathrm{dB} + 20 \log D + 20 \log f] \quad (2\text{-}3)$$

Using the above equation, Table 2-2 is developed showing the antenna gains in dB for the operating frequencies of interest.

Table 2-2. Gain Over Isotropic Antenna

Antenna Paraboloid Diameter - ft	Efficiency %	Gain (dB)			
		@850 MHz	@1.5 GHz	@4 GHz	@6 GHz
5	68	21.0	26.0	34.5	38.0
8	68	25.0	30.0	38.5	42.0
15	68	30.5	35.5	44.0	47.5
30	68	36.5	41.5	50.0	53.5
40	68	39.0	44.0	52.5	56.0
60	68	42.5	47.5	56.0	59.5
85	68	45.5	50.5	59.0	62.5

c. G/T Ratio

The ratio of receiver-antenna gain G to system noise temperature T of the receiver will hereafter be called the G/T of the earth station. This ratio, which is also referred to as the figure of merit of the earth station, determines the sensitivity of the station. Throughout this discussion G/T is calculated at 5° antenna elevation. in most installations this is the elevation at which the ratio is a minimum and thus represents a worst case condition.

Specifically, G is the gain of the antenna and T is the system noise temperature, in degrees Kelvin (includes the noise figure of the preamplifier, antenna noise temperature, feeds, elevation angle, indigenous noise, etc.)

For the frequencies considered the following representative system noise temperatures will be used:

T_1 = 68° Kelvin (18.3 dB)* - Using cooled parametric amplifier

T_2 = 200° Kelvin (23 dB) - Using uncooled parametric amplifier

T_3 = 630° Kelvin (28 dB) - Using Tunnel Diode Amplifier (TDA)

*10 log T (°K)

The receiving system sensitivity, or figure-of-merit, G/T is:

$$G/T\ (dB/°K) = G\ (dB) - 10 \log T\ (°K) \tag{2-4}$$

where

G = antenna gain in dB

T = system noise temperature in degrees Kelvin

Table 2-3 gives the G/T ratios for typical receiving systems.

Table 2-3. G/T Ratio as a Function of Reflector Size, Frequency, and System Noise Temperature

Reflector Diameter - ft. (η = 68%)	G/T dB/°Kelvin				
	TDA @ T_3		Uncooled Paramp @ T_2		Cooled Paramp @ T_1
	@850 MHz	@4 GHz	@850 MHz	@4 GHz	@4 GHz
85	17.5	31.0	22.5	36.0	40.7
60	14.5	28.0	19.5	33.0	37.7
40	11.0	24.5	16.0	29.5	34.2
30	8.5	22.0	13.5	27.0	31.7
15	2.5	16.0	7.5	21.0	25.7
8	-3.0	10.5	2.0	15.5	20.2
5	-7.0	6.5	-1.0	11.5	16.2

d. Satellite Effective Isotropic Radiated Power (Down-Link)

The Satellite Effective Isotropic Radiated Power (EIRP) is expressed in dBW as:

$$EIRP\ (dBW) = P_t\ (dBW) + G_t\ (dB) \tag{2-5}$$

where

P_t = is the satellite transmitted power in dBW

G_t = is the satellite antenna gain in dB

The received signal strength is given in dBW by the following equation*

$$C = [\,EIRP - \alpha + G\,]\ \text{dBW} \tag{2-6}$$

where

C = received carrier in dBW

α = path loss in dB.

Substituting T (dB) = 10 log T (°K) (system noise temperature) from both sides of Equation (2-6), we obtain

$$C - 10 \log T\ (°K) = EIRP - \alpha + G = 10 \log T(°K). \tag{2-6a}$$

All the terms of Equations (2-6) and (2-6a) are in logarithmic form. Equivalently,

$$C - 10 \log T\ (°K) = 10 \log \frac{c}{T}, \tag{2-6b}$$

where

c is now in watts.

To simplify the notation, the following accepted method will be used:

$$\frac{C}{T} = 10 \log \frac{c}{T} = C - 10 \log T\ (°K). \tag{2-6c}$$

where

$\frac{C}{T}$ = carrier-to-total thermal noise in dBW/°K

---

*Circular polarization has been assumed, and hence the losses due to Faraday rotation have been neglected.

Similarly,

$$\frac{G}{T} = 10 \log \frac{g}{T} = G - 10 \log T \;(°K), \qquad \text{(2-6d) (refer to Equation (2-4))}$$

where

g = gain as a ratio*.

Using this simplified notation, we obtain an expression for C/T from Equation (2-6a):

$$\frac{C}{T} = \left[\text{EIRP} - \alpha + \frac{G}{T} \right] \quad \text{dBW/°K} \tag{2-7}$$

Solving for EIRP we obtain

$$\text{EIRP} = \left[(\alpha + \frac{C}{T}) - G/T \right] \quad \text{dBW} \tag{2-8}$$

Examining Equation (2-8) we note that (α + C/T) is a constant depending on the grade of performance and α is determined by the path distance and operating frequency. Therefore, once (α + C/T) is established, the economic and performance trade-off between EIRP and G/T becomes evident. More will be said of this in the discussion that follows.

e. Up-Link (Earth Station Transmitter Power)

The received carrier level at the satellite (the preamplifier input) may be determined by adding the system gains to the transmission losses. Circular polarization is assumed and hence losses due to Faraday rotation can be neglected. The equation for the received carrier level in dBW for the up-link is:

$$C_u = [\,Ptg + G + G_t - \alpha\,] \quad \text{dBW} \tag{2-9}$$

---

*The notation derived in Equations (2-6c) and (2-6d) is an accepted form for expressing a ratio in dB. Elsewhere in this report this notation is used for other ratios, such as C/N and S/N.

where

C_u = carrier level on up-link dBW

Ptg = ground transmitter power dBW

G = ground antenna gain

G_t = is the satellite antenna gain.

In terms of Carrier-to-Noise ratio, Equation (2-9) is modified as follows:

$$(C/N)_u = [Ptg + G + G_t - \alpha - N] \text{ dB} \tag{2-10}$$

where

N = 10 log n in dBW

and

$n = kT B_{if}$

where

k = Boltzmann Constant 1.38×10^{-23} joules/°K

T = system noise temperature

2.1.2.2 Color TV Service

The TV performance using vestigial sideband amplitude and frequency modulation will be derived. Using these results the parameters for the earth terminals will be developed.

Vestigial sideband amplitude modulation will be used for UHF operation only (receive 818 to 890 MHz - transmit 1.5 to -.572 GHz). The audio program is on an FM subcarrier above the TV video information. The baseband frequency spectrum for TV video and TV audio is approximately 5 MHz.

FM operation will be used in the commercial satellite frequency bands (receive 3.7 to 4.2 GHz and transmit 5.925 to 6.425 GHz). A separate RF carrier for the TV video and program information is assumed. The audio (program) channel capacity is 24 voice channels (FDM/FM). The possibility of sending the program information above the video information via a subcarrier has not been considered; however, this approach should be considered, as it would eliminate an extra RF carrier. Use of the former approach is in accord with current INTELSAT practice.

Table 2-4 shows the TASO* TV performance for Service Grades 1 through 6. The table is based upon subjective evaluations by viewers observing a TV monitor.

Table 2-4. TASO TV Performance Characteristics*

Grade	Median Observer Signal-to-Interference Ratio (dB)	Impairment	Quality
1	44.5	None	Excellent
2	34	Perceptible	Fine
3	27	Not Objectionable	Passable
4	23	Somewhat Objectionable	Marginal
5	17	Definitely Objectionable	Inferior
6	-	——	Unusable

*G.L. Fredendall and W.L. Behrend, "Picture Quality - Procedures for Evaluating Subjective Effects of Interference," Proc. IRE, Vol. 48, pp. 1030-1034; June, 1960.
C.E. Dean, "Measurements of the Subjective Effects of Interference in Television Reception," Proc. IRE, Vol. 48, pp. 1035-1049; June, 1960.

For reception to cable heads (CATV) or interfacing with terrestrial microwave links for TV distribution, a peak-to-peak signal-to-rms noise ratio $(S/N)_O$ of 53dB has been selected as a representative value. This value allows for noise degradation by the terrestrial equipment, thus making it possible for the user to receive Grade 1 performance. The demodulated baseband of the earth station has a format similar to that which is currently used in terrestrial microwave terminals.

For reception directly to the home, a peak-to-peak signal-to-rms noise ratio $(S/N)_O$ of 33dB has been selected as a representative value, thereby making possible Grade 3 or better performance to the user.

The preamplifier used in the satellite is a TDA. A representative system noise temperature of 1000° Kelvin (30 dB) will be assumed.

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*Television Allocations Study Organization.

Equation (2-10) will be used in calculating the earth terminal transmission (transmitter) requirements.

a. Vestigial Sideband Amplitude Modulation (VSAM)

(1) TV Video Reception (818 to 890 MHz)

The VSAM equation for TV video reception is:

$$(S/N)_o = \frac{W}{K}\left(\frac{C}{N}\right) = \frac{1}{K}\,\frac{C}{kT\,B_{if}}\,W \text{ (for high C/N ratio case)} \quad (2\text{-}11)$$

where

$(S/N)_o$ = output peak-to-peak signal-to-rms noise in dB

K = constant which depends on the detector efficiency and fade margin (assume K = 6 dB)

T = Equivalent receive temperature °Kelvin

k = Boltzmann constant 1.38×10^{-23} joules/°K (-228.4 dBW)

C = receiver rms carrier in dBW

B_{if} = IF Bandwidth (1.25 fm) ≈ 6 MHz (nominal television bandwidth with video and TV audio); fm ≈ 4.8 MHz upper baseband frequency

W = crest factor for the video carrier - peak-to-peak to rms (assume = 9 dB)*

∴ Substituting in Equation (2-11) and converting to dB yields:

$$(S/N)_o = \left(\frac{C}{T} - K + W + 160.4\right) \text{dB} \quad (2\text{-}12)$$

But

K = 6 dB and W = 9 dB.

*W can vary from 9 to 13 dB, since the signal exhibits noise-like characteristics.

Therefore:

$$(S/N)_o = \frac{C}{T} + 163.4 \qquad (2\text{-}13)$$

Only $(S/N)_o = 53$ dB and $(S/N)_o = 33$ dB are considered. Calculation of the carrier-to-total noise temperature ratio (C/T — dBW/°K) using Equation (2-13) yields Table 2-5.

Table 2-5. VSAM Performance C/T Ratio for $(S/N)_o = 53$ dB and 33 dB

	$(S/N)_o = 53$ dB	$(S/N)_o = 33$ dB
C/T dBW/°K	-110.4	-130.4

EIRP versus G/T ratio at 850 MHz is calculated for the two $(S/N)_o$'s using Equation (2-8), which is repeated here:

$$\text{EIRP} = [(\alpha + C/T) - G/T]\ \text{dBW}, \qquad (2\text{-}14)$$

where

$$\alpha = 183 \text{ dB @ 850 MHz (From Table 2-1.)} \qquad (2\text{-}15)$$

Therefore, we obtain Table 2-6.

Table 2-6. The Equations of EIRP as Function of G/T Using $(S/N)_o$ as a Fixed Parameter (VSAM)

Frequency of Operation	$(S/N)_o = 53$ dB	$(S/N)_o = 33$ dB
850 MHz	EIRP = (72.6 - G/T) dBW	EIRP = (52.6 - G/T) dBW

Using the equations derived in Table 2-6, the required EIRP for various G/T ratios for both $(S/N)_o$'s can be calculated. Tables 2-7 and 2-8 are sample calculations at 850 MHz. Graphical presentations of these tables are shown in Figures 2-1 and 2-2. These figures illustrate the system trade-offs between EIRP and G/T for the given grades of performance.

The earth station low-noise receivers (LNR) considered in the calculations were uncooled parametric amplifiers and TDA's.

Table 2-7. Performance VSAM @ 850 MHz
$(S/N)_o$ = 53 dB for C/T = 110.4 dBW/°K
EIRP = (72.6 - G/T) dBW

EIRP dBW	Antenna Diameter ft	Gain* eff. = 68% dB	Effective Noise Temp. °K	G/T** dB/°K	Remarks
50.1	85	45.5	200 °K (23 dB)	22.5	Uncooled Paramp
53.1	60	42.5	200 °K (23 dB)	19.5	Uncooled Paramp
56.6	40	39.0	200 °K (23 dB)	16.0	Uncooled Paramp
59.1	30	36.5	200 °K (23 dB)	13.5	Uncooled Paramp
65.1	15	30.5	200 °K (23 dB)	7.5	Uncooled Paramp
55.1	85	45.5	630 °K (28 dB)	17.5	TDA
58.1	60	42.5	630 °K (28 dB)	14.5	TDA
61.6	40	39.0	630 °K (28 dB)	11.0	TDA
64.1	30	36.5	630 °K (28 dB)	8.5	TDA
70.1	15	30.5	630 °K (28 dB)	2.5	TDA

*From Table 2-2
**From Table 2-3

Table 2-8. Performance VSAM @ 850 MHz
$(S/N)_o$ = 33 dB for C/T = 124.4 dBW/°K
EIRP = (52.6 - G/T) dBW

EIRP dBW	Antenna Diameter ft	Gain* eff. - 68% dB	Effective Noise Temp. °K	G/T** dB/°K	Remarks
30.1	85	45.5	200 °K (23 dB)	22.5	Uncooled Paramp
33.1	60	42.5	200 °K (23 dB)	19.5	Uncooled Paramp
36.6	40	39.0	200 °K (23 dB)	16.0	Uncooled Paramp
39.1	30	36.5	200 °K (23 dB)	13.5	Uncooled Paramp
35.1	15	30.5	200 °K (23 dB)	7.5	Uncooled Paramp
35.1	85	45.5	630 °K (28 dB)	17.5	TDA
38.1	60	42.5	630 °K (28 dB)	14.5	TDA
41.6	40	39.0	630 °K (28 dB)	11.0	TDA
44.1	30	36.5	630 °K (28 dB)	8.5	TDA
50.1	15	30.5	630 °K (28 dB)	2.5	TDA
59.6	5	21.0	630 °K (28 dB)	-7.0	TDA

*From Table 2-2
**From Table 2-3

SATELLITE EIRP VS. G/T RATIOFOR TV RECEPTION USING VESTIGIAL SIDEBAND AMPLITUDE MODULATION (VSAM)
NOTE: ONE CURVE DESCRIBES THE USE OF BOTH UNCOOLED PARAMP (T 200°K) AND TDA (T 630°K).

The T's are system noise temperatures.

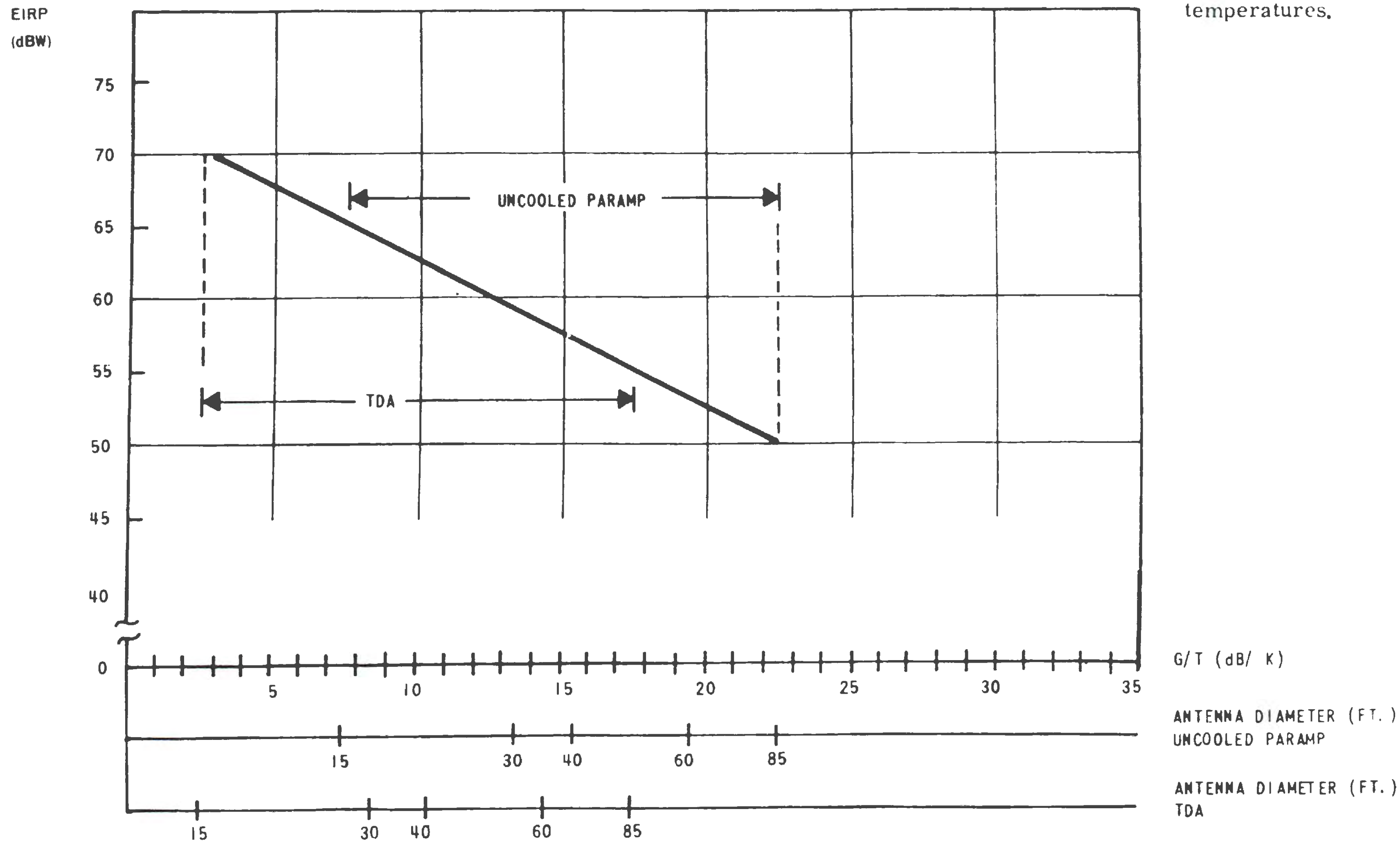

Figure 2-1. EIRP Versus G/T-VSAM @ 850 MHz, $(S/N)_O = 53$ dB

SATELLITE EIRP VS. G/T RATIO FOR TV RECEPTION USING VESTIGIAL SIDEBAND AMPLITUDE MODULATION (VSAM)
NOTE: ONE CURVE DESCRIBES THE USE OF BOTH UNCOOLED PARAMP (T 200° K) AND TDA (T = 630° K).

The T's are system noise temperatures.

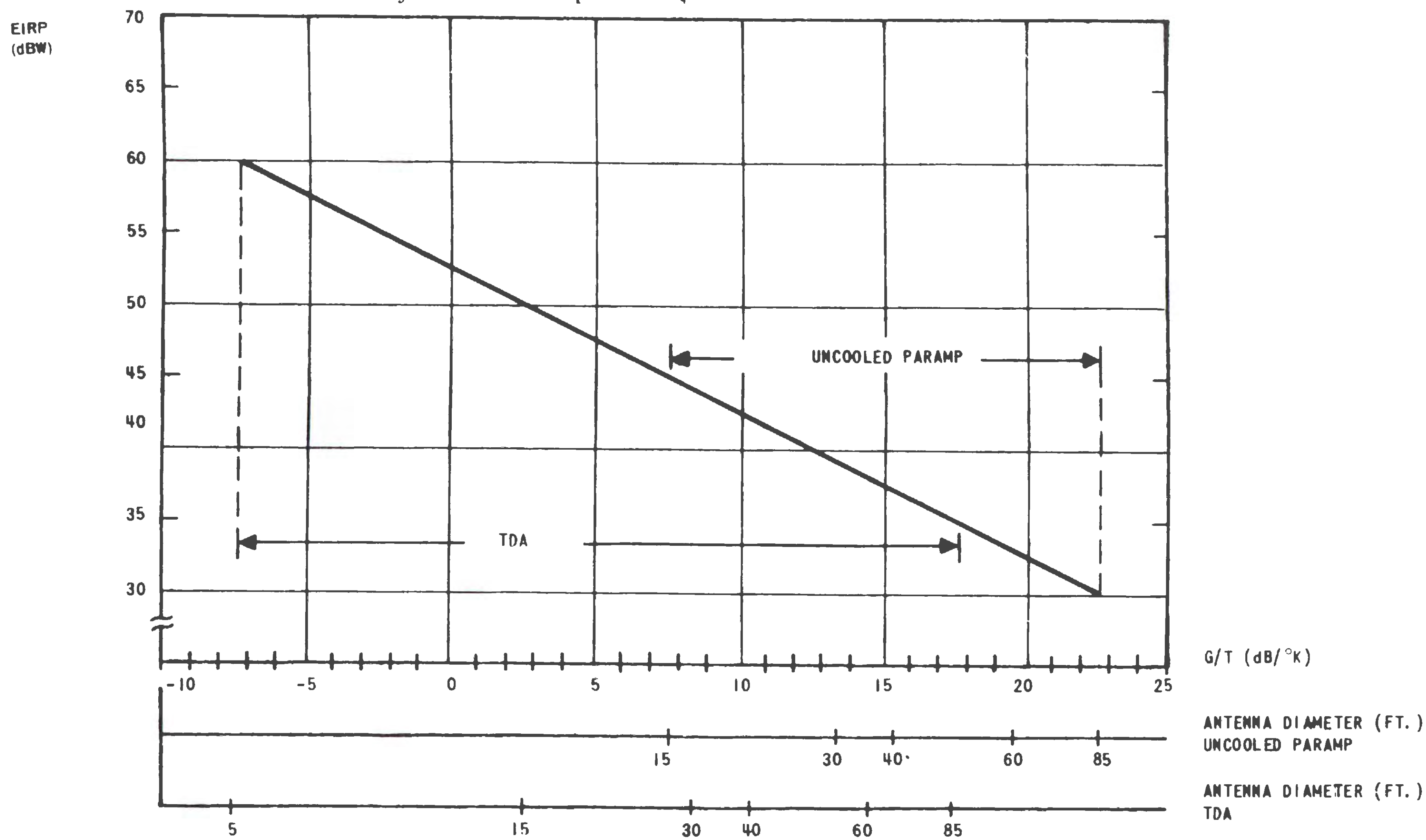

Figure 2-2. EIRP Versus G/T-VSAM @ 850 MHz, $(S/N)_o$ = 33 dB

(2) TV Audio Reception

The TV Audio information is transmitted on an FM subcarrier at 4.5 MHz. Assume that the subcarrier FM deviation is 100 kHz peak-to-peak, and that the highest audio frequency is 15 kHz. Furthermore, assume that the first demodulation is linear, and that the TV audio is separated from the composite baseband (TV video and TV audio) via a bandpass filter located at 4.5 MHz with a bandwidth of 250 kHz nominal, followed by an FM demodulator (limiter discriminator). Then the signal-to-noise ratio of the demodulated audio is given by the following equation:

$$(S/N) = \left(\frac{C}{N}\right)' \left(\frac{B_{if}}{B_{if_2}}\right) \frac{3}{2} \left(\frac{f}{f_m}\right)^2 \left(\frac{B_{if_2}}{f_m}\right) \qquad (2\text{-}16)$$

where

(S/N) = output signal-to-rms noise

f = 25 kHz peak deviation

f_m = 15 kHz

B_{if_2} = 100 kHz (post second predetection bandwidth)

B_{if} = 6 MHz (post predetection bandwidth VSM detector)

$(C/N)'$ = rms carrier-to-rms noise ratio

Converting Equation (2-16) into decibels we obtain:

$$(S/N)_{audio} = \left(\frac{C}{N}\right)' \text{dB} + 10 \log\left(\frac{3}{2}\right) + 20 \log\left(\frac{f}{f_m}\right) + 10 \log\left(\frac{B_{if}}{f_m}\right) \qquad (2\text{-}17)$$

Solving the above equation for $(S/N)_{audio}$ in terms of $(C/N)'$ and using the above values for f, f_m, and B_{if}, we obtain:

$$(S/N)_{audio} = (C/N)' \text{ dB} + 32.2 \text{ dB} \qquad (2\text{-}18)$$

This equation can be related to the $(S/N)_{o\ video}$ as follows:

$$(C/N)' = (C/N) \text{ dB} - 9 \text{ dB*} \qquad (2\text{-}19)$$

---

*Peak-to-peak-to-rms signal ratio (crest factor).

But from Equation (2-11), we have:

$$(S/N)_{o\ video} = C/N + 3\ dB$$

Using Equation (2-19) and the above equation, we can solve for (C/N)':

$$(C/N)' = (S/N)_{o\ video} - 12\ dB.$$

Using Equation (2-18), we obtain:

$$(S/N)_{audio} = (S/N)_{o\ video} + 20.2\ dB \qquad (2-20)$$

Obviously, the $(S/N)_o$ video is the parameter of greater concern, since $(S/N)_{audio}$ exceeds $(S/N)_{o\ video}$ by a considerable amount (+20.2 dB). Thus, in specifying the model parameters for receive and transmit earth stations, we shall concern ourselves only with the TV video performance.

(3) TV Transmission (1.5 to 1.572 MHz)

The equation relating ground terminal transmitter power (P_{tg}) versus ground and satellite antenna gain will be derived.

Converting Equation (2-11) to dB, we obtain:

$$(S/N)_o = [W - K + C/N]\ dB \qquad (2-21)$$

But

$$(S/N)_o = 53\ dB \text{ and } W\text{-}K = 3\ dB$$

Therefore

$$(C/N)_D = 50\ dB \text{ (down-link)}$$

However, since we are concerned with the up-link carrier-to-noise ratio $(C/N)_U$, an additional 10 dB will be added to $(C/N)_D$. Thus

$$(C/N)_U = (C/N)_D + 10\ dB \qquad (2-22)$$

or

$(C/N)_U$ = 60 dB (the received carrier-to-noise ratio at the satellite receiver input.)

The effect of adding the 10 dB to $(C/N)_D$ is to minimize the thermal noise contribution of the up-link path (ground to the satellite).

Equation (2-10) is repeated here:

$$(C/N)_U = \left[P_{tg} + G + G_t - \alpha - N \right] \text{dB}$$

But

$$N = 10 \log n = -130.6 \text{ dBW},$$

where

$$n = kTB_{if} \text{ but } (B_{if} = 6 \text{ MHz})$$

$$(T = 1000\,°K)^*$$

and

$$\alpha = 188 \text{ dB @ } 1.54 \text{ GHz (From Table 2-1.)}$$

Thus solving for P_{tg} and substituting the known values, we obtain:

$$P_{tg} = [\,117.4 - (G + G_t)\,] \text{ dBW} \tag{2-23}$$

Equation (2-23) shows the system trade-off between P_{tg} and the hop (up-link) antenna gains $(G + G_t)$

b. Frequency Modulation

(1) TV Video Reception (3.7 to 4.2 GHz)

The FM equation for TV video reception is:

$$(S/N)_o = \frac{C}{N}\,\frac{3}{2}\left(\frac{f_p}{f_m}\right)^2 \left(\frac{B_{if}}{f_m}\right) \text{ WP} \tag{2-24}$$

*System noise temperature of the satellite receiver.

where

$(S/N)_o$ = peak-to-peak signal-to-rms noise in dB

f_p = peak frequency deviation MHz

f_m = nominal television bandwidth--assume 4.5 MHz

C = RF carrier level in dBW

k = Boltzmann's constant 1.38×10^{-23} joules/°K (-228.4 dBW)

T = equivalent receive temperature °Kelvin

W = relationship between peak-to-peak and rms signal, 13 dB*

P = emphasis, +3 dB

B_{if} = $2 (f_p + f_m)$--Predetection IF bandwidth (Carson's Rule)

N = kTB_{if} - Boltzmann's Equation

Since a conventional FM demodulator is assumed, the validity of Equation (2-24) depends on carrier-to-noise ratio (C/N) exceeding 10 dB, which is the typical FM threshold point. Therefore, C/N = 16 dB will be assumed, allowing for 4 to 6 dB of rain margin.

Only TV distribution ($(S/N)_o$ = 53 dB) will be considered here. Using this assumption, the peak deviation f_p will be calculated for this grade of service.. Knowing the peak deviation, the IF bandwidth B_{if} and the C/T ratio can be derived.

To simplify the calculation and the solving of a cubic equation, the following assumption will be made:

$$B_{if} \approx 2 f_p$$

$$\therefore \quad (S/N)_o \approx \frac{C}{N} \, 3 \left(\frac{f_p}{f_m}\right)^3 WP \qquad (2\text{-}25)$$

*W can vary from 9 to 13 dB, since the signal exhibits noise-like characteristics.

Let $M = \left(\frac{f_p}{f_m}\right)$ modulation index

Thus, converting Equation (2-25) to dB, and solving for M, we get:

$$10 \log M^3 = (S/N)_o \text{ dB} - \left(\frac{C}{N}\right) \text{dB} - 10 \log 3 - 16 \text{ dB} \qquad (2\text{-}26)$$

For Grade 1, C/T = ?

Using Equation (2-26) and $(S/N)_o = 53$ dB we obtain:

$$10 \log M^3 = 16 \text{ dB}$$

$$M^3 = 40$$

$$\therefore M = 3.42 = \left(\frac{f_p}{f_m}\right)$$

Solving for f_p

$$f_p = 3.42 \times 4.5 = 15.2 \text{ MHz}$$

$$\therefore B_{if} = 2(15.2 + 4.5) = 39.4 \text{ MHz}$$

B_{if} = 40 MHz* and f_p = 15.2 MHz* will be used.

Thus

$$C/T = [C/N + 10 \log kB_{if}] \text{ dBW/°K}$$

$$C/T = -136.4 \text{ dBW/°K}$$

Substituting the calculated value for (C/T) in Equation (2-7) and referring to Table 2-1 for the path loss (α), the equation relating satellite EIRP versus G/T ratio is now developed. (See Table 2-9).

---

*Substitution of these assumed values into Equation (2-24) yields $(S/N)_o = 52.6$ dB $\approx$ 53 dB.

Table 2-9. Satellite EIRP as Function of G/T at 4 GHz for $(S/N)_o$ = 53 dB

Frequency of Operation	$(S/N)_o = 53$ dB
4 GHz	EIRP = $(60.6 - \frac{G}{T})$ dBW

Table 2-10 is a sample calculation performed at 4 GHz for $(S/N)_o = 53$ dB using the equation contained in Table 2-9.

A graphical presentation of Table 2-10 is shown in Figure 2-3. This figure illustrates the system trade-off between Satellite EIRP and G/T for the given grade of performance.

The figure also shows the maximum flux density allowed by current CCIR Standards (Recommendation 358, Oslo 1966). *

(2) <u>TV Audio Reception (3.7 to 4.2 GHz)</u>

A separate RF carrier for TV audio (program) is assumed. Its capacity is equivalent to 24 voice channels, and its performance requirements are discussed in Paragraph 2.1.2.3.a.

In Paragraph 2.1.2.3.a, it will be shown that the C/T ratio for audio is much lower than that for the TV video; hence, it will require a lower satellite EIRP. The TV video requirements will thus predominate in the choice of antenna size and low noise receiver type.

(3) <u>TV Video Transmission (5.925 - 6.425 GHz)</u>

The equation relating ground station transmitter power (P_{tg}) versus total (station plus satellite) antenna gain ($G + G_t$) will be derived.

In order to minimize the thermal contribution of the up-link path (ground to the satellite), 10 dB will be added to the carrier-to-noise ratio $(C/N)_D$ used in the down-link calculation (satellite to the ground). Therefore,

$$(C/N)_U = (C/N)_D + 10 \text{ dB} \qquad (2\text{-}27)$$

*For a 5° elevation angle at synchronous orbit the maximum flux density = 9.9 dBW/4kHz. For $(S/N)_o$ = 53 dB, flux density = 49.9 dBW/40 MHz

where

$(C/N)_U$ = up-link carrier-to-noise ratio at the satellite receiver input.

But

$(C/N)_D$ = 16 dB (value used in paragraph 2.1.2.2.b(1))

Therefore, substituting in Equation (2-27), we obtain:

$(C/N)_U$ = 26 dB

Equation (2-10) is repeated here:

$$(C/N) = \left[P_{tg} + G + G_t - \alpha - N \right] \text{ dB}$$

But

N = 10 log n

where

n = kT B_{if} (B_{if} = 40 MHz)
(T = 1000° K)

$\therefore N$ = -122.4 dBW

and

α = 200 dB @ 6 GHz (From Table 2-1)

Thus, solving for P_{tg} and substituting the above values into the Equation (2-10), we obtain:

$$P_{tg} = \left[103.6 - (G + G_t) \right] \text{ dBW} \tag{2-28}$$

Equation (2-28) shows the system trade-off between P_{tg} and the hop (up-link) antenna gains $(G + G_t)$.

Table 2-10. Performance FM Video @ 4 GHz; $(S/N)_o$ = 53 dB for C/T - 136.4 dBW/°K; EIRP = (60.6 - G/T) dBW

EIRP dBW	Antenna Diameter ft	Gain * eff. = 68% dB	Effective Noise Temp. °K	G/T** dB/°K	Remarks
24.6	85	59.0	200°K (23 dB)	36.0	Uncooled Paramp
27.6	60	56.0	200°K (23 dB)	33.0	Uncooled Paramp
31.1	40	52.5	200°K (23 dB)	29.5	Uncooled Paramp
33.6	30	50.0	200°K (23 dB)	27.0	Uncooled Paramp
39.6	15	44.0	200°K (23 dB)	21.0	Uncooled Paramp
45.1	8	38.5	200°K (23 dB)	15.5	Uncooled Paramp
29.6	85	59.0	630°K (28 dB)	31.0	TDA
32.6	60	56.0	630°K (28 dB)	28.0	TDA
36.1	40	52.5	630°K (28 dB)	24.5	TDA
38.6	30	50.0	630°K (28 dB)	22.0	TDA
44.6	15	44.0	630°K (28 dB)	16.0	TDA
50.1	8	38.5	630°K (28 dB)	10.5	TDA

*From Table 2-2
**From Table 2-3

(4) TV Audio Transmission (5.925 to 6.425 GHz)

A separate RF carrier is postulated for the transmission of the audio information. Its capacity is 24 voice channels and its allocated spectrum bandwidth is 3 MHz (from the analysis in Section 2.1.2.3.)

The T's are system noise temperatures.

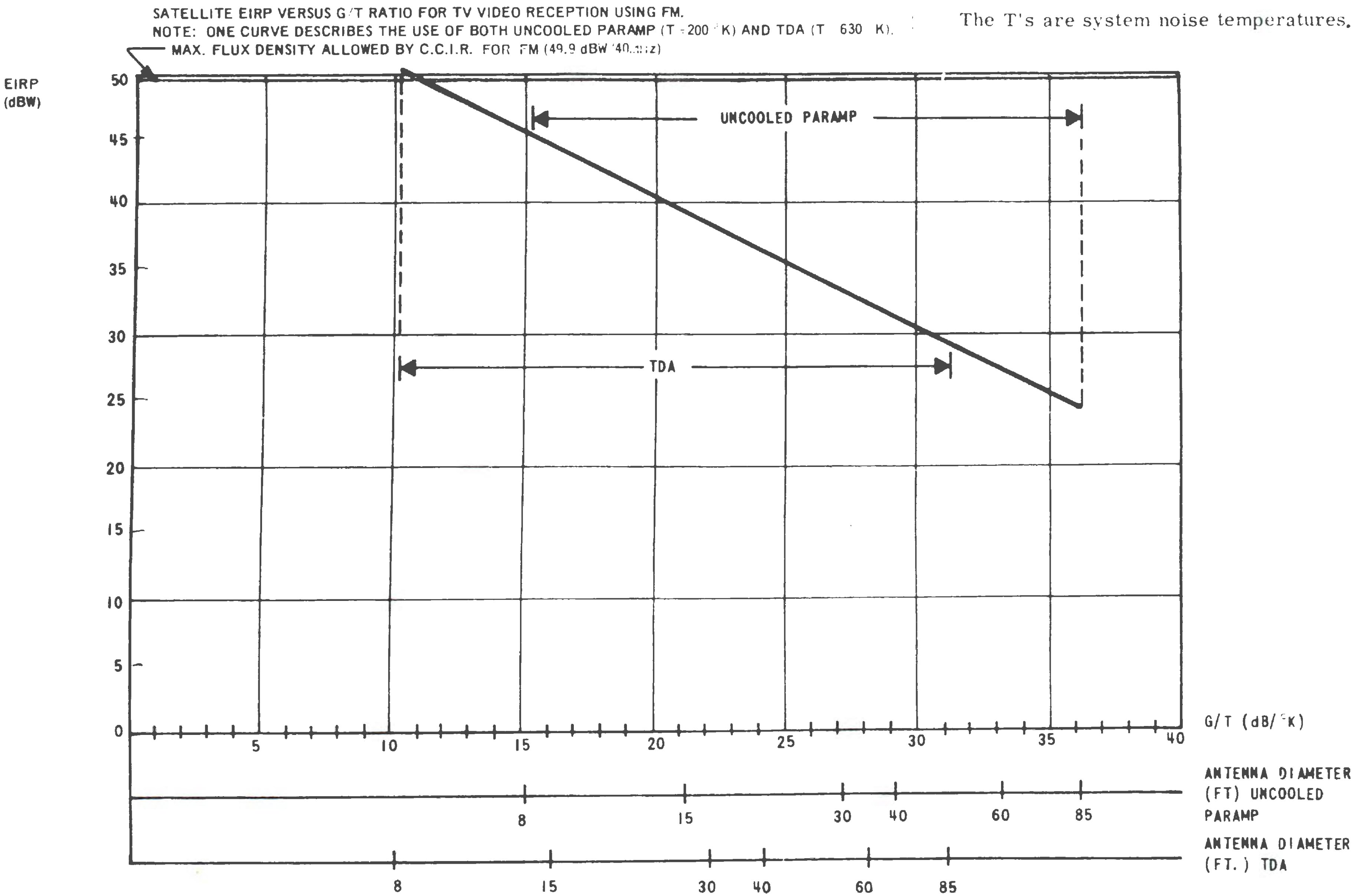

Figure 2-3. EIRP Versus G/T-FM Video @ 4 GHz, $(S/N)_o$ = 53 dB

Performing a calculation similar to what was performed previously in Paragraph 2.1.2.2.b (3) of this Section, the Equation (2-28) is modified. We obtain:

$$P_{tg} = \left[91.4 - (G + G_t) \right] \text{ dBW} \qquad (2\text{-}29)$$

A common antenna and high power amplifier (HPA) are used for transmission for the TV Video and TV Audio Information. Examination of Equations (2-28) and (2-29) reveals that the TV video requirements predominate, and thus it dictates the choice of antenna size and HPA power output.

2.1.2.3 Communications Service

The Satellite Communications Service has duplex capability, as opposed to the Broadcast Service, which is one-way.

Frequency Modulation is used for both Preassigned and Demand-Assigned operation. The commercial satellite frequency bands (receive 3.7 to 4.2 GHz and transmit 5.925 to 6.425 GHz) will be used in the analysis. Also, only conventional (limiter-discriminator) demodulators are considered. The per-channel test tone deviation used will be 200 kHz rms maximum. This deviation used complements current CCIR standards for Terrestrial LOS Microwave links using FDM/FM. Therefore, in the case of FDM/FM, the effect will be a "softer" modulation as compared to current ICSC deviation requirements.

The Preassigned Model will use FDM/FM modulation with 24, 60, 132, 300 and 600 voice capacity per RF carrier. In the calculations that follow, the output signal-to-noise ratio (S/N) in an FDM/FM voice channel will be of toll quality (52 to 53 dB psophometrically weighted).

The Demand-Assigned Model will use a separate carrier for each voice channel. The modulation technique used is SCC/FM*. An RF spectrum of 100 kHz will be assigned to each message carrier. The (S/N) will be of toll quality.

The performance parameters and trade-offs, C/T versus number of voice channel, satellite EIRP versus G/T, earth station transmitter power versus total system antenna gain, etc. for both models will be calculated and used in the development of the specific earth station models. In connection with the Demand Assigned, only the analog voice channel will be analyzed.

---

*Single Channel Carrier/Frequency Modulation

a. Preassigned

(1) FDM/FM Reception (Down-Link) (3.7 to 4.2 GHz)

(a) Performance - Message Calculation

The FM equation as simplified for narrowband systems is

$$(S/N) = \frac{C}{N} \left(\frac{d\ rms}{f\ max} \right)^2 \quad \frac{B_{if}}{bc} \ WP \qquad (2\text{-}30)$$

where

(S/N)	=	signal-to-rms noise ratio
D	=	peak deviation kHz
drms	=	rms single channel deviation
(C/N)	=	carrier-to-noise ratio in dB
fmax	=	maximum modulation frequency (kHz)
B_{if}	$\approx$	2 (D + f_m) MHz
bc	=	voice channel bandwidth (3.1 kHz)
W	=	psophometric weighting factor (+2.5 dB)
P	=	emphasis (+4 dB)
L	=	CCIR loading plus peak factor

Expressing Equation (2-31) in dB form, we obtain

$$(S/N)\ dB = \left(\frac{C}{N} \right) dB + 20 \log \left(\frac{d\ rms}{f\ max} \right) + 10 \log \left(\frac{B_{if}}{bc} \right) + W + P \qquad (2\text{-}31)$$

The following is assumed:

(S/N) dB	$\geq$	52 dB (PSO)
peak factor	=	13 dB
drms	=	200 kHz for n = 60, 132, 300, or 600 voice channels
drms	=	140 kHz for 24 voice channels

Using Equation (2-31) and the above assumptions, the peak factor, the IF bandwidth (B_{if} nominal), the carrier-to-noise ratio (C/N), and the C/T ratio have been determined and tabulated (See Table 2-11).

(b) Satellite EIRP Requirements Per RF Carrier

Substituting the calculated values for (C/T) (see Table 2-11) into Equation (2-7) and referring to Table 2-1 for the path loss (α), the equations relating EIRP versus G/T ratio are developed, (refer to Table 2-12).

Table 2-13 contains sample calculations of satellite EIRP versus (G/T) for 24, 132, and 600 voice channels using the equations listed in Table 2-12.

A graphical presentation of Table 2-13 is shown in Figure 2-4. This Figure illustrates the system trade-offs between EIRP and G/T, using uncooled parametric amplifiers and TDA's.

Figure 2-4 also shows the maximum flux density allowed by current CCIR Standards* (Recommendation 358, Oslo 1966).

(2) FDM/FM Transmission (Up-Link) (5.925 to 6.425 GHz)

The equations relating ground station transmitter power (P_{tg}) versus total antenna gain (Terminal (G) plus Satellite (G_t)) will be derived.

In order to minimize the thermal contribution of the up-link path (ground to the satellite), 10 dB will be added to the carrier-to-noise ratio $(C/N)_D$ used in the down-link calculation (Satellite to the ground).

Therefore, repeating Equation (2-27), we have:

$$(C/N)_U = (C/N)_D + 10 \text{ dB},$$

*For a 5° elevation angle at synchronous orbit the maximum flux density = 9.9 dBW/4 kHz, or

For n	=	24 voice channels
flux density	=	38.7 dBW/3 MHz
n	=	132 voice channels
flux density	=	42.2 dBW/7 MHz
n	=	600 voice channels
flux density	=	45.6 dBW/15 MHz

Table 2-11. FDM/FM Message Performance @ 4 GHz

Carrier Capacity Voice Channels	24	60	132	300	600
Baseband Frequency Range in kHz	12-108	12-252	12-552	60-1300	60-2600
Multichannel Loading, dB (CCIR)*	4.5	6.1	7.5	9.7	13
Peak Loading L = CCIR Loading +13 dB	17.5 dB (7.5)	19.1 dB (9)	20.5 dB (10.5)	22.7 dB (12.6)	26 dB (20)
4 kHz rms deviation in kHz (drms)	140	200	200	200	200
Peak Carrier Deviation in kHz (f x antilog $\frac{L}{20}$)	±1050	±1800	±2100	±2500	±4000
B_{if} in MHz Nominal	3.0	5.0	7.0	10	15
$20 \log \left(\frac{drms}{fm}\right)$, dB	2.0	-2.0	-9	-16.3	-22
$10 \log \left(\frac{Bif}{bc}\right)$, dB	29.8	32	34	35	37
(C/N), dB	13.7	15.5	20.5	26.8	31.5
will use (C/N) dB	15	16	21	27	31.5
(S/N) (PSO) dB	53	52.5	52.5	52.2	53
C/T dBW/^{o}K	-148.4	-145.4	-138.9	-131.4	-124.9

*It is recognized that future traffic trends will show a substantial increase in digital data traffic for both domestic and international communications links. Thus, modification to the loading factor is anticipated.

Table 2-12. FDM/FM Message Performance @ 4 GHz

Satellite EIRP as a Function of G/T
For 4 GHz and (S/N) = 52 to 53 dB (PSO)

No. of Voice Channels	C/T dBW/°K	α @4 GHz dB	Equation
24	-148.4	197	EIRP = (48.6 - G/T) dBW
60	-145.4	"	EIRP = (51.6 - G/T) dBW
132	-138.9	"	EIRP = (58.1 - G/T) dBW
300	-131.4	"	EIRP = (65.6 - G/T) dBW
600	-124.9	"	EIRP = (72.1 - G/T) dBW

where

$(C/N)_U$ = Up-link carrier-to-noise ratio at the satellite receiver input

Table 2-14 is the tabulation of $(C/N)_U$ as a function of voice channel loading using the above equation (2-27) (Table 2-11 was used in finding the values for $(C/N)_D$).

Equation (2-10) is repeated here:

$$(C/N)_U = \left[P_{tg} + G + G_t - \alpha - N \right] \text{ dB},$$

where

$$N = 10 \log kT^* B_{if}$$

and

$$\alpha = 200 \text{ dB @ 6 GHz (From Table 2-1).}$$

*Assume T = 1000°K of the Satellite

Table 2-13. FDM/FM Performance (Preassigned Operation)
(S/N) = 52 to 53 dB @ 4 GHz

n = 24 VC EIRP = (48.6 - G/T) dBW
n = 132 VC EIRP = (58.1 - G/T) dBW
n = 600 VC EIRP = (72.1 - G/T) dBW

EIRP dBW n=24	132	600	Antenna Diameter ft	Gain* $\eta = 68\%$	System Noise Temp.	G/T** dB/°K	Remarks
12.6	22.1	36.1	85	59.0	200°K (23 dB)	36.0	Uncooled Paramp
15.6	25.1	39.1	60	56.0	200°K (23 dB)	33.0	Uncooled Paramp
19.1	28.6	42.6	40	52.5	200°K (23 dB)	29.5	Uncooled Paramp
21.6	31.1	45.1	30	50.0	200°K (23 dB)	27.0	Uncooled Paramp
27.6	37.1	51.1	15	44.0	200°K (23 dB)	21.0	Uncooled Paramp
33.1	42.6	56.6	8	38.5	200°K (23 dB)	15.5	Uncooled Paramp
17.6	27.1	41.1	85	59.0	630°K (28 dB)	31.0	TDA
20.6	30.1	44.1	60	56.0	630°K (28 dB)	28.0	TDA
24.1	33.6	47.6	40	52.5	630°K (28 dB)	24.5	TDA
26.6	36.1	50.1	30	50.0	630°K (28 dB)	22.0	TDA
32.6	42.1	56.1	15	44.0	630°K (28 dB)	16.0	TDA
38.1	47.6	61.6	8	38.5	630°K (28 dB)	10.5	TDA

* From Table 2-2
**From Table 2-3

NOTE: ONE CURVE DESCRIBES THE USE OF BOTH UNCOOLED PARAMP (T=200°K) AND TDA (T=630°K)
The T's are system noise temperatures.

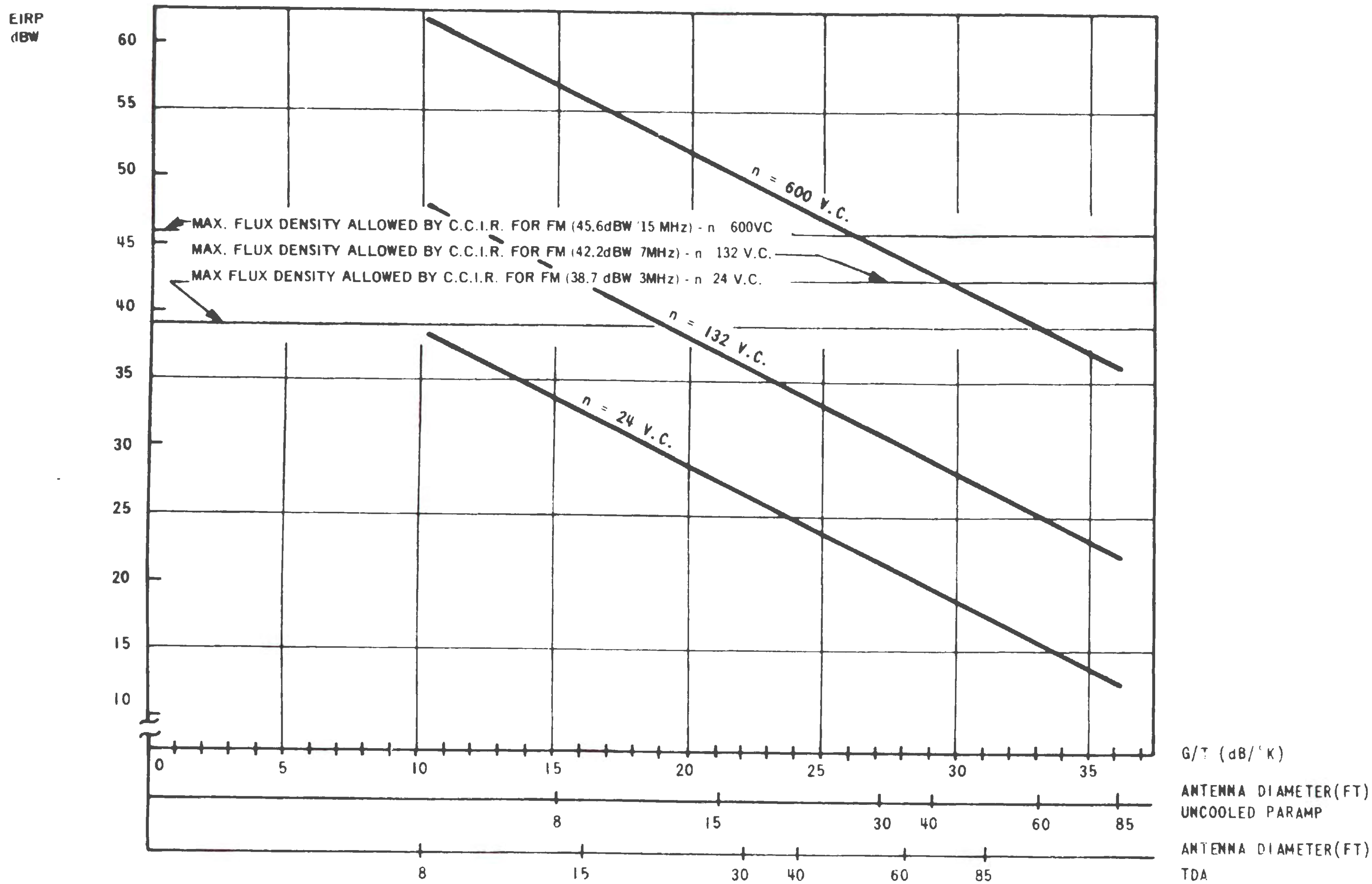

Figure 2-4. EIRP Versus B/T for FDM/FM Reception Using Various Voice Channel Loadings

Table 2-14. FDM/FM Message Performance
Carrier-to-Noise Ratio Up-Link
$(C/N)_U$ Versus Voice Channel Loading (N)

	Number of Voice Channels				
	24	60	132	300	600
$(C/N)_U$ dB	25	26	31	37	41.5

Using the above equation, the value of α (path loss), the values of $(C/N)_U$ tabulated in Table 2-14, and the calculated values of B_{if} (Table 2-11), the equations relating P_{tg} to the total antenna gain $(G + G_t)$ for the different noise channel loading are calculated (See Table 2-15).

Table 2-15. FDM/FM Message Performance
Station Transmitter Power (P_{tg}) Versus Total Antenna Gain
Function of Voice Channel Loading
@ 6 GHz

$$P_{tg} = \left[(C/N)_U + \alpha + N - (G + G_t)\right] \text{ dBW}$$

No. of Voice Channels	Equations
24	$P_{tg} = \left[\ 91.4 - (G + G_t)\right]$ dBW
60	$P_{tg} = \left[\ 94.6 - (G + G_t)\right]$ dBW
132	$P_{tg} = \left[101.0 - (G + G_t)\right]$ dBW
300	$P_{tg} = \left[108.6 - (G + G_t)\right]$ dBW
600	$P_{tg} = \left[114.3 - (G + G_t)\right]$ dBW

b. Demand-Assigned

(1) FM Reception (Down-Link) (3.7 to 4.2 GHz)

(a) Performance - One Voice Channel

The FM equation is:

$$(S/N) = (C/N)\left(\frac{f_p}{f_m}\right)^2 \frac{3}{2}\frac{B_{if}}{f_m} \quad WP, \qquad (2\text{-}32)$$

where

(S/N) = signal-to-rms noise ratio

f_p = peak deviation kHz

$(C/N)_D$ = carrier-to-noise ratio

f_m = maximum modulation frequency (kHz)

B_{if} ≈ $2\,(f_p + f_m)$ MHz

W = psophometric weighting factor (+2.5 dB)

P = emphasis = 0 dB

Expressing Equation (2-32) in dB form, we obtain

$$(S/N)\ dB = (C/N)_D\ dB + 20\log\left(\frac{f_p}{f_m}\right) + 10\log\left(\frac{B_{if}}{f_m}\right) + W + P + 10\log\left(\frac{3}{2}\right) \qquad (2\text{-}33)$$

Let

$(C/N)_D$ = 16 dB (provides a 6-dB fade margin)

B_{if} = 100 kHz*

---

* Includes frequency stability of local oscillators.

f_p = 30 kHz peak deviation

f_m = 4 kHz

Substituting the above values into Equation (2-32), the output signal-to-noise ratio is calculated.

$$(S/N) = 51.7 \text{ dB} \approx 52 \text{ dB}$$

(b) <u>Satellite EIRP Requirement</u>

The equation relating EIRP versus G/T ratio is:

$$\text{EIRP} = [\alpha + (C/T - G/T)] \text{ dBW (Equation (2-7))}$$

The path loss α = 197 dB @ 4GHz (From Table 2-1). The value of (C/T) is given by the following relationship:

$$(C/T) = (C/N)_D + 10 \log k B_{if} \quad (2\text{-}34)$$

But

$$(C/N)_D = 16 \text{ dB}$$

and

$$10 \log k B_{if} = -178.4 \text{ dBW } (B_{if} = 100 \text{ kHz})$$

$$\therefore (C/T) = -162.4 \text{ dBW/°K},$$

or

$$\text{EIRP} = (34.6 - G/T) \text{ dBW} \quad (2\text{-}35)$$

Equation (2-35) relates EIRP to G/T for S/N_o = 51.7 dB.

Table 2-17 contains a sample calculation of Equation (2-35) using uncooled parametric amplifiers or TDA.

A graphical presentation of Table 2-17 is shown in Figure 2-5. This Figure depicts the system trade-offs between satellite EIRP and G/T.

Table 2-16. Performance of SCC/FM (Demand-Assigned)

C/T = -155.4 dBW/°K @4GHz
Satellite EIRP = (34.6 - G/T)dBW

EIRP dBW	Antenna Diameter ft	Gain* $\eta = 68\%$ dB	System Noise Temp. °K	G/T** dB/°K	Remarks
-1.4	85	59.0	200°K (23 dB)	36.0	Uncooled Paramp
11.6	60	56.0	200°K (23 dB)	33.0	Uncooled Paramp
5.1	40	52.5	200°K (23 dB)	29.5	Uncooled Paramp
7.6	30	50.0	200°K (23 dB)	27.0	Uncooled Paramp
13.6	15	44.0	200°K (23 dB)	21.0	Uncooled Paramp
19.1	8	38.5	200°K (23 dB)	15.5	Uncooled Paramp
3.6	85	59.0	630°K (28 dB)	31.0	TDA
6.6	60	56.0	630°K (28 dB)	28.0	TDA
10.1	40	52.5	630°K (28 dB)	24.5	TDA
12.6	30	50.0	630°K (28 dB)	22.0	TDA
18.6	15	44.0	630°K (28 dB)	16.0	TDA
24.1	8	38.5	630°K (28 dB)	10.5	TDA

*From Table 2-2
**From Table 2-3

NOTE: ONE CURVE DESCRIBES THE USE OF BOTH UNCOOLED PARAMP ($T=200°K$) AND TDA ($T=630°K$).
The T's are system noise temperatures.

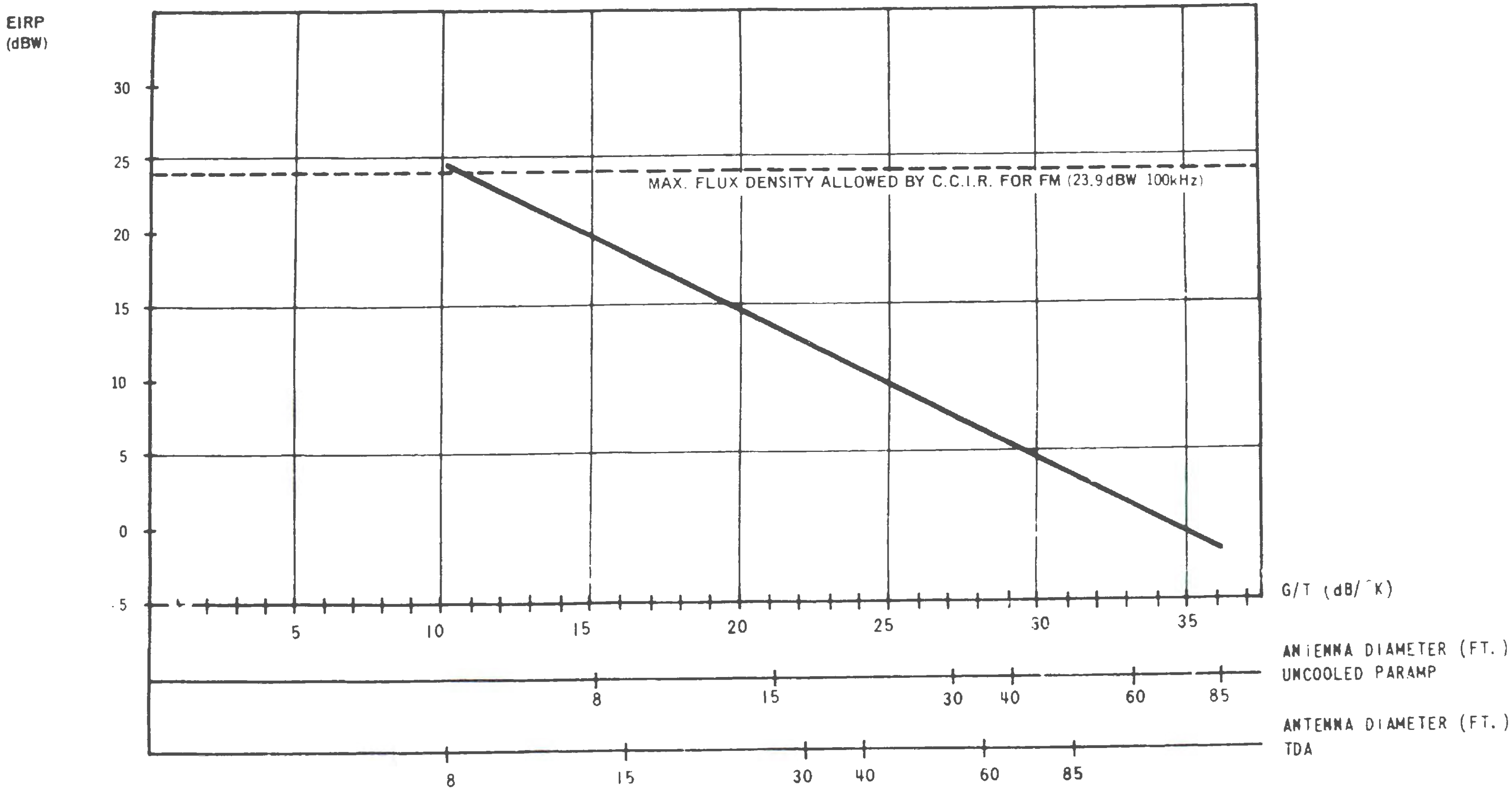

Figure 2-5. EIRP Versus G/T for FM Reception per RF Carrier for one Voice Channel (Demand-Assigned)

The Figure also shows the maximum flux density allowed by current CCIR Standards* (Recommendation 358, Oslo, 1966).

(2) FM Transmission - Up-Link (5925 to 6425 MHz)

The general equation relating ground station transmitter power P_{tg} to total system antenna gain (station (G) plus satellite (G_t) is:

$$P_{tg} = \left[(C/N)_U + \alpha + N - (G + G_t) \right] \quad \text{(From Equation (2-10)).}$$

But

$$(C/N)_U = (C/N)_D + 10 \text{ dB},$$

$$(C/N)_U = 26 \text{ dB},$$

$$\alpha = 200 \text{ dB @ 6 GHz (From Table 2-1), and}$$

$$N = 10 \log kT B_{if} = -148.4 \text{ dBW},$$

where

$$T = 1000°K \text{ (30 dB)},$$

$$B_{if} = 100 \text{ kHz, and}$$

$$10 \log k = -228.4 \text{ dBW}.$$

Therefore,

$$P_{tg} = [\ 77.6 - (G + G_t)\ ] \text{ dBW}. \qquad (2\text{-}36)$$

*For a 5° elevation angle at synchronous orbit, the maximum flux density =9.9 dBW/4kHz, or 23.9 dBW/100 kHz

2.2 EARTH STATION MODELS

The block diagrams and the tabulated performance characteristics for the various earth station models will be developed. The earth station models considered are:

a. Color TV Service

   (1) TV Reception

      (a) National Stations - multiple TV channels (FM and VSAM)
      (b) Regional Stations - single TV channel (FM and VSAM)
      (c) Direct service to the home (VSAM)

   (2) TV Transmission

      (a) Regional Stations (FM and VSAM)

b. Communications Service (Message Traffic)

   (1) Preassigned (FDM/FM)

      (a) Multi-Destination Carrier (MDC)
      (b) Single-Destination Carrier (SDC)

   (2) Demand-Assigned (FM - one RF Carrier per Channel) - for developed and developing nations.

The rationale used in the model development is:

a. For multipoint TV and Communications Services, the price of the earth stations must be reduced in order to decrease the total system cost. To effect this cost reduction, the Satellite Effective Isotropic Radiated Power must be increased sufficiently to minimize earth station G/T ratio for the given grade of service. The trade-off to find the optimum point between EIRP and G/T ratio of the earth stations is a study effort in itself and depends on the objectives of the particular system; it has not been considered herein.

b. The satellite(s) will provide U.S. continental coverage via multiple antenna beams. The increase in required Satellite Effective Isotropic Radiated Power (EIRP) will be achieved using greater satellite antenna gains rather than by means of kilowatt actual power. Satellite 3-degree time-zone coverage is assumed (antenna gain ≈ 34.6 dB).

c. The most expensive portions of current earth stations are: the antenna subsystems and associated tracking requirement; the cryogenically cooled low-noise receiver subsystems; the high-power amplifier subsystem; the interfacility link; and the multiplex equipment. It is in these areas that economies are initiated in the model development.

d. All models use small antennas (30 feet or less in diameter); the advantage is possible roof-top operation and minimum real estate requirements for antenna diameters (15 feet or less). The resulting broader antenna beams will result in minimal tracking requirements. All antennas considered are fixed-position ground antennas and have manual tracking capabilities (a number of discrete positions). The disadvantage of using smaller antennas, aside from the loss of gain, is the problem of interference that may result with both terrestrial microwave links and other satellites operating on the same frequencies. However, performance curves of EIRP versus G/T ratio for a particular grade of performance have been developed for each model system (Figures 2-1 through 2-5), thus allowing for system trade-off.

e. The frequencies used in the model developments are primarily the commercial satellite frequencies (receive - 3700 to 4200 MHz, and transmit - 5925 to 6425 MHz). For the case of Vestigial Sideband Amplitude Modulation (TV service), the frequencies used are: receive - 818 to 890 MHz, and transmit - 1.5 to 1.572 GHz. These frequencies have been selected for modeling only; other frequencies in the 0.8- to 10-GHz band are not precluded.

f. The modulation techniques employed in the models do not preclude the use of other modulation techniques, but are simply used as a basis for establishing a frame of reference. Regardless of which modulation technique is used, the antennas, low-noise receivers, and power amplifiers would not change markedly.

g. All receivers would use either uncooled parametric amplifiers, TDA's, or other RF low-noise amplifiers.

h. No threshold extension demodulators are required for FM demodulation, since higher satellite EIRP's are postulated.

i. The satellite transponder(s) has (have) an RF bandwidth exceeding 500 MHz, the exception being the systems which use Vestigial Sideband Amplitude Modulation.

2.2.1 Color TV Service

The TV performance parameters using vestigial sideband amplitude and frequency modulation have previously been derived (see paragraphs 2.1.2.2.a and b). The results will now be employed.

For reception to cable heads (CATV) or interfacing with terrestrial microwave links for TV distribution, a peak-to-peak signal-to-rms noise ratio $(S/N)_o$ of 53dB has been selected as a representative value. This value allows for noise degradation by the terrestrial equipment, thus making it possible for the user to receive Grade 1 performance. The demodulated baseband of the earth terminal has a format similar to that currently utilized in terrestrial microwave terminals.

For reception directly to the home, a peak-to-peak signal-to-rms noise ratio $(S/N)_o$ of 33dB has been selected as a representative value, thereby making possible Grade 3 or better performance to the user.

2.2.1.1 Vestigial Sideband Amplitude Modulation (VSAM)

a. <u>Reception (818 to 890 MHz*)</u>

(1) Regional and National Earth Stations - $(S/N)_o$ =53dB. Figures 2-6 and 2-7 are block diagrams of Vestigial Sideband Amplitude Modulation TV receive earth stations with RF protection. Both single (regional) and multicarrier (National) TV receive stations are shown.

The 30-foot diameter antenna, the redundant low-noise receiver (LNR), the power splitter, and the first mixer are all broadband (100 MHz or greater). The narrowband receiver that follows, as the name implies, is narrowband: it has a predetection bandwidth of 6 MHz. A double-heterodyne technique is depicted; the function of the first mixer is to allow for ease of tuning to any of 12 TV RF channels.

The format of the demodulated signal is an FDM signal with the TV video occupying a band from 20 Hz to 4.0 MHz, and the TV audio (program) on an FM subcarrier at approximately 4.5 MHz.

The reception characteristics of the model systems are represented in Table 2-17.

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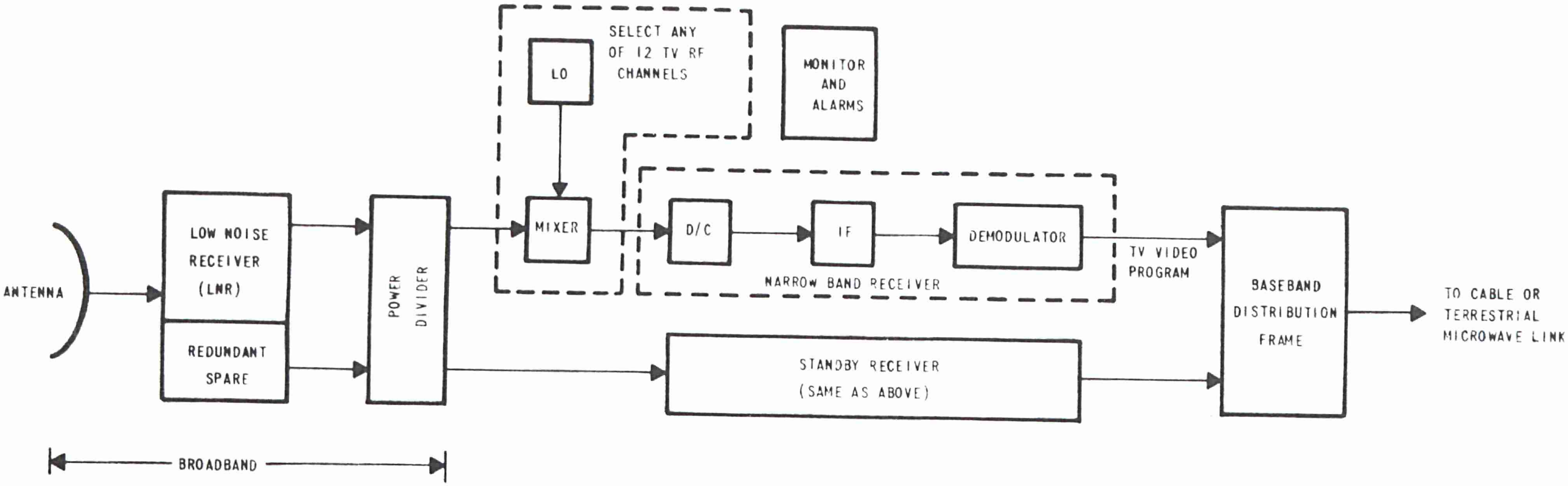
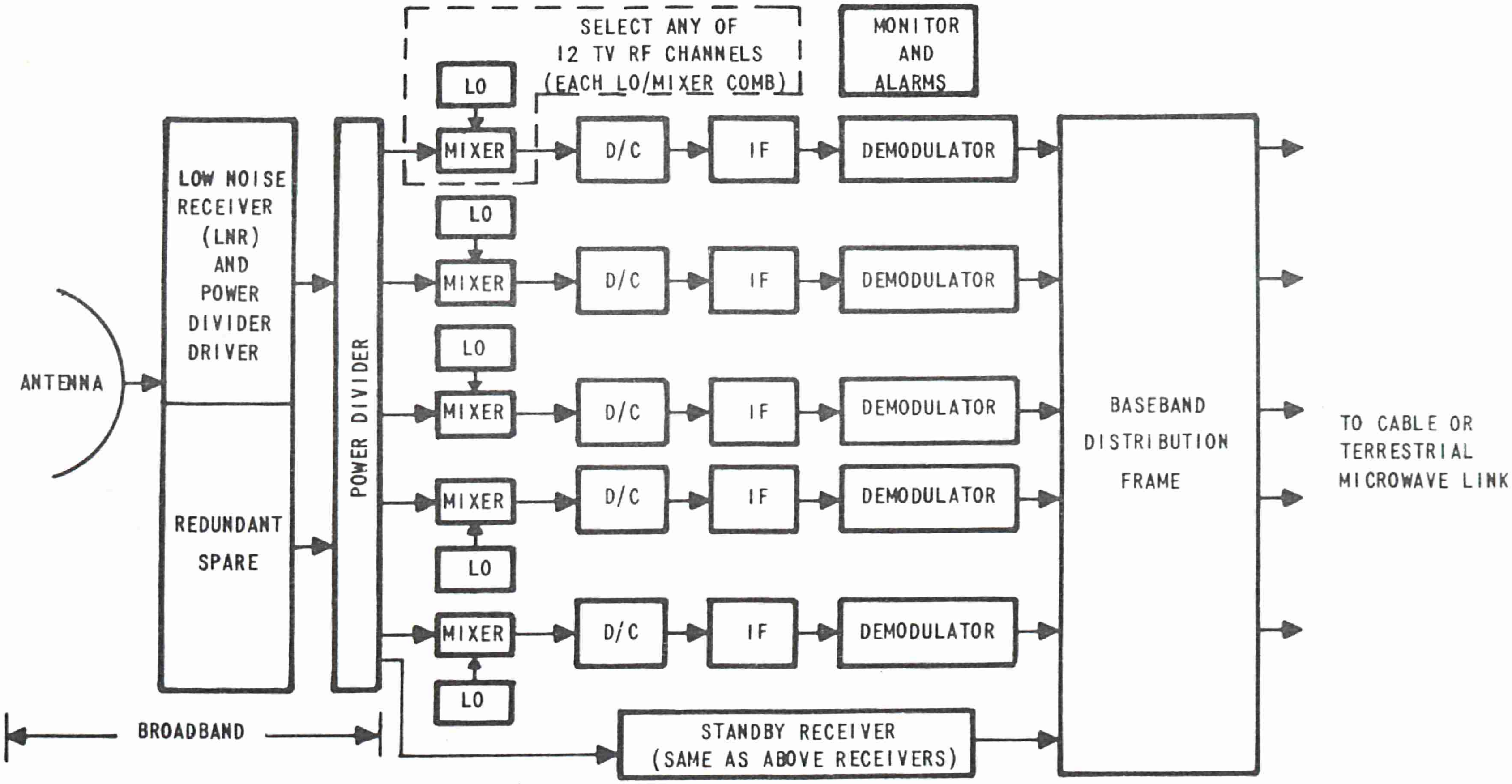
* Last 12 channels of the TV video UHF band.



NOTE: D/C IS DOWN-CONVERTER WITH LO.
IF IS IF AMPLIFIER AND FILTER.
SPARE (STANDBY) EQUIPMENT CAN BE SWITCHED IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-6. Simplified Block Diagram of a Regional Receive Earth Station Using Vestigial Sideband Amplitude Modulation for TV Video and Audio Reception (With 1:1 Backup)



NOTE: D/C IS DOWN-CONVERTER WITH LO.
IF IS IF AMPLIFIER AND FILTER.
SPARE (STANDBY) EQUIPMENT CAN BE SWITCHED IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-7. Simplified Block Diagram of a National Receive Earth Station Using Vestigial Sideband Amplitude Modulation for TV Video and Audio Reception (Provides 1:5 Backup) (Reception of Five Different RF Carriers Containing TV Video and Audio (Program)

Table 2-17. Regional and National TV Reception Characteristics for Earth Stations Using Vestigial Sideband Amplitude Modulation (Figure 2-6 and Figure 2-7)

Parameters	Description
RF Frequency Range	818 to 890 MHz (allocation for 12 TV channels)
Tunability	Tunable to any one of the 12 allocated TV video channels.
Modulation Technique	Vestigial Sideband
Predetection IF Bandwidth	6 MHz
Capacity	
(a) Regional Block Diagram, Figure 2-6 (with 1:1 back-up)	One TV Video plus TV program (sound) at baseband
(b) National Block Diagram, Figure 2-7 (with 1:5 back-up)	Five different TV Video plus TV program (sound)
$(S/N)_o$ (peak-to-peak signal-to-rms noise)	53 dB (TV Video)
(S/N) (signal-to-rms noise)	73.2 dB (TV Program)
Carrier-to-Total Noise Temperature, C/T	-110.4 dBW/°K
Antenna Diameter	30 ft (mechanical tracking only)
Antenna Gain	36.5 dB at 850 MHz
Equivalent Noise Temperature	200° Kelvin (uncooled paramp front end)
Figure of Merit of the Earth Station G/T	13.5 dB/°K
Satellite EIRP (from Figure 2-1)	59.1 dBW per TV channel

Assume Satellite 3-degree time-zone coverage - antenna gain ≈ 35 dB

∴ Satellite Transmitter Power = 24.1 dBW (approximately 600 watts) per channel.

(2) Directly to the Home - $(S/N)_o = 33dB$

Figure 2-8 is a block diagram of TV service directly to the home. A 5-ft diameter antenna with a TDA front end has been assumed. The receiver that follows is a commercial television set.

The reception characteristics of the model system are shown in Table 2-18.

b. Transmission (1.5 to 1.572 GHz*)

Figure 2-9 is a block diagram of a Vestigial Sideband Amplitude Modulation TV Video and Audio Transmit Earth Station. One-for-one RF protection is provided.

The narrowband transmitter converts the baseband input to Vestigial Sideband Amplitude Modulation via the modulator. The signal is then up-converted to RF by the up-converter. By changing the local-oscillator (LO) frequency associated with the up-converter, the RF frequency of operation can readily be changed to select any one of the 12 video channels.

The subsystems which follow the transmitter/exciter are broadband - 100 MHz or greater; this includes the redundant high-power amplifier (HPA), the antenna, etc.

A National Transmit TV Earth Station would be made up by using as many of these Transmit Earth Stations as required. Each station would carry a different TV video program. A separate HPA is used for each RF carrier to avoid intermodulation problems. However, a common antenna could be used to transmit more than one RF carrier.

The transmission characteristics of the model system are depicted in Table 2-19.

Refer back to Equation (2-23), which is repeated here:

$$P_{tg} = [117.4 - (G + G_t)] \text{ dBW};$$

but from Table 2-12,

$$G = 41.5 \text{ dB (30 ft diameter at 1.5 GHz)},$$

* This frequency band has been assigned as a frame of reference for model development.

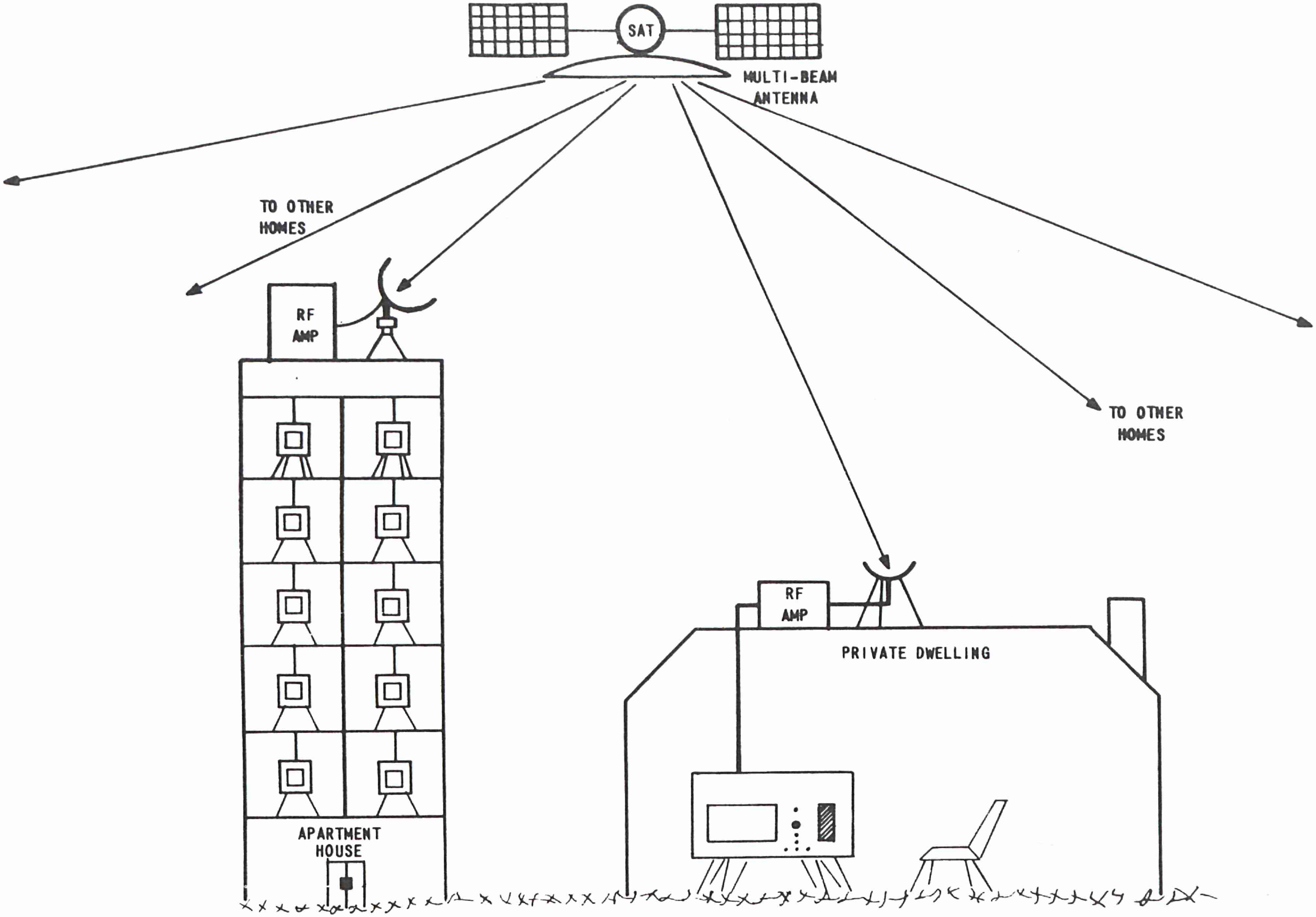
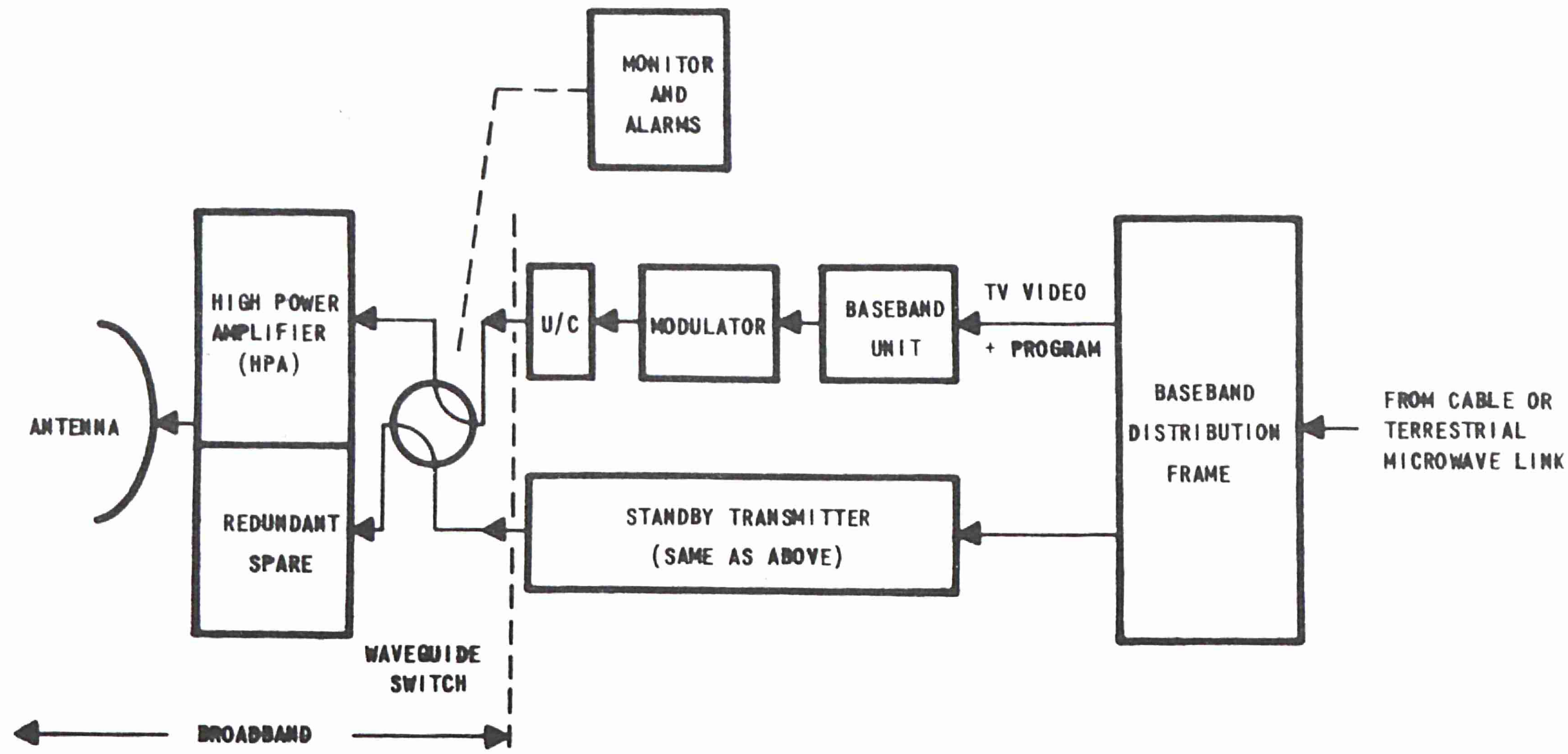


Figure 2-8. Block Diagram of TV Service Directly to Private Dwellings from Satellite (VSAM $(S/N)_o = 38dB$)

Table 2-18. TV Service Directly to the Home Using Vestigial Sideband Amplitude Modulation (See Figure 2-8)

Parameters	Description
RF Frequency Range	818 to 890 MHz (12 TV channels)
Modulation Technique	Vestigial Sideband
Predetection IF Bandwidth	6 MHz
Capacity	One TV Video plus TV Program (sound) at baseband
$(S/N)_o$ (peak-to-peak signal-to-rms noise)	33 dB (TV Video)
(S/N) (signal-to-rms noise)	53.2 dB (TV Program)
Carrier-to-Total Noise Temperature	-130.4 dBW/^{o}K
Antenna Diameter	5 ft (mechanical tracking only)
Antenna Gain	21 dB at 850 MHz
Equivalent Temperature Noise	630^{o}K (TDA or equivalent RF amp front end)
Figure of Merit of the Earth Station, G/T	-7 dB/^{o} Kelvin
Satellite EIRP (from Figure 2-2)	60 dBW per TV channel



NOTE: U/C IS UPCONVERTER WITH LO.
SPARE (STANDBY) EQUIPMENT CAN BE SWITCHED IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-9. Simplified Block Diagram of Transmit Earth Station Using Vestigial Sideband Amplitude Modulation for TV Video and Audio Transmission (Provides 1:1 Backup)

Table 2-19. Regional and National TV Transmission Characteristics for Earth Station Using Vestigial Sideband Amplitude Modulation (See Figure 2-9)

Parameter	Description
RF Frequency Range	1.5 to 1.572 GHz (allocation for 12 TV channels)
Tunability	Tunable to any one of the 12 allocated TV video channels
Modulation Technique	Vestigial Sideband
Predetection IF Bandwidth	6 MHz
Capacity	
Block Diagram, Figure 2-6 (with 1:1 back-up)	One TV Video plus TV program (sound) at baseband
Antenna Diameter	30 ft (mechanical tracking only)
Antenna Gain	42 dB at 1.5 GHz
HPA	
Power Output	12 kW
Bandwidth	100 MHz Nominal
Satellite Antenna Gain	34.4 dB Minimum at 1.5 GHz *

* Obviously, if the satellite does not have this antenna gain, the ground-terminal antenna or the HPA power must be increased.

and

$$P_{tg} = 41 \text{ dBW (12 kW)}.$$

Therefore, solving the above equation for G_t (satellite antenna gain), we obtain:

$$G_t = +34.9 \text{ dB}. \quad \text{(Time Zone Coverage)}$$

2.2.1.2 Frequency Modulation (TV Performance)

a. <u>Reception (3.7 to 4.2 GHz)</u>

Figures 2-10 and 2-11 are block diagrams of Regional and National FM TV Receive Earth Stations.

In the case of the Regional Earth Station, one-for-one RF carrier backup is provided. However, for the National Earth Station one-for-five backup is used.

A separate RF carrier is depicted for the TV video and the TV audio (program) information. The possibility of sending the audio information via a subcarrier has not been considered. However, this approach should be considered, as it would eliminate an extra RF carrier. Use of the present approach is consistent with current earth station practices.

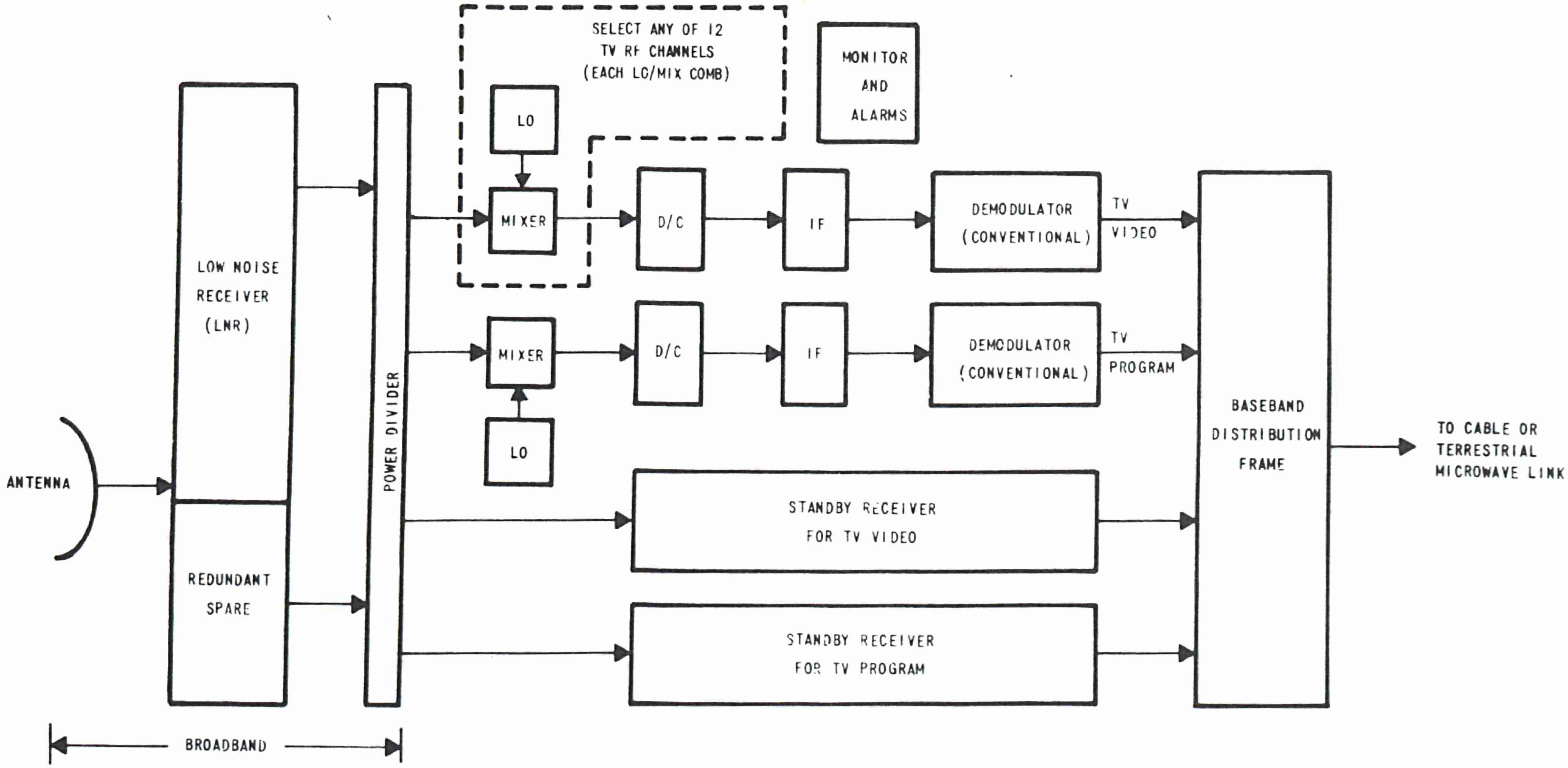
The 15-foot diameter antenna, redundant low-noise receiver (LNR), the power splitter, and the first mixer are all broadband - 500 MHz or greater. The receiver that follows is narrowband - 40 MHz for the TV video and 3.0 MHz for the TV audio. A double-heterodyne technique is shown; the function of the first mixer is to allow for ease of tuning to any of the 12 TV RF channels.

The demodulated signal consists of TV video and the TV audio signals. This signal can then be distributed to either a cable head or a terrestrial microwave link.

The reception characteristics of the system are shown in Table 2-20.

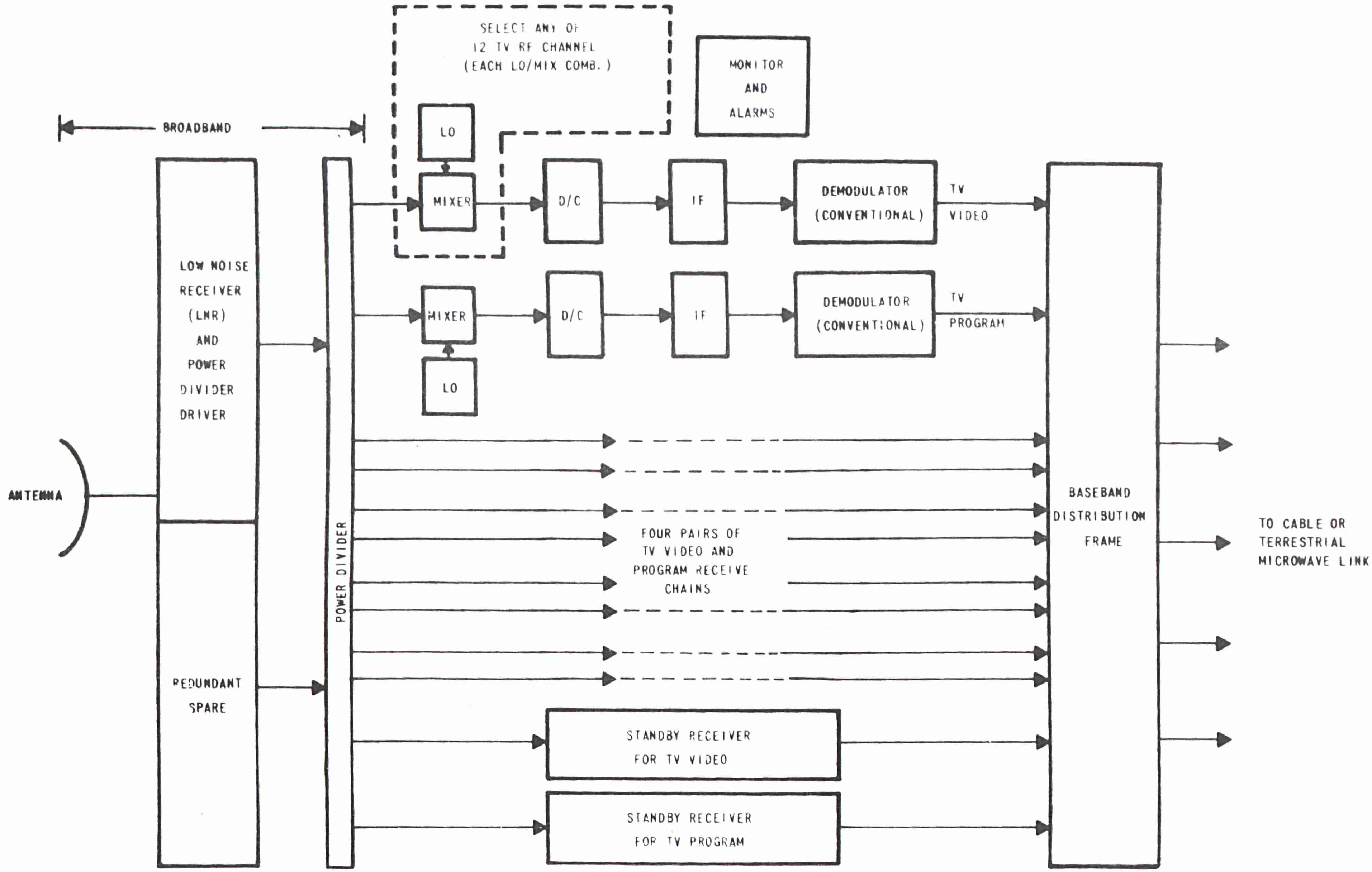
b. <u>Transmission (5925 to 6425 MHz)</u>

Figure 2-12 is a block diagram of a Regional FM TV Transmit Earth Station. One-for-one RF protection is provided.



NOTE: D/C IS DOWN-CONVERTER WITH LO.
IF IS IF AMPLIFIER AND FILTER.
SPARE (STANDBY) EQUIPMENT CAN BE SWITCHED IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-10. Simplified Block Diagram of a Regional Receive Earth Station Using FDM/FM for TV Video and Audio Reception (With 1:1 Backup for Video and Audio Chains)



NOTE: D/C IS DOWN-CONVERTER WITH LO.
IF IS IF AMP AND FILTER. SPARE (STANDBY) EQUIPMENT CAN BE SWITCHED IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-11. Simplified Block Diagram of a National Receive Earth Station Using FDM/FM for TV Video and Audio Reception (Provides 1:5 Backup)
(Reception of 10 Different RF Carriers: Five Which Contain TV Video and Five Which Contain TV Audio)

Table 2-20. Regional and National TV Reception Characteristics for Earth Stations Using Frequency Modulation (Figures 2-10 and 2-11)

Parameters	Description
RF Frequency Range	3.7 to 4.2 GHz (can accommodate 12 TV channels)
Tunability	Tunable to any of the 12 allocated TV video channels.
Modulation Technique	FM
Capacity	
Block Diagram Figure 2-10 (with 1:1 Back-up)	1 TV Video Carrier 1 TV Sound Carrier (24 voice channels per carrier)
Block Diagram Figure 2-11 (with 1:5 Back-up)	5 TV Video Carriers 5 TV Sound Carriers (24 voice channels per carrier)
TV Video	
$(S/N)_o$ (peak-to-peak to rms noise)	+53 dB
Peak Deviation	15.2 MHz
Predetection IF Bandwidth	40 MHz
Carrier-to-Total Noise Temperature, C/T	-136.4 dBW/^{o}K
C/N	≥16 dB
Antenna Diameter	15 ft.
Antenna Gain	44.0 dB
Equivalent Noise Temperature	200^{o}K (uncooled paramp)

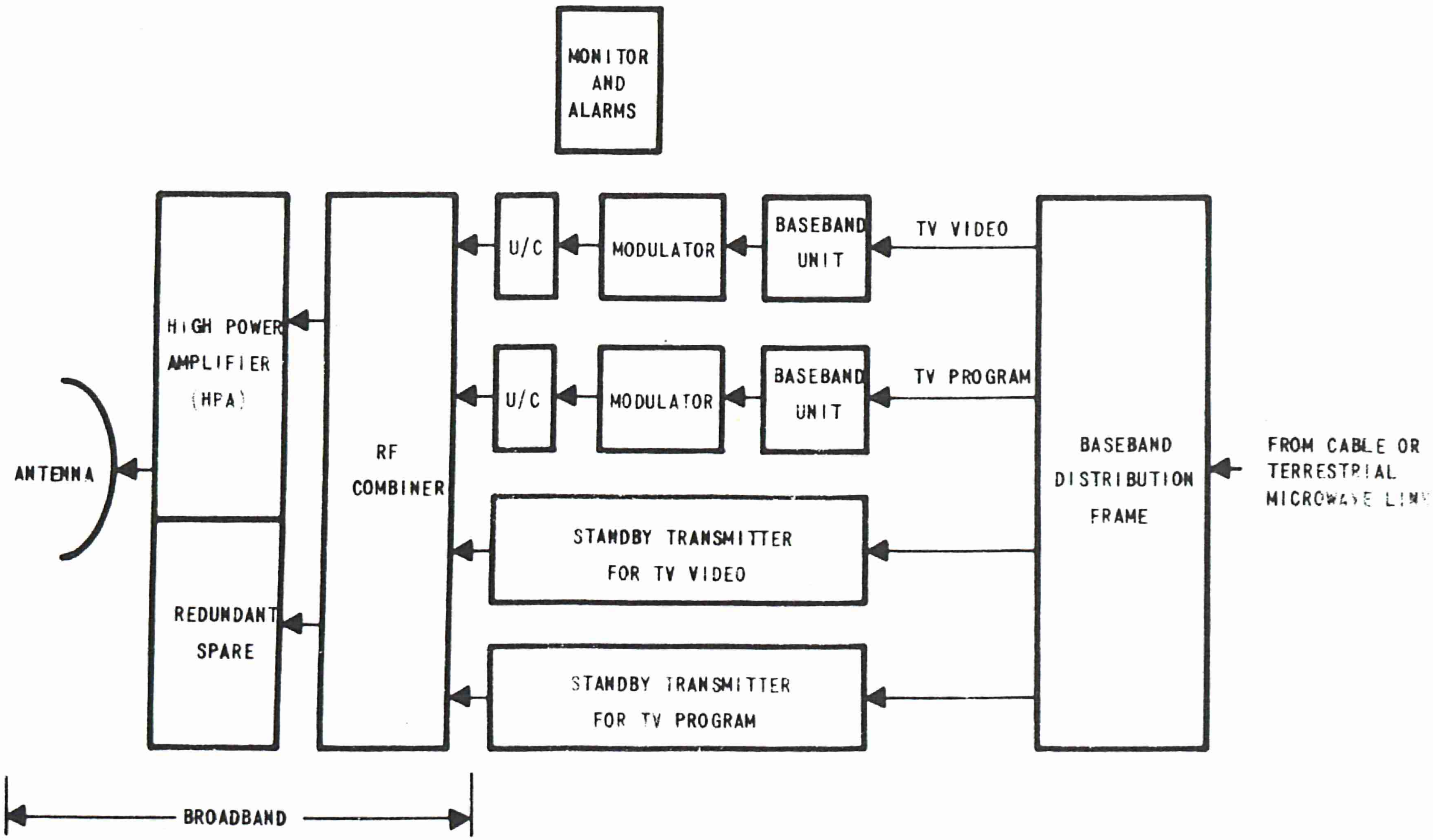
Table 2-20. Regional and National TV Service Characteristics for Earth Stations Using Frequency Modulation (Figures 2-10 and 2-11) (Continued)

Parameters	Description
Figure of Merit of the Earth Station G/T	21.0 dB/°K
TV Audio	
(S/N) (signal-to-rms noise)	53 dB
Number of Voice Channels	24-voice channel capacity
Single-Channel Test-Tone Deviation	140 kHz rms
Predetection IF Bandwidth	3.0 MHz
Carrier-to-Total Noise Temperature	-148.4 dBW/°K
C/N	15 dB
Satellite EIRP (From Figure 2-3) (From Figure 2-4)	+39.6 dBW per TV channel +27.6 dBW per TV channel program (audio)

Assume Satellite 3-degree time-zone coverage - antenna gain ≈ +35 dB

∴ Satellite Transmitter Power Requirements are:

4.4 dBW (2.8 watts) TV Video
-7.6 dBW (0.174 watt) TV Audio (Program)



NOTE: U/C UPCONVERTER WITH LO.
SPARE (STANDBY) EQUIPMENT CAN BE SWITCH IN AND OUT BOTH MANUALLY AND AUTOMATICALLY.

Figure 2-12. Simplified Block Diagram of Transmit Earth Station Using FDM/FM for TV Video and Audio Transmission (Provides 1:1 Backup)

A separate RF carrier is used for the transmission of the TV video and the TV audio information.

The baseband input is applied to the FM modulator where it is converted to an FM signal; following this, the signal is then up-converted to RF by the up-converter. The frequency of operation can readily be changed via the LO frequency associated with the up-converter.

The subsystems which follow the transmitter/exciter are broadband - 500 MHz or greater; this includes the RF combiner, the common redundant HPA, the antenna, etc.

A National Transmit TV Earth Station would look similar except that RF transmitter pairs, one for TV video and one for TV audio, would be added to accommodate the different TV programs. The RF combiner, the HPA, and the antenna would all be common.

The transmission characteristics of the model systems are depicted in Table 2-21.

Refer back to Equation (2-28), which for informational purposes is repeated here:

$$P_{tg} = [103.6 - (G + G_t)] \text{ dBW};$$

but, from Table 2-12,

$$G = 47.5 \text{ dB and}$$

$$P_{tg} = 27 \text{ dBW (for Regional Station with back-off for TV program).}$$

Therefore, solving the above equation for G_t (satellite antenna gain), we obtain:

$$G_t = +29.1 \text{ dB.}$$

This is greater than time zone coverage.

2.2.2 Communications (Message) Service

The Communications Service has duplex capability, as opposed to the TV Distribution Service, which is one-way.

Table 2-21. TV Transmission Characteristics for Regional and National Earth Stations Using Frequency Modulation

Parameters	Description	
RF Frequency Range	5925-6425 MHz (can accommodate 12 TV channels)	
Tunability	Tunable to any one of 12 allocated TV video channels.	
Modulation Technique	FM	
Deviation	TV Video: 15.2 MHz peak TV Audio Program: 140 kHz rms	
	Regional (Block Diagram Figure 2-12)	National
Capacity Baseband Input	1 TV Video Carrier 1 TV Sound Carrier (24-voice-channel capacity per sound carrier)	3 TV Video Carriers 3 TV Sound Carriers (24-voice-channel capacity per sound carrier)
Narrowband transmitters		
TV Video Carriers	1	3
TV Audio Program	1	3
TV Video Carriers (Back-up)	1	1
TV Audio Program (Back-up)	1	1
Antenna		
Diameter	15 ft	30 ft *
Gain	47.5 dB at 6 GHz	53.5 dB at 6 GHz

* Allows for back-off for multiple carrier operation at the HPA input.

Table 2-21. TV Transmission Characteristics
for Regional and National Earth Stations
Using Frequency Modulation
(Continued)

Parameters	Description	
HPA		
Power Output	+30 dBW (1 kW)	Can handle 3 TV carriers plus 3 TV audio carriers
Bandwidth	500 MHz	nominal
Satellite Antenna Gain	+29.1 dB min.	

The Preassigned Models will use FDM/FM modulation with a message (voice channel) capacity of 24, 60, 132, 300, 600 or TV per RF carrier. Multi-Destination Carrier (MDC) and Single-Destination Carrier (SDC) models will be considered. In the case of MDC, TV video capability will also be enumerated. The two models developed differ from current earth stations in the following ways:

a. Uncooled front ends are used.

b. Smaller antennas can be used.

c. Tracking requirements will be minimal (e.g., manual tracking).

d. Requirements of the interfacility link are eliminated.

e. Only conventional demodulators (limiter-discriminators) are used.

f. A greater number of voice channels can be transmitted per RF carrier.

g. Lower per-channel test-tone deviation (for message operation) similar to that currently used on terrestrial LOS microwave links (200 kHz rms per channel deviation) can be used; this yields higher satellite channel-handling capacity.

Obviously, to initiate these changes, the satellite must become more sophisticated and have increased EIRP capability. The output signal-to-noise will be of toll quality (52 to 53 dB psophometrically weighted). The performance parameters have previously been enumerated (see Paragraphs 2.1.2.3.a and b). In particular, the results of Table 2-11, the graphical results of Figure 2-4 (EIRP versus G/T ratio), and the equations shown in Table 2-15 will be used. For TV transmission the results are derived in Paragraph 2.1.2.2.f.

The modulation technique used in the Demand-Assigned Model is a form of SCC/FM. An RF spectrum of 100 KHz will be allocated to each message carrier. The output signal-to-noise ratio will exceed 52 dB. The performance parameters are derived in Paragraphs 2.1.2.3.b(1) and (2).

2.2.2.1 Preassigned

a. Multi-Destination Carrier (MDC)

The Multi-Destination Carrier model is a type of multiple-access communications satellite system currently in use. In this approach maximum use is made of the broadband satellite transponder by using multi-destination carriers, which results in each earth station transmitting fewer RF carriers than it receives. The RF channels at a particular earth station destined for several other earth stations are FDM'd on a single outgoing FM carrier, with each distant earth station required to receive and demodulate the complete carrier and then extract the channels destined for it. Consequently, the quantity and characteristics of the baseband-to-RF and RF-to-baseband equipment in any earth station will depend on the quantity and kinds of communications service required. This technique can be used for both developed and developing nations, the difference being the voice-channel capacity, or number of destinations (number of RF receive carriers), or both.

Figure 2-13 is a block diagram of a Multi-Destination Carrier Earth Station. The station has the facilities for the transmission of three carriers and the reception of seven carriers with a spare for back-up.

The typical capacity of this type of earth station is as follows:

Transmit	3 RF Carriers:	One TV video One TV audio (program) One redundant telephone (300-voice-channel capability)

The redundant telephony RF channel can be used as back-up for the TV video or TV audio channel.

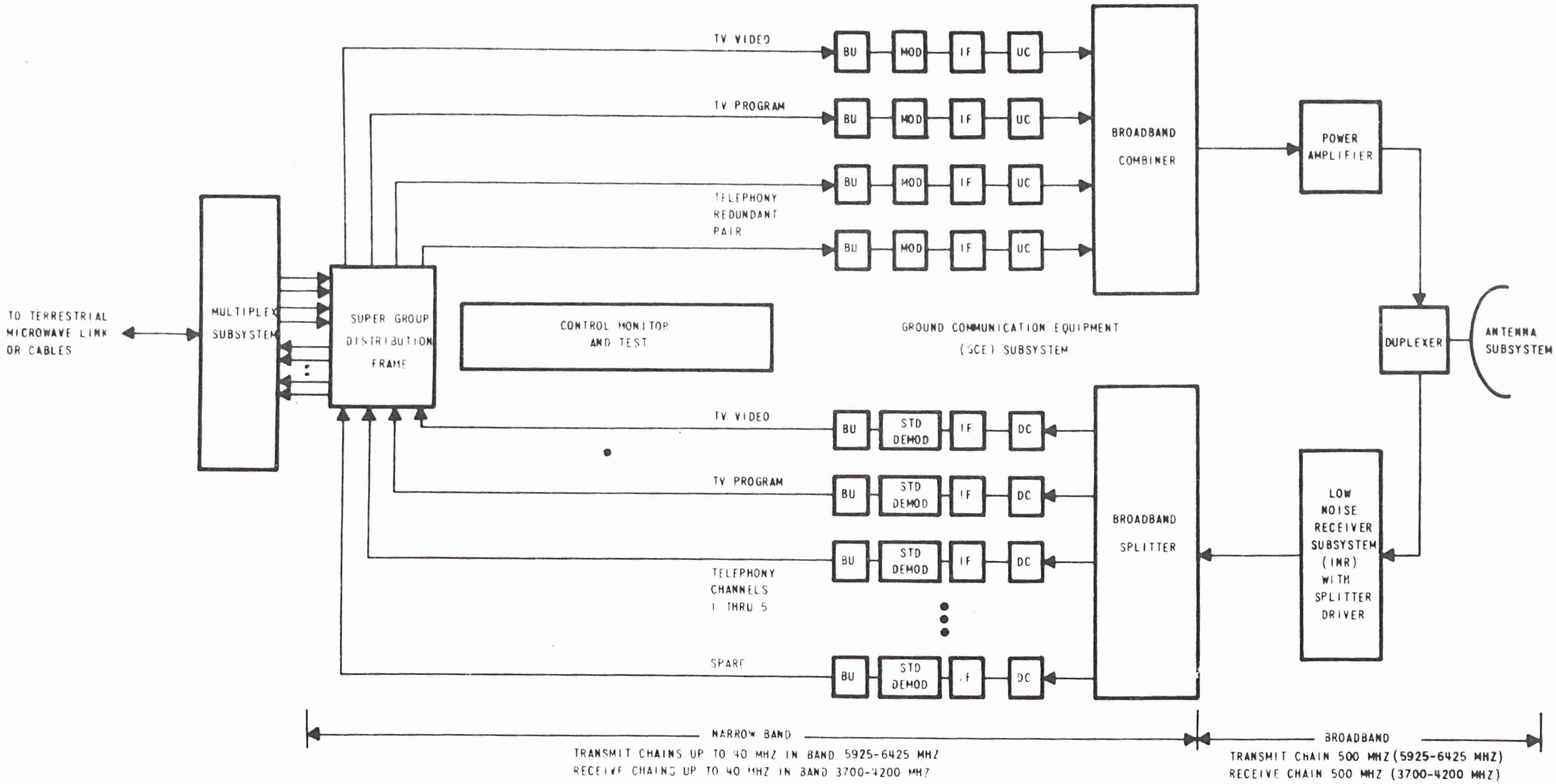


Figure 2-13. Multi-Destination Carrier Satellite Communications Earth Station Model

Receive	7 RF Carriers	Five telephone channels (300-voice-channels capacity)
		One TV video
		One TV audio (program)
		One spare; provides 1:7 back-up

The reception and transmission characteristics are shown in Tables 2-22 and 2-23 respectively. The performance requirements for other voice channel loadings are depicted in Table 2-11 (Paragraphs 2.1.2.3.a and b); this supplements the existing Comsat requirements for a "softer" modulation technique.

The TV video performance is a hard modulation approach as compared to the telephony which is softer*. Hence, for 300 voice channels or greater, the voice channel satellite EIRP requirements predominate and will govern the earth station antenna size. This also holds true in the selection of the HPA for transmission.

b. Single-Destination Carrier (SDC)

This type of communications system is a special case of the MDC system. It is designed primarily for developed nations and is intended for heavy loaded point-to-point systems covering large distances, e.g., an east coast location (Washington, D.C.) to West Europe (Brussels) or to the west coast (San Francisco).

An 1800-voice channel FDM/FM capacity is assumed per earth terminal (see Figure 2-14). This capacity is accomplished by means of three RF carriers. Each carrier handles 600-voice channels.

The total bandwidth required is approximately equal to that required for one TV video channel. One-for-three RF back-up is provided.

At a current cost of approximately $1,000 a voice channel, the cost of the multiplex equipment alone exceeds 1.8 million dollars. This is probably the most expensive subsystem of the earth station, and cost economics must be exercised in this direction.

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* Obviously, if the satellite EIRP is available, the TV modulation can also become softer and utilize less bandwidth. The problem is simply one of bandwidth exchange versus EIRP.

Table 2-22. MDC Receive Performance Characteristics, FDM/FM

Parameters	Description	
Carrier Frequency Range	3700 to 4200 MHz	
Modulation Technique	FDM/FM	
Capacity	7 carriers 1 TV Video 1 TV Program (audio) 5 Telephony (300 voice channels)	
TV Video	**Grade 1**	
$(S/N)_0$ peak-to-peak signal-to-rms noise	53 dB	
C/T carrier-to-total noise temperature	-136.4 dBW/°K	
$(C/N)_D$	16 dB	
Peak Deviation	15.2 MHz	
Predetection IF Bandwidth	40 MHz	
Satellite EIRP (from Figure 2-3)	33.6 dBW/carrier	
Telephony	**n =24***	**n =300**
(S/N) signal-to-rms noise	53 dB	52.2 dB
C/T carrier-to-total thermal noise	-148.4 dBW/°K	-131.4 dBW/°K
drms per channel rms deviation	140 kHz	200 kHz
Predetection IF Bandwidth	3.0 MHz	7.0 MHz
C/N	15 dB	27 dB
Satellite EIRP (from Figure 2-4)	21.6 dBW/carrier	38.6 dBW/carrier

* TV Program

Table 2-22. MDC Receive Performance Characteristics, FDM/FM (Continued)

Parameters	Description
Antenna	
Diameter	30 ft (mechanical tracking only)
Gain	50.2 dB at 4 GHz
Equivalent Receive Noise Temperature	200° K (23 dB) Using uncooled paramps
Figure of Merit of Earth Station G/T	27.0 dB/° K

Table 2-23. MDC Transmission Performance Characteristics, FDM/FM

Parameters	Description
Carrier Frequency Range	5925 to 6425 MHz
Modulation Technique	FDM/FM
Capacity	3 Carriers
	1 TV Video
	1 TV Program (audio)
	1 Telephony (300 voice channels)
Deviation	TV Video: 15.2 MHz peak
	TV Audio (Program): 140 kHz
	Telephony: 200 kHz
Antenna	
Diameter	30 ft (mechanical tracking only)
Gain	53.5 dB
HPA**	
Power Output	2 kW (33 dBW)
Bandwidth	500 MHz
TV/carrier *	+23.6 dBW (235 watts)
TV program/carrier *	+11.4 dBW (13.8 watts)
Telephony/carrier *	+28.6 dBW (720 watts)

* Satellite antenna gain of approximately 26.5 dB is assumed; this corresponds to continental coverage - 7.5° satellite beamwidth. (Equation (2-28) and Table 2-15)

** The common HPA enumerated above has more than enough capacity for back-off.

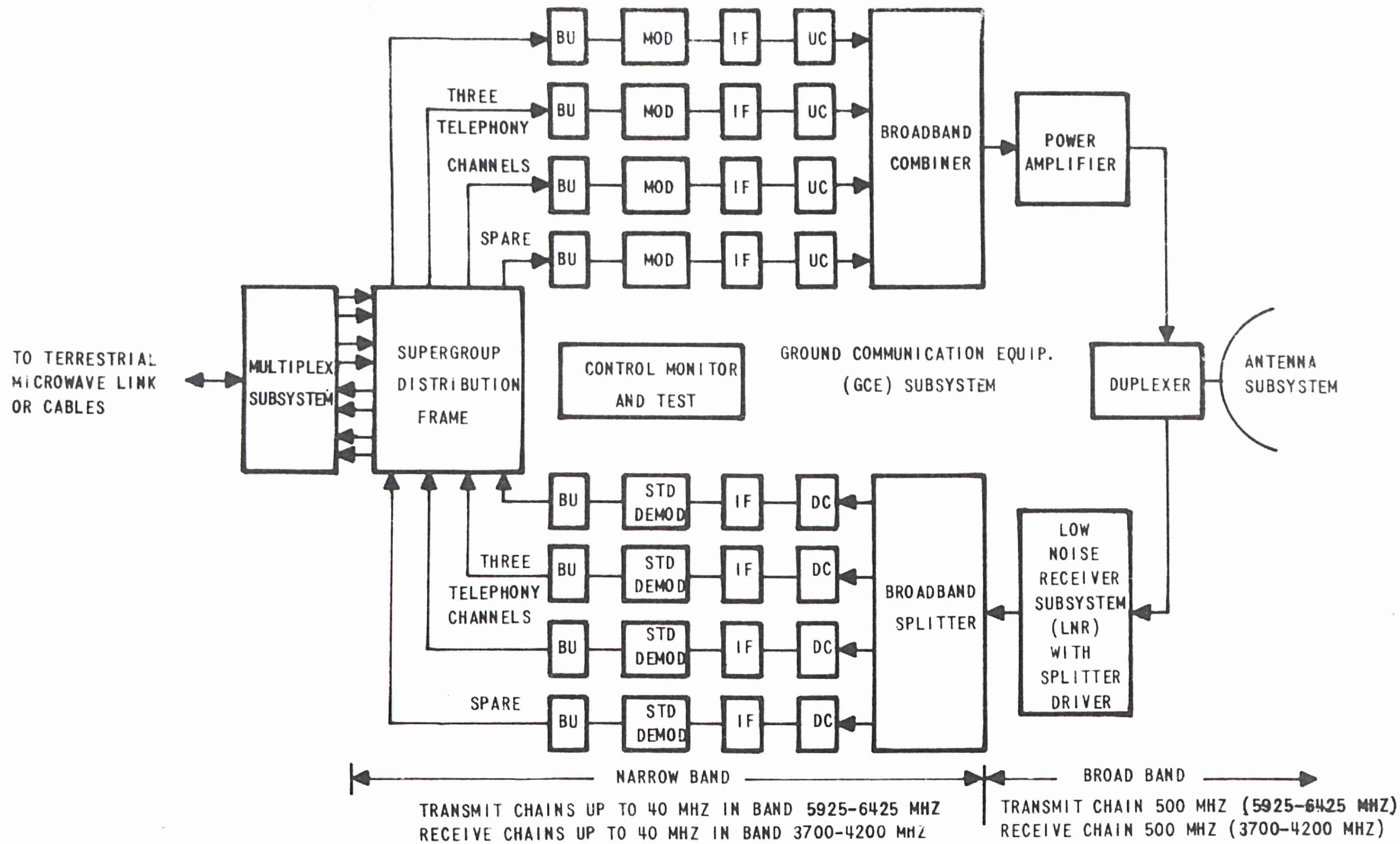

Figure 2-14. Single-Destination Carrier Satellite Communications Earth Station Model (1:3 Backup)

The receive and transmit performance characteristics are depicted in Table 2-24.

Table 2-24. Point-to-Point Heavy Message Loading (1800 Voice Channels) Performance Characteristics (Figure 2-13)

Parameters	Description
A. Receiver Performance	
Carrier Frequency Range	3700 to 4200 MHz
Modulation Technique	FDM/FM
Capacity	3 carriers (600 voice channels per carrier)
(S/N) Signal-to-rms Noise	+53 dB
Predetection IF Bandwidth	15 MHz nominal
Single-Channel Test-Tone Deviation	200 kHz rms
C/T (Carrier-to-Total Noise Temperature)	-124.9 dBW/° K
C/N	+31.5 dB
Satellite EIRP per Carrier (from Figure 2-16)	45.1 dBW per carrier
Antenna	
Diameter	30 ft (mechanical tracking only)
Gain	+50.5 dB
Equivalent Noise Temperature	200° K (uncooled paramp front end)
Figure of Merit (G/T)	+27.0 dB/° K
B. Transmitter Performance	
Carrier Frequency Range	5925 to 6425 MHz
Modulation Technique	FDM/FM
Capacity	3 carriers (600 voice channels per carrier)
Single-Channel Test-Tone Deviation	200 kHz rms

Table 2-24. Point-to-Point Heavy Message Loading (1800 Voice Channels) Performance Characteristics (Figure 2-13) (Continued)

Parameters	Description
Antenna	
Diameter	30 ft (mechanical tracking only)
Gain	+53.5 dB at 6 GHz
HPA	
Power Per Carrier	500 watts per carrier *
Power Output of Common Power Amplifier	1 to 2 kW
Bandwidth	500 MHz nominal

* Satellite antenna gain of approximately 34.6 dB is assumed; this corresponds to time-zone coverage - satellite antenna beamwidth of 3°.

2.2.2.2 Demand-Assigned Model

The model used will be a modified STAR* system. The designation STAR system is derived from Satellite Telecommunications with Automatic Routing.

In this system, which is a form of SCC/FM, each voice channel frequency modulates one carrier, and the carriers are arranged within the transmission bandwidth of the satellite.

The channel capacity of the system is limited not only by the bandwidth of the satellite, but also by its output power and the performance of each earth station which is linked to one another by means of the common satellite.

Voice channels through the satellite are not assigned to each earth station, but are assigned on a demand basis. This on-demand assignment is the so-called automatic routing operation.

*M. Marita, T. Fukami, and S. Yamoto, "Project STAR", Telecommunications, October 1967, Volume 1, No. 2 pp. T22-T25.

In an operating voice channel, the carrier is not continuously transmitted; that is, a technique in which the wave is emitted only for the time in which a voice is present, and in which the wave (signal) is cut off for the period during which no voice is presented, is the so-called Start-Stop function. Using this approach, the number of usable channels is increased by utilizing the limited output power of a satellite most effectively, and the interference to other channels is minimized by cutting off the unmodulated waves.

The earth stations are always connected through the routing center by means of data transmission links for channel assignment. Time-division multiplex is used for the data link. However, the voice channels are transmitted using frequency modulation. Thus, each earth station has an analog system for voice-channel transmission, and a digital system for voice-channel demand assignments.

The system consists of many earth stations which use a common satellite. Associated with this network is a separate earth station, whose function is the automatic routing of the voice channels. This station is the Routing Center. Figure 2-15 is a block diagram depicting this system.

Figures 2-16 and 2-17 are block diagrams of a Demand-Assigned Earth Station and the Routing Center.

A system for developed and developing nations is proposed. The essential difference between the two is the earth station channel capacity and the application of the Start-Stop function. Thus, conversion from developing to developed nation earth terminals is readily accomplished.

Each demand channel has been allocated a 100-kHz spectrum, thereby accommodating a single voice channel.

The satellite has a bandwidth of 500 MHz; therefore, 5000 voice channels are available. The number of earth stations that can be accommodated by the satellite is a function of the expected traffic (data, voice, etc.) the allowable delays, etc., and is a traffic engineering problem.

Obviously, many earth stations can use the satellite. The applications of the Start-Stop function further decrease the activity factor, thereby reducing the average power requirement in the satellite.

The reception and transmission characteristics for the Message Earth Station and the Routing Center are depicted in Table 2-25, Table 2-26, and Table 2-27.

Paragraphs 2.1.2.3.b (1) and (2) are the calculated results used in establishing the model parameters.

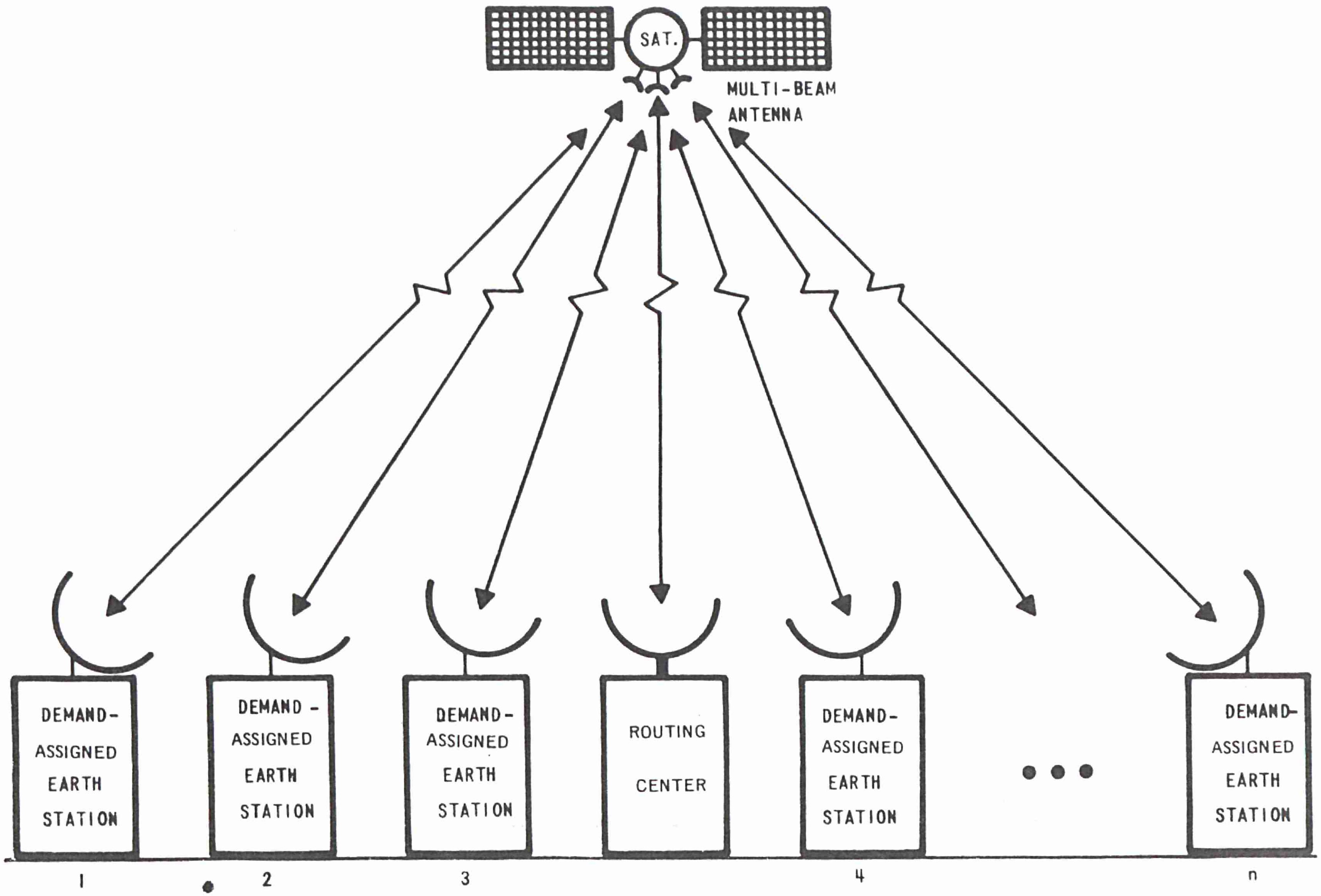

Figure 2-15. Block Diagram of Demand-Assigned Communications System

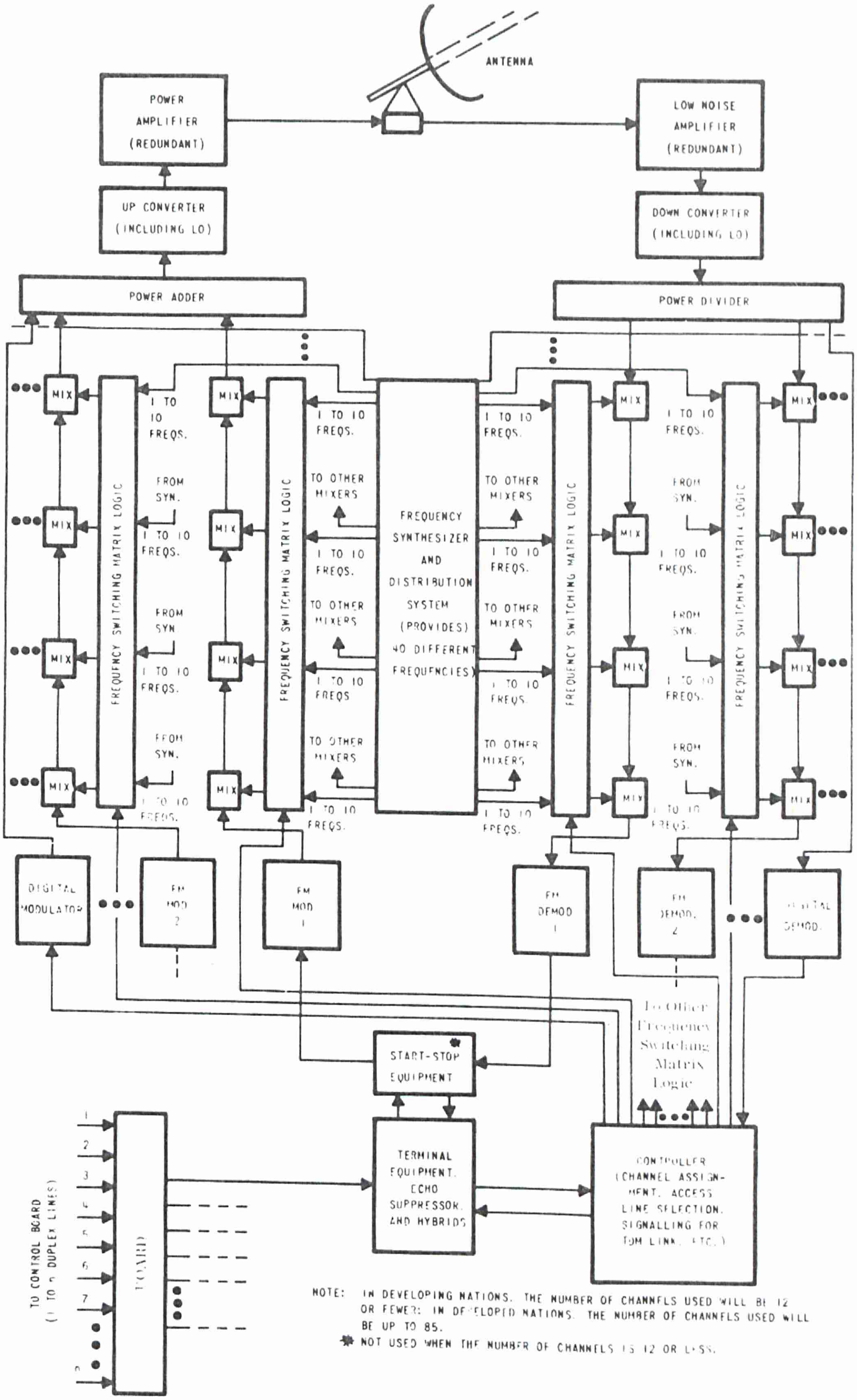

Figure 2-16. Block Diagram of Demand-Assigned Earth Station

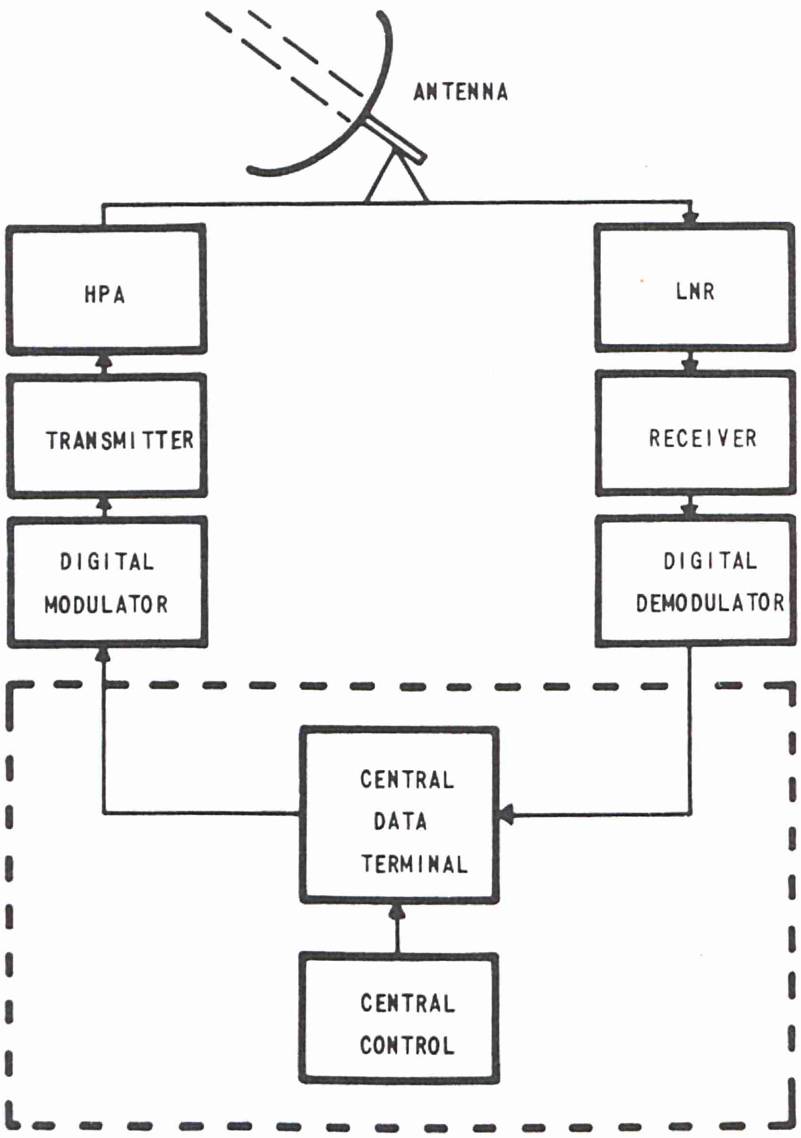

Figure 2-17. Block Diagram of Routing Center

Table 2-25. Demand Assigned Receiver Performance Characteristics (Figure 2-16)

Parameters	Characteristics
A. <u>Message</u>	
RF Frequency	3700 to 4200 MHz
Modulation	SCC/FM
Channel (Single Carrier) Predetection IF Bandwidth	100 kHz nominal
Capacity	Developing nations: 12 carriers Developed nations: 85 carriers (each carrier can receive one voice channel)
(S/N) (signal-to-rms Noise)	52 dB
Carrier-to-Noise Ratio	16 dB
Equivalent Noise Temperature	200°K (uncooled paramp)
Carrier-to-Total Noise Temperature	-162.4 dBW/°K
Antenna	
Diameter	15 ft. (mechanical tracking only)
Gain	+44.2 dB at 4 GHz
Figure of Merit (G/T)	21.0 dB/°K
Satellite EIRP (from Figure 2-5)	13.6 dBW per carrier
B. <u>TDM Receive Channel</u>	
RF Frequency Range	4100 to 4200 MHz
Modulation	TDM
Predetection Bandwidth	1.0 MHz nominal
Capacity	1 carrier
Data Capability	1.0 Megabit (binary)
Carrier-to-Noise Ratio	+16 dB
Satellite EIRP	+24.2 dBW per carrier

Table 2-26. Demand-Assigned Transmission Performance Characteristics (Figure 2-17)

Parameters	Characteristics
A. Message	
RF Frequency Range	5925 to 6425 MHz
Modulation	SCC/FM
Channel (Single Carrier) Predetection Bandwidth	100 kHz
Capacity	Developing nations: 12 carriers Developed nations: 85 carriers
Antenna	
Diameter	15 ft. (mechanical tracking only)
Gain	47.5 dB
HPA	
Power Required per carrier	13W (11.1 dBW) per carrier*
Power Output (Common P.A.)	1.0 kW
Bandwidth	500 MHz nominal
B. TDM Transmit Channel	
RF Frequency	6325 to 6425 MHz
Modulation	TDM
Capacity	1 carrier
Data Capacity	1 Megabit (binary)
Bandwidth Allocation	1 MHz nominal

* Satellite antenna gain of approximately 19 dB; this corresponds to global coverage — 18° satellite beamwidth.

Table 2-27. Performance Characteristics of Routing Center

Parameters	Characteristics
RF Frequency	
Transmit	6325 to 6425 MHz
Receive	4100 to 4200 MHz
Modulation	TDM
RF Bandwidth Allocation	1.0 MHz Nominal
Data Capability	1.0 Megabit (Binary)
Capacity	One duplex channel
Carrier-to-Noise Ratio	16 dB
Equivalent Noise Temperature	200^{o}K (uncooled paramp)
Antenna	
Aperture	15 ft.
Gain	44.2 dB at 4.1 GHz 48 dB at 6.3 GHz
Figure of Merit (G/T)	+21.0 dB/^{o}K
Satellite EIRP	+24 dBW per channel
HPA (6325 to 6425 MHz)	
Power	20 Watts
Bandwidth	5.0 MHz minimum

2.3 COST MODELS

Figure 2-18 is a block diagram of a typical multidestination carrier Comsat type of earth station that complements the Intelsat III satellite type. This type of earth station will be used in the 1968 to 1976 time frame, and will be used as the cost model.

The typical capacity of this type of earth station is as follows:

Transmit	3 RF carriers:	one TV video; one TV audio (program) one redundant telephony (132 voice channel capability).
Receive	7 RF carriers	five telephony (132 voice channel per RF carriers); one TV video; one TV audio (program) One spare, provides 1:7 back-up.

This type of station will be used as the standard for price comparison and hereafter will be referred to as the standard earth station.

The current earth stations require system G/T ratios exceeding 40.7 dB and a top voice channel signal-to-noise ratio of 52 dB. To accomplish this, 85-foot dishes with cooled parametric and threshold extension demodulators are used. However, in the case of TV video, a standard limiter-discriminator is used. The TV reception characteristics are similar to those depicted in Table 2-20, except that the G/T ratio exceeds 40.7 dB.

Table 2-28 shows the current Intelsat III transmission parameters for message traffic.

The cost range of the equipment which makes up a current standard type of earth station is shown in Table 2-29. The prices developed reflect the cost received from vendors in the U.S. and other countries over the past 18 months.

This information has been utilized in deriving Table 2-30, which is the equipment cost breakdown of the MDC earth station shown in Figure 2-28. The cost of the earth stations range from $2,650,000 to $5,173,000, the mean value being $3,911.500.

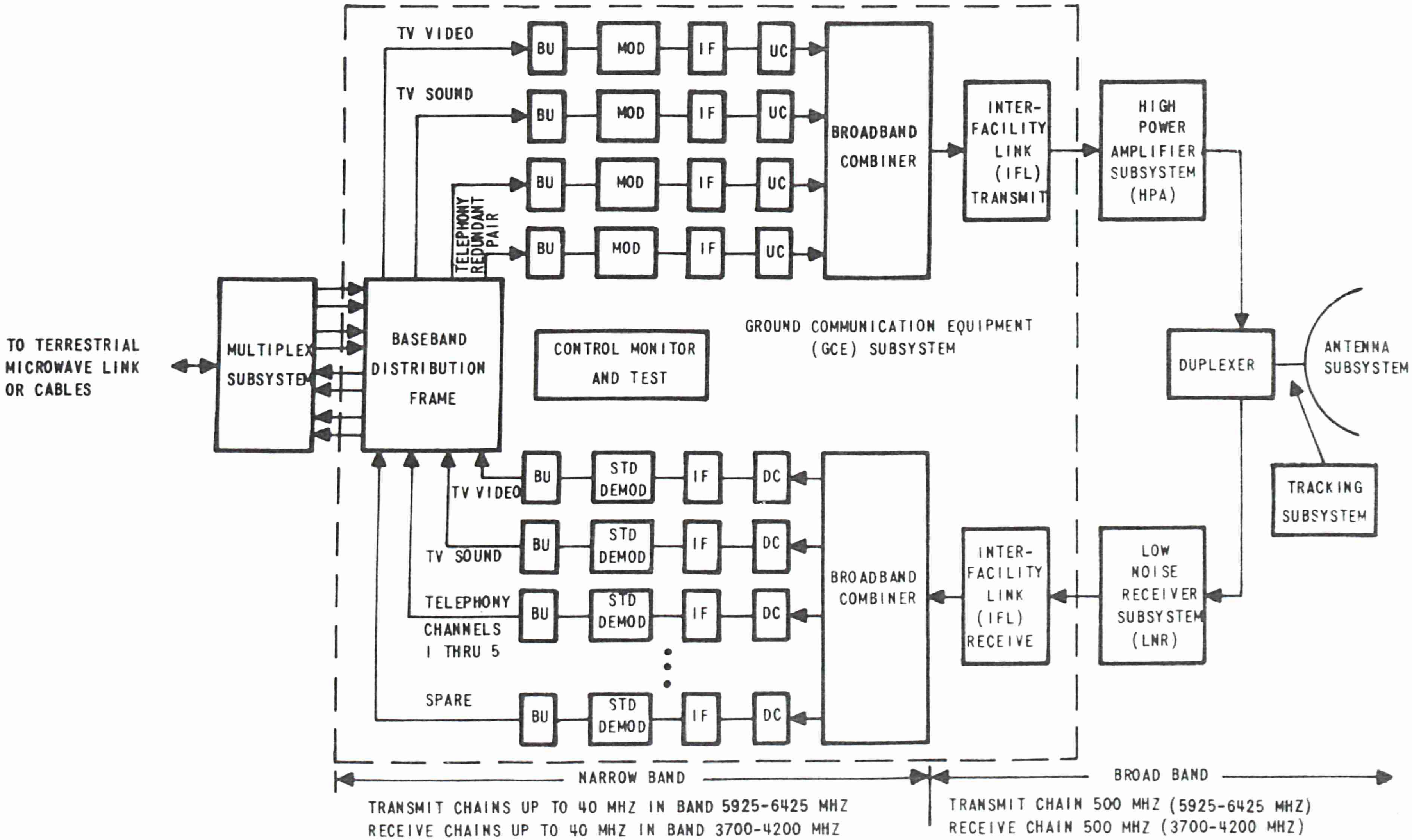

Figure 2-18. Satellite Communications Earth Station (Standard)

Table 2-28. Intelsat III Transmission Parameters

Parameters	Symbols	Units	Values		
1. Carrier Capacity	n	Voice Channels	24	60	132
2. Allocated Satellite Bandwidth	b_a	MHz	5	10	20
3. Bottom Baseband Frequency	fb	kHz	12	12	12
4. Top Baseband Frequency	fm	kHz	108	252	552
5. Demo Test Tone Deviation	fr	kHz	250	410	630
6. Multi-channel rms Deviation	fmc	kHz	420	830	1490
7. Satellite Bandwidth with 268 Guardband	bsg	MHz	5.0	10.0	18.2
8. Carrier-to-Total Noise Temperature Ratio	$\frac{C}{T}$	dBW/°K	-154.8	-151.3	-148.5
9. Satellite Bandwidth without Guardband	bs	MHz	3.95	7.95	14.4
10. IF Bandwidth	Bif	MHz	2.9	5.8	10.5
11. Earth Station Received Flux Density		dBW/m^2	159.0	-155.5	-152.7
12. Excess Margin	E	dB	4.0	4.0	4.0
13. Rain Margin	M	dB	6.0	6.0	6.0
14. Satellite EIRP (10°EL)	EIRP sat	dBW	4.4	7.9	10.7
15. Satellite EIRP (10°EL)	EIRP sat	W	2.75	6.2	11.8
16. Satellite EIRP per channel	EIRP sat	mW	115	103	89
17. Satellite Illumination	$Wsat_n$	dBW/m^2	-89.8	-86.3	-83.5
18. Earth Station Transmit EIRP (10°EL)	EIRP es	dBW	73.6	77.1	79.9

The Cost Model price used for the cost analysis will be $4.0 million. This price will be used as the frame of reference.

The cost analysis will consist of comparing the mean cost of the earth stations developed previously (Section 2.2) using 1972 to 1980 as the time frame for cost, with the Cost Model. The costs developed will be expressed as a percentage of the Cost Model ($4.0 million) price.

Tables 2-31 and 2-32 shows the result of the analysis for color TV and communications services respectively. Furthermore, the cost of the antennas and the multiplex equipment, where applicable, are expressed as percentages of the particular earth stations.

In addition, the equipment lists for the various models are depicted Tables 2-33 through 2-45. These tables were used in the cost analysis for equipment cost estimation.

Table 2-29. Current Earth Station Equipment Cost Range

Item	Equipment	Descriptions	Cost *
1.	Antenna System	Includes the antenna pedestal, structure, reflector, the feed, duplexer, subreflector, and dual servo drive	$1.25M to 2.0M
2.	Dual Low Noise Receiver	Cryogenically colled low noise parametric amplifier (20 degee Kelvin); provides a minimum of 33 dB of gain	$175k to 250k
3.	Interfacility Link (Transmit and Receive)	Is completely redundant, includes TWT amplifiers (low noise or intermediate type), waveguide runs from antenna complex to control building, waveguide switches, pilot tone injection, etc.	$30k-50k (Receive or Transmit)
4.	Dual High Power Amplifier	A dual high power TWT amplifier in the 8kW range complete with power supply, heat exchanger/monitor, control and switching equipment.	$200k to 280k
5.	a. Power Divider	Power divider, reception (Low Level) 1:16	$2k to 5k
	b. Power Combiner	Low level, transmission 1:4	$1k to 3k
6.	Narrowband Transmitter	Low level, includes power supply, modulator, baseband unit, and upconverter	$18k to 25k

Table 2-29. Current Earth Station Equipment Cost Range (Continued)

Item	Equipment	Description	Cost *
7.	Narrowband Receiver		
	A. Message	Message service assembly with power supply, threshold extension demodulator, baseband unit and down-converter.	$20k to 25k
	B. TV	Television service assembly with power supply, conventional demodulator, baseband unit and down-converter.	$18k to 22k
8.	Baseband Distribution Frame	Provides the baseband coupling and switching between the MUX and the narrowband receivers and transmitters	$25k to 50k
9.	Alarms/Monitor Control Equipment Plus Test Equip.	Depends on customer requirements	$100k to 275k
10.	Multiplex	The multiplex price is based on redundant frequency generation equipment from group up, but no terminations, signaling and conditioning equipment. A 132 channel consisting of one transmit path and voice receive paths is assumed.	$100k to 150k
11.	Installation Cost	Includes engineering, site preparation, cost of land, etc.	$500k to 1.75M

*In cost figures k = thousands, M = millions } of dollars

Table 2-30. Estimated Cost Breakdown of a Typical MDC Earth Station

Items No.	Equipment	Qty.	1968-1972 Unit Cost Thousands of Dollars Range	1968-1972 Cost in Thousands of Dollars Range
1	Antenna System	1	1,250 - 2,000	1,250 - 2,000
2	Dual Low Noise Receiver	1	175 - 250	175 - 250
3	a) IFL Transmit (Redundant)	1	30 - 50	30 - 50
	b) IFL Receive (Redundant)	1	30 - 50	30 - 50
4	a) Power Divider (1:16)	1	2 - 5	2 - 5
	b) Power Combiner (Low Level, 4:1)	1	1 - 3	1 - 3
5	Dual High Power Amplifier	1	200 - 280	200 - 280
6	a) Narrow Band Transmitter	4	18 - 25	72 - 100
	b) TV Baseband Unit (To convert redundant mess. to video operation)	1	2 - 4	2 - 4
7	Narrow Band Receiver (Low level)			
	a) Message	7	20 - 25	140 - 175
	b) TV Video	1	18 - 23	18 - 23
	c) Spare Standard Demod. & TV Baseband Unit plus IF Filters, Etc.	1	5 - 8	5 - 8
8	Baseband Distribution Frame	1	25 - 50	25 - 50

Table 2-30. Estimated Cost Breakdown of a Typical MDC Earth Station (Cont)

Items No.	Equipment	Qty.	1968-1972 Unit Cost Thousands of Dollars Range	1968-1972 Thousands of Dollars Range
9	Multiplex (Message 132 voice channels)	1	100 - 150	100 - 150
10	Control Monitor & Test (Alarm/Monitor Control Equipment plus test equip.)	1	100 - 275	100 - 275
11	Installation Cost	1	500 - 1500	500 - 1750
Total Cost			$2, 650 - $5, 173	
Mean Value			$3, 911, 500.	

Table 2-31. Cost Analysis of Color TV Earth Stations

Description	Block Diagram Figure No.	Grade of Service	Equip. List Table No.	Capacity	User	Cost**	Antenna Cost Normalized
A. Reception							
Regional (VSAM) @ 850 MHz	2-6	No. 1	2-33	One channel	Commercial*	2.0%	40%
National (VSAM) @ 850 MHz	2-7	No. 1	2-34	Five channels simultaneously	Commercial*	5.0%	20%
Home (VSAM) @ 850 MHz	2-8	No. 3.5	2-35	12 channels	Home	.01%	10%
Regional (FM) @ 4 GHz	2-10	No. 1	2-37	One channel	Commercial*	2.0%	14%
National (FM) @ 4 GHz	2-11	No. 1	2-38	Five channels simultaneously	Commercial*	5.0%	6.0%
B. Transmission							
Regional (VSAM) @ 1.5 GHz	2-9	No. 1	2-36	One channel	Commercial*	5.0%	20%
National (VSAM) @ 1.5 GHz	---	No. 1	2-36	Transmits three channels simultaneously	Commercial*	13%	7.0%
Regional (FM) @ 6 GHz	2-12	No. 1	2-39	One channel	Commercial*	3.0%	10%
National (FM) @ 6 GHz	---	No. 1	2-40	Transmits three channels simultaneously	Commercial*	5.0%	20%

** The ratio of the particular earth station to the Cost Model expressed in percent

* Cable head or interfaces with terrestrial microwave for distribution by TV stations.

Table 2-32. Cost Analysis of Communications Service Earth Stations

Description	Block Diagram Figures	Crade of Service	Equip. List Table No.	Capacity	User	Cost*** Comparison	Antenna Cost Normalized	Multiplex Cost Normalized
A. Preassigned 1. Multi-Destination Carrier (FDM/FM Station)	2-13	TV-No. 1 Message-Toll quality (S/N=52dB)	2-41	Ties in with a network of five ground stations-300 voice capacity plus one TV channel	Developed or Developing* Nations	12%	7%	30%
2. Single Destination carrier (FDM/FM Station)	2-14	Message-Toll Quality (S/N=52dB)	2-42	1800 voice channels point to point	Developed Nations (e.g., USA to Europe	30%	3%	72%
B. Demand Access								
1. SCC/FM System**	2-16	Toll Quality or Better	2-43	85 demand access voice channels		15%	3%	60%
2. SCC/FM System**	2-16	Toll quality or better	2-44	12 demand access voice channels		6%	8%	30%

*** Ratio of the particular earth station to the Cost Model in percent.
** The cost of the routing earth station is counted with the cost of the satellite. (See Table 2-45 for est. cost).
* Could reduce cost by having a multiplex of lower capacity, e.g., 132 voice channels.

Table 2-33. Regional TV Receive Earth Station Equipment List
(Figure 2-6)
VSAM

Item No.	Equipment	Description	Qty.
1	Antenna	30 ft diameter, mechanical tracking	1
2	LNR	Redundant Uncooled Paramp.	1
3	Power Divider	1:2	1
4	Receiver Equipment	LO, Mixer, D/C, IF, Demodulator, and Power Supply	2
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 2 channels)	1
6	Monitoring and Alarms		1
7		Installation Cost	1

Table 2-34. National TV Receive Earth Station Equipment List
(Figure 2-7)
VSAM

Item No.	Equipment	Description	Qty.
1	Antenna	30 ft diameter, mechanical tracking	1
2	LNR	Redundant Uncooled Paramp with Power Supply	1
3	Power Divider	1:6	1
4	Receiver Equipment	LO, Mixer, D/C, IF, Demodulator, and Power Supply	6
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 6 channels)	1
6	Monitoring and Alarms		1

Table 2-35. Home TV Receive Earth Station Equipment List
(Figure 2-8)
VSAM

Item No.	Equipment	Description	Qty.
1	Antenna	5 ft diameter mechanical tracking	1
2	RF Amplifier		1
3	TV Receiver	Color, reception of UHF channels 71-83 only	1
4		Installation Cost	1

Table 2-36. Regional and National TV Transmit Earth Station Equipment List
(Figure 2-9)
VSAM

Item No.	Equipment	Description	Qty.*	
			R	N
1	Antenna	30 ft diameter mechanical tracking	1	1
2	High Power Amplifier	Redundant Amplifier, 12 kW, 100 MHz. Bandwidth, with Waveguide Switch	1	3
3	Transmitter Equipment	U/C, Modulator, and Base-band Unit	2	6
4	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 2 channels)	1	3
5	Monitoring and Alarms		1	3
6		Installation Cost	1	1

*R = Regional
N = National

Table 2-37. Regional TV Receive Earth Station Equipment List (Figure 2-10)
FM

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	LNR	Redundant Uncooled Paramp	1
3	Power Divider	1:4	1
4	Receiver Equipment	LO, Mixer, D/C, IF, Demodulator, and Power Supply	4
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 4 channels)	1
6	Monitoring and Alarms		1
7		Installation Cost	1

Table 2-38. National TV Receive Earth Station Equipment List (Figure 2-11)
FM

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	LNR	Redundant Uncooled Paramp	1
3	Power Divider	1:12	1
4	Receiver Equipment	LO, Mixer, D/C, IF, Demodulator, and Power Supply	12
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 12 channels)	1
6	Monitoring and Alarms		1
7		Installation Cost	1

Table 2-39. Regional TV Transmit Earth Station Equipment List
(Figure 2-12)
FM

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	High Power Amplifier	Redundant Amplifier, 1 kW, 500 MHz Bandwidth	1
3	RF Combiner	4:1	1
4	Transmitter Equipment	U/C, Modulator, Baseband Unit	4
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 4 channels)	1
6	Monitoring and Alarms		1
7		Installation Cost	1

Table 2-40. National TV Transmit Earth Station Equipment List FM

Item No.	Equipment	Description	Qty.
1	Antenna	30 ft diameter, mechanical tracking	1
2	High Power Amplifier	Redundant Amplifier, 1 kW, 500 MHz Bandwidth	1
3	RF Combiner	8:1	1
4	Transmitter Equipment	U/C, Modulator, Baseband Unit	8
5	Baseband Distribution Frame	Video Amps, Processors, etc. (accommodates 8 channels)	1
6	Monitoring and Alarms		1
7		Installation Cost	1

Table 2-41. MDC Satellite Communications Earth Station Equipment List (Figure 2-13)

Item No.	Equipment	Description	Qty.
1	Antenna Subsystem	30 ft diameter, mechanical tracking with Duplexer	1
2	LNR	Uncooled Paramp with splitter driver	1
3	HPA	1-2 kW, 500 MHz nominal bandwidth	1
4	Broadband Splitter	1:8	1
5	Broadband Combiner	4:1	1
6	Receivers		
	a) TV Video	DC, IF, STD Demod, baseband unit	1
	b) Telephony	DC, IF, STD Demod, baseband unit	7
	c)	TV Baseband unit, IF filter (to convert spare rec.)	1
7	Transmitter/Exciters		
	a) TV Video	Baseband unit, mod, IF, UC	1
	b) Telephony	Baseband unit mod, IF, UC	3
	c)	TV Baseband unit (to convert redundant telephony to TV video	1
8	Super Group Distribution Frame	Amps, Processors, etc.	1
9	Multiplex Subsystem	300 VC Capacity	1
10	Control Monitor and Test Equip.		1
11		Installation Cost	1

Table 2-42. SDC Satellite Communications Earth Station Equipment List
(Figure 2-14)

Item No.	Equipment	Description	Qty.
1	Antenna Subsystem	30 ft diameter, mechanical tracking with Duplexer	1
2	LNR	Uncooled Paramp with Splitter Driver	1
3	Power Amplifier	1-2 kW, 500 MHz nominal bandwidth	1
4	Broadband Splitter	1:4	1
5	Broadband Combiner	4:1	1
6	Receiver Equipment	D/C, IF, Std-Demodulator, Baseband Unit	4
7	Transmitter Equipment	U/C, IF, Modulator, Base-band Unit	4
8	Super Group Distribution Frame	Amps, Processors, etc. (accommodates 4 channels)	1
9	Multiplex Subsystem	Handles 3 carriers (600 voice channels per carrier)	1
10	Control Monitor and Test Equip.	- - -	1
11	- - -	Installation Cost	1

Table 2-43. Demand-Assigned Earth Station for Developed Nations Equipment List
(Figure 2-16)

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	Power Amplifier	Redundant, 1 kW, 500 MHz Bandwidth	1

Table 2-43. Demand-Assigned Earth Station for Developed Nations Equipment List (Cont)
(Figure 2-16)

Item No.	Equipment	Description	Qty.
3	Low Noise Amplifier	Redundant Uncooled Paramp	1
4	Transmitter Equipment	Up Converter, LO, Power Adder (85:1)	1
5	Receiver Equipment	Down Converter, LO, Power Divider (1:85)	1
6	Transmitter Chain	FM Modulator, Mixers (4), Frequency Switching Matrix Logic	85
7	Digital Modulator		1
8	Receiver Chain	FM Demodulator, Mixers (4), Frequency Switching Matrix Logic	85
9	Digital Demodulator		1
10	Frequency Synthesizer and Distribution System	Provides 40 different frequencies	1
11	Start-Stop Equipment		85
12	Terminal Equipment	Includes Echo Suppressor and Hybrids	85
13	Controller	Channel Assignment, Access Line Selection, Signalling for TDM Link, etc.	1
14	Board	(Switchboard)	1
15		Installation Cost	1

Table 2-44. Demand-Assigned Earth Station for Developing Nations Equipment List (Figure 2-16)

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	Power Amplifier	Redundant, 1 kW, 500 MHz Bandwidth	1
3	Low Noise Amplifier	Redundant Uncooled Paramp	1
4	Transmitter Equipment	Up Converter, LO, Power Adder (12:1)	1
5	Receiver Equipment	Down Converter, LO, Power Divider (1:12)	1
6	Transmitter Chain	FM Modulator, Mixers (4), Frequency Switching Matrix Logic	12
7	Digital Modulator		1
8	Receiver Chain	FM Demodulator, Mixers (4), Frequency Switching Matrix Logic	12
9	Digital Demodulator		1
10	Frequency Synthesizer and Distribution System	Provides 40 different frequencies	1
11	Terminal Equipment	Includes Echo Suppressor and Hybrids	12
12	Controller	Channel Assignment, Access Line Selection, Signalling for TDM Link, etc.	1
13	Board	(Switchboard)	1
14		Installation Cost	1

Table 2-45. Routing Center Equipment List (Figure 2-17)

Item No.	Equipment	Description	Qty.
1	Antenna	15 ft diameter, mechanical tracking	1
2	HPA	20 W, 5 MHz Bandwidth (min.)	1
3	LNR	Uncooled Paramp	1
4	Transmitter	TDM	1
5	Receiver	TDM	1
6	Digital Modulator		1
7	Digital Demodulator		1
8	Central Equipment	Data Terminal and Control	1
9		Installation Cost	1

2.4 EARTH STATION ANTENNA ECONOMICS

2.4.1 Introduction

Since the satellite transmitting powers and operational frequencies during the next 10 to 15 years may change considerably over that of today or of those assumed for purposes of this report, it is of interest to consider the cost of antennas between the sizes of 5-foot to 105-foot diameter and for operational frequencies from 1 GHz to 35 GHz. The present-day costs of basic materials used in antenna fabrication are shown in Table 2-46. It is anticipated that the materials shown in Table 2-46 will continue to be used for a large number of the commercial antennas that will be built within the next 15 years. Since the type of material and fabrication techniques used depends upon the type and size of antenna, it is convenient to consider three classes of antennas:

a. Large (over 30-foot diameter) steerable antennas.

b. Large nonsteerable antennas

c. Small nonsteerable antennas

Table 2-46. Basic Fabrication Costs for Large Antennas

Metal Castings	\$0.80 - 1.00/lb
Structural Steel	\$0.25 - 0.30/lb
Structural Aluminum	\$0.75 - 0.90/lb
Reflector Panels *	\$5.50/ft^2
Concrete **	\$0.50 - 3.00/cubic foot
Reinforced Concrete **	\$3.50 - 4.50/cubic foot
Lead (used in counterweights)	\$0.20/lb
Fiberglass	
Laminate 181 glass cloth	\$0.25/ft^2
Impregnated with resin	\$0.15 - 0.25/ft^2
Polyurethane Foam	\$0.80/lb

* Solid panels includes initial tooling and painting

** Includes cost of installation

2.4.2 Antenna Reflector Surface Considerations

The most important aspect of a reflector antenna is the reflector surface itself. The performance and cost of the antenna is highly dependent upon the type and quality of reflector surface that is used. The quality of the reflector surface is normally given in terms of its root-mean-square deviation from the desired surface. The required surface accuracy depends upon the highest radio frequency to be used.

It can be shown that the gain/loss is given by the following expression: *

$$\text{Power/gain/loss in decibels} = 5.555\ (\sigma\ f)^2 \tag{2-37}$$

where: f is the RF frequency in GHz

σ is the effective standard deviation (root-mean-square) in inches of the surface errors relative to desired surfaces.

A common rule of thumb is that the rms surface tolerance should be less than $\lambda/12$, where λ is the radio-frequency wavelength. This is based upon the fact that the maximum gain of the antenna is achieved when the operating frequency wavelength is 12 times that of the rms surface tolerance.

This maximum gain is

$$G_{max} = \frac{\eta}{43}\left(\frac{D}{\sigma}\right)^2 \tag{2-38}$$

and is 4.3 dB less than the gain that would have been obtained with a perfect reflector. The frequency at which the maximum gain occurs is called the gain-limit frequency. Figure 2-19 illustrates the relationship between the gain-limit frequency and the σ/D ratio of a reflector.

2.4.3 Large Steerable Antenna Costs

2.4.3.1 Introduction

A number of factors determine the cost of large steerable antennas. The important factors are:

a. The antenna reflector surface

b. The wind environment

c. The type of mount

d. The type of servo drive system

* John Ruze. "Antenna Tolerance Theory - A Review," Proceedings of IEEE, Volume 54, No. 4, April 1966

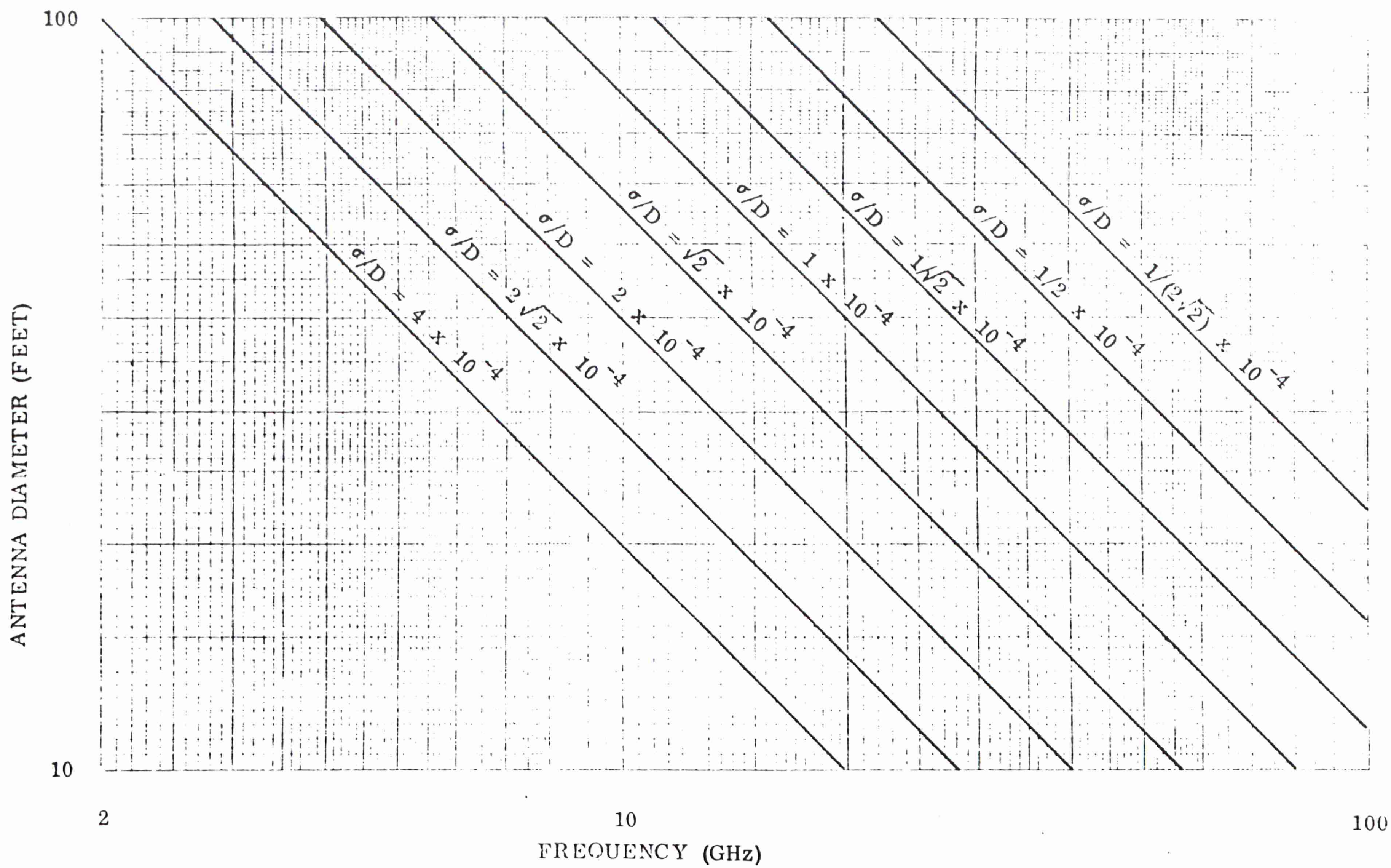

Figure 2-19. Gain Limit Frequency

Large reflector antenna surfaces are normally made up of individual accurately contoured panels. The panels in turn are usually supported by adjustable mounts on a rigid back-up support structure. This approach permits the back-up structure to be designed for strength and overall rigidity without requiring precision dimensional control in the structural members. This approach, in general, has proven to result in the lowest cost in fabricating large reflectors for commercial use.

The panel design involves optimization of several design parameters which affect the cost of the panels as well as the cost of the back-up support structure. For operating frequencies below 3 GHz it is common practice to use mesh-surface panels, since this reduces the weight of the reflector panels and the wind loading of the entire reflector structure. The higher the radio frequencies the smaller the required hole size of the mesh. For example, at 850 MHz, 1/4-inch hole sizes are acceptable, whereas at 2.3 GHz 3/16-inch hole sizes are common.

A variety of materials and fabrication techniques have been used to construct low-cost, light-weight and rigid reflector surface panels. Many of these have been described in the literature[1]. The most common type of solid-surface reflector panel is the framed-skin type where a contoured sheet of metal is bonded to a light-weight rigid panel frame. However, the use of plastic materials has been increasing in recent years. The cost and weight per square foot for three of the most common panel construction techniques are compared in Table 2-47.

Table 2-47. Approximate Relative Costs of Typical Solid-Surface Reflector Panels[2]

	Honeycomb Sandwich	Framed Skin	Foam Sandwich
Weight	1.05 lb	1.5 lb	2.0 lb
$/ft^2 - Qty. 1	21	18	10
$/ft^2 - Qty. 10	15	13	8
$/ft^2 - Qty. 40	12	1.05	7
$/ft^2 - Qty. 100	10.5	9	6

The above costs can vary by a factor of two depending upon the size, shape accuracy and quantity. The cost of mesh type of reflector surface panels is typically 1/2 to 1/3 that of solid-surface panels.

1. S. Pugh & D.E. Walker "Reflector Surfaces for Communication and Radar Aerials" Design & Construction of Large Steerable Aerials, IEE Conference Publication Number 21, June 1966

2. "A Proposal for a Very Large Array Radio Telescope" Vol. II Chapter 11 prepared by the National Radio Astronomy Observatory, January 1967

2.4.3.2 Effect of Wind on Antenna Costs

The wind distorts the reflector surface, offers additional resistance to the antenna drive system, and attempts to overturn the antenna. Thus, the wind environment affects the cost of the reflector back-up structure, the drive system, the pedestal and foundation. The wind loading in turn depends upon whether or not the reflector surface is solid or mesh. Figure 2-20 illustrates the typical reduction in wind loading with mesh reflector panels. The wind loading also depends upon the antenna pointing angle. This is illustrated in Table 2-48.

Table 2-48. Relative Effect of Antenna Pointing Angle on Cost[1]

Elevation angle	0	10°	20°	25°	30°
Wind drag loading	1.0	0.96	.91	.88	.70
Wind moment at ground	1.0	.90	.67	.58	.51
Counter weight	1.0	.87	.80	.73	.70
Tower structure weight	1.0	.88	.74	.66	.60
Pedestal cost	1.0	.938	.885	.848	.825

The effect of wind on the required drive torques at the antenna axes is illustrated in Figure 2-21.

2.4.3.3 Drive System Costs

The type of antenna drive and control system used also influences the antenna costs. The two basic drive systems used are electric motor and hydraulic motors. It has been reported[2] that at 10 hp the cost of a hydraulic drive is about half that of the electric equivalent. At 100 hp the cost of a hydraulic drive is about two-thirds of the electric equivalent. For hydraulic drives up to 20 hp, valve control is considered to cost less. Above 20 hp pump control is slightly less costly. For 100 hp hydraulic drives, the pump control costs are approximately 15 percent less than the valve control equivalent. Figure 2-22 shows the relative cost of servo drive systems as the horsepower requirements vary for a static SCR bidirectional drive amplifier, with dc drive motors arranged in a parallel antibacklash configuration and servo electronics. The servo electronics is assumed to have multiple mode selections, automatic acquisition, position follow-ups, remote and/or computer control and/or

1. Ibid VLA Proposal

2. K.N. Hastings and J.G. Chaplin "Drives For Steerable Aerials - Hydraulics Versus Electromechanical "Design and Construction of Large Steerable Aerials, British IEE Conference Publication Number 21, p. 135-139.

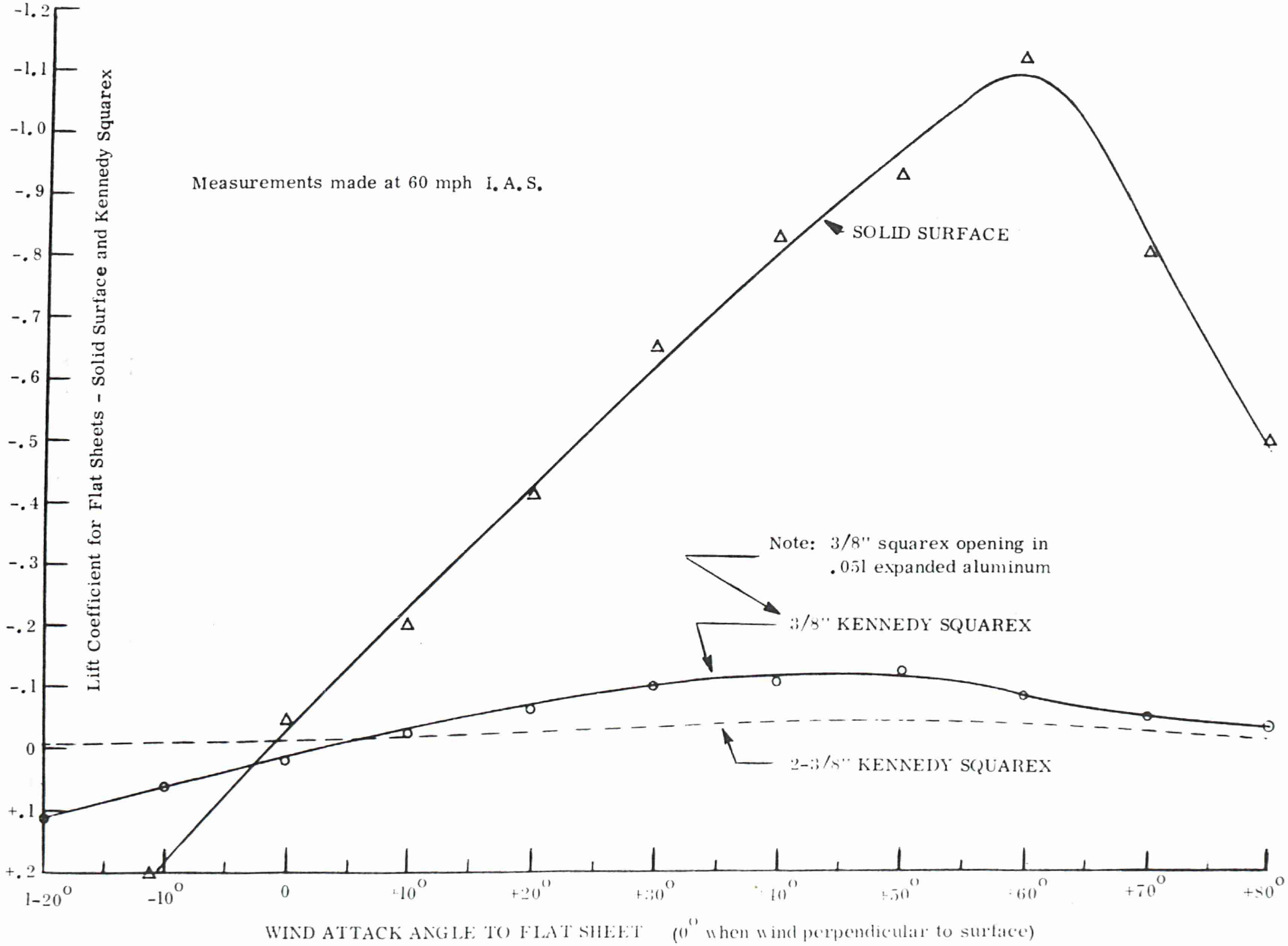

Figure 2-20. Wind Tunnel Measurements by MIT-Lincoln Lab (Aug. 1956) (MIT Test Report No. 950)

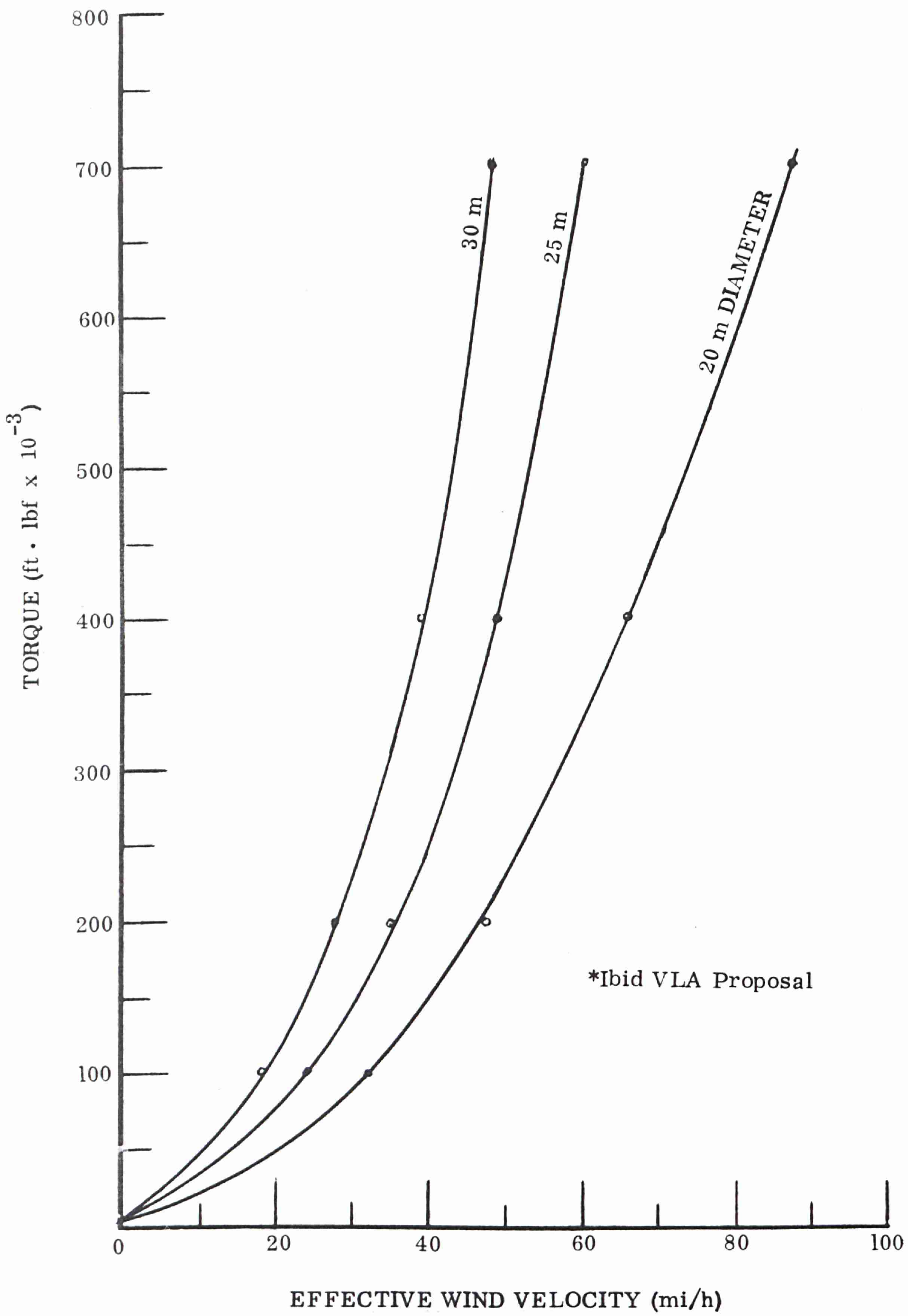

Figure 2-21. Torque Requirements Versus Wind Velocity For Different Size Reflectors*

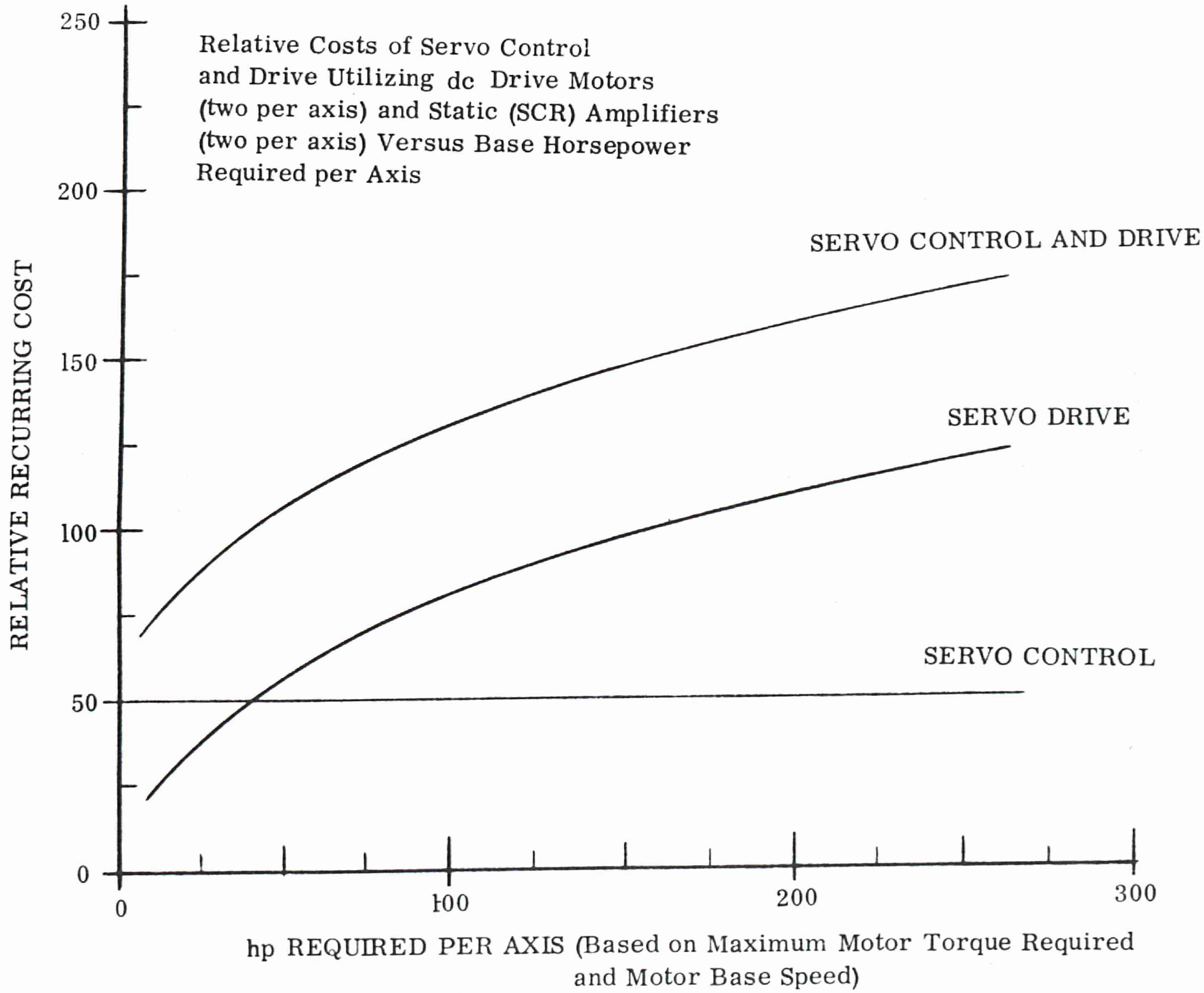

Figure 2-22. Relative Cost of Servo Drive Systems Versus Power Requirements

monitoring capabilities. Non-recurring costs depend highly on the amount of dynamic analysis and interfacing required to integrate the servo control and drive into the system, and can easily vary by a factor of two.

The base horsepower is defined as the maximum required continuous torque (greater than one minute) times the base speed of the dc motors. Motor overloads of 150 percent of the maximum required continuous torque are allowable as long as the rms horsepower is below the base horsepower and the overload is not sustained continuously longer than one minute.

2.4.3.4 Parametric Relationship of Large Steerable Antenna Costs

As indicated in previous sections the antenna cost is a function of the size of the antenna, the wind environment and the required surface tolerance. It has been shown [1, 2, 3] that the costs of large steerable antennas can be expressed in the following form:

$$C = C_o V^n f^m D^k \tag{2-39}$$

where

C_o is a proportionality constant

D is the diameter of the antenna

k is a constant whose value is between 2.7 and 3.1

v is the wind velocity

f is the highest operational radio frequency

m is a constant whose value is approximately 1/3

n is a constant whose value is approximately 2/3.

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1. W.K. Victor, "Ground Equipment for Satellite Communication" J.P.L. Tech Report No. 32-137 Oct. 30, 1961

2. R.N. Bracewell, Swarup and Seeger, Nature 142, Vol. 193, pp. 412-416

3. P. Blacksmith and A.C. Schell "A Comparison of Three Antenna Techniques in Terms of Cost vs Performance" Design & Construction of Large Steerable Aerials, British IEE Conference Publication Number 21. P. 135-139.

The cost includes the foundation and drive system as well as erection costs. The proportionality constant depends upon the type of antenna mount. Figures 2-23 and 2-24 illustrate how the costs vary with size of the antennas, type of reflector surfaces and type of mounts.

2.4.3.5 Effect of Reliability Requirements on Antenna Cost

Communications Satellite Antennas will normally be required to provide for continuous 24 hr/day operations. For steerable antennas, this means a cost of approximately 1.5 times greater than the same size of steerable antennas which do not operate continuously, such as radio astronomy antennas.* This increase in cost is partly due to the quality of materials required for greater reliability, but is primarily due to the requirement to continue operation under practically all weather conditions.

The need for continuous operation requires that the antenna-mounted equipment must be readily accessible. To illustrate, many of the large present-day earth-terminal antennas are equipped with large equipment rooms with near-laboratory ambient conditioning. Some are even equipped with elevators to ferry the electronic technicians back and forth.

For use with synchronous satellites, a steerable autotracking antenna can spend a considerable amount of time rocking back and forth on one or two gear teeth. Gear failure rates are normally rated under the assumption that all of the gear teeth over the lifetime will be loaded approximately the same percentage of time. Where this is not the case, higher stress gears are required.

One way which has been suggested to reduce the wear on the gear teeth is to stop the antenna drives and turn them on only when needed to correct the antenna pointing for satellite drift. For most drive systems, the wear and tear of starting and stopping a great number of times is many times greater than if they were permitted to run continuously.

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*P. Potter, W. Merrick and A. Ludwig "Large Antennas and Arrays for Deep Space Communications," JPL Technical Report 32-348, November, 1965.

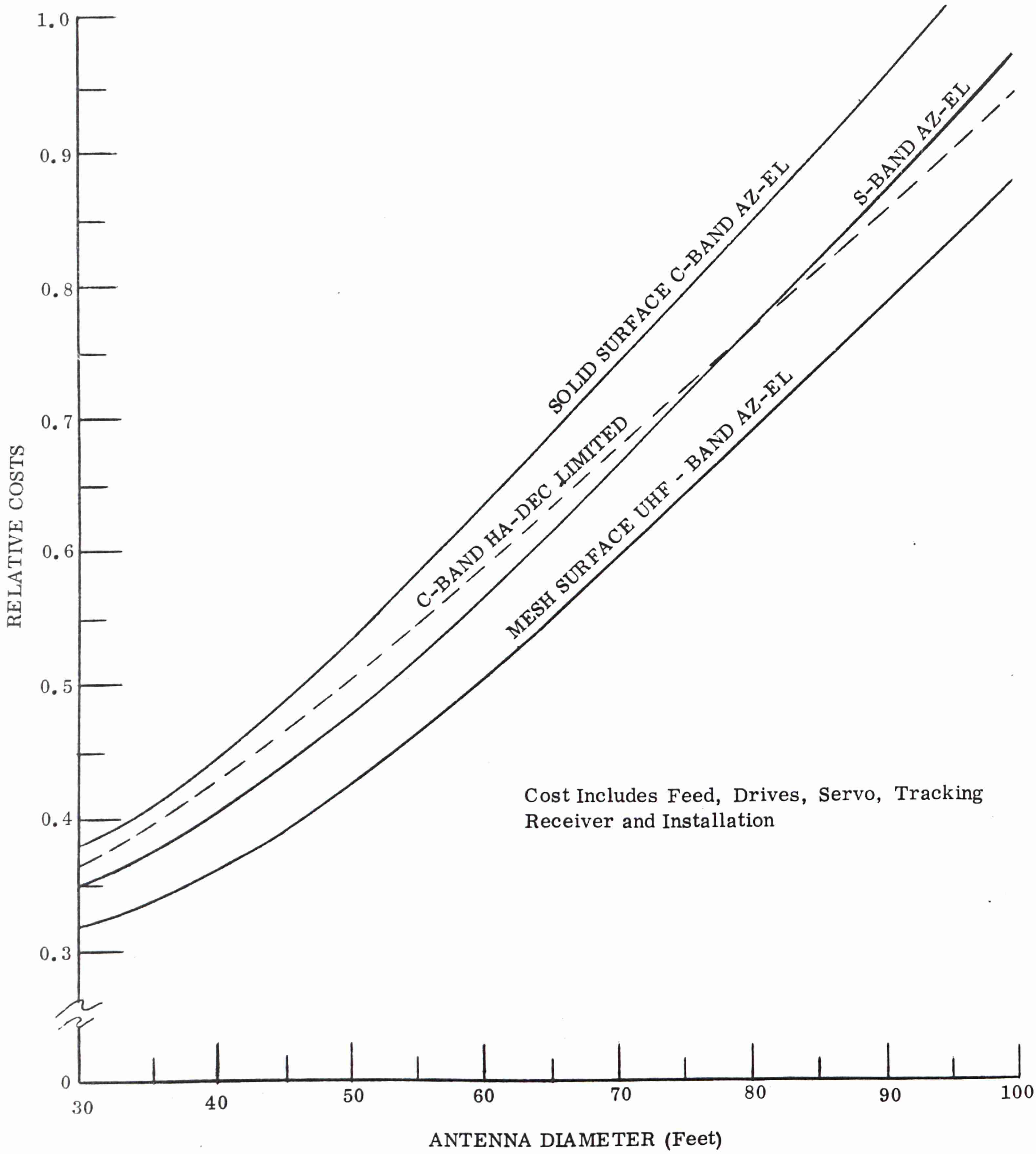

Figure 2-23. Steerable Antenna Costs Versus Diameter

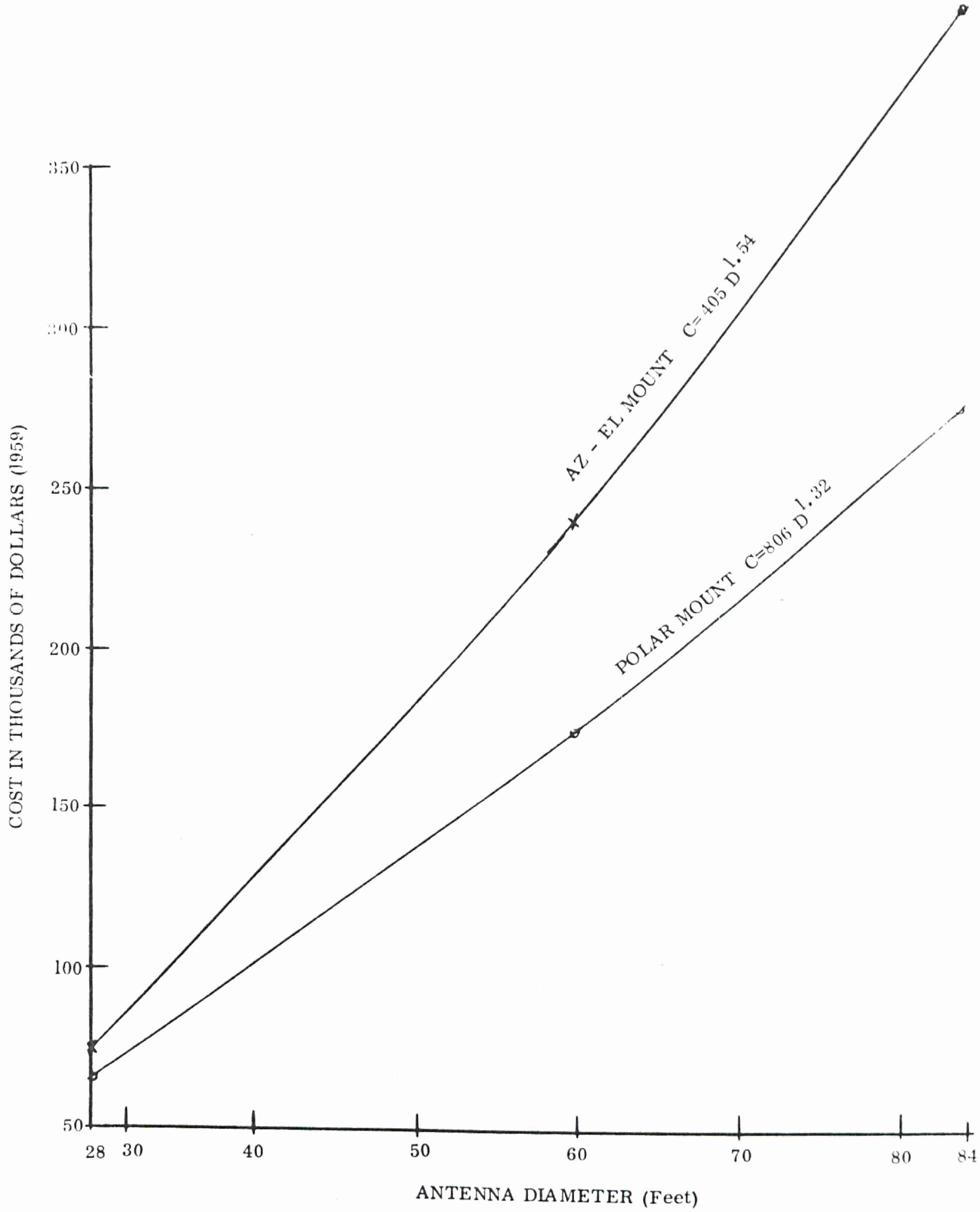

Figure 2-24. D. S. Kennedy Mesh Surface Steerable Antenna F.O.B. Factory Costs With Electric Drive and Front-Fed Feed

2.4.4 Large Non-Steerable Antenna Costs

It has been reported [1, 2] that the cost of large fixed mesh-surface reflector antennas is about $9.40 per square foot. Hutchinson[2] has estimated that the increased cost of a solid reflector surface suitable for 4 GHz is threefold. He further concludes that an 80-foot diameter fixed reflector antenna would cost one-half that of a fully steerable 60-foot antenna. Other studies [3, 4] have indicated that the cost ratio between fixed reflectors and limited motion reflectors at 4 GHz and in sizes from 10 to 60-foot diameters is 0.7 to 0.8.

2.4.5 Small Reflector Antenna Costs

The most common technique for manufacturing solid-surface parabolic reflectors up to 15 feet in diameter is the spin-shaping technique. This technique forces a spinning section of heavy sheet metal to conform to a parabolic shaped mandrel. On occasions this technique is also extended to reflectors up to 25 feet in diameter.

More recently plastic antenna reflectors to which a metallic skin or coating is applied to form the reflecting surface have been gaining in popularity. Metal-coated plastic reflectors up to 30 feet in diameter are currently in use. This technique has been applied successfully for millimeter wave types of antennas. For millimeter-wave type of applications the low cost of the material and its excellent thermal stability make it very competitive with metal antennas.

The costs of small conventional microwave relay antennas and tropospheric antennas are known and are illustrated in Figure 2-25. It was indicated in earlier sections that the majority of the earth station costs remained fixed regardless of the antenna. When a large number of stations are contemplated, techniques which reduce the antenna costs even when the antenna is not the dominant cost item of the station can become significant. Some of the possibilities in this direction have been explored by the

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1. Ibid, P. Blacksmith and A.C. Schell, "A Comparison of Three Antenna Techniques in Terms of Cost Vs. Performance, "Design & Construction of Large Steerable Aerials British IEE Conference Publication Number 21, p. 135-139.

2. G.L. Hutchinson, "A Review of Microwave Problems in the Designs of Large Steerable Aerials" presented at the Conference on Design & Construction of Large Steerable Aerials, London, June 21, 1966.

3. R.D. Swenson, "Economic Comparisons of Domestic Satellite Television Distribution System"

4. "An Approach to Low Cost, High Performance Antenna Systems for Satellite Communications Ground Stations," Andrew Corporation Report dated March 1967.

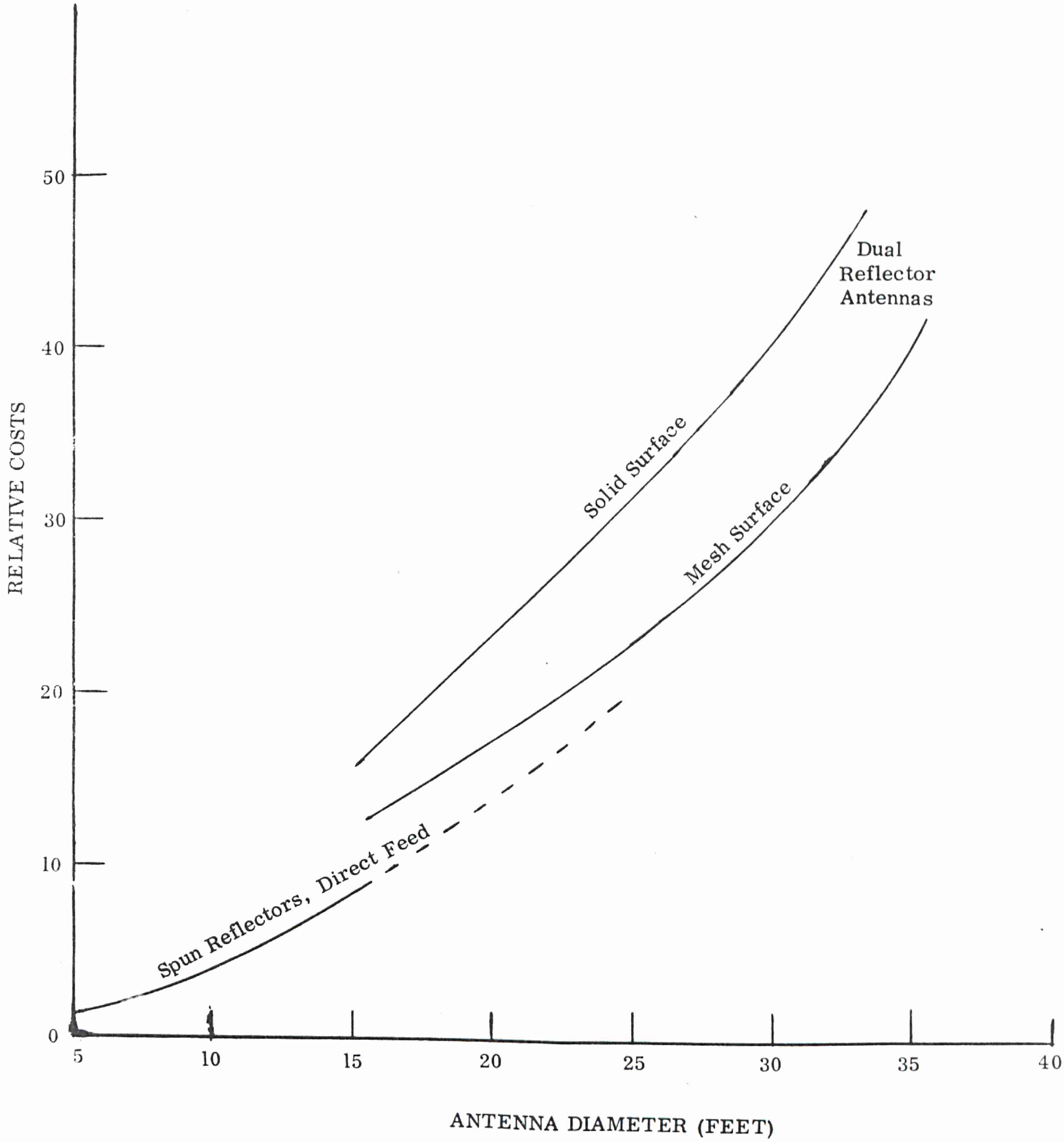

Figure 2-25. Fixed Commercial Antenna Costs Versus Diameter (Cost Includes Feed and Installation)

engineering students at Stanford*. Their estimated fabrication costs for a large number of small reflectors range from $18 for a four-foot reflector to $55 for an eight-foot reflector.

2.4.6 Antenna Feed Costs

The antenna feeds currently used for commercial communications satellite earth terminals are fairly sophisticated. This is primarily because current earth-terminal antennas are 85 feet to 105 feet in diameter. For these sized antennas autotracking is normally required. In addition, the sophistication of the antenna feed system can be justified by the savings in the size of the antenna.

A recent survey of the antenna feed suppliers indicates that the present-day price for feed systems varies from $95, 000 to $200, 000. All of these feeds are capable of low-noise high-efficiency reception and autotracking in the 3.7 to 4.2 GHz frequency band, while simultaneously transmitting up to 10 kilowatts of power in the 5.925 to 6.425 GHz frequency band. All of these feeds are capable of operating in linear or circular polarization modes. When using the linear polarization mode, the feeds are equipped for positioning of the polarization orientation.

A variety of fabrication techniques are employed, such as casting, machining, electroforming, dip-brazing, etc. All of the fabrication processes require a great deal of individual attention by a skilled craftsman. In addition, a great deal of mechanical and electrical testing is required, which again requires highly skilled craftsmen, technicians, and engineers. The net result, much like that of the communications satellites, is a high cost per pound. Thus, as long as sophisticated antenna feed systems are used, the price will not significantly decrease.

Most of the sophistication is in the communications portion of the antenna feeds so that elimination of the autotracking requirements will result in, at most, moderate reductions in the feed cost, i.e., 5 to 15 percent. In the communications portion of the feed system, more effort is directed towards optimizing the receive performance so that elimination of the transmit requirement would only result in 10 to 15 percent reduction in the cost of the feed system.

To achieve similar sophistication as present-day feeds at other frequency bands requires $100, 000 to $350, 000 in development costs. The only way to anticipate a reduction in feed costs within the next 10 to 15 years is to anticipate a reduction

*ASCEND - Advanced System For Communications and Education in National Development. Final Report Space Systems Engineering Report, Stanford University June 1967.

in the sophistication. This can be achieved through improved satellites and relaxation of the accessibility requirements. To illustrate, commercial microwave communications antenna feeds which are designed to feed the parabolic reflector from the front cost anywhere from $500 to $2,000.

Present-day earth-terminal feeds are designed to feed the reflector from the rear by means of a subreflector. This permits the low-noise receiver to be mounted behind the main reflector in an equipment room. This technique uses a secondary reflector whose cost alone is about $600 per foot in diameter. Subreflector diameters are typically 0.1 to 0.15 of main reflector diameter. The use of a subreflector permits improved G/T performance but it also requires a large feed system. For example, the feed systems for present-day earth-terminals weigh on the order of 3500 to 6000 pounds, compared to 50 to 150 pounds for a front-fed feed.

2.4.7 Receiving System Cost Tradeoffs

From the previous sections it would appear that the reduction of the antenna diameter by a factor of two could result in reducing the cost of large steerable antennas by a factor of 6.5 to 8.5. The net cost savings depends upon the amount of expenditure required to achieve the more sophisticated design; i.e., the net cost savings is approximately equal to:

$$\Delta C = \Delta C_a + \Delta C_e \qquad (2\text{-}40)$$

where

$$\Delta C_a \cong C_o \left(\frac{D_1}{D_2}\right)^k$$

and

ΔC_e is the extra cost to achieve the more sophisticated design.

It should be noted that the cost ΔC_e is, for all practical purposes, independent of the size of the antenna.

System design engineers try to use the smallest antenna diameter with the highest antenna efficiency possible to meet the system requirements, since this usually results in the lowest cost. This is particularly true in the case of a quantity of antennas. There is, of course, a limit to the increase in antenna gain that can be achieved by increasing the efficiency. Most microwave parabolic antennas can be designed to produce an efficiency of 55 percent by cookbook methods. Table 2-49 compares the

Table 2-49. Comparison of Performance of Different Types of Large Microwave Antennas at 4 GHz

Feed System	Maximum Theoretical Efficiency (Percent)	Typical Maximum Efficiency (Percent)	Anticipated Maximum Efficiency (Percent)
Primary Focus Conventional 10 dB Taper	75.0	52.5	58
Primary Focus Conventional 20 dB Taper	71.6	50	55
Primary Focus Shaped-Beam 20 dB Taper	71.6	60	65
Conventional Cassegrain	81-85	55	6
Cassegrain with Shaped Subreflector	81-85	62	67
Shaped Dual Reflector	81-85	72	80
Dielguide	81-85	68	73
Horn-Reflector	91-95	77	87
Spherical Reflector With Corrective Subreflector	60	40	50

relative efficiency of various types of antennas. Thus, the maximum reduction in antenna diameter that is theoretically possible (i.e. 100 percent efficient) is a factor of 0.74 over one that is 55 percent efficient. It is believed that the upper limit for a physically realizable parabolic reflector antenna is 85 percent, allowing a reduction in the antenna diameter by a factor of 0.804. The differential cost reduction, ΔC, which results from an increase in efficiency, ΔN, is given by the following expression:

$$C = C\,(1 - \alpha^{k}) \tag{2-41}$$

where

α = antenna diameter reduction factor

$$\alpha = \left[\frac{N}{N + \Delta N}\right]^{1/2} \cong \left[1 - \frac{\Delta N}{N}\right]^{1/2} \tag{2-42}$$

$$\frac{\Delta C}{C} \cong \frac{k}{2} \qquad \frac{\Delta N}{N} \quad (\text{if } \Delta N/_{N} \text{ less than } 0.1)$$

The above equation assumes that the gain of the antennas is the same in both cases, and C is the cost of the larger antenna. Table 2-50 illustrates the differential antenna costs predicted by the above expression compared to a 55 percent efficient antenna while holding the antenna gain constant.

Of course, part of the above savings must be applied to the cost of achieving the additional antenna efficiency. If the reference antenna alreadv has a high efficiency (say 65 percent), it may cost more to increase the efficiency significantly than can be saved by reducing the antenna diameter accordingly.

If the quotient of antenna gain/noise temperature (G/T) is the prime figure of merit, a similar cost and antenna performance tradeoff may be performed by reducing the antenna noise temperature. If the antenna noise temperature is reduced withou affecting the antenna efficiency (which is rarely the case in practice) and the anten. cost follows Equation 2-42, then

$$C = C\,(1 - B^{k})$$

where

B = antenna reduction factor

$$B = \left[1 - \frac{\Delta T}{T}\right]^{1/2} \tag{2-43}$$

Table 2-50. Theoretical Antenna Cost Reduction For Improving Antenna Efficiency Above 55 Percent

Efficiency In Percent	Diameter Reduction Factor	$\frac{\Delta C}{C}$ k = 2.7	$\frac{\Delta C}{C}$ k = 2.8	$\frac{\Delta C}{C}$ k = 2.9	$\frac{\Delta C}{C}$ k = 3.0	$\frac{\Delta C}{C}$ k = 3.1
55	1.000	.000	.000	.000	.000	.000
60	.957	.111	.115	.119	.122	.126
65	.920	.202	.209	.215	.222	.228
70	.886	.278	.287	.295	.304	.312
75	.856	.342	.352	.362	.372	.382
80	.829	.397	.408	.419	.430	.441
85	.804	.444	.456	.468	.480	.491

$$\frac{\Delta C}{C} \cong \frac{k}{2} \quad \frac{\Delta T}{T} \quad \left(\text{if } \frac{\Delta T}{T} \text{ less than } 0.1\right) \tag{2-44}$$

Table 2-51 illustrates the differential costs predicted by Equation 2-43 compared to an antenna having a noise temperature of 50°K while holding the gain constant.

2.4.8 High Power Amplifier and Antenna Tradeoffs

The required Effective Isotropic Radiated Power (EIRP) from the ground-based station depends upon the modulation, the satellite receiver characteristics, and the quality of service. The EIRP is given by the product of the antenna gain and the transmitter power output, i.e.:

$$\text{EIRP} = \text{GP} = \eta \left(\frac{\pi D}{\lambda}\right)^2 \beta P_t \tag{2-45}$$

where

- G is the antenna power gain
- P is the transmitting power
- η is the antenna gain efficiency
- D/λ is the antenna diameter-to-wavelength ratio
- P_t is the transmitter saturation power
- β is the transmitter back-off factor to minimize the intermodulation.

Table 2-51. Theoretical Antenna Cost Reduction For Improving Antenna Noise Temperature

Antenna Temperature Degrees Kelvin	Diameter Reduction	$\frac{\Delta C}{C}$ k = 2.7	$\frac{\Delta C}{C}$ k = 2.8	$\frac{\Delta C}{C}$ k = 2.9	$\frac{\Delta C}{C}$ k = 3.0	$\frac{\Delta C}{C}$ k = 3.1
50	1.000	.000	.000	.000	.000	.000
49	.990	.027	.028	.209	.030	.031
48	.980	.054	.056	.057	.059	.061
47	.970	.080	.083	.086	.089	.091
46	.959	.106	.110	.114	.118	.121
45	.949	.133	.137	.142	.146	.151
44	.938	.159	.164	.169	.174	.180
43	.927	.184	.190	.196	.202	.208
42	.917	.210	.217	.223	.230	.237
41	.906	.235	.243	.250	.257	.265
40	.894	.260	.268	.276	.284	.292
39	.883	.285	.294	.303	.211	.320
38	.872	.310	.319	.328	.337	.346
37	.860	.334	.344	.354	.363	.373
36	.849	.358	.369	.379	.389	.399
35	.837	.382	.393	.404	.414	.425

The cost of the high-power amplifier increases as its saturated (maximum output) power output increases. The cost also depends upon a number of other factors, such as bandwidth requirements, operating frequency, etc.

Narrow-bandwidth (1 to 3%) high-power microwave amplifiers usually employ klystron amplifiers and are suitable for single-carrier transmission. Wide-bandwidth (10% to 15%) high-power microwave amplifiers usually employ Traveling-Wave-Tubes (TWT) and are suitable for multiple-carrier operation (with a suitable backoff).

Although the cost of a high-power amplifier increases with the increase in its saturated output power, the cost per unit of output power decreases as the saturated power output increases. This is illustrated below.

Table 2-52. Relative Cost Per Unit of Power for Microwave High-Power Amplifiers*

Saturated Output Power	Type of Amplifier	
	Klystron	TWT
100 watts	$70/watt**	$100/watt
1000 watts	$20/watt	$ 35/watt
10,000 watts	$ 6/watt	$ 11/watt

* L.L. Fisher, "High Power Wideband TWT Power Amplifier Systems," presented at 1968 IEEE Region 6 Conference.

**extrapolated

From Table 2-52 it appears that the high-power amplifier costs are inversely proportional to the square root of the saturated power level.

2.4.9 Satellite Orbital Spacing Versus Earth Station Antenna Diameter

Dramatic increase in satellite EIRP is projected in the 1970's. This increase in EIRP will be attained by increased satellite transmitter power coupled with the use of higher-gain satellite antennas (national, regional, "pencil beam" coverage). With this increase in EIRP, the cost of the earth terminals served can be drastically reduced from the current range of 2.65 million to 5 million to under 0.5 million dollars. This cost reduction is achieved primarily by having earth stations with smaller antennas (mechanical positioning only) and uncooled low-noise receivers. (The result is an earth terminal with a lower station figure of merit, (G/T) ratio.) The latter does not affect the separation between satellites operating at common frequencies. However, as the earth terminal antennas are reduced in size, the antenna beamwidth gets wider and the spacing between satellites must be increased to maintain a tolerable interference level.

Figure 2-26* is a plot of a family of curves that shows the earth antenna diameter changes in discrete steps, while maintaining 4,350 picowatts each for thermal noise and for interference from the adjacent satellites. The figure further shows that as the earth terminal antenna gets smaller, the satellite EIRP must increase, as would be expected, to maintain the same quality of performance.

We have postulated that achieving the required satellite EIRP in the 1970's is a fact of life and is within our technological grasp. The adverse effect of reducing the earth station antenna diameter is that the channel capacity per orbital degree decreases. The curves substantiate this fact and, indeed, show that changing the antenna diameter from 85 feet to 30 feet changes the channel capacity per orbit degree (at the peak of the curves) from approximately 22,500 channels per orbital degree to 8,000 per orbital degree. Further reducing the earth antenna diameter from 30 feet to 15 feet leads to a change of 8,000 channels per orbital degree to 4000 channels per orbital degree. Thus, the relationship between channel capacity per orbital degree and antenna diameter is a linear one, and can be expressed as such:

$$C = KD \tag{2-46}$$

where:

C is the channel capacity per orbital degree

K = performance constant

D = antenna diameter

The point of this discussion is to show that the reduction in channel capacity per orbital degree as a function of antenna diameter is a linear one. However, the <u>economic cost savings</u> by using smaller antenna sizes in the earth station has been shown to be more dramatic. Obviously a tradeoff point exists, and this itself depends on the particular circumstances.

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*Figure is extracted from a communique between Dr. Samuel G. Lutz of Hughes and Mr. Paul Bachar of ITT. This communique was an attachment to the Minutes of TR-34 Committee on Space Telecommunications Equipment and Systems, dated April 24, 1968.

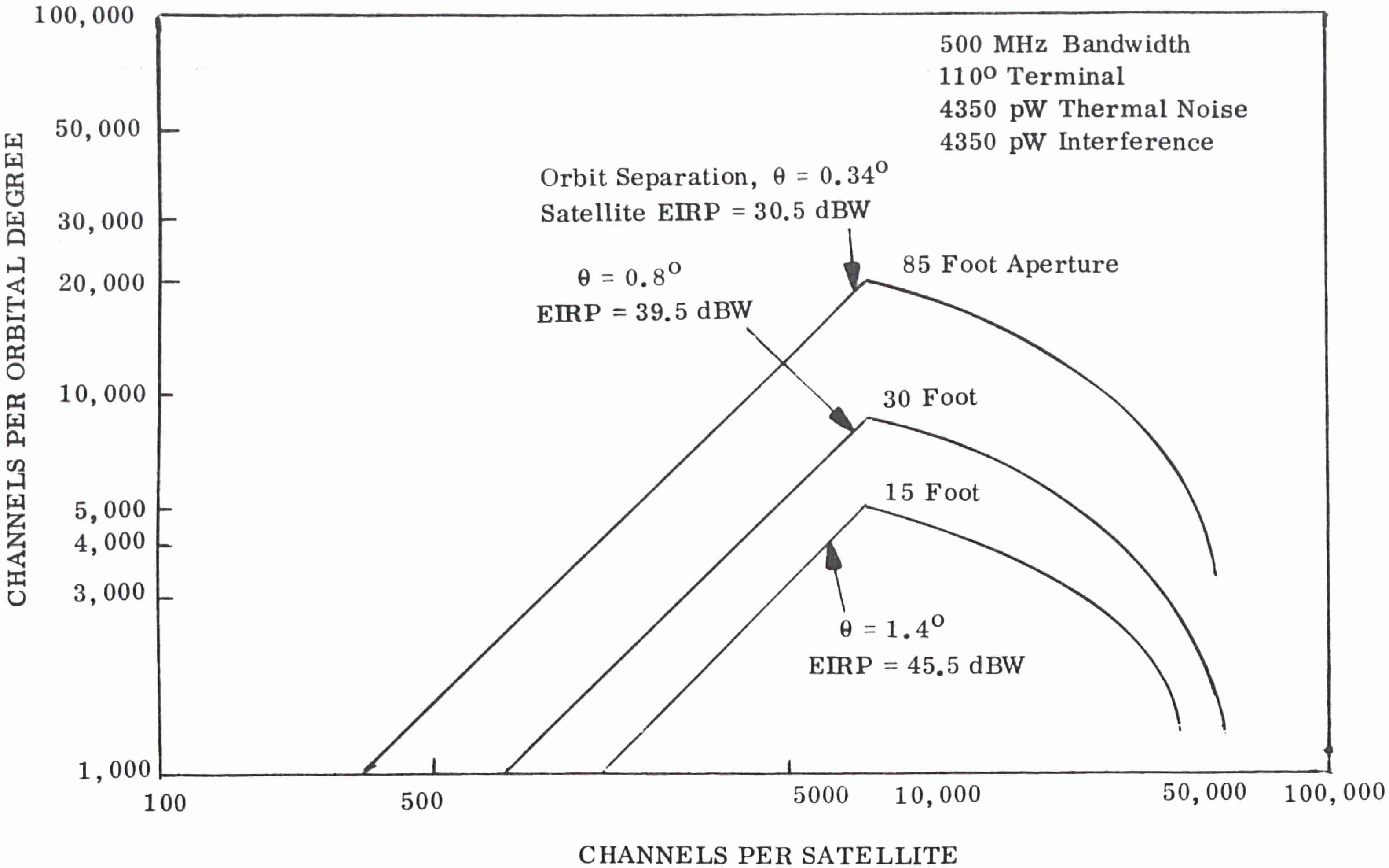

Figure 2-26. Channels per Orbital Degree Versus Channels per Satellite (With Earth Station Aperture Size as a Parameter)

2.5 EFFECTS OF OPERATING AT MILLIMETER WAVE FREQUENCIES

2.5.1 General

This subsection compares the factors which will affect satellite communications above and below 10 GHz. The frequencies selected for comparison are 16 GHz, 35 GHz, and 94 GHz. These frequencies were selected because they lie in the low propagation attenuation regions between water vapor and oxygen absorption frequencies.

Table 2-53 below summarizes the link loss factors which are sensitive to frequency. If the satellite beamwidth is fixed (constant antenna gain) to provide the same earth coverage from synchronous altitude, the increase in ground antenna gain as the frequency is increased (for a fixed antenna size) exactly cancels the increase in free-space loss. Thus the only changes in the link calculations are in the receiver noise temperature (which gets worse with increasing frequency), and in the increase in attenuation through the atmosphere due to rain, cloud, oxygen, and water vapor absorption. To maintain the same satellite EIRP, increased transmitter power in the satellite is required.

As the table shows, the margins required for 35 GHz and 90 GHz become quite large. The propagation loss margins shown are estimates of the values required to provide the link availability values shown. For instance, the margins shown in Table 2-53 for a 97-percent link availability are values which would be exceeded only three percent of the year (12 days) for a ground station with a 15-degree elevation angle and 100 cm/yr average annual rainfall. The major propagation uncertainty at this time results from a lack of statistics on the frequency, extent, density, and thickness of cloud cover. The cloud attenuation for a high-availability link at 35 GHz or higher can be a significant factor, as shown in Figure 2-29.

Table 2-53. Link Loss Factors

Frequency	4 GHz	16 GHz	35 GHz	90 GHz
Satellite Antenna Gain	Constant (constant beamwidth required for coverage)			
Free-Space Loss $\left(\frac{\lambda}{4\pi R}\right)^2$ (dB)	197	208.5	215.8	224
Ground Antenna Gain (dB)				
15-Foot	43	54.5	61.8	70
30-Foot	49	60.5	67.8	76

Table 2-53. Link Loss Factors (Cont)

Frequency	4 GHz	16 GHz	35 GHz	90 GHz
System Noise Temperature (dB)	28	28	32	35
	TDA	TDA	Uncooled Paramp	Mixer
Propagation Loss Margin (dB)				
Link Availability - 97% (weather only)	0.2	3.4	14.3*	90.2*
Link Availability - 99.9% (weather only)	0.4	10.9	44.2**	203.5**

*Due mainly to cloud cover attenuation. These may be reduced when better data on cloud density and coverage statistics is available.

**Use of space diversity at ground stations may significantly reduce these values.

Figure 2-27 shows a graph of relative antenna costs (including pedestal, servo, and reflector) for 15-foot and 30-foot antennas at 4 GHz and 35 GHz. The data is insufficient to obtain any general trends, but does indicate that 35-GHz antennas are on the order of twice as expensive as an equivalent size antenna at microwave frequencies.

2.5.2 Propagation Considerations

Rain, snow, and fog introduce an absorption in the atmosphere which depends on the amount of moisture and the operating frequency. In addition to the effect of condensed water vapor, some selective absorption will result from the oxygen and water vapor in the atmosphere.

In earth-to-satellite communications, the effective atmospheric path length is a function of the angle of elevation of the transmission path and of the depth of the atmosphere in which most of the radio attenuation occurs. Since most of the absorption above a frequency of one GHz occurs in the lower levels of the atmosphere, there is less attenuation from mountain-top sites.

In the case of attenuation resulting from heavy rain storms, considerable improvement can, in general, be obtained by the use of space diversity: two earth stations spaced several miles apart being employed.

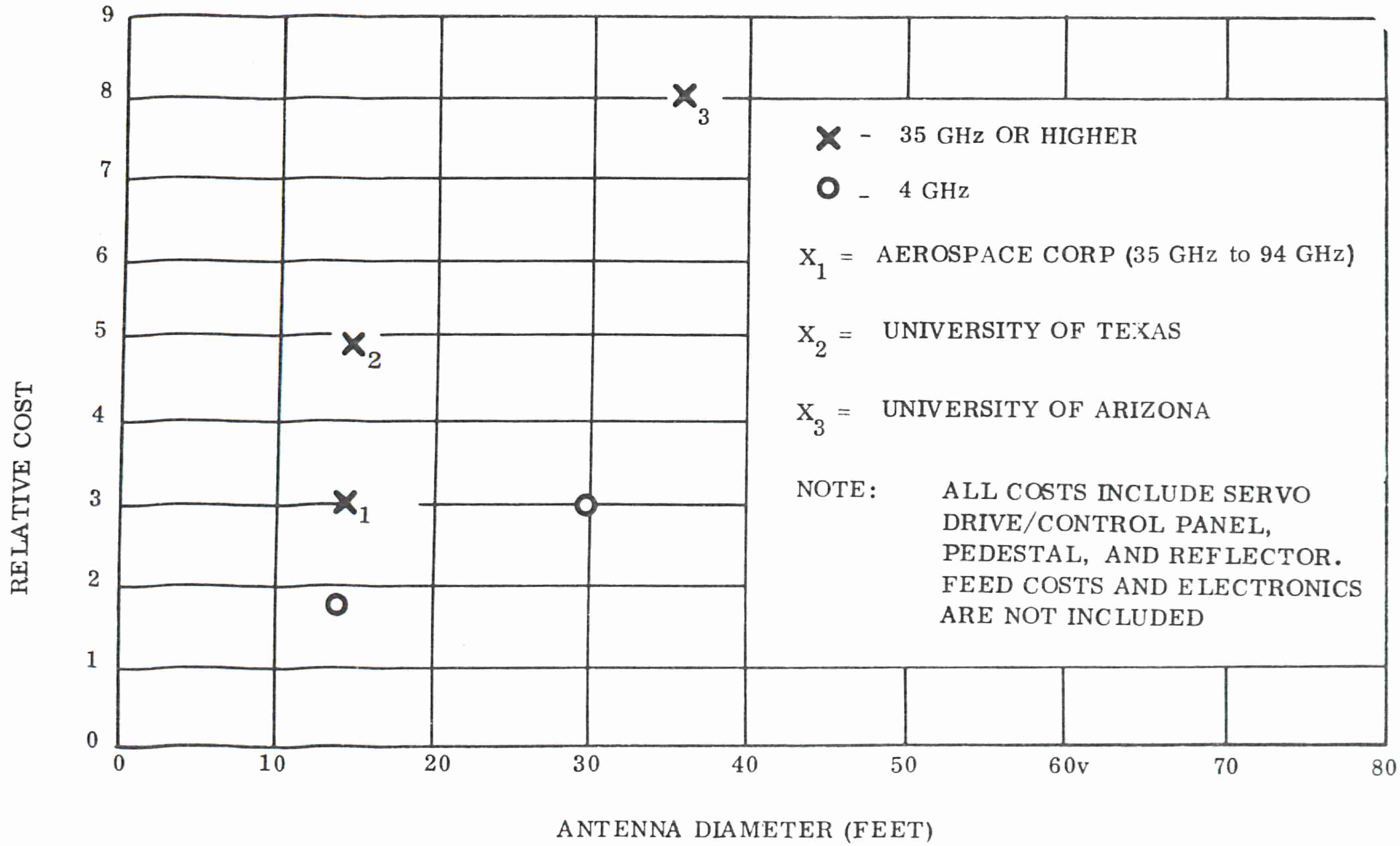

Figure 2-27. Relative Antenna Costs, 4 GHz Versus 35 GHz

2.5.2.1 Rain Attenuation

Normal Rain Storms - The rate of absorption A of rain in dB/km may be expressed in terms of the rainfall rate R, in millimeters per hour, by[1]:

$$A = KR^a$$

The values of the functions K and a for four frequencies are given below:

GHz	K	a
8	9×10^{-3}	1.27
16	5.6×10^{-3}	1.20
35	$3.2. \times 10^{-1}$	0.92
94	2.5	0.82

In earth-to-satellite communications, the effective path length depends on the elevation angle of the transmission path. Under normal rainfall conditions, most of the rainfall occurs below an altitude of 2 km. It has been estimated that the effective path length for rain attenuation, as a function of elevation angle, is as follows:

Elevation Angle (degrees)	Effective Path Length (km)
5	20
10	8
90	2

Long-term cumulative distribution of rain absorption has been estimated from statistics analyzed by Bussey[2]. The cumulative distribution of instantaneous path surface rainfall rates depends on how the rainfall rate varies with height above the earth's surface and upon the correlation of rainfall with distance along the path.

The rainfall attenuation has been estimated for a central U.S. site having an average annual rainfall of 74 cm. The rain attenuation exceeded for only 0.01 percent of the year has been estimated assuming elevation angles of 5, 15 and 90 degrees. Figure 2-28 shows the rain attenuation at this site as a function of frequency for three elevation angles.

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1. National Bureau of Standards, Technical Note 101.

2. Bussey, H.E., "Microwave Attenuation Statistics Estimated from Rainfall and Water Vapor Statistics," IRE, P 281-285, July 1950.

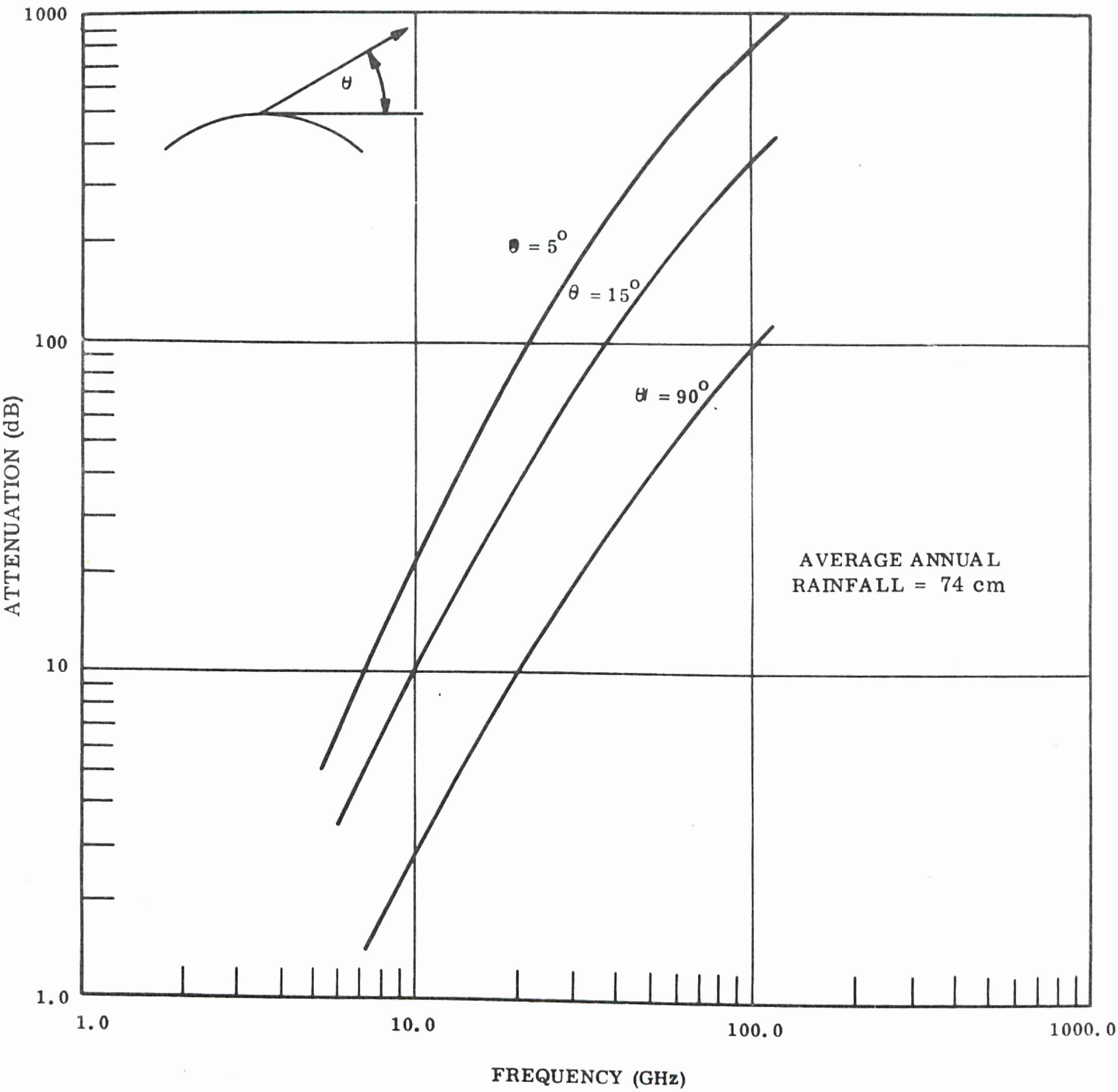

Figure 2-28. Rain Attenuation Versus Frequency

2.5.2.2 Cloud Attenuation[1,2,3,4,5]

The attenuation of radio waves by fog or clouds increases rapidly with increasing frequency, and is proportional to the liquid water content. Water concentration in clouds generally ranges from 1 to 2.5 g/m^3, although isolated instances have reported values as high as 4 g/m^3. The attenuation of water clouds increases with decreasing temperature, but ice clouds give attenuations about two orders of magnitude smaller than water clouds of the same water content.

Figure 2-29 shows the attenuation of clouds as a function of frequency for four values of water content. The attenuation shown assumes an elevation angle of 15 degrees, a temperature of 0°C, and a uniform water cloud extending from an altitude of 3 km to 5 km.

At 10°C, cloud attenuation in dB/km/g/m^3 at 9 GHz is about 0.78 and, at -8°C, 1.35 times the attenuation at 0°C. The visibility in cloud of 1 g/m^3 is about 175 feet, and a cloud of 2.5 g/m^3, about 90 feet.

2.5.2.3 Oxygen and Water Vapor Attenuation[1,2]

The attenuation of radio waves by suspended water droplets and rain usually exceeds the combined oxygen and water vapor absorption. The absorption of oxygen reaches a peak of about 10 dB/km at 60 GHz, but decreases rapidly to about 0.015 dB/km at 10 GHz. The absorption by water vapor reaches a first peak of about 0.2 dB/km at 24 GHz, but decreases very rapidly to about 0.002 dB/km at 10 GHz. At frequencies below 10 GHz, the sum of the attenuation resulting from oxygen and water vapor is thus chiefly due to oxygen absorption.

---

1. National Bureau of Standards, Technical Note 101.

2. Bean and Dutton, Radio Meteorology.

3. Handbook of Geophysics and Space Environments, Air Force Cambridge Research Laboratories, McGraw Hill 1965.

4. Bertoni, "Clear Line of Sight from Aircraft," AFCRL 67-0435.

5. Solomon, "Estimated Frequencies of Specified Cloud Amounts Within Specified Ranges of Altitude," Tech. Report 167; Air Weather Service, USAF.

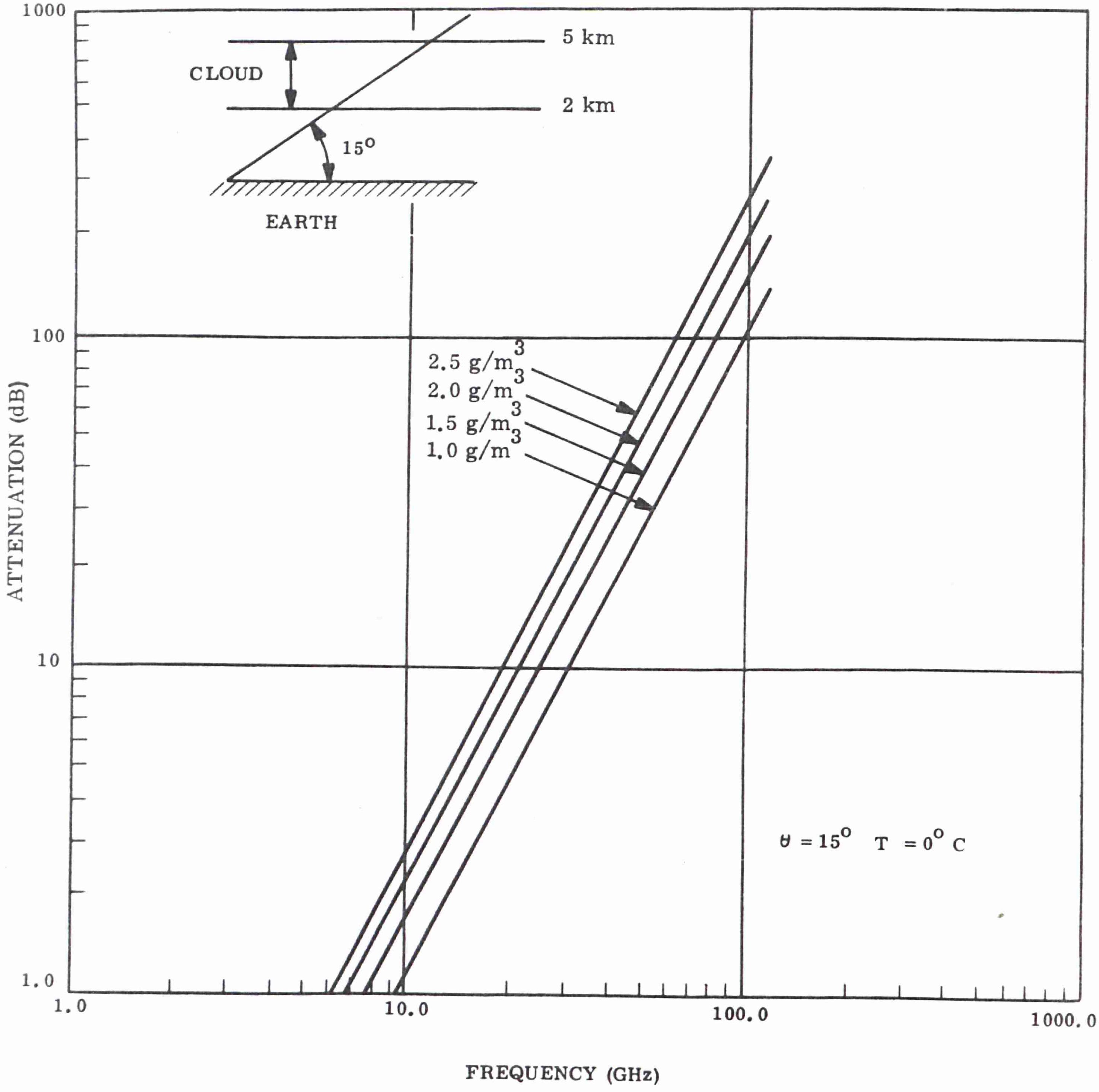

Figure 2-29. Cloud Attenuation Versus Frequency

2.5.2.4 STATISTICS[1,2,3,4]

Adequate meteorological statistics are not available to enable accurate estimates to be made of the rain and cloud attenuation which will be exceeded for a small percentage of the year. However, from the limited data available, approximate estimates can be made of the magnitude of rain and cloud attenuation likely to be exceeded for only 0.01 percent of the time, or about one hour per year, on an earth-to-satellite transmission path in a given area.

Cumulative distribution of rain attenuation may be estimated from statistics analyzed by Bussey[1] who relates the cumulative distribution of instantaneous path average rainfall rates for 25, 50 and 100 km paths, respectively, with the cumulative distributions for a single rain gauge of half-hour, one hour and two-hour mean rainfall rates recorded for a year. If no space diversity is used, then, for example, the total attenuation during the worst hour of the year will be the sum of the rain, cloud, oxygen and water vapor attenuation during the worst hour. However, with space diversity, the maximum rain attenuation will be reduced considerably, and perhaps also the cloud attenuation to some extent. It has been shown by Hogg[5] that the rain attenuation in dB was reduced by about one-half by the use of the diversity system having a spacing of 2 km, located near Bedford, England, where the annual rainfall is about 63 cm.

High rainfall rates are usually of only limited extent, rarely exceeding 15 km. The rate of rainfall may be associated with a particular extent of rain by the empirical relationship[6]:

$$\text{Extent in km} = 41.4 - 23.5 \log \text{mm/h} \qquad (2\text{-}46)$$

---

1. Bussey, H.E., "Microwave Attenuation Statistics Estimated from Rainfall and Water Vapor Statistics," IRE, P281-285, July 1950.

2. Handbook of Geophysics and Space Environments, Air Force Cambridge Research Laboratories, McGraw Hill, 1965.

3. Bertoni, "Clear Line of Sight from Aircraft," AFCRL 67-0435.

4. Solomon, "Estimated Frequencies of Specified Cloud Amounts Within Specified Ranges of Altitude," Tech. Report 167; Air Weather Service, USAF.

5. Hogg, "Path Diversity in Propagation of Millimeter Waves through Rain," P 410-415, AP-15-May 1967.

6. International Conference on Satellite Communication, London, Nov. 1962.

Thus at a worst-case U.S. site, where it is estimated that a rainfall rate of 48 mm/h is only exceeded for 0.01 percent of the year, the extent of such a rainfall rate would be only about 1.7 km. In the case of cloud, some statistics are available for the time and space distribution of clouds at various altitudes[1,2].

2.5.3 Conclusion

The following table shows the estimated attenuation for link availabilities of 99.99 percent (~ 1 hour per year outage) and 99.9 percent (~ 10 hours per year outage) and 97 percent (~ 12 days per year outage) at a site having an annual average rainfall of 100 cm.

Table 2-54. Estimated Attenuation

Link Availability		Frequency (GHz)			
		4	16	35	90
99.99%	Rain (dB)	0.5	26.4	105	320
(48 mm/h)	Clouds (2 g/m^3, 0°C) (dB)	0.5	5.6	24	150
	Oxygen and Water Vapor (dB)	-	0.3	0.8	3.5
	Total (dB)	1.0	32.3	139.8	573.5
99.9%	Rain (dB)	0.1	6.6	26.4	80
(12 mm/h)	Clouds (1.5 g/m^3, 0°C)(dB)	.3	4.0	17	120
	Oxygen and Water Vapor (dB)	-	0.3	0.8	3.5
	Total (dB)	0.4	10.9	44.2	203.5
97%	Rain (dB)	-	0.4	1.5	4.7
(0.7 mm/h)	Clouds (1.0 g/m^3, 0°C)(dB)	.2	2.7	12	82
	Oxygen and Water Vapor (dB)	-	0.3	0.8	3.5
	Total (dB)	0.2	3.4	14.3	90.2

1. Bertoni, "Clear Line of Sight from Aircraft," AFCRL 67-0435.

2. Solomon, "Estimated Frequencies of Specified Cloud Amounts Within Specified Ranges of Altitude," Tech. Report 167; Air Weather Service, USAF.

TRW

EXECUTIVE OFFICES

September 16, 1969

Mr. Clay T. Whitehead
Staff Assistant
The White House
Washington, D. C.

Dear Mr. Whitehead:

TRW Systems Group is pleased to respond to your inquiry regarding our current thoughts on the use of satellites for domestic commercial communications. We understand from your letter of August 19 that the principal interest of your working group is in the economic and organizational aspects of the communications industry rather than in the technical aspects of satellite design.

TRW Systems Group is a leading supplier of satellites for a wide variety of scientific, military, and applications missions including the Intelsat III communications satellites which we build for the Comsat Corporation. We are not involved in the operational use of these communications satellites and we are not a part of the communications industry insofar as institutional structures, rates, competition, regulation, ground station ownership, frequency allocations, traffic forecasts, and so forth are concerned. Therefore, we do not feel qualified to offer new information regarding these matters.

We are of the firm opinion that the technology now exists to permit practical long-life satellites of much greater capacity than Intelsat III and IV to be developed. We agree with most of the public record in this regard. For example, we believe that multiple access features can be provided and that narrow beam antennas are practical. As another example, we find considerable reason to doubt that direct TV broadcast to the present home receivers will ever be economically feasible or practicable. We expect that continuing technological

SYSTEMS GROUP OF TRW INC. · ONE SPACE PARK, REDONDO BEACH, CALIFORNIA 90278

development will produce equipment with lower weight and higher performance capabilities in an evolutionary manner, but at present we know of no areas of technology breakthrough which could have a revolutionary impact on satellite communications comparable to the advent of earth satellites themselves.

It is our observation that the constraints on the development of domestic communications satellite systems lie in the administrative, economic, regulatory, political, and legal areas--which are the main content of the questions included with your letter. The issues involved in these areas are highly complex and include interrelations among many technical disciplines and many modes of communication. Several studies in this area have been made by the government through the use of committees composed of part-time senior people, limited staff, and consultants. We suggest that these problems are so important, comprehensive, and difficult that a specially constituted government commission or agency is needed to supervise total system studies, which might be performed by contract to private industry or to a nonprofit organization. The effort should be substantial; it might, for example, involve on the order of hundreds of professionals working for several years.

We also suggest that an exploratory domestic satellite communications system be implemented soon. Such a system could be initiated by making use of a satellite of the Intelsat III configuration and representative user ground stations to experiment with services such as TV distribution, educational TV, and communications to Alaska, for instance. This experimental program could proceed in parallel with the system and economic studies mentioned above. The two efforts would be complementary and mutually stimulating. Hopefully, the results of such efforts would provide a sound base for formulating domestic government policy, for guiding United States discussions with other nations, and for implementing an operational system.

Very truly yours,

Richard D. DeLauer

Richard D. DeLauer
Vice President & General Manager
TRW Systems Group, TRW Inc.

HUGHES Research Laboratories
A DIVISION OF HUGHES AIRCRAFT COMPANY
3011 MALIBU CANYON ROAD
MALIBU, CALIFORNIA

5 September 1969

Mr. Clay T. Whitehead
Staff Assistant
The White House
Washington, D. C.

Dear Mr. Whitehead:

I have just received a copy of your August 19th letter to Mr. Butler, of EIA, which transmitted the excellent list of issues which your working group on domestic satellite communication is considering. In view of the short time until my departure for Geneva (for the CCIR Study Group IV meeting, September 15 - October 3) I will not be able to participate in preparing any response which the Satellite Subdivision of EIA may submit. Instead, I am writing this personal letter an an expression of encouragement, best wishes and cooperation.

I am enclosing two papers which contain material relating to these issues. The "Economic Factors Influencing the Break-Even Relations Between Satellite and Terrestrial Point-to-Point Communication" paper was published in the ITU Telecommunication Journal, July 1969, while the "Future Satellite-Relayed Digital Multiple Access Systems" paper is to be presented in London this November. Both are concerned primarily with point-to-point systems, rather than with distribution or broadcasting. Though both emphasize principles important to global systems, many parts are relevant to domestic applications.

In your list of issues, I was pleased to note the attention given to "innovation" and to spectrum and orbit utilization. My personal opinion (and a rather general one) is that the innovation of satellite services has been "policy-limited,"

Mr. Clay T. Whitehead
5 September 1969

and that this is both unnecessary and unfortunate. Our knowledge of satellite technology, system trade-offs, orbit utilization and of "international acceptability" of new systems is achieving maturity. This makes it unlikely that private industry would now invest in any new satcom system which had questionable viability and acceptability, because of orbit-waste or similar reasons. Also, I have no worries about disruptive growth of the communication industry. Instead, I worry about the continued policy-protection of certain powerful segments of our telecommunication industry.

With best wishes for your important assignment, I remain,

Sincerely,

S. G. Lutz

S. G. Lutz
Chief Scientist

SGL/dmc

Attachments (2)

CC: John Sodolski EIA

FUTURE SATELLITE-RELAYED DIGITAL
MULTIPLE ACCESS SYSTEMS

S. G. Lutz

Summary — When messages are relayed through one satellite, as at present, adding satellites to carry additional traffic prevents direct communication between the stations of separate satellites, except as nations install multisatellite stations. By analogy to metropolitan telephone systems, it will be possible for stations of one satellite to establish a circuit to any station of another satellite through a (space) relay link, thus avoiding most needs for multisatellite stations despite tremendous traffic growth. Relaying to satellites within ±60° will avoid excessive propagation delays. With enough satellites and with earth stations located as explained, direct communication to all distances will be possible between stations at lower latitudes, with antipodal paths at higher latitudes requiring relatively short terrestrial extensions. Switching aboard the satellites seems eventually necessary.

Preprinted paper to be presented at IEE International Conference on Digital Satellite Communications, London, England, November 25-27, 1969.

FUTURE SATELLITE-RELAYED DIGITAL MULTIPLE ACCESS SYSTEMS

S. G. Lutz

Introduction — Nearly 25 years ago, Arthur Clarke[1] showed that three geostationary satellites could provide essentially global coverage. Today, we have Intelsats over the Atlantic, Pacific, and Indian Oceans, much as Clarke envisioned. We are just now starting to use a second Intelsat III for the heavy traffic of the Atlantic region, and certain of the complications involved in doing this will be discussed later.

Long before geostationary satellites came into use, it was recognized that large numbers of such satellites could reuse the same frequencies from separate orbit stations.[2,3] Questions relating to satellite density and minimum angular separation seemed academic, until early 1968 when both Canada and the U.S. became interested in multisatellite domestic systems and began coordinating plans for sharing the orbit. There have now been extensive studies of the factors which affect orbit utilization,[4] and these show that a hundred or more high-traffic satellites could share the orbit and the same frequency bands.

To date it appears that comparable attention has not been focused on the coordination of many satellites and their many uses. Of course, a large fraction might be used for TV and other program distribution of national scope. In addition, there may be justification for a few satellite systems for national telephony,[5] where these meet conditions which will be discussed later. However, it appears that greater attention should be devoted to the integrated use of many satellites, even ones with multiple earthward beams, to provide telephone and related services for routes of all economic lengths, national to global.

Following an introductory discussion of "regional" satellite systems and their apparent limitations, and a discussion of the "second satellite problem" of intercontinental satellite communication, this paper will discuss an integrated system based upon demand-selective ("multiple access") relaying between satellites which could establish circuits between earth stations having a wide range of separations. Such a system is analogous to a metropolitan telephone system, in which the caller's exchange (calling station's satellite) selects a trunk circuit to the exchange of the called party (satellite serving the destination station), where the connection is completed.

Some readers may reject this prediction on the basis that there is no foreseeable requirement to justify such complexity. Consider however how incredible today's direct distance dialing

S.G. Lutz is with Hughes Research Laboratories, Malibu, California, U.S.A.

and electronic switching systems might have seemed to Alexander Graham Bell, even without the suggestion that telephone "centers" be placed 36,000 km above the equator.

Domestic Satellite Systems; Television Distribution Versus Telephony — Interest in domestic applications of satellite communication was kindled in 1965 by the American Broadcasting Company's proposal[6] to distribute television programs via satellite, for reception at or near the local broadcasting stations. Because it is a one-way point to points service of a basically national character, and for other obvious reasons, domestic TV distribution remains a simpler and more generally attractive application for satellite technology than seems true for domestic telephony. It is not without problems, however. We can postulate that program distribution will account for some fraction of the orbit's future use, and thus direct further attention to personal communication.

Telephony presents the more difficult and restrictive problems, especially for nations which are not now covered by terrestrial telephone networks. These problems will be reviewed to provide a foundation for subsequent discussions of the integration of national and intercontinental satellite services. The foremost of these relates to multihop propagation delay times when domestic or regional satellite systems are to be interconnected through an intercontinental satellite, as shown in Fig. 1. Here it is assumed that regions A and B have used retelsats (regional tel-sats) to provide their longer intercity circuits, and that each region also has a single Intelsat earth station. Interregional calls then might require three hops and the pause-to-reply delay would approach 2 sec. With such delays, conversation still is possible, as conversations with lunar astronauts have demonstrated. Moreover, the information flow in such conversations can easily exceed that via long HF radio circuits, where frequent repeats may be required. With these qualifications, one must admit that three-hop delays are excessive, and that they would not remain acceptable for commercial telephony, especially after the novelty had worn off. Even two-hop delays are well in excess of limits now recommended by the CCITT.[7] Thus, a nation that decided to link its cities by its own satellite system, in lieu of terrestrial links, could find that it had impaired its access to international satellite service.

Regions previously covered by surface networks would not face such a limitation. Calls within the United States, for example, might be carried by satellite between convenient stations of its national system, but overseas calls would be routed via surface circuits to an Intelsat earth station. Canada presents an interesting case because its telecommunication system is highly developed in the south, but not in the far north. Southern Canada, like the United States, can use surface circuits to eastward or westward Intelsat stations. Centers in the far north are most likely to want to communicate with southern Canada (and to obtain television programs) via a Canadian satellite. Any demands for overseas service probably would be to Europe or Australia, which are already served by cables from Southern Canada.

A second interesting constraint is imposed by the economic break-even relations between circuits of satellite and terrestrial routes.[8] Briefly, terrestrial circuit costs depend on the traffic volume and the length of the route considered. The (trend) cost becomes less for heavier routes, falling approximately as $N^{-0.7}$ for N circuits per route. Additionally, their cost is proportional to the route length. For example, the annual cost per circuit mile for a 10 circuit open-wire route may be about 100 times more than for a 10,000 circuit radio relay system (it should be recalled that the latter would be an expensive economy in the event of 10-circuit traffic).

In contrast, the annual cost of a satellite circuit is independent of the distance between earth stations and can be essentially independent of the number of circuits per (inter-station) route, assuming that the total number of circuits per station (for all routes) is held constant. Therefore, satellite communication acquires its economic "leverage" for long, light traffic routes, with multiple access providing many such routes and adequate total traffic per station.

Nations which have not had good communication between remote centers may forecast light traffic for these routes. For five circuits or less per route, between 100 circuit stations, the break-even distance may be anticipated to drop well below 1000 km. Thus, satellite communication can be economically attractive for domestic routes, but this may not make a strictly national system preferable to a larger one. Since the economic leverage of satellite circuits is proportional to length, why saw off that lever at the nation's border? If a 500 km circuit breaks even, a 10,000 km circuit at the same cost should be twenty times better. This suggests that the international satellites might be used for national circuits as well when possible.

The probability of traffic growth introduces an interesting consideration. The bonds of friendships and common interests are reflected in communication traffic and these tend to become much stronger at shorter distances, especially if communication is of good quality and low cost. Typically, a nation's domestic communication traffic may greatly exceed its international traffic. Thus, a nation might first link two cities by five satellite circuits, which it calculated to be less costly than a five circuit troposcatter route. With the advent of good communication, traffic might quickly grow to 50 circuits, for which a surface system might have been more economical. However, with growth to 500 circuits now foreseeable, the administration might install a radio relay route. A nation thus might find it healthy to initiate service on light routes via satellite, anticipating that this might stimulate the traffic growth needed for subsequent expansion of its surface systems.

Such a changeover to heavy surface routes need not reduce a nation's use of its earth station, providing that its satellite service has been integrated with the global system. The economic development associated with this expansion of national telecommunication should also increase its international traffic through these same stations.

The "Second Satellite" Problem — Let us now examine the global system, and especially its Atlantic portion, where the inadequacies of a three-satellite system have already become apparent. The foreseeable traffic requirements for the Atlantic region exceeded the 1200 channel capacity of Intelsat III even before the first of them was placed in service, making it clear that a second Intelsat III would be needed long before a satellite of sufficiently higher capacity could be developed.

So long as all stations of this region could use the same satellite, it was possible for every station to communicate with every other station, requiring only one antenna and its equipment. In practice, of course, many stations did not talk with each other because only the preassigned form of multiple access has been in service and these stations could not anticipate sufficient traffic with each other to justify the costs of receiving each other's signals and maintaining a seldom-used circuit. With demand-assigned multiple access, there should be some traffic between any two stations.[9] It would then appear more important that access to these light routes not be withdrawn as a result of the system's growth.

Let us now consider the uses of a second satellite. Without a space-relay link between these satellites, nations must use one or the other, unless they invest in a second station in order to use both satellites. Single-station nations can communicate directly with only their satellite's stations.

There are two extremes in the possible use of a second satellite. In the first, the users could be divided (perhaps geographically, as those east or west of the Atlantic). This obviously would be unacceptable because of the heavy demand across the North Atlantic. Any similar north-south division would be even less advantageous to Africa and South America! The opposite approach would be to require that the routes with the heaviest traffic be carried via the second satellite, while all nations would continue using the first to maintain full multiple access. This might require that both satellites be used by the United States, Canada, and several European nations. As might be expected, the actual Intelsat III plan is a compromise; an east-west system with a few cross ties to Western Europe and North America.[10] Three European nations will use the western Intelsat III for routes to the Americas only, while the remaining three (plus two North American stations) will use the eastern Intelsat III for routes to Africa and the Middle East. Thus, there will not be an impenetrable Atlantic curtain, only a high-latitude fence!

It is interesting to note (Table I) that just eight heavy traffic routes from the United States and Canada (which both have two stations) total 939 circuits, leaving only 808 circuits for the remaining 68 routes.* Thus, if two or three European nations were to put this heavy traffic through one satellite,

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*Neglecting NASCOM ROUTES

the second could be made available to stations of all 24 nations. If the same satellite were used, more than these 68 routes would soon develop. Providing a demand-assigned service would make available (24 x 23)/2 = 276 routes!

TABLE I

Atlantic Heavy Routes

USA	U. K.	239 circuits
"	France	131
"	Puerto Rico[a]	190
"	Germany	102
"	Spain	89
"	Italy	89
Canada	U. K.	59
"	France	40
Total	8 routes	939 circuits

[a]Puerto Rico plans only an additional five circuits to Spain.

Let us next assume that the Atlantic basin traffic will continue to grow until four satellites are required, even if they are Intelsat IV's or larger. Extending the present Intelsat approach might lead to four continental subsystems, each having a few links to major nations in other continents. In this case even fewer nations might maintain access to the entire Atlantic region, since this would require four earth stations. Communication between light traffic nations certainly would be constrained to their own continents and this would be a regrettable loss of multiple access capability.

The alternative would be to reserve one satellite for light-traffic demand-assigned multiple access service between stations of all nations, and let the remaining three carry the heavy-traffic routes, using preassigned circuit-groups. More nations would require additional stations, but even the light users with single stations would retain full access.

The above discussion also should explain the strong trend toward greatly increasing the channel capacity of individual satellites, as with Intelsat IV. However, this trend may only postpone the need for a cluster of Atlantic satellites and it could actually <u>impair</u> utilization of the Atlantic arc of the orbit. For example, crowding too many FDM-FM channels into a satellite would lead to a sharp reduction in channels per degree of orbit, because of the rapid increase in the separation required between satellites.

<u>The Case for Intersatellite Relaying</u> — In order to examine multiple satellite systems more broadly it is helpful to note that the problem of maintaining interconnectability seems

analogous to a problem which was recognized and overcome early in the development of telephone systems. The first cord-type switchboards served few subscribers, but their capacity was increased as service grew, until the operator became the limitation. She could reach any one of 10,000 jacks. Even if it had been feasible to put 100,000 smaller jacks within her reach, finding the right one would have become too slow and difficult. The solution was tandem switching, wherein the caller gave his operator the name of the called party's exchange, as well as his four digit number. The originating or "A" operator selected an idle circuit in her "trunk" to the called (B) exchange and gave the "B" operator the number to select and ring. Although the exchanges now are automatic, their tandem switching is essentially the same.

The problem of heavy-traffic satellite systems seems analogous, in that we should be able to relay from the caller's satellite to that of the called party, provided that the relay path does not increase the propagation time excessively.

Figure 2 assumes the CCITT maximum propagation time of 400 msec and shows the dependence of the geocentric angle ϕ and relay time T between satellites as a function of α, the elevation angle to either satellite. Thus, for $\alpha = 5°$ a satellite could relay to satellites eastward or westward as much as 53°, and the propagation time between satellites would not exceed 0.1254 sec. This, added to 2 x 0.1373 sec earth to satellite and back,equals the allowable 0.4 sec. With higher angles to the satellites the earth/satellite path is shortened slightly, so the relay path can be lengthened correspondingly. However, increasing the relay path in this way may shorten the maximum distance between earth stations, as will be shown later.

There should be few problems in obtaining adequate frequency bands for these relay links. With an all-space path, the atmospherically absorbed bands in the millimeter wave spectrum appear ideal. Laser links also are promising. Because the relay paths are at nearly right angles to the paths to earth, their antenna directivity should provide added interference protection to and from earth.

Location of Earth Stations Relative to Their Satellite — Today some earth stations may prefer that their satellite be at a longitude close to the station's, and hence at a high angle above the horizon. Such a location permits the longest north-south routes, but the length of east-west routes is badly limited. The radius of coverage (for $\alpha = 5°$) is about 8500 km, or little more than a third of the earth's antipodal distance.

On the other hand, the U. K. wishes to have the Indian Ocean satellite as far east as Goonhilly can see it (at $\alpha \simeq 5°$) because this provides the longest routes, to central Australia or even to southern Japan. Similarly, a satellite at 70° W would give routes to western Canada, possibly to Whitehorse in the Yukon. However, a 6° W satellite brings Pakistan within reach of Andover, but would cut off Mexico, and so on.

With intersatellite relaying, it may become desirable for each satellite's stations to be within a belt, so that all will see the satellite within relatively low elevation angle limits. In this way, Mexico might use a 30° W satellite but relay to one at 5° W for routes to western South America, or to Karachi, while it might relay oppositely to a 60° W satellite used by Western Europe. Additionally, Mexico might use a 170° W satellite, whose belt might include the Philippines and Taiwan, but it might need to relay easterly to Japan's satellite, or westerly for a route to Hong Kong.

Finally, it should be recognized that satellites with multiple earthward beams, each arbitrarily narrow, surely will be in use before this multisatellite relayed system is needed. Consequently, in speaking of a "belt" of earth stations, it is not implied that the satellites will continue using earth-covering antennas, nor even that antennas with ring-shaped patterns will be developed. It seems probable that individual satellites of this "all-route" system would use multiple narrow beams directed toward chosen land areas near the satellite's earth horizon. Stations within such areas would "see" this satellite at a suitably low elevation angle. In addition, these satellites might serve stations in more central areas, and thus at higher look-angles, whenever justified by special demands, geographic considerations, increased reuse of frequencies, etc. Frequency-reuse is an especially important consideration in relation to multiple earthward beams.

Another related consideration is that the traffic from some centers may exceed the capacity of a pair of earth-stations (to an eastward and westward satellite), as imposed by allocated bandwidths. In such cases it will be necessary to use additional satellites and earth facilities. Such heavy traffic concentrations would be most probable in "developed-regional" systems, e.g., from the New York traffic center of a United States (or North America) subsystem. The additional satellites required for this "relatively local" traffic could and should be at higher angles; this means that these stations would be in the more central areas of their "domestic" satellites. It seems highly improbable that even New York or London would ever have more intercontinental demand-assigned (light-route) traffic than could be carried via its eastward and westward satellites of this "all route" system.

Polar Diagrams of Relay Routing Capabilities — Without further qualifying explanations, this section will assume an all-land, uniformly populated earth, surrounded by geostationary satellites at 10° intervals or less, each having relay links to those other satellites which are within the delay limit (see Fig. 2). The earth stations of each satellite are assumed to lie in a belt bounded by elevation angles (α's) which initially will be taken as 5° and 15°, with relaying limited to ±50° (although 53° would be permissible).

We now consider the regions of the earth which would be accessible with such a system, using the polar diagram of Fig. 3.[11] This is a view of the earth from far above the north pole, with the concentric circles designating latitudes. The straight line between the 76° and 284° equatorial points marks the coverage limit at 5° elevation of a 0° geostationary satellite, while the parallel dashed line is the 15° elevation locus to this same satellite. Thus this satellite alone would be used for routes between earth stations located between these lines, such as A-B, remembering that this belt passes through both the northern and southern hemispheres. Moreover, a station located at A could use relay links to the earth stations of satellites stationed within ±50° of the 0° satellite, these two station belts also being shown. Thus A could reach stations C or E by relaying to the 50° satellite. It could reach D via a shorter relay, e.g., to a 40° satellite.

On the other hand, if A had direct access only to the 0° satellite, it could not reach stations farther to the west, e.g., from 126° to 234° longitudes. However, if A also uses the 220° satellite it can relay into coverage belts of satellites between 170° and 270°, the former of these providing alternate routes to E and D.

Unfortunately, this choice of parameters does not provide routes into the darkened areas, E and F, in the vicinity of 0° and 220°, where look-angles above 15° or longer relays would be required.

To correct this difficulty, let us assume that stations are confined to a 15° to 25° look-angle belt, but that 60° relaying is permitted. According to Fig. 2 the relay should not exceed 56°, but extending this to 60° increases the maximum propagation time only to 408.4 msec, which seems inconsequential. Figure 4 is the polar diagram for these conditions and shows that the two coverage holes have been eliminated. In fact, station A now has a choice of two ways of relaying to B, or to C. Antipodal route capability has been retained, at least between low latitude stations A and D. For A to reach E, the satellite route might be relayed to F and be completed via a terrestrial circuit.

The ability to span long routes between stations at higher latitudes could be improved by relaxing the minimum α as a function of latitude, with a 5° being permitted at maximum latitude.

Some Traffic and Route Considerations — To illustrate the following discussion, Fig. 5(a) shows (conceptually) six linked satellites being used by fourteen stations. Although vastly more complex systems may evolve, this example should illustrate the major principles. If 14 traffic centers each were to use all six satellites, in order to have access to all routes with no intersatellite relays, each would need six earth stations, or the absurd total of 84. In this example centers will use single stations, except that one center is assumed to have such heavy traffic that satellites B and C must be used exclusively by stations 4 and 5, shown enclosed by the dashed line. Note the relay routes shown between all satellites, except between B and C which are used by the same traffic center.

Figure 5(b) shows the traffic matrix for this system, in symbolic form. The H,H minors of this matrix show traffic (numbers omitted) for the nonrelayed routes, those involving only satellite H. The H-K minors similarly show the routes which are relayed between satellites H and K. The zeros along the principal diagonal denote that stations do not talk to themselves. The B, C minor also is shown as zero, as previously explained.

The H, H minors are of additional interest, with respect to the choice of stations able to use the same satellite and their mutual traffic. It certainly should be simplest to establish demand-assigned circuits through a single satellite, when this can be done. Similarly, it would seem less expensive if a route need not be relayed. These views would favor serving short routes from the same satellite, thus improving their competitiveness with terrestrial routes. However, the rate charged by the satellite operator becomes a cost element to the earth stations, and there might be little if any rate-differential for single satellite routes.

Spectrum use is another possible consideration, especially with respect to efficient use of the 4 and 6 GHz earth/space bands. However, since each circuit must use these bands twice, whether at the same satellite or from a linked pair, spectrum use does not seem a valid consideration.

The strongest motivation toward clustering a satellite's earth stations within national boundaries may be the nation's desire to orbit its flag!

Demand Assignment; Terrestrial or Orbital Switching — Beyond pointing out the desirability of providing demand-assigned circuits for the light or infrequently used routes between a large number of earth stations, it becomes difficult to discuss techniques, especially those applicable in the far future. In part, this relates to the continuing absence of demand-assigned service within Intelsat, even though several systems have been developed and at least one has been demonstrated.

To date, the approach to demand-assignment has been to keep the switching or channel assignment function on earth, in order to continue using simple satellites. This may always seem desirable, from a weight and reliability viewpoint, but it is no longer as essential as it once seemed. Spacecraft design has advanced and astronauts trust their lives to complex electronic systems. Surely we can now consider circuit switching aboard satellites if it is necessary or sufficiently desirable.

Present single-satellite demand-assignment systems require that some number of satellite channels (or channel pairs) each be selectable, at one or both earth stations, in response to demands. Introducing the need to relay between any two satellites from among many introduces another selection in establishing the station-to-station circuit. This additional selection will become prohibitively difficult or inefficient to perform on earth as the number of satellites increases.

At first, with links between only two or three satellites and with few earth stations per satellite, these link channels could be preassigned between satellites and even to one earth station, if a semivariable system were considered. Thus, station 1 of satellite A might have some number of transmitting channels preassigned to it, with provision to select an equal number of receiving channels from among those on which other stations may transmit. This station might have x preassigned transmitting channels for use with other stations of satellite A, upon demand. These channels would be received and retransmitted by A alone. In addition, this earth station might have Y preassigned transmitting channels which A would relay to B for retransmission to its stations, which also would select the designated channels upon demand. Similarly, A's station 1 would have selection facilities for receiving Y channels from among those repeated by A from B. Finally, this station also would have Z channels to and from stations of satellite C.

A serious growth-limitation of such a system is that each station is required to subdivide its "pool" of these channels among more and more satellites, thus lowering its traffic efficiency or degrading its service by raising the loss probability. This station could make fuller use of its X + Y + Z channels if, at times, it could temporarily release some of its Z channels via C and add them to its Y channels, during a traffic peak with stations of satellite B. It is clear that the need for such additional flexibility would become compelling as the number of satellites and stations increased. Thus, we can anticipate the advent of switching in orbit, with evolution toward closer analogy with terrestrial switching practices.

The Digital System Aspect — Let us now consider this system concept in relation to the theme of this meeting, digital satellite communication. Of course, circuit switching is, itself, a digital process for establishing communication circuits. Dial telephones pre-date PCM!

Beyond this, the excellent papers of this meeting offer ample evidence of the impending shift to digital modulation for satellite systems. The future advent of relaying between orbital "exchanges" will not influence this shift, because it may follow by many years. We could perform these switching and trunking functions for circuits with analog signals, as we have done here on earth. It certainly should not be more difficult when both the signalling and information are digital.

In view of today's use (or misuse) of a second Atlantic Intelsat, it seems more important that more people devote more thought to the use of more satellites for much more traffic to and from more of the world.

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10. Intelsat satellite system operation plan through year end 1970 (Rev. of September 24, 1968).

11. S. G. Lutz, and G. Dorosheski, "Coverage and overlap of satellites in circular equatorial orbits - with applications to multiple access communication satellite systems," IEE (London) proceedings, Vol. 113 No. 9, pp. 1495-1503, September 1966 (see Fig. 7 for prior use of this type of diagram).

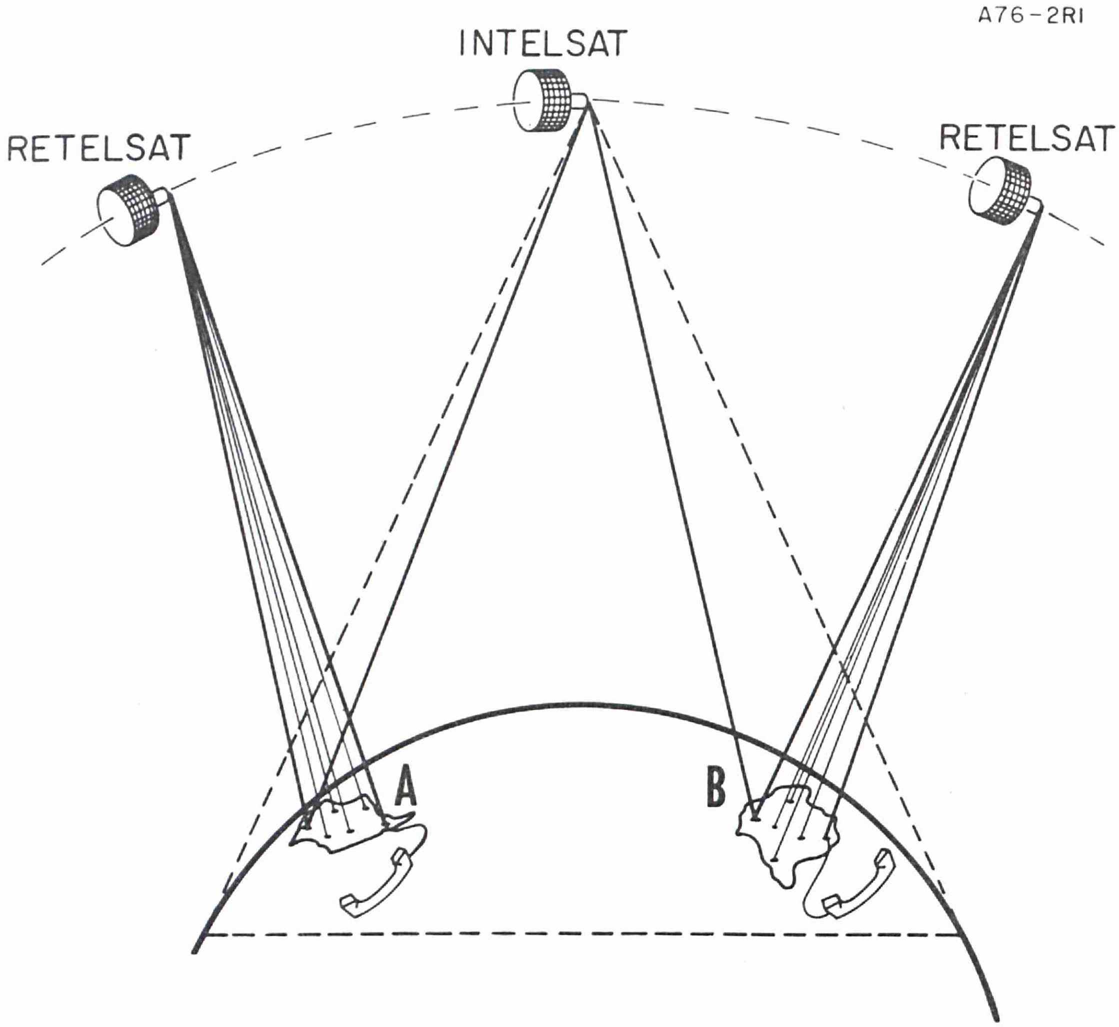


Fig. 1. Strictly regional systems could require three-hop international circuits.

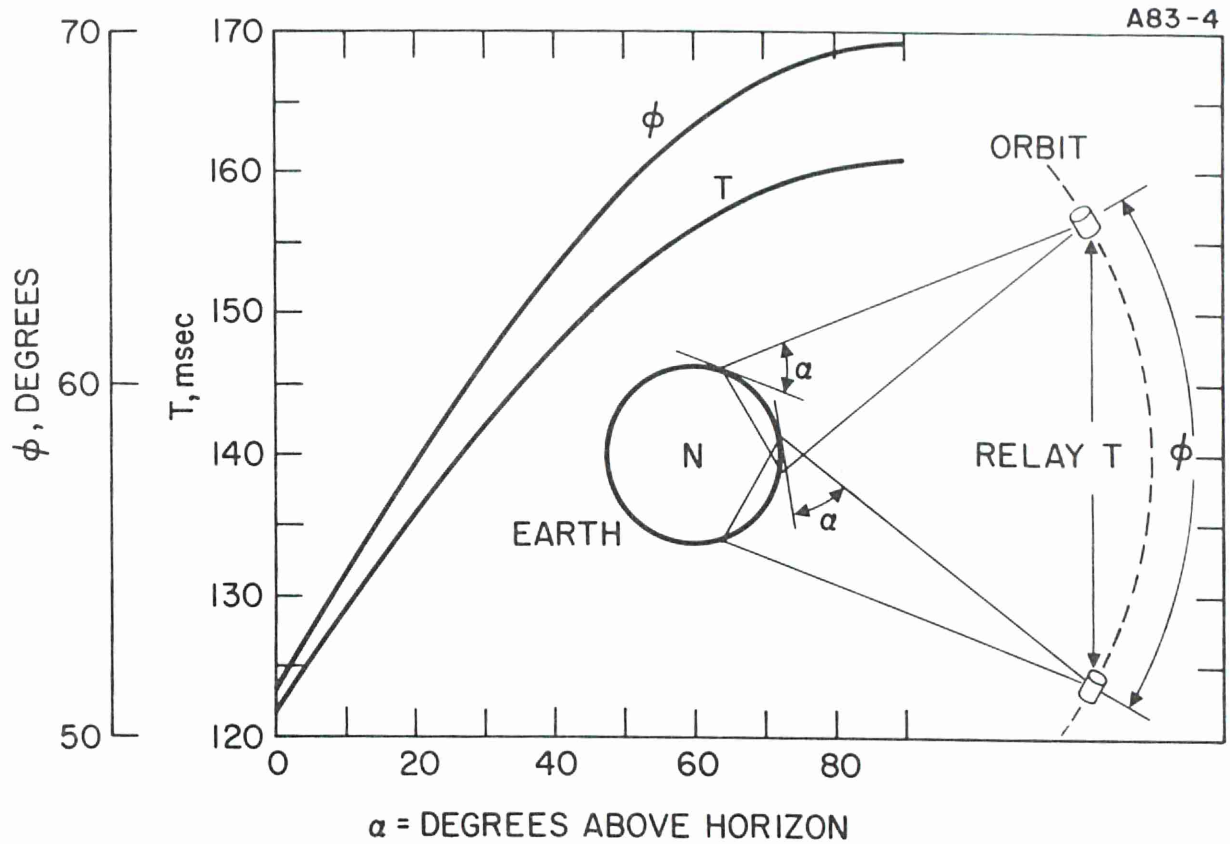


Fig. 2. Relay angle ϕ and additional time T as functions of elevation α to the satellite.

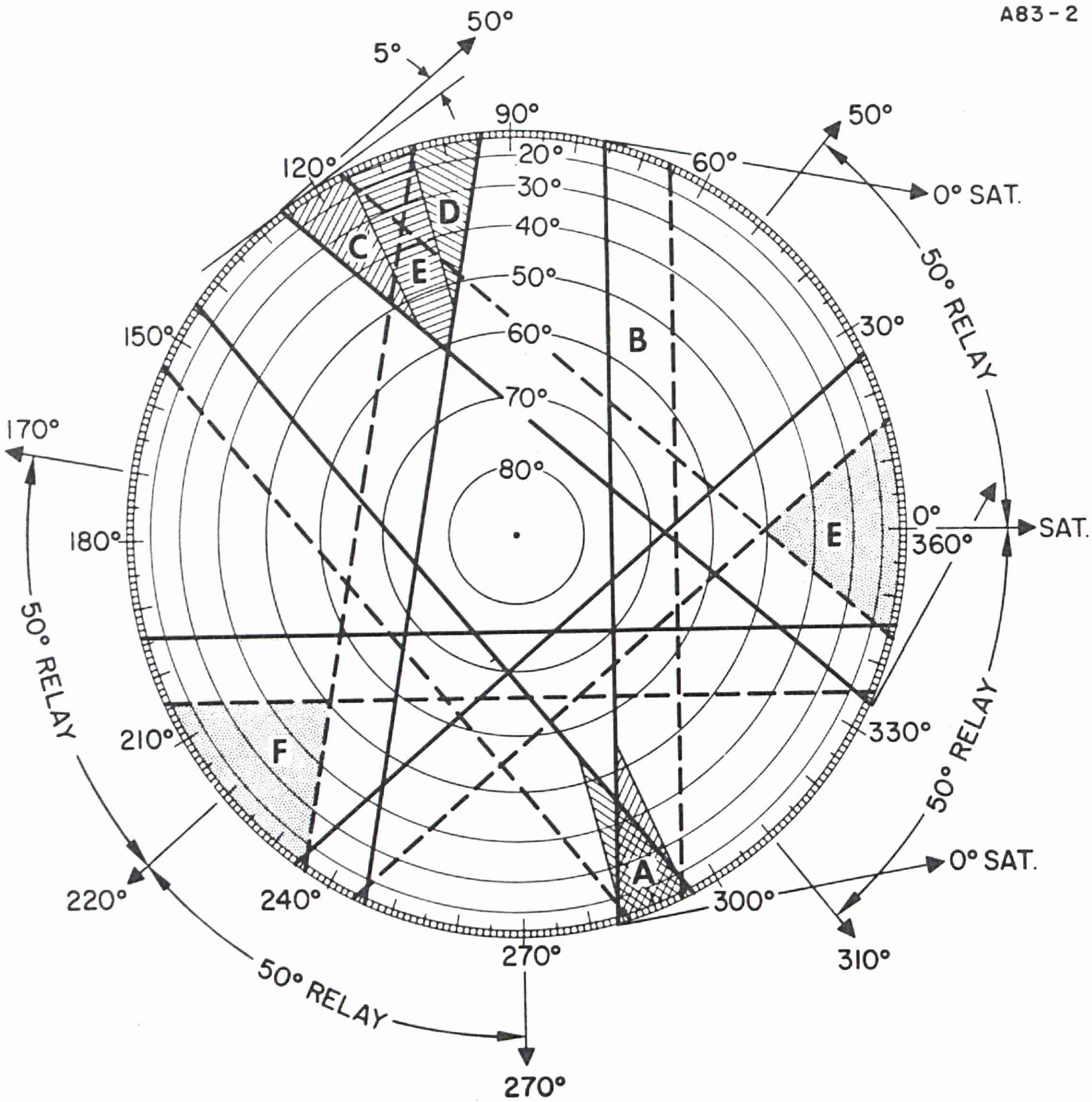


Fig. 3. Polar routing diagram for 5° to 15° elevation to satellites and relaying ±50° or less.

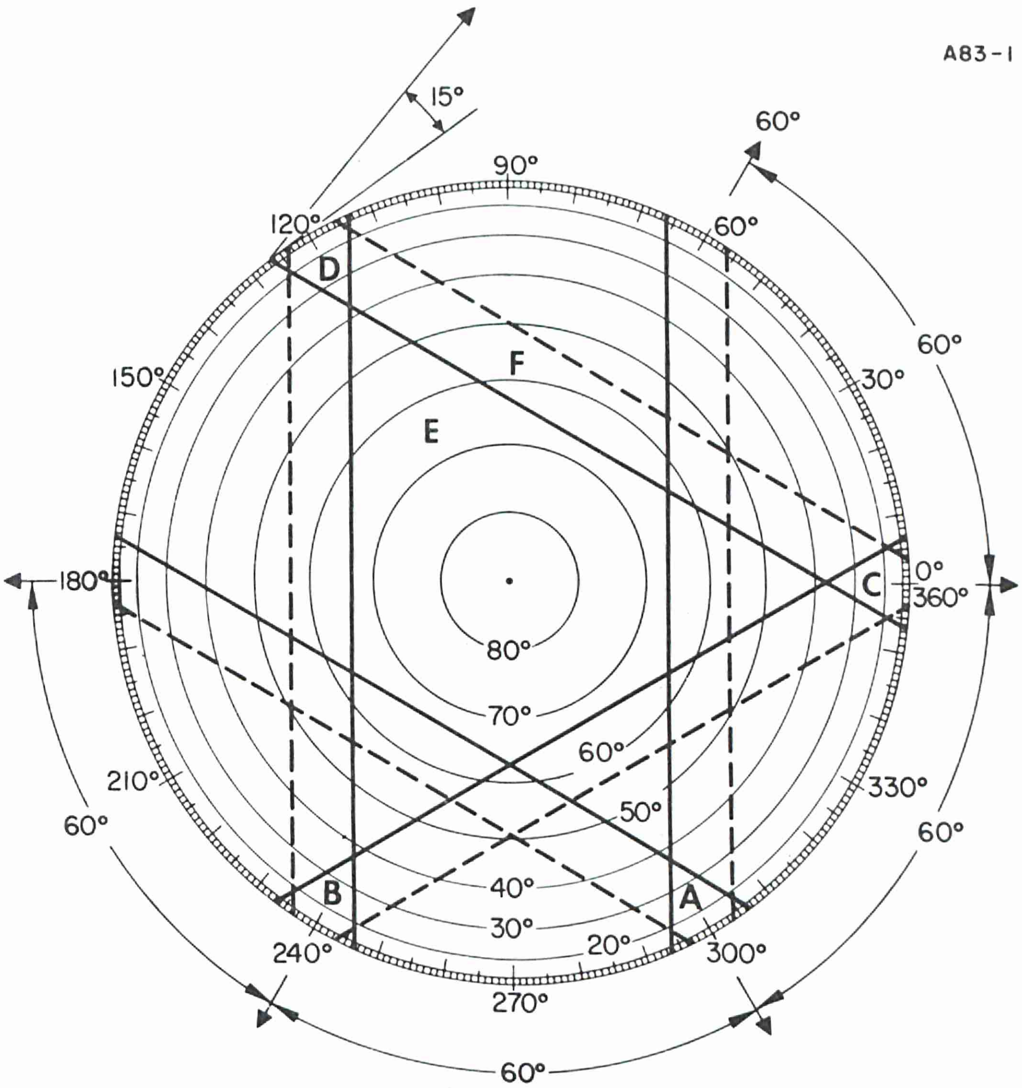
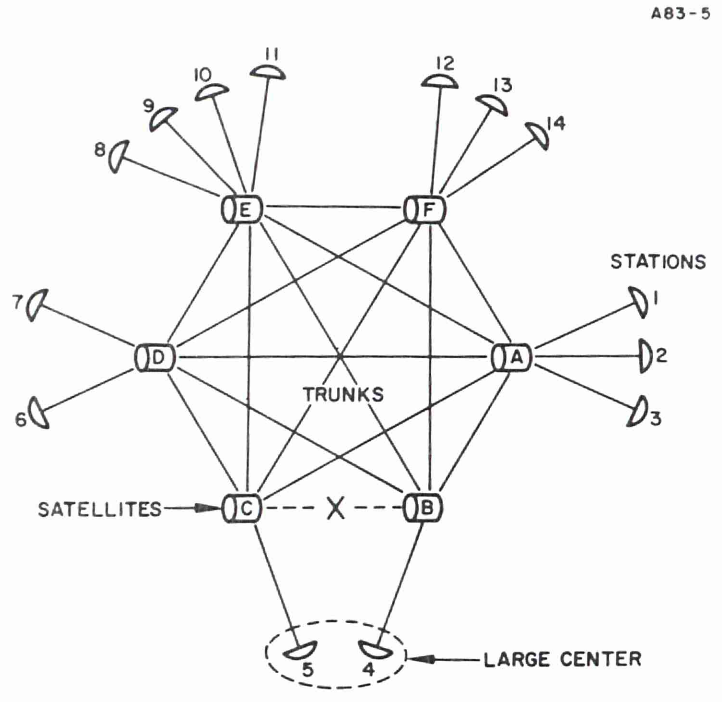
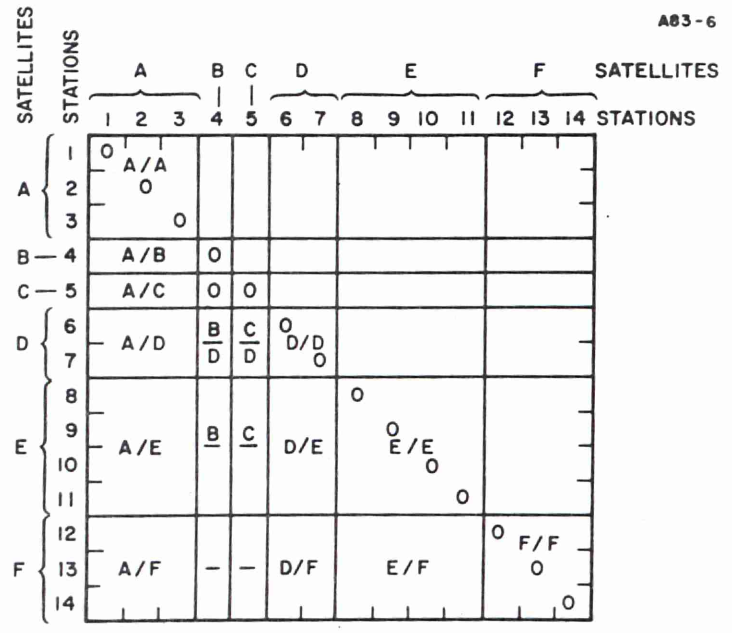


Fig. 4. Polar routing diagram for 15° to 25° elevation and relaying ±60°.



(a) Route diagram



(b) Traffic matrix

Fig. 5. Six satellite, fourteen station example.

economic factors influencing the break-even relations between satellite and terrestrial point-to-point communication

by S. G. LUTZ
Hughes Research Laboratories, Malibu, California

I. Introduction

WITH the advent and implementation of the International Telecommunications Satellite Consortium (INTELSAT) communication system and the rapid development of submarine telephone cables with increasing circuit capacities, numerous efforts have been made to compare these forms of communication and to establish conditions under which one or the other may enjoy a cost advantage. Such economic comparisons [1, 2] generally have assumed that satellites would provide " space-cables " between pairs of earth stations, as was true with *Intelsat-I (Early Bird)*. *Intelsat-II* introduced multiple access, the ability of each earth station to distribute its circuits and maintain direct communication routes to numerous other stations, at little (if any) greater cost than if all circuits ran to only one other station. If a comparable number of direct routes of few circuits each were provided by cables or equivalent terrestrial facilities, such routes would have to be correspondingly shorter or else their cost would become non-competitive.

Multiple access thus far has provided satellite circuits which have been preassigned at both ends, whereas the assignment of circuits in response to " demands " offers more efficient utilization of circuits, especially for light-traffic routes. [3, 4] No restriction to either form of multiple access will be made in the following analysis. Results will be expressed as annual circuits costs. Demand assignment should permit increasing the traffic per circuit, thus tending to lower the cost per paid minute.

It should now be evident that the break-even relation, or relation for cost equality between satellite and terrestrial communication, must be a function of both the length and circuit capacity of each route. With terrestrial communication other than HF radio, circuit costs are directly proportional to distance; however, they are inversely related to the circuit capacity when the capacity is reasonably filled. With satellite communication, the cost per circuit is *independent of distance* out to the one-hop limit of about 17 000 km. It is equally significant that satellite circuit costs can be *much less dependent on the number of circuits per route*. Though these costs are reduced by increasing the number of circuits per station, a multiple access system should provide each station with so many routes that a small circuit-change to one route would be insignificant to the stations total and to its cost per circuit.

This paper will outline a simple method of analyzing the annual costs of satellite circuits, considering multiple access, and of comparing these with terrestrial circuit cost trends in order to determine the break-even relations. As with any economic analysis, the values of cost coefficients are subject to change with time, differences of opinion, etc. Numerical coefficients have been used to clarify the examples, but their values and the derived results should be regarded as illustrative and not necessarily accurate. The reader is urged to substitute whatever values he considers most appropriate to his own conditions.

Finally, it is recognized that an administration or operating company's decisions regarding the use of satellite communication for specific routes may be heavily influenced by its own marginal cost considerations, the routing of its terrestrial systems and by important non-economic considerations. Nonetheless, an analysis using the method described herein may provide a useful reference for weighing such decisions.

II. Satellite circuit cost relations

An Intelsat-type system will be assumed, in the sense that the space-segment operator establishes a *rate* of S dollars per year per " unit of utilization " (i.e., per voice channel-pair between the satellite and a " standard " earth station). The latter has been defined thus far as having a figure of merit (G/T) of 40. 7 dB, which can be achieved by using a helium-cooled receiver and an antenna aperture of 26 m or more. Stations which have a lower figure of merit are penalized by being charged P units of utilization per voice channel-pair, on the principle, that P channel-pairs (circuits) between standard stations could have been provided by the same fraction of the satellite's power and bandwidth required for the one circuit between the sub-standard stations.

It will be further assumed that this space-segment rate is accurate, so that there need be no additional compensatory payments between the earth stations and the satellite operator. With this qualification, the space segment rate is a component of the annual cost of circuits between stations. The station operators have no concern (costwise) with the technical characteristics of the present and future satellites, except as they may change the $P \times S$ which must be paid. It will be seen that this provides a major simplification over attempting to include satellites and other costs of the space segment operator directly in the analysis. Moreover, the economic analysis of some proposed national or regional system can be simplified by separating its space segment and calculating S to recover its costs on any basis considered appropriate.

For the earth station with multiple access capability, major (annual) cost components may be identified readily for the presently operating system which employs FM-FDM on " multi-destination carriers " to provide fixed-preassigned multiple access. Station A modulates its carrier with N_A channels, of which N_{AB} are to be received by station B, N_{AC} by station C, etc. In turn, it must receive and demodulate B's carrier and select its N_{AB} return channels, and similarly for station C and each other station. In the present system A needs (at least) an additional down-converter and threshold extension demodulator to receive from each station which terminates its R routes. This equipment and its maintenance is assumed to add T_r dollars annually per route. In addition, each of the N_A circuits will require modems, filters, echo suppressors, etc., each adding an annual cost T_1. Finally, each station has an annual cost component T_0' which is independent of its number of routes and circuits; this reflects the annual cost for the buildings and grounds, antenna and paramp, transmitter and power, all of which costs are necessary for even a single circuit. Therefore, A's total annual costs may be expressed as

$$T_0' + RT_r + N_A (T_1 + PS) \text{ dollars/year.}$$

At this point we recognize that T_0' is large compared with RT_r and that the values of both terms are still so uncertain that they may as well be combined as $T_0 = T_0' + RT_r$. We then examine the cost of adding one more route with N_r

Table I

Illustrative parameters, standard (G/T = 40.7) stations

		dollars
T_0	no-circuit annual cost	
	" today " (actually 1966-67)	1 500 000
	" soon "	500 000
	" someday "	150 000
T_1	per circuit annual cost	3 000
T_r	per route annual cost	10 000
S	space segment rate (annual)	
	" today " (Intelsat-II)	20 000
	" soon "	5 000
	" someday "	0
	(i.e., $T_1 \times S$ = $3000, T_1 may be lower)	

Table II

Illustrative parameters, standard and sub-standard stations

— Antenna aperture (metres)	26	12.6	9	4.5	3
— No-circuit cost coefficient, T_0 (thousands of dollars) (1967 estimates)	1500	500	270	100	60
— Assumed system T, degrees Kelvin	50	100	200	200	200
— G/T in dB (G at 4.0 GHz, 55% eff.)	41	32	26	20	16.5
— Power limited penalty factors, P (present Intelsat values) used in figure 8	1.0	6.5	27	—	—
— Inferred penalty factors, P, for EIRP = 32 dBW (see figure 9), used in figure 10	1.0	1.8	2.7	8.4	21.0

circuits, each carrying its share of the additional T_r as follows:

$$\frac{T_0}{N_A} + \frac{T_r}{N_r} + T_1 + PS \text{ dollars/circuit year } (A\text{'s share}).$$

Next, assuming N_r circuits between stations A and B, which have equal cost coefficients and figures of merit, we obtain

$$\frac{T_0}{N_A} + \frac{T_0}{N_B} + 2\left(\frac{T_r}{N_r} + T_1 + PS\right) \text{ dollars/circuit year} \qquad (1)$$

Here we note that

$$\frac{T_0}{N_A} + \frac{T_0}{N_B} = T_0\left(\frac{N_A + N_B}{N_A\, N_B}\right)$$

which would result if the T_0 of each were spread over $2N_A N_B\ (N_A + N_B)$ circuits. Thus, without loss of generality, we need only consider $N_A = N_B = N$ for which we have

$$2\left(\frac{T_0}{N} + \frac{T_r}{N_r} + T_1 + PS\right) \text{ dollars/circuit year} \qquad (2)$$

III. Illustrative parameter values

Table I shows parameter values which will be used in examples for " standard " earth stations.* The space segment rate is a matter of record. Future space segment rates should decline substantially, although the extent and time-scale of this decline are uncertain. In respect to the lower limit of S, it should be recognized that T_1 may be reduced also, so long as $T_1 + PS$ = 3000 dollars.

The " present " values of T_0 for the 26 m, 12.6 m, and 9 m stations (table II) actually were chosen in mid-1967, based on judgments of the point-to-point panel of the National Academy of Sciences (Woods Hole) Summer Study of Space Technology Applications. For example, it was considered then that the investment in standard earth stations (mostly prior to 1967) averaged about 6 000 000 dollars and that the amortization of this investment, plus maintenance, operating, and other costs led to a 1 800 000 dollars annual cost. Assuming a 100-circuit station and deducting 3000 dollars per circuit left T_0 = 1 500 000 dollars per year. The T_0 estimates for stations using smaller antennae were obtained in similar fashion, with fewer circuits assumed. In comparison, Mackay, *et al.*,[2] estimated the annual operating cost (in their table 8) to be 1 620 000 dollars for standard

* Sub-standard stations will be considered later; see table II.

stations, with *no change* for capacities of 40, 100, 300, or 600 circuits. Assuming the least of these, at 3000 dollars per circuit, again leads to $T_0 =$ 1 500 000 dollars.

The " soon " and " someday " values of T_0 for standard stations (table I) were chosen just to span a 10 to 1 range, with no time predictions. It is interesting that the average cost of standard earth stations has already dropped to less than 4 000 000 dollars, and one expects a corresponding reduction in T_0. The " someday " value of only 150 000 dollars anticipates the use of earth-supported (concrete) antenna reflectors (with perhaps a 20 m aperture becoming " standard "), the elimination of cryogenics, advantages from equipment standardization and from further " learning ", longer amortization periods, automatic unattended operation, etc.

The per channel and per route components T_1 and T_r are the least certain, little better than " guesstimates," but they should serve as illustrations. For preassigned multiple access using standard FDM modems, the $T_1 = 3000$ dollars per year may seem high; there may be indirect contributions to T_1, however. For example, the designer of a 600-circuit station might consider it appropriate and almost necessary to have a more expensive building with more power, redundancy, test equipment, etc., [5] than is necessary for a 40-circuit station. If certain forms of demand-assigned multiple access are considered, this T_1 value may be too low. $T_r = 10\,000$ dollars may be somewhat high. The effects of a lower value would be less noticeable, however.

Figures 1 and 2 are graphic presentations of satellite circuit costs. The " per station " curve in figure 1 shows the annual circuit cost versus circuits *per station* N, neglecting T_r and using the T_0, T_1 and PS values for present standard stations. The horizontal " per route " line indicates that if an additional route did not add to the cost (i.e., $T_r=0$) and if circuits for this route were *taken from* other routes of these stations so that each continued to have $N=60$ circuits, these circuits would cost 96 000 dollars per year each, irrespective of N_r. The effect of the per route coefficient $T_r = 10\,000$ dollars is shown in figure 2 for standard stations and today's parameters; both have 60 circuits initially and a variable N_r circuits for their joining route. The upper of the two solid curves assumes these N_r circuits to be taken from the $N=60$, as before, whereas the lower curve considers that these N_r are *added to* an initial $N=60$ circuits per station. In both cases, a single-circuit route must carry all of the additional $2T_r = 20\,000$ dollars. For a 30-circuit route, however, each circuit's share would be only 666 dollars, which would be an almost negligible addition to the 96 000 dollars per circuit year for a 60-circuit station, or to the 79 333 dollars per circuit year for stations with $60+30=90$ circuits. The " taken from " type of curves will be used in the subsequent discussion, since constant-capacity stations are conservative and less confusing. For $N \gg N_r$ there is little difference between the methods.

IV. Cost trends and equations for terrestrial circuits

A classic exposition of the way in which terrestrial systems with higher circuit capacities lead to lower costs per circuit is shown in figure 3 for the American Telephone and Telegraph Company (AT&T) systems as of 1957. [6] The straight trend line appeared with the original curves and is fit by $360/N^{0.7}$. Although the ordinate scale was qualified as being a comparative cost per circuit mile, and although more than ten years have passed, it appears that this scale is sufficiently close to probable actual costs in dollars, at least for illustrative purposes.

Most of these system cost curves have shapes similar to the " per station " satellite circuit cost curves shown previously because they also have similar cost components. For example, an open-wire voice-frequency system has a " no-circuit " component for its poles and right of way, plus a " per circuit " addition for each wire and its insulators. This should not be interpreted as implying that circuits would be added one by one, with the capacity always filled. Instead it is believed that AT&T intended that these curves show the circuit-range for each system and the corresponding

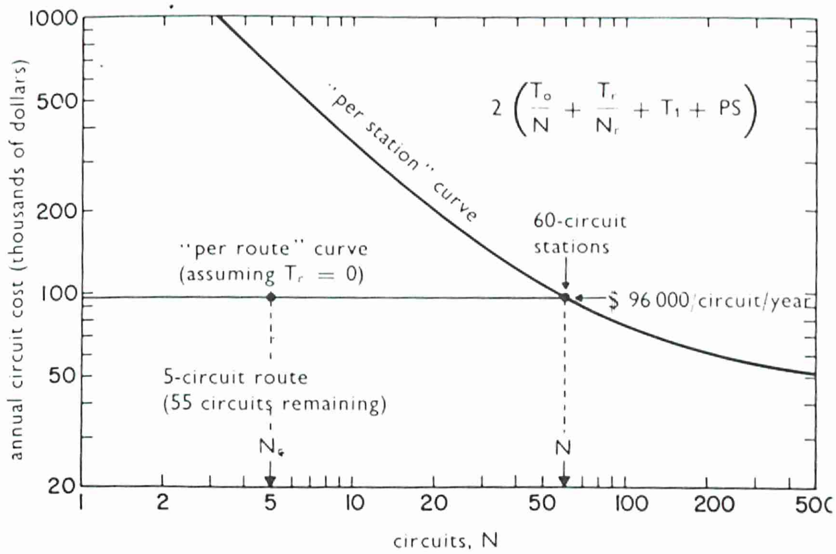


Figure 1

The relation of the circuits per station and circuits per route curves of annual circuit cost, standard stations and present parameter values

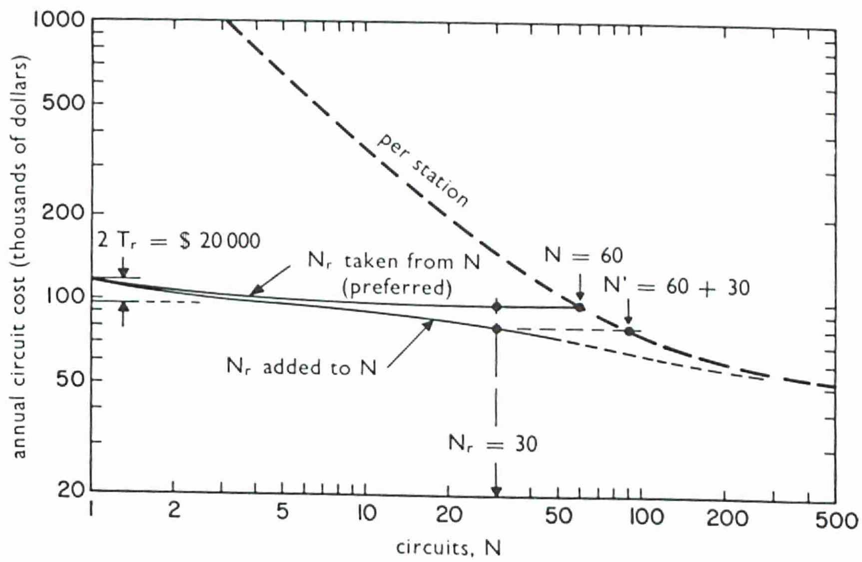


Figure 2

Explanation of the " taken from " and " added to " methods of using the route cost coefficient T_r; assumes standard stations and present parameter values

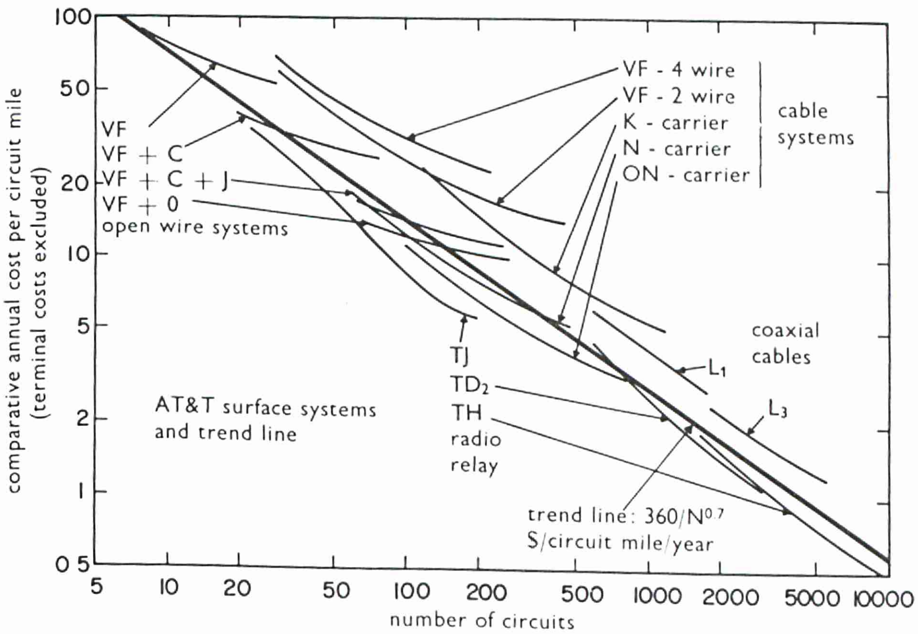


Figure 3

Surface system annual costs per circuit mile, and cost-trend line (AT&T Exibit 2253 to FCC Docket No. 11866, 1967) costs for a range of circuit loading. The usefulness of the trend relation is evident, since only the VF cable curves deviate from it by more than 2 to 1.

A similar trend relation, from the RAND Corporation and the Communications Satellite Corporation (COMSAT), is $300/N^{2/3}$. Although this relation may be as good or better, it has not been chosen because we have not located a reference to its publication or any back-up comparisons with costs for various terrestrial systems. These relations yield equal costs when $N=237$ circuits, and their difference is not significant over the range of interest. The trend relation also appears applicable to present and future submarine telephone cables, for which the right-of-way cost-savings tend to offset the inherently greater cost of the cable. For example, the annual cost estimates given by Mackay [2] for submarine cables of 160, 360, 640, and 1520 circuit capacities agree with the trend cost when 30% to 50% filled, and fall to 70% to 80% of the trend cost when 100% filled. Cost data for the *TAT-3* and *TAT-5* cables are in similar agreement with the trend cost relation.

Unlike satellite or HF radio circuits, these terrestrial systems follow somewhat indirect routes whose lengths average about 1.3 times the airline distance. Therefore, if D is the airline distance:

$$\text{dollars per circuit year} = 1.3\ D \times \frac{360}{N^{0.7}}$$

$$= 468\ N^{-0.7}\ D \text{ (statute miles)}$$

$$\simeq 300\ N^{-0.7}\ D \text{ (km)}.$$

This relation has been used to prepare the trend-cost curves for various distances, used as underlays for subsequent comparisons with satellite circuit cost curves.

It should be re-emphasized that these trend-cost curves are approximate and are used primarily to illustrate the analytical method. When costs of satellite circuits are to be compared with those of a known terrestrial system, the best available cost data for the latter should be used. In this connection, note that the terminal costs were excluded in figure 3. As a result, the switching costs also were excluded, as were the costs of using one or more transit-centres on long international routes. The switching costs may greatly exceed the circuit costs; their neglect merely indicates that satellite circuits may be more attractive than the subsequent examples may indicate. On the other hand, terrestrial routes can pick up and drop off traffic at intermediate points and thus obtain economies.

A. Break-even relations and examples

Figure 4 shows two satellite circuit cost curves from figure 2 superimposed on the family of terrestrial circuit cost-trend lines for various great-circle distances in kilometres. The " per station " curve shows that, without multiple access, two standard stations joined by 30 to 40 circuits would be competitive with terrestrial circuits at any distance greater than about 5300 km (slightly less than North Atlantic path lengths). The 140 000 dollars per circuit year would be high, however, because submarine cables (such as the 120-circuit TAT-3) are carrying heavier traffic at lower costs. With 60 circuits, the cost would decrease to 96 000 dollars per circuit year, but the break-even distance relative to the terrestrial cost-trend would be starting to increase. Extrapolating to 300 circuits, the break-even distance would increase to 10 000 km, even though the cost would drop to 56 000 dollars per circuit year; this results because the trend cost of surface systems decreases more rapidly, to about 30 000 dollars for 300 circuits and 5300 km.

If we consider instead a 5-circuit route between the 60-circuit stations, their 100 000 dollars per circuit year would break even at about 1000 km because of the much higher trend-cost of thin-route terrestrial systems. Multiple access clearly gives satellite communication an important advantage with its ability to combine the traffic from many relatively light routes, which thus can be shorter than the heavier routes.

Figure 5 shows the per route curves for seven cases, 10 to 1000 circuits per station, for standard stations of present parameter values, but with the assumed 5000 dollars near-future space segment rate. The circuits per station curve shows that if the earth stations worked only in pairs, as terminals

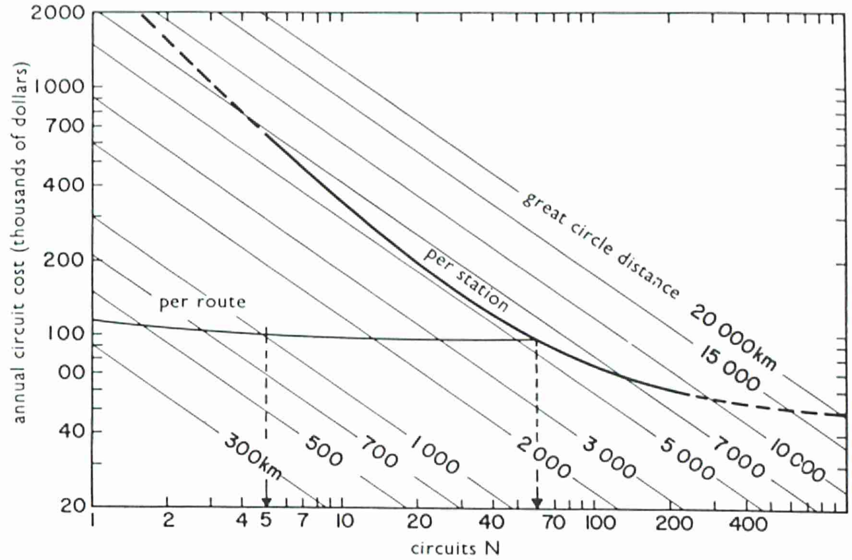


Figure 4

Comparison of surface system trend costs with satellite circuit costs, 60-circuit standard stations, and present parameter values, showing lower break-even distances with fewer circuits per route

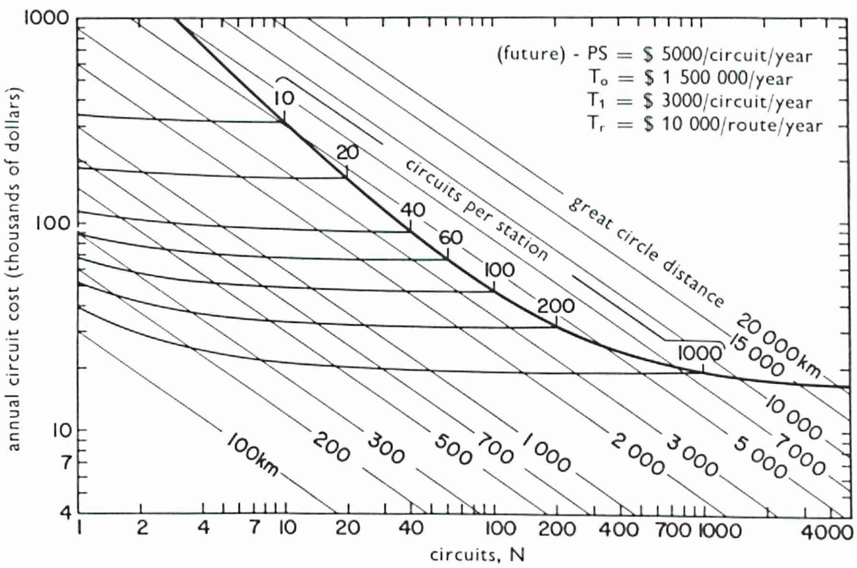


Figure 5

Break-even relations for present standard stations, of 10 to 1000 circuit capacity, with future S = 5000 dollars per year

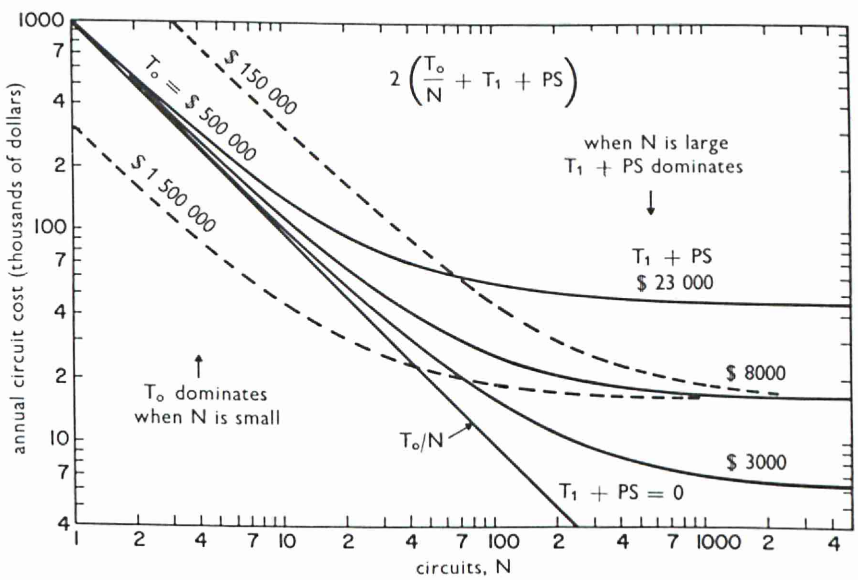


Figure 6

Comparative effects of varying T_o *and varying* $T_1 + PS$

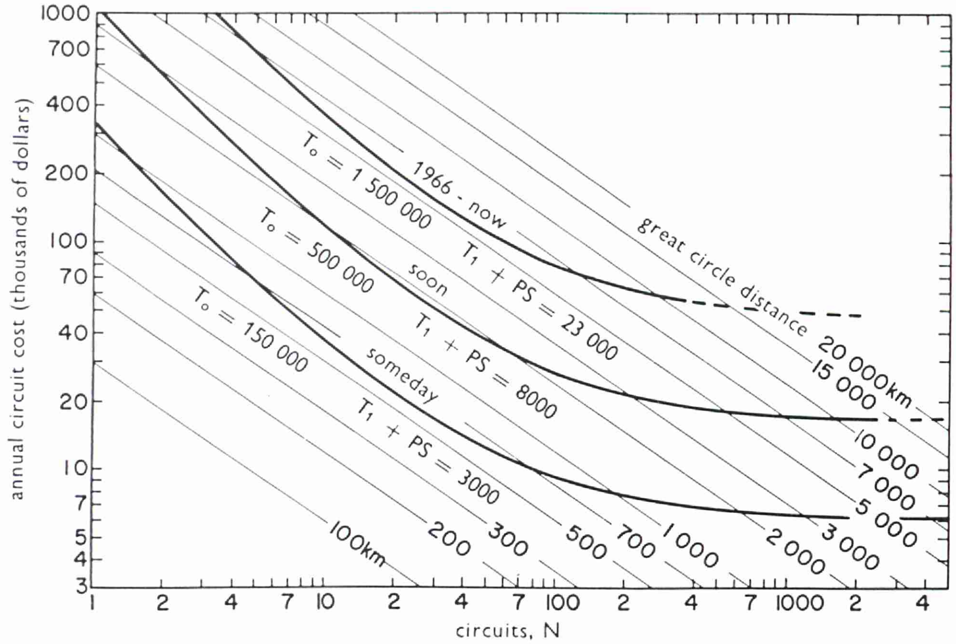


Figure 7

The probable time-trend of annual costs per satellite circuit versus circuits per station

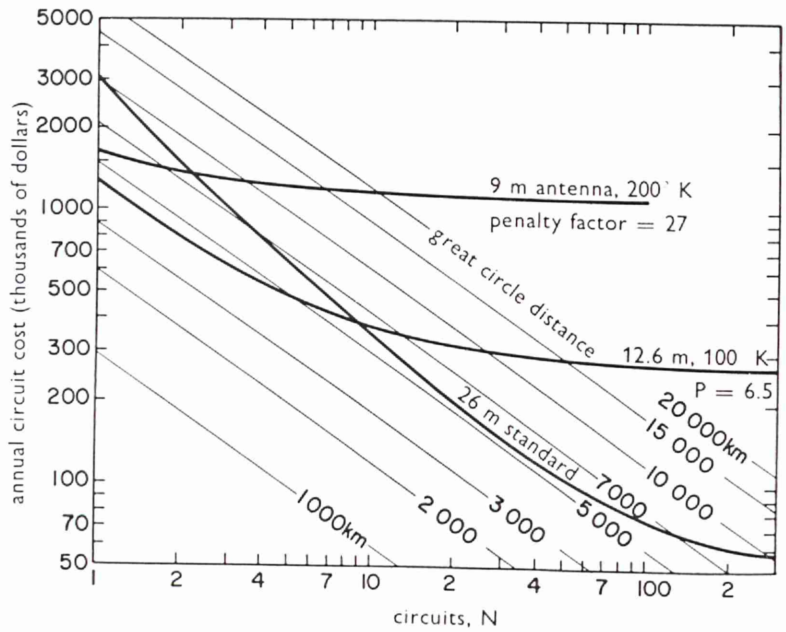


Figure 8

Comparison of annual circuit costs for standard and sub-standard stations, present (power limited) penalty factors, and parameter values (from table II)

of "space-cables," this drastic rate reduction would only reduce the minimum break-even distance to 4000 km (i.e., about 25%) while letting it occur for 60 to 100 circuits. Primarily, the lower rate decreases the cost per circuit year when there are relatively many circuits per station; it is approximately halved for 200-circuit stations and is 38% for 1000-circuit stations. These heavy-traffic stations show impressive break-evens for lighter routes. For example, 200-circuit stations could use 5-circuit routes as short as 400 km, while using 25-circuit routes at 1000 km or more.

This promise of short break-evens for a multiplicity of lighter routes clearly indicates that satellite communication should not remain an intercontinental service; it should become useful *within* continents and even within larger nations. However, it always will provide the best bargains for the *longest* routes. For example, note that the trend cost for 25 surface circuits spanning 10 000 km is *ten times greater* than for the 1000 km route mentioned earlier. This advantage would be lost in a satellite system whose coverage was restricted nationally or regionally to shorter routes.

It should be noted, however, that the shorter routes generally have a greater traffic potential than the longer ones, for obvious reasons.

Subsequent figures will compare the " per station " curves for various parameter values. It should be remembered that these are worst-case curves for break-even distance. Multiple access makes available the region to the left of these curves, in which appropriate " per route " curves should be visualized by the reader.

Figure 6 shows the effects of the T_0/N and the T_1+PS terms in equation *(2)* (with T_r neglected). The dashed curves show the dominant effect of the no-circuit cost component T_0 when it must be spread over relatively few circuits per station. The solid curves show the greater importance of the constant terms T_1+PS when the number of circuits per station becomes large. Note that $T_1+PS=3000$ dollars may be interpreted as $T_1=1500$ dollars$=PS$, or any reasonable division between T_1 and PS may be assumed. It would not be reasonable for either term to become zero.

Figure 7 shows a possible time-trend in satellite circuit costs, assuming that better satellites of the future will lead to reductions in PS, while improvements in earth stations will result in corresponding reductions in T_0 and possibly in T_1. Concerning the " now " curve, the $S=20\,000$ dollars space segment rate became effective with Intelsat-II, in 1966, and $T_0=1\,500\,000$ dollars also was valid at that date. T_0 already has decreased to perhaps 1 000 000 dollars and S may decrease within the next year or two. The " soon " curve may therefore apply in the *Intelsat-IV* era, or possibly later.

The " someday " curve definitely should not be dated, but means of achieving or bettering its parameters should be studied. For example, someday our earth stations should be unattended; use earth-supported (concrete) antenna reflectors, Peltier cooled paramps, and less costly sites and buildings; and have the investment amortized over a longer period. Even the antenna aperture may be reduced, when or if this can be done without excessively increasing the penalty factor, remembering that the " someday " $T_1+PS=3000$ dollars is debatably low, even when not burdened by a large penalty factor. Nonetheless, the attractiveness of satellite circuits at a cost of less than 10 000 dollars per year between stations of about 100-circuit capacities makes these " someday " objectives desirable.

If the thought of 100 km routes *via* satellite appears absurd today, it should be recalled that 15 000 km routes, or any routes *via* artificial satellites, seemed more absurd only 12 years ago.

B. Circuit costs for small antenna earth stations

The large steerable antennae of today's " standard " stations are so costly that there has been continuing interest in the use of smaller and less costly antennae. There are also cost objections to helium-cooled low-noise amplifiers, but the related cost of the space segment (satellite) service cannot be neglected. The operator of the satellite will expect the same revenue from a given fraction of its power and bandwidth whether that fraction is fully used by standard or substandard stations. Thus far, INTELSAT has accomplished this equalization, approximately, by penalizing sub-standard earth stations an appropriately greater number of utilization units per channel. This has been taken into account here as PS, where P denotes the penalty factor.

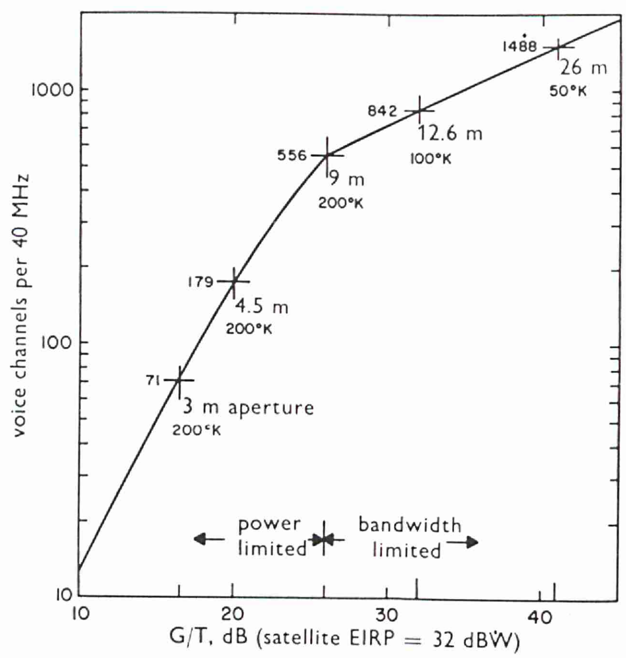
With today's power-limited Intelsat satellites, the penalty factors for sub-standard earth stations have been closely correlated with their lower figures of merit (after an adjustment for differences in rain-cloud degradations) and are shown in table II.

As satellite signal strength increases in the future, the FM modulation index can remain constant (at threshold plus margin) while channels are added, but only until the allocated bandwidth is filled. Thereafter, channels still can be added by decreasing the modulation index, to narrow them, but this will require a more rapid increase in signal strength. In this case, operation is said to be bandwidth-limited.

The impact of the present (power limited) penalty factors on the choice of a standard or sub-standard earth station is shown dramatically in figure 8. Even for hundreds of circuits between 9 m stations, today's minimum cost is greater than a million dollars per circuit year. The standard station, despite its present high T_0 shows a cost advantage if there are more than two circuits. The 12.6 m station, with its 6.5 penalty factor, achieves parity with the standard station at 9 circuits, each costing about 380 000 dollars per year. Except for certain temporary or traffic-limited applications, the probability of heavier future traffic and the desirability of lower cost per circuit have favoured standard stations.

For examining the transition into bandwidth-limited operation, figure 9 shows the number of voice channels which can be frequency modulated on a single carrier, within a 40 MHz band, plotted as a function of earth station figure of merit, G/T (using gain at 4.0 GHz with 55% aperture efficiency), and assuming the peak to RMS ratio to be 13 dB and the satellite EIRP to be 32 dB.** This choice puts a 9 m 200°K station (G/T=26 dB) at the point of change from power to bandwidth limited operation as shown. The standard station's 15 dB greater G/T (rain degradation neglected) gives it 1488 channels per 40 MHz, only 2.7 times more than for the 9 m station and 1.8 times more than for the 21.6 m station, both being much less than the power limited penalty factors used in figure 8.

For G/T 26 dB, operation becomes power limited and the channel capacity declines rapidly, as shown. The 71 channels obtainable with the 3 m station is "sub-standard" by a factor of 21, and poorer than the 9 m station's capacity by 7.8 times, so one can expect it to be economically handicapped, at least at the assumed satellite EIRP. Table II summarizes these data and the T_0 estimates used in plotting figure 10, which also assumes a future space-segment rate S=5000 dollars. At this point one should observe that increase of the satellite EIRP is likely to be obtained by increasing the antenna gain and thereby narrowing the beam



to less than an earth-subtending value, as is being done with Intelsat-IV. One notes that this may restrict the maximum path lengths, say to 5000 km or less in certain directions. The alternative of increasing the satellite's transmitter power, while retaining earth coverage, would tend to increase the satellite size and cost, with a corresponding influence on the space segment rate.

Figure 10 shows curves for the five stations defined by figure 9 and table II. On this basis, the sub-standard stations appear much more competitive, provided they have bandwidth-limited operation. For example, the 9 m station appears preferable to the 12.6 m one if there are less than 50 circuits, whereas 250 circuits are needed before the standard station would become advantageous.

Dropping into the power-limited range, the 4.5 m/9m cross-over is at 6 circuits and at relatively high cost. The 3 m

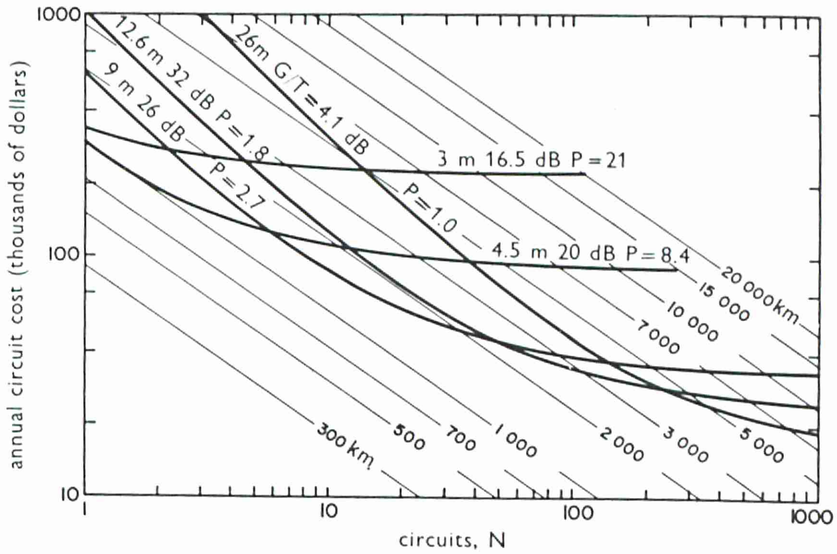
** This curve corresponds to curve 1, figure 2 of CCIR *Doc. IV/79* revised, and curve 1, figure 5 of *Doc IV/181*, 1968; the same computer print-out having been used. The abscissa has been changed by EIRP = 32 dBW, to locate the inflection between power and bandwidth limited operation at G/T = 26 dB.

◄ *Figure 9*

Satellite voice-channel capacities per 40 MHz repeater between earth-station pairs shown, assuming single-carrier FM-FDM, 13 dB peak ratio and 32 dBW satellite EIRP

Figure 10 ►

Comparison of annual circuit costs, based on penalty factors derived from figure 9, parameter values of table II, and S = 5000 dollars future rate



station has higher costs, even for a single circuit. Of course, a further 10 dB increase in the satellite EIRP would give even this 3 m station the advantage of bandwidth-limited operation; reducing all the (inferred) penalty factors as well. However, one should recognize the " cost " of this 10 dB, either in satellite power and weight, or in the shortening of routes within the narrower earthward beam.

Another frequently overlooked consideration is that of orbit-utilization. The beamwidth of a 3 m earth antenna is nearly nine times that from a standard station, requiring correspondingly greater minimum orbital separation between satellites. Of course, orbital stations resemble frequency channels in seeming to be valueless — until no longer available!

V. Predictions or prophecies

One is tempted to draw " conclusions " from this study, but this term implies a certainty which may be inconsistent with the " illustrative " uncertainty of the parameter values which have been used. Basically, a method of analysis has been presented which should be more meaningful than the earlier methods which have assumed that earth-station costs are independent of the number of circuits per station, or per inter-station route. A significantly novel aspect of this method is that the satellite design features, its life, capacity and fill, orbiting costs and risks, management of the space segment, etc., all have been accounted for in the parameters P and S, insofar as the owners of the earth stations are concerned.

There is, however, a closer coupling between earth-system needs, satellite design, and resultant changes in P and S than might be inferred from the preceding statement. In some respects this coupling is so complex that an adequate discussion would digress from the purpose of this paper. One can generalize that this coupling has " positive feedback," in the sense that satellites with successively larger circuit capacities and related improvements lead to lower costs per circuit, which should lower the space-segment rate. Satellites resemble terrestrial systems in respect to this " economy of scale." In the far future this feedback may decrease and even reverse, because frequency/orbit spectrum limitations may require the exploitation of more expensive ways of expanding the circuit capacity, but this merely illustrates one complexity of this coupling.

A quite different and rather nebulous factor is the inverse relation of communication demand to distance, even if cost were no more a constraint than postal rates. Considering the telephone calls of the (nonexistent) average person, we might find that for each call to a 10 000 km (intercontinental) distance, he would make a hundred " international " ($\sim$1000 km) calls and ten thousand " interurban " ($\sim$100 km) calls. Perhaps the International Telecommunication Union World Plan Committee could use its data to derive a better traffic/distance trend relation, but such should not be needed to show that lowering the break-even distance relative to terrestrial communication will increase satellite traffic beyond present expectations. To date most people accept satellite communication as an intercontinental system, whose traffic may grow to a few thousand circuits. It will be interesting to observe how forecasts and plans will expand as soon as 1000 km break-evens are realized. Skeptics should remember that this implies many more earth stations for the realization of these shorter circuits.

On the other hand, consider a large nation whose remote cities are not yet terrestrially interconnected (except *via* HF radio) and assume that it decides to install earth stations at two or more such cities, based on seemingly reasonable forecasts of international plus domestic traffic. Initially, two cities might forecast only 12 circuits for their route, which is many more than their HF circuits but well below the break-even for their distance. These satellite circuits probably would " open the valve " to the traffic-potential of these cities, for which this bond of more useful telecommunication would create new business ties, social contacts, and other traffic demands, soon leading to a forecast revision — for perhaps 300 circuits. Since this volume might exceed the break-even, the administration probably would accelerate its terrestrial system planning. Thus, these break-even relations seem healthy ones in respect to accelerating the growth of telecommunications systems. The satellite system's ability to provide many direct routes of few circuits each, at a distance-independent cost, should complement (and be complemented by) the terrestrial systems' advantages for shorter, heavier routes.

A final word of caution in respect to the planning of domestic or regional satellite systems concerns the use of a directive satellite antenna which covers and provides a strong signal to only the system's nation or region. In effect, this may " fence in " the system to relatively short routes, denying it the satellite's long-route economic leverage. This may be unimportant if the system is intended for one-way service of national character (e.g., for broadcasting educational television to village receivers), but the method of cost analysis given here is *not* directly applicable to these or other point-to-point services. For telephony, cities which depend on circuits of a domestic satellite to reach an Intelsat earth station will encounter the additional costs of this second hop, together with the correspondingly increased propagation time, or " delay." Although the acceptability of echo-suppressed two hop delays for telephony is still being debated, it should be considered objectively by " smaller system " planners.

(Original language: English)

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[3] F. Anguera: " Traffic considerations for demand assigned telephone service through a satellite system " — *Proceedings of the Fifth International Teletraffic Congress*, New York, June 1967, pp. 18-24

[4] S. G. Lutz: " A traffic study of multiple access satellite communication, based on an Atlantic system model " — *Telecommunications*, Vol. 2, July, pp. 27-32, August, 1969, pp. 25-31

[5] CCITT Com XIII, No. *56* (period 1964/1968); see figure 1

[6] From Exhibit No. 2253 to Federal Communications Commission Docket, No. *11866*, 1957

[7] F. A. O'Nians, J. L. Blonstein: " Some aspects of the economics of satellite communications " — *Telecommunication Journal*, Vol. 35, No. *12*, 1968, pp. 662-669

IBM International Business Machines Corporation

Armonk, New York 10504

Office of the President

September 4, 1969

Mr. Clay T. Whitehead
Staff Assistant
The White House
Washington, D. C.

Dear Mr. Whitehead:

I am pleased to respond to your letter of August 19, 1969, in which you ask for our current ideas and information which may be useful in your review of alternative policies for the timely introduction of satellites to domestic commercial communications.

As you know, IBM is a manufacturer of information handling systems that increasingly rely on rapid and efficient transmission of large volumes of data, frequently combined with voice and other communication. Accordingly, our primary interest in communications satellites, both foreign and domestic, is the creation of a means of communication which will supplement terrestrial communication facilities with a high degree of reliability and at a reasonable cost.

Recent actions of the FCC, such as the rendering of the Carterfone decision, and the changes made to interstate tariffs by the domestic common carriers, will result in an increased use of customer provided equipment with common carrier services. The possibilities of innovation and experimentation have been thereby improved and this should assist in providing the public with more efficient and economic communication services. As satellites are an extension of existing communication technology, we believe a philosophy of encouraging innovation and experimentation should continue to apply.

Experience to date, both experimental and operational, with the international transmission of data via satellite has confirmed our earlier expectation that satellite technology can be successfully applied to the needs of users of information handling systems. IBM, therefore, favors the introduction of a domestic communications satellite system as soon as possible.

The ideas and information we have at this time concerning the technical and policy questions you raise which might be of interest to your working group are set forth in the attached memorandum. I trust they will be helpful.

Sincerely,

T. Vincent Learson

TVL/vf
Attachment

INTERNATIONAL BUSINESS MACHINES CORPORATION

Domestic Communications Satellite Considerations

The growth and vitality of data processing is dependent on the timely availability of communication facilities with characteristics (such as data rates, error performance, connect time, reliability) which complement data processing equipment. To date, these facilities have been provided for the most part by communication common carriers. They have been responsive to data processing communication requirements by offering a growing variety of data and voice transmission services. Most of these services make use of regular private line and exchange voice facilities, although some adaptation has been necessary. We expect communication common carriers to continue to be the prime source of communication services required for data processing systems in the future.

At this time satellite communication must be considered as a supplement to wire, cable and microwave transmission techniques. Its addition to terrestrial networks now furnishing voice and data services will improve their versatility and thereby open the way to further innovation.

We are not aware of any specific data communication services which can be provided only through the use of satellite technology, setting aside economic considerations. The unique capabilities of satellite communication technology, such as multiple access and broadcast capabilities, in conjunction with the use of existing terrestrial facilities of nationwide telecommunication networks, may offer possibilities of enhanced data processing system operations. However, there are technical, operational and economic unknowns in considering new communication services based on these unique capabilities and it is difficult to reach positive conclusions concerning potential use at this time.

Communication Service Potential

It is important to insure that users of data processing equipment have the widest possible latitude in selecting and combining their data processing systems and communication services. IBM believes that the prime interest of data processing users in satellite communication technology is in the following areas:

(1) Cost

Lower communication costs are a key element in making data processing available to more and broader elements of the public. Current experience and study indicates that, depending upon certain factors such as distance and terrain, satellite technology offers an improved cost structure over alternative terrestrial transmission techniques.

(2) Availability

Satellite technology as a supplement to terrestrial facilities should help to meet the rapidly expanding need for communication services.

(3) Reliability

Satellite communications technology and terrestrial transmission systems have unique reliability characteristics and would not necessarily be subject to service interruptions from the same causes. For this reason the use of all technologies should improve the overall reliability of the entire domestic communication system.

Special Considerations for Future Services

Compatability with existing satellite communication facilities for data communication has been demonstrated by experimental and operational use of international satellite facilities. There are differences between terrestrial and satellite technologies in certain transmission and operational characteristics, however, which can have important implications for data processing systems. Some of these are:

(1) Propagation Delay

The propagation delay of satellite transmission links has proved acceptable for data communication based upon existing experience. However, since delays in satellite transmission are considerably greater than for terrestrial links, it will be important to the data communication user in the future to know what type of links will be in use and what delays may be encountered in his particular application.

(2) Transmission Considerations

The design of a communication system integrating satellite and terrestrial communication facilities requires the utmost care to insure maximization of the best data transmission qualities in each system.

New Services

We recognize that the difficulty of predicting the demands of the young and rapidly evolving data processing industry adds to the complexity of the considerations that carriers face in offering new services. However, information relating to possible new and different communication services is important to the data processing industry and continued dialogue between the carriers and the data processing industry will be beneficial.

Incentives for Innovation

The entities which operate the satellite system and the regulatory environment should be structured to encourage innovation. This is particularly important during the early stages when the system facilities are being constructed and expanded to provide national coverage. The regulatory process should include procedures to ensure that services required by prospective users are made available as rapidly as possible and under rates equitable to the carrier and the user.

IBM International Business Machines Corporation

Armonk, New York 10504

Office of the President

August 26, 1969

Mr. Clay T. Whitehead
The White House
Washington, D.C.

Dear Mr. Whitehead:

I am in receipt of your letter of August 19, 1969 with its attachments and I wish to assure you that we will try to cooperate with you as quickly as possible.

We have a limited competence in this area. We will submit data to you as soon as possible.

Sincerely,

Vin Learson

T. Vincent Learson

TVL/ec

TW
W/K

GENERAL ELECTRIC
COMPANY
777 FOURTEENTH STREET, N. W.
WASHINGTON, D. C. 20005

L. B. DAVIS
VICE PRESIDENT

September 16, 1969

Dr. Clay T. Whitehead
White House
Washington, D. C.

Dear Dr. Whitehead:

This is in response to your letter of August 19, 1969 requesting the views of the General Electric Company concerning the policy questions involved in reaching a domestic communications satellite policy for the United States. I trust that the following will be of interest to you.

As you know, General Electric quite recently has had occasion to consider many of the questions raised in your letter and the attachment thereto. As a result of that study, we submitted to the Federal Communications Commission (FCC) a document dated February 19, 1969, designated "Additional Comments of the General Electric Company" in FCC Docket No. 16495. Although I am sure you have copies of this filing available to your office I am enclosing additional copies for your convenience.

The FCC accepted our filing and provided an opportunity within which interested parties might submit comment concerning the questions raised by our document. Such comment was received from a number of entities and I am sure that you also have available to you copies of these submissions.

Upon review of the document that we submitted to the FCC and the comments of other parties with respect to that document, I believe that the thrust of our submission would continue to represent our thinking in the areas covered.

GENERAL ELECTRIC

To the extent that the comments of other parties took issue with specific portions of our document they consisted essentially of differing views reflective of the different positions from which the questions raised were being viewed. Our analysis of these comments did not indicate to us that we had been in error in the approach adopted, or the positions taken, in our filing with the FCC.

Information bearing upon the types of questions that are raised in your letter is spread throughout the enclosed document. For example, Parts II, III and IV deal in considerable detail with the types of domestic satellite services that were envisioned, the role that the satellite operation would play in our domestic communications system, and the related technical and operational concepts. In Part V we have directed attention to a number of the considerations bearing on the selection of a domestic entity to utilize satellite technology as a common carrier.

In view of the recent date of our filing, and its extensive nature, I believe our response to your letter can best be accomplished by referring you to the enclosed document. We would be pleased, of course, to review with your panel and staff any further details concerning the matters involved that might be helpful to you in the very difficult task with which you are confronted.

I would be pleased to hear from you if we can be of any further assistance.

Very truly yours,

L B Davis

L. B. Davis

LBD:n
Attachments

BEFORE THE

Federal Communications Commission

WASHINGTON, D. C. 20554

Docket No. 16495

In the Matter of

ESTABLISHMENT OF DOMESTIC NON-COMMON CARRIER COMMUNICATION-SATELLITE FACILITIES BY NON-GOVERNMENTAL ENTITIES

ADDITIONAL COMMENTS OF THE GENERAL ELECTRIC COMPANY

By JAMES A. MCKENNA, JR.

By JOSEPH M. KITTNER

By CARL R. RAMEY
MCKENNA & WILKINSON
1705 DeSales Street, N.W.
Washington, D. C. 20036

Its Attorneys

Of Counsel:

BERNARD H. WHITE
General Electric Company
Missile & Space Division
King of Prussia, Pennsylvania 19406

RAYMOND E. BAKER
General Electric Company
Communications Products Department
Lynchburg, Virginia 24503

February 19, 1969

WILSON - EPES PRINTING CO. - RE 7-6002 - WASHINGTON, D. C. 20001

BEFORE THE

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February 19, 1969

TABLE OF CONTENTS

BEFORE THE

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Docket No. 16495

In the Matter of

ESTABLISHMENT OF DOMESTIC NON-COMMON CARRIER COMMUNICATION-SATELLITE FACILITIES BY NON-GOVERNMENTAL ENTITIES

ADDITIONAL COMMENTS OF THE GENERAL ELECTRIC COMPANY

These Additional Comments of the General Electric Company (GE) are submitted in the belief that they may contribute usefully to the resolution by the Commission of the difficult policy issues which it now confronts in considering whether to authorize space satellite facilities for domestic communication purposes. For the reasons set forth below, and in a simultaneously filed request for acceptance of this document, we respectfully submit that good cause exists for its acceptance and consideration by the Commission.

A. Good Cause Exists For Acceptance

1. *General Considerations:*

1. GE is already a participant in this proceeding, having filed comments initially on April 3, 1967. These earlier comments, of a general nature, pointed in part to the possible use

of satellites for domestic communication purposes in systems requiring simultaneous multipoint communication, and as a means for providing communication services not now available to the public. It was pointed out that technical considerations, eligibility criteria, and related matters would require further inquiry. However, as we discuss more extensively at a later point, neither we nor others submitting comment in the earlier stages of this proceeding were in a position to detail the manner in which such objectives might be accomplished or the possible consequences that might ensue. We are now in a position to be far more definitive concerning these vital considerations.

2. GE has maintained an active and continuing interest in the matters involved because of its highly diversified activities in the whole communications field. As the Commission has previously been advised, the soaring costs of communication to meet GE's needs as a user has also been a source of great concern to the company and has occasioned a thorough review within GE of this basic problem.[1] This review has encompassed all promising approaches, including the possible role that privately owned and operated satellite facilities might play and the regulatory, operational and other problems that might be involved. At an early stage it was concluded that although in special instances, private (i.e., non-common carrier) satellite systems to meet unique industry requirements might well be foreseeable, a general policy authorizing a multiplicity of individual private systems, even if they were economically viable, could not be anticipated for the near future. However, the data which had become available suggested dramatic and new possibilities for major expansion and improvement in our national public communications system, using domestic satellites on a common carrier basis, to achieve objectives such as those indicated in broad terms in the earlier GE filing.

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[1] Letter, March 5, 1968 from G. L. Phillippe, then Chairman, GE Board of Directors to Chairman Rosel H. Hyde, Federal Communications Commission.

3. As a result, GE committed the resources for a detailed study of these new possibilities. Its study has progressed sufficiently, in its judgment, to warrant submission of the results to the Commission and other interested parties. It is GE's purpose to do so in this document.

4. We are aware, of course, that the schedule for filing comment herein has passed and that the question whether these comments are to be accepted is a matter for the discretion of the Commission. Unfortunately, however, in a field as new and complex as that involving the possible contribution that domestic satellite operation might make to the public interest, answers are not always readily available on a time-schedule that might be desired. We respectfully submit that, even taking the current status of the proceeding into account, the material submitted herein holds sufficient promise of usefulness in arriving at appropriate policies to warrant its receipt and consideration at this time.

5. In this connection, we note that at various times during the course of this proceeding, and subsequent to the formal schedule for comment herein, the Commission has found it appropriate to accept additional filings which might be useful in the resolution of the questions involved. (See, *e.g.*, FCC Public Notice 67-989, August 29, 1967, authorizing the acceptance of further comments of the Ford Foundation and others). The serious and far-reaching questions of national policy involved, and the rapidity with which our knowledge and the characteristics and capabilities change in the satellite field, explain and justify such action in the past and warrant similar action with respect to this document.

2. *Previous Filings Do Not Provide Similar Data*

6. In this context particularly compelling justification for acceptance of this additional filing is the fact that the type of data and analysis offered is not provided by earlier filings.

Presently before the Commission in the instant proceeding are the submissions of more than thirty different parties, commenting on the items of inquiry in the Commission's March, 1966 Notice and, in a few cases, offering specific proposals for the establishment of a domestic satellite communications system. Indicative of these filings are the following summary descriptions.

7. It will be recalled that this proceeding began in March, 1966 as a result of a proposal made by the *American Broadcasting Companies, Inc. (ABC)* for the establishment of its own domestic TV program distribution system using a synchronous satellite. Under the ABC proposal then submitted, programs would be transmitted from earth stations located in New York City and Los Angeles to ABC owned and affiliated stations throughout the United States, including Hawaii and Alaska, Puerto Rico and the Virgin Islands. The ABC application also proposed to provide facilities for the interconnection of non-commercial educational TV stations in these same areas.

8. Another, but different, concept for provision of broadcast services was presented by the *Ford Foundation.* Proposing non-profit operation of a domestic satellite, the Ford Foundation submitted models of private satellite systems for the provision of television transmission for both commercial and non-commercial programming. Termed a Broadcaster's Non-Profit Satellite System (BNS), the proposal envisions establishment of a non-profit corporation authorized by the Commission to inaugurate communication satellite facilities for the interconnection and transmission of commercial and non-commercial television and radio broadcasting. Participation would be by both commercial and educational broadcasting entities.

9. *Western Union,* while opposing the Ford Foundation and ABC dedicated or single-purpose systems, on both legal and policy grounds, has supported the concept of multi-purpose domestic satellites operated by Comsat with earth stations being

owned and operated by domestic carriers. As to its particular operations, it proposes to interconnect by satellite the national telegraph system.

10. *Aeronautical Radio, Inc. and the Air Transport Association* proposed two aeronautical satellite systems—one to serve in the North Atlantic and another to provide aeronautical communications in the United States. Until the specialized services prove feasible, these parties would apparently support the immediate establishment of a non-carrier owned, multi-purpose satellite that would include an air navigation communication service. It is said that satellites can meet the requirements of the air transport industry through the availability of an aeronautical mobile satellite relay system for international air routes, domestic point-to-point satellite communications (by either a separate aeronautical system or a shared multi-purpose private satellite system as described above), and ground-to-air communications for aeronautical long-haul domestic services.

11. *AT&T* has proposed a multi-purpose system integrated into the terrestrial system and owned by the existing communications common carriers. While significantly AT&T does not contend that the FCC may not authorize the private use of satellites, it maintains that the public interest would be best served and the full advantages of satellite communications best realized through exclusive employment by common carriers; that due to the limited amount of frequency spectrum available, international and domestic satellites can best be balanced if no private interests are permitted to use satellites. As to the ABC proposal, AT&T argues that network television is now handled adequately by the telephone industry—and that improvements in program transmission via satellite should be handled by it through an integrated terrestrial and space system.

12. *Comsat's* comments urged a multi-purpose system, operated by Comsat in conjunction with carriers and the international system. Its position is that it is the only entity lawfully

authorized to operate domestic satellites. In its April, 1967 submission, Comsat proposed a pilot, or experimental, system designed to, on an interim basis, serve non-commercial and commercial television and general domestic communication needs. Among other things, the purpose, according to Comsat, would be to develop, under the auspices of the Commission and in conjunction with "other appropriate entities," a program plan to demonstrate communication satellite operations for a variety of services including commercial and non-commercial broadcasting, voice and record transmissions.

13. At the request of the Commission, Comsat elaborated on its proposal, suggesting a twelve-channel television system with sending and receiving earth stations in New York, Los Angeles, one station each in the Southeast and Northwest, and thirty receive-only stations in the Rocky Mountain and Pacific Coast time zones.

14. To some extent, basic policy and legal issues have been framed by these prior submissions. However, basically, the proposals thus far argue for creation of domestic satellites for the specialized purpose of relaying broadcast signals or aeronautical communications; or advance arguments for the establishment of multi-purpose satellites that would service broadcast needs and tie-in with existing common carrier communication services. Thus, whether prior proposals encompass a specialized service or a multi-purpose service, the emphasis appears to be, to the extent they are at all detailed, upon service that is essentially available at present in terms of scope and utility.[2]

[2] A concern whether this was the proper emphasis was voiced from the beginning of legislative deliberations on the Communications Satellite Act of 1962 with considerable dispute whether a satellite system is really something new and revolutionary or is merely an extension of present facilities. See House Comm. on Science and Astronautics, *Commercial Applications of Space Communication Systems,* H.R. Rep. No. 1279, 87th Cong., 1st Sess. (1961), p. 11; *Hearings on S. 2650 and S. 2814 Before the Senate Committee on Aeronautical and Space Sciences,* 87th Cong., 2d Sess. 387, 389-93 (1962). See also, Lessing, *Laying the*

B. Introductory Statement

15. Recognizing that there would be efficiencies available from expanding existing services through utilization of domestic satellites, the question raised is whether the public interest might be better served if at least the initial venture into this field focused on the desirability of achieving new communication services commensurate with demonstrated needs, as well as major enlargement of the scope and flexibility of existing services. We see the opportunity for domestic satellites to make possible this latter objective in the record communications field, using that term in its broadest sense, and our submission herein is directed to this exciting possibility.

16. As a result of the study and investigation described in this pleading, GE has concluded that introduction of satellite communication technology into our domestic communication system can provide the means for a revitalization of the business useage of the record communications system in the United States —as we have indicated, using the term "record communications" in its broadest sense. As such, it offers a unique opportunity for the achievement of a repeatedly recognized basic legislative and administrative policy objective, i.e., the development of a balanced national communications system including not only the excellent voice switched network system provided by the Bell System but also a viable and effective truly competitive record communications alternative.

17. In the discussion following, premised on and in recognition of the foregoing fundamental policy objective, we describe

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Great Cable in Space, Fortune, July 1961, p. 156; H.R. Rep. No. 2560, 87th Cong., 2d Sess. (1962). Moreover, even the Commission's initial step forward into the satellite field was in terms of the proposed creation of a single satellite system, based upon some kind of joint venture among existing international carriers, which would supplement existing communications systems "thereby becoming an integrated part of the total communication system of each carrier." *An Inquiry Into the Administrative and Regulatory Problems Relating to the Authorization of Commercially Operable Space Communications Systems,* First Report (Docket No. 14024), 21 RR 1625, 1627 (1961).

the basis upon which we believe the use of domestic satellite facilities can revitalize the existing record communications market, and also open the door to such new opportunities as

—Telemail service providing instantaneous business-to-business communication at a price that can drop to approximately 33 cents by 1975, and ultimately to approximately 10 cents for the equivalent of a 600-word letter;

—a Remote Access Computer Service (RACS) between terminals throughout the country providing the type of backbone data communication service needed by the data processing industry at rates that will spur the continued development and growth of that industry;

—a Multiple Access Video Service (MAVS) that could make possible the assembly on short notice of video facilities, for varying time periods, to bring together various locations for business meetings, coverage of seminars or meetings in academic or other institutions, etc.;

—other variations that might evolve from these initial developments.

—At the same time that services such as these are being instituted and developed, the basic satellite facilities would also be available to existing services for use as backbone transmission links enabling cost savings which, we believe, could lead to lower rates for such services.

We propose to describe in considerable detail just how the system we envisage would operate and the benefits that would flow therefrom.

18. Before turning to a detailed presentation of our views, there is a preliminary matter to be noted at this time. We have referred to certain past proposals for the domestic use of satellites urging the authorization of domestic non-common carrier satellite systems to meet specialized requirements such as those of the broadcasting or airline industries. The approach that we describe herein would not in any way prejudice con-

sideration of these proposals on their merits. For example, the economic viability of the system here described would not be dependent upon the program transmission revenues such as those now received by the Bell System for its services to the broadcasting industry. We have assumed that even though public policy would not appear to warrant authorization of a multiplicity of private satellite systems, the Commission might well decide that the specialized and unique requirements of broadcasting, or certain other industries would warrant authorizing the establishment of one or more separate satellite systems for those industries. If this were the case there would be capacity in the space portion of the system we perceive which could be made available subject to mutual agreement of the parties and whatever policy conditions the Commission might impose.

19. The remaining portions of this document cover the following basic areas:

I. The General Electric Space Background

II. Public Policy Favors the Development of New and Expanded Services to the Public

III. The Role of a Domestic Satellite System In the Development of a Balanced System And New and Expanded Services.

A. Feasible Services

B. Market Potential

IV. Basic Technical and Operational Description

V. Considerations Bearing on Selection of a Domestic Entity to Utilize Satellite Technology as a Common Carrier

VI. Concluding Statement

I. GENERAL ELECTRIC SPACE BACKGROUND

20. By way of background, GE has been involved in the space technology field for over 20 years. For instance, the first

space-to-earth radio transmission took place in 1949, from an altitude of 250 miles, as part of the Bumper project conducted by GE under cognizance of the United States Army. From this early pioneering effort GE has continued to vigorously pursue all aspects of space technology. These efforts have included research and development as well as production of missile re-entry vehicles, satellites, and spacecraft for various missions.

21. The Missile and Space Division of GE has devoted innumerable man-hours to space technology. In addition, other units in the Company have contributed substantial effort. Approximately 20,000 employees, including more than 6,000 engineers and scientists, are engaged in the efforts of GE's Missile and Space Division. They have available approximately 4,751,-160 square feet of plant and laboratory facilities for their use.

22. In connection with the early proceedings of the Commission concerning the international aspects of satellite communication GE undertook a detailed review of the technical, economic, business, and related policy considerations that would be involved in the establishment and operation of a satellite relay system for the handling of communications traffic over long distances on a commercial basis. A detailed report on this subject, entitled "Final Report, Telecomsat Study", was completed in the early fall of 1960. It was filed with the Commission as Volume II of the Comments of GE in Docket No. 13522, March 1, 1961. Volume I of the GE Comments in Docket No. 13522 dealt more generally with the technical aspects of frequency needs for a number of probable space activities, including a satellite relay system for commercial communications traffic.

23. GE, therefore, has been an active participant in the nation's communication satellite programs for many years. Satellites, satellite subsystems, and related ground equipment and services have also been provided to perform other functions, ranging from weather data collection to observation of space phenomena. GE is also a major producer of terrestrial com-

munication equipment having supplied products and systems to many business and private users. In addition, the Company is one of the major consumers of communication services directly connected to daily business operations.

24. In its continuing studies of space communications, GE has pioneered in the use of the small aperture earth terminal with synchronous communication satellites. In June of 1968 the Company with a team of engineers from NASA demonstrated voice and data communications from downtown Philadelphia using a 15 foot diameter antenna and the NASA Application Technology Satellite (ATS-3). This demonstration was featured at the IEEE International Communication Conference then in progress. The ground antenna used for this demonstration was manufactured for NASA by GE.

25. Subsequent to the Philadelphia demonstration GE received a contract from Western Union International with respect to "splash down" television coverage. Under this contract GE has performed on the Apollo 7 and 8 missions providing television transmission from the U. S. Navy's aircraft carriers deployed for the recovery to the nations broadcast networks. This GE system used a 15 foot diameter antenna aboard the carrier for transmission of the TV coverage to the United States via NASA's Application Technology Satellites. During the Apollo 7 mission about 30 hours of television transmission was achieved. The hours of coverage for the Apollo 8 mission were significantly more.

26. The actual operational experience gained in the above activity is reflected in the system presented herein. It provides a measure of confidence in the feasibility of small earth station operation with synchronous communication satellites.

27. GE is also conducting research on other components that would be useful in advanced space satellite systems, including larger unfolding directive antennas, rotary joints, solar power subsystems, power converters, attitude control elements,

etc. Laboratory work is being done on methods of efficiently using solar power on multiple access systems and on high power transponders. Developments of earth station receiving antennas and converter/preamplifiers are also in progress.

28. As a result of its work in areas such as those mentioned above, GE may well be in a unique position to speak of the technical feasibility of many space applications.

II. PUBLIC POLICY FAVORS THE DEVELOPMENT OF NEW AND EXPANDED SERVICES TO THE PUBLIC

29. From its inception, the Commission, supported by judicial decision,[3] has rightfully interpreted its "public interest, convenience, and necessity" mandate broadly. Inextricable to such standard is the responsibility to "study new uses for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest." [4]

30. It is evident, moreover, that although such technological advances as television, FM, facisimile, CATV, stereo, etc. are not expressly mentioned in the basic statute as originally enacted, the Commission's jurisdiction over them is now unquestioned. In view of the broad mandate of the Communications Act and the established principle that all authority of an agency need not be found in the explicit language of the statute creating an agency to deal with a host of problems whose exact nature is unforeseen, the Commission has ample authority to adopt

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[3] *FCC* v. *RCA Communications, Inc.,* 346 U. S. 86, 90 (1953); *United States* v. *Storer Broadcasting Co.,* 351 U. S. 192, 203 (1956); *FCC* v. *Pottsville Broadcasting Co.* 309 U. S. 134 (1940); *National Broadcasting Co.* v. *United States,* 319 U. S. 190, 219 (1943); *American Broadcasting Company* v. *FCC,* 191 F. 2d 492, 498 (1951); *United States* v. *Southwestern Cable Co.,* —— U.S. ——, 20 L.Ed. 1001, 1013 (1968).

[4] 47 U.S.C. Sec. 303(g); See also 47 U.S.C. Sec. 151.

policy encouraging the effective implementation of the concept here presented.

31. As expanded means of communication have developed, the Commission has correspondingly exercised its administrative discretion. It has launched an inquiry into the interrelationship of computers and communications [5] and staked out expansive regulatory authority over the operations of CATV.[6] It has also continually been alert to its aforementioned statutory obligation to "study new uses for radio, provide for experimental uses of frequencies, and generally encourage the larger and more effective use of radio in the public interest" Sec. 303(g).[7] The Commission has undertaken to do no less as it weighs in this proceeding the public interest factors in the domestic satellite field.

32. Essential to the foregoing statutory responsibilities, therefore, is the encouragement of technical resources looking toward increased public availability of expanded and improved communications services. Recognition of this objective is reflected in both specific statutory provision and Commission policy

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[5] *In re Regulatory and Policy Problems Presented by the Interdependence of Computer and Communication Services and Facilities* (Docket No. 16979, 7 FCC 2d 11 (1966).

[6] *CATV Second Report and Order,* 2 FCC 2d 725, 6 RR 2d 1717 (1966); *In re Amendment of Part 74, Subpart K of the Commission's Rules and Regulations Relative To CATV; and Inquiry Into the Development of Communications Technology and Services to Formulate Regulatory Policy and Rulemaking and/or Legislative Proposals* (Docket No. 18397), Notice of Proposed Rulemaking and Notice of Inquiry, released December 13, 1968; *United States* v. *Southwestern Cable Co.,* —— U.S. ——, 20 L.Ed. 1001 (1968).

[7] See *Connecticut Committee Against Pay TV* v. *FCC,* 301 F. 2d 835, *cert. denied* 371 U.S. 816 (1962) where the Court of Appeals for the District of Columbia, in the context of Sec. 303(g), declared that the FCC ". . . has an affirmative duty . . . to experiment with and develop the most desirable deployment and utilization of the nation's communications facilities", 301 F. 2d at 837. See also *Crosley Corp.* v. *FCC,* 106 F. 2d 833, 836, *cert. denied,* 308 U.S. 605 (1939); *High Frequency CATV Relay,* —— FCC 2d ——, 13 RR 2d 1543 (1968).

and practice based thereon—including institution of this very proceeding.

33. Concomitant with a recognition of the need for new services is the national policy goal of achieving, in greater measure, the availability of alternative services to the public in the domestic common carrier communications market.[8]

[8] A review of pertinent legislative and regulatory policy as reflected in existing legislation, regulatory rules, policies and decisions, and related matter, reveals a basic national public policy objective favoring the development of a balanced national common carrier communications system which includes a far more effective competitive record communication alternative then is now available. See, *e.g.*, *Communications Act of 1934*, Sections 1, 221, 222, and 314, 47 U.S.C. Sections 151, 221, 222 and 314; *Communications Satellite Act of 1962*, Sections 102(c), 102(d), and 201(c), 47 U.S.C. Sections 701(c), 701(d) and 721(c); *S. Rep. No. 1584*, 87th Cong., 2d Sess. 49-55 (1962); *Hearings on H.R. 10115 and H.R. 10138 before the House Committee on Interstate and Foreign Commerce*, 87th Cong., 2d Sess., pt. 2 at 565 (1962); Letter from President John F. Kennedy to the President of the Senate and the Speaker of the House of Representatives, February 7, 1962; *Domestic Telegraph Merger Act of 1943*, 57 Stat. 5, 78th Cong., 1st Sess. (March 6, 1943); *Report of the FCC Telephone and Telegraph Committees* (Docket No. 14650) pp. 212-226 (April 29, 1966); Kingsbury Commitment of 1913 (Jones, *Regulated Industries*, 1967, p. 23); *RCA Communications, Inc.* v. *FCC*, 201 F. 2d 694 (D.C. Cir. 1952), *rev'd.* 346 U.S. 86 (1953); *Senate Rep. No. 13*, 78th Cong., 1st Sess. (Jan. 18, 1943) p. 2; *House Rep. No. 69*, 78th Cong., 1st Sess. (Feb. 1, 1943) p. 3; *FCC Report on the Telegraph Industry*, Submitted to the Senate Committee on Interstate and Foreign Commerce, Dec. 1939, p. 54; *House Document No. 83*, 74th Cong., 1st Sess. (Jan. 21, 1935) p. 5; Senate Document No. 53; 83rd Cong., 1st Sess. (June 22, 1953); House Report No. 2664, 77th Cong., 2d Sess.; Senate Report No. 769, 77th Cong., 1st Sess.; 13 *Antitrust Bulletin* 873, 876-879; 13 *Antitrust Bulletin* 973, 977 (1968). Moreover, in light of the "consistent position of Congress that the nation should not be compelled to rely upon a sole supplier for [domestic] communications", this Commission "has held the same long-term interpretation of national communications policy." *Report of the Telephone and Telegraph Committees of the FCC in the Domestic Telegraph Investigation* (Docket No. 14650) April 29, 1966 pp. 212, 214 and 246. For instances of specific Commission action premised on this objective see: *In re Allocation of Frequencies in the Bands Above 890 Mc*, 27 FCC 359 (1959), 29 FCC 825 (1960); *Television Inter-City Relay Stations*, 17 RR

34. Fundamental, therefore, to the Commission's approach is the desirability of improving the range and variety of communications services available to the consumer. The domestic satellite proposal here presented, to which we now address ourselves in detail, takes into account these correlative objectives—provision of new and enlarged services within the framework of an essentially balanced domestic communications system.

III. THE ROLE OF A DOMESTIC SATELLITE SYSTEM IN THE DEVELOPMENT OF A BALANCED SYSTEM AND NEW AND EXPANDED SERVICES

A. Feasible Services

35. The recent combination of two factors, (1) the emergence of technical feasibilities permitting either alternative or supplemental communications systems and (2) the FCC's encouragement of the availability of such developments [9]—has opened up dramatic possibilities for meeting the foregoing basic objectives. As to (1) above, we know now that it is technically feasible for customers to build and operate their own communication systems, principally private microwave; we know also, from the comments previously submitted in this proceeding, that there are no significant technical barriers to the establishment of domestic satellite communication systems. These two technical feasibilities alone, private microwave and domestic satellites, go a long way in building the practical basis on which the pertinent policies may be implemented.

1621 (1958); *Microwave Communications, Inc.* [Initial Decision, FCC 67 D-56, October 19, 1967]; *In re Use of the Carterfone Device in Message Toll Telephone Service* (Carter v. AT&T Co.), 13 FCC 2d 420, reconsideration denied, 14 FCC 2d 571 (1968); *ITT World Communications, Inc.*, 2 FCC 2d 573 (1964); *ITT Mobile Telephone, Inc.*, —— FCC ——, 1 RR 2d 957, 963 (1963). See also Irwin, *The Communication Industry and the Policy of Competition*, 14 Buffalo Law Review 256 (1964).

[9] See illustrative Commission actions in this respect noted at p. 14, fn. 8, *supra*.

36. The concept envisioned and the system proposed would concentrate on such areas of data and other record message transmissions between particular points not requiring the availability of complex switching arrangements. In significant effect, therefore, it offers an alternative to substantial reliance on the terrestrial switching hierarchy as well as trunking facilities.[10] The basic array of services conceived can be sub-divided as follows:

(1) *Multiple Access Digital Services (MADS)*

a. Record Services

b. Remote Access Computer Services (RACS)

(2) *Multiple Access Video Services (MAVS)*

The economic and market justification for institution of such services is outlined subsequent to the following brief description of these services.

37. *MADS—Record Services*—This message service market involves record communications of the nature of Telex, TWX,[11] and Private Wire Systems. The services are presently offered by existing carriers using facilities of the terrestrial network. The record service contemplated would be provided via satellite, however, eliminating most of the present hierarchy of switching on the terrestrial network, and realizing substantial and significant economies. As a result, the service would become available to a number of users far greater than those who can afford to utilize presently available services.

38. The MADS category would also include a type of message service, new in many respects, designated *Telemail.* In the relatively distant future it is likely that a substantial portion of

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[10] See *Figure 3* at p. 38, *infra.*

[11] Negotiations for the acquisition of TWX by Western Union (Telex) have seemingly been consummated recently in at least tentative agreement form. *Wall Street Journal,* Jan. 16, 1969; *Wall Street Journal* February 3, 1969, p. 21.

first class and air mail can be handled electronically. It is, however, immediately apparent that transmission of a significant portion of all mail by electronic means would necessarily entail the availability of an exceedingly large number of subscriber terminals at individual homes, offices, etc. Nevertheless, there are certain types of communication now handled by mail which would be susceptible in the immediate future to electronic transmission.

39. One such communication segment is that now handled by mail from business firm to business firm. The overall volume of business-to-business mail currently represents 26% of all mail.[12] Of this total business-to-business mail, 76% is first class or air mail. Clearly, much of this communication is of the type that could be electronically handled, if the price were acceptable to the user, with the added advantage of instantaneous reception. Specifically, the segment most amenable to electronic handling is the so-called "transaction" mail.[13] The business-to-business segment of this type of mail amounts to 17% of all mail. For reasons set out subsequently we believe the capital and other investment requirements to provide this service at a price acceptable to the customer is one of the most critical aspects. Significantly, the development of Telemail does not require the creation of new demands—rather it entails the substitution of electronic transmission for the mails in order to meet and extend existing demands.

40. The Telemail service ultimately envisioned would likely have terminals very similar to the typewriter located, for instance, on the desk of the business or professional man's secretary. Upon typing a letter the secretary would be able to press

[12] Information here reported is derived from statistics contained in the Reports of the President's Commission on Postal Organization, June, 1968, Annex II.

[13] Generally mail that involves some form of business transaction, *e.g.*, orders, agreements, confirmations, etc.

a button, whereupon the letter would be transmitted to the selected receiver party and typed out on the latter's typewriter.

41. *MADS—Remote Access Computer Services (RACS)*—As the Commission is aware by virtue of its timely inquiry into the interrelationship of computers and communications [14] an exceedingly important domestic use of communications promises to be related to computer operations. Consequently, a key service of the proposed system would involve the provision of communications needed for computer-to-computer and computer-to-individual user purposes. These operations are generally referred to as remote access computer services (RACS). Communications needed for access to time-sharing computer facilities comprise one aspect of RACS. However, the projected service would be useful for many other types of computer uses that, while not involving time-sharing, depend on communications capabilities. It would offer to the data processing industry a type of backbone communication service needed to enable unimpeded growth of this important industry. It would, moreover, make available nationwide "metropolitan area" access to time-sharing centers regardless of physical location. This feature should increase the practicality of nationwide data banks or library services provided from very large storage facilities in one location.

42. *Multiple Access Video Service (MAVS)*—GE's studies have shown what we believe to be a significant future need for business, professional, government and social groups to communicate with each other and express themselves meaningfully with the advantages of—but without the necessity for—face-to-face confrontations. The increased number of meetings, conferences, seminars of all sorts at widely scattered national locations, the amount of time spent on planes and trains (not to mention the time expired "waiting at the station" or on the runway) attest

[14] FCC Docket No. 16979, *supra* note 5.

strongly to the need for new methodologies to handle these facets of contemporary life. As this need becomes more urgent, the requirement for a random assembled video network emerges. Such a network would be premised on achieving complete flexibility. It would, for instance, be capable of being set up on short time notice for a single one-shot application. In addition, it would be geared to provide simplex or duplex service, with the added capability of reaching two or several locations simultaneously.

43. The MAVS concept is depicted in *Figure 10.*[15] The applications listed include business, government, and educational organizations as illustrative and typical, not necessarily exclusive. The primary objective of the MAVS service would be to provide mobile ground stations for transmission, reception, or both. The number of vehicles [16] for this purpose would depend on the access from a specific area to the satellite or vice versa.

44. The service provided could be simplex, half-duplex or full-duplex video with duplex audio. Two channels would be needed for full duplex applications. A CCIR relay grade service (SNR of 47.9 dB unweighted) would be maintained; this service is superior to the TASO Grade 1 picture which is classified as excellent, *i.e.*, no impairment.

45. Due to its responsive nature, there could be considerable diversity of application inherent in the MAVS system. For example, a mobile unit could pick up from a remote location and feed into another system. Illustrative of this would be the coverage of a special program which is fed into a CATV system. The transmit and receive centers may both be distributed via a mobile unit.[17] For example, a new product introduction may be in New York with closed circuit viewing in San Francisco

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[15] p. 64, *infra;* See also *Figures* 13 and 16 at pp. 67 and 70 *infra.*

[16] See *Figures* 10 and 16 at pp. 64 and 70 *infra.*

[17] See *Figure* 16 at p. 70, *infra.*

and Chicago—or a Department of Defense briefing on the status of a government contract may be between personnel in Washington and Seattle.

46. Two other basic video services are foreseen in addition to those mentioned above as part of a random assembled network system. One such additional service may be termed *Public Video Exchange (PVX)*. The need for point-to-point video service need not be limited to single events in a specific location. However, the requirements of any one person or group may be insufficient to require a dedicated facility. It is, therefore, in this sense and situation in which a need for a public video exchange is perceived. The PVX can be conceived as a conference room or studio with audio and video communication capability with a similar unit in a distant location.[18] A primary distinction between this PVX service and the previously discussed random assembled network type service is that in this case the subscriber or user is required to be at the studio.

47. This service and several applications thereof are delineated in *Figure* 10.[19] The service would be provided at TASO-1 with appropriate color specifications. With this level of service, moreover, picture quality promises to be near perfect, measurably better than normal home television.

48. An additional service offering is possible as an outgrowth of the public video exchange service. For instance, under circumstances in which the usage of a video center by a single customer is large, a need may be created for a *private video exchange*. This facility would be more convenient than a public video exchange since it could be located in the subscriber's facilities. Intra-facility video communications could be incorporated in the system as illustrated in *Figure* 10.[20] A potential application would be the daily contact between engineers in the cen-

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[18] See *Figures* 13 and 16 at pp. 67 and 70, respectively, *infra*.

[19] p. 64, *infra*.

[20] *Ibid*.

tral office of a large corporation and a remote production facility. In the education field, a central university could arrange course lectures, debates, etc. with extension facilities. Military service organizations could maintain closer liaison between major installations and the Pentagon. State governments could facilitate coordination among regional and county centers. The quality of service would be similar to that described for the public video exchange. The subscriber would pay only for his scheduled time use of the transmission service once financial arrangements had been made for the ground facility.

49. These, then, are illustrative of basic service offerings attainable from a new, needed record communications satellite. However, even as demands for data and video service grow, the satellite capacity would not be fully used and extra transponders would be available. These units could be made available to common carriers (such as telephone carriers) and private network users (broadcast networks, airline entities, for example) on whatever mutually agreeable basis would be consistent with Commission policy. Control of this portion of the facilities, under these circumstances, could be lodged with the user of the transponder who could also provide related ground facilities.

B. Market Potential

50. The specific system described herein has been directed primarily toward providing the Multiple Access Digital Services (MADS). Markets for such services presently exist, thereby providing a reasonable basis for ascertaining potential.

51. The system envisaged also would be capable of offering the Multiple Access Video Service (MAVS), as well as making available unused transponders on a long-term lease or similar basis. The extra investment required for MAVS, however, is purposely constrained within this plan to be no more than that necessary to make the offering and to determine the marketability of such services. For 1980, our projection for these services accords only modest growth; at that time only 10% of an-

ticipated revenues would be derived from the combination of MAVS and leased transponders. Obviously, if demand for these services expanded far more rapidly than anticipated, additional investment would be required—but always within levels of incremental revenues to be anticipated.

52. In view of the aforementioned substantial dependence on MADS in the initial years of the proposed system, our more detailed market evaluations have been directed to record and data communications opportunities. At the conclusion of this section, however, we do discuss briefly the potential MAVS market.

53. Moreover, in the discussion that follows covering both potential market characteristics and more basic technical data relative to the proposed system, while considerable effort and thought has proceeded these explanations, the basic uncertainty regarding the nature and scope of a final system prevents precise calculation. It does not foreclose, however, a full scale discussion of the considerations likely to be critical to the basic technical and economic operation of a proposed satellite system for the purposes envisioned, and it is in this light that we proceed.[21]

54. The overall concept of the proposed MADS system is premised upon achieving a substantially lower cost domestic record message transmission service, permitting a subscriber price that would insure a large increase in demand.

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[21] In order to facilitate analysis we have assumed in these cost and pricing calculations that the services under consideration would be provided by a new entity. We have not involved ourselves in cost "allocation" problems that might arise from, in the case, for example, of existing carriers already providing multiple services. The approximate customer charges for the services described herein other than video reflect a consideration of the total cost of establishing and operating needed facilities and a rate of return similar to that found in the common carrier field. The costs taken into account in describing approximate charges for the video services are of an incremental nature and take into account the probable need initially of promotional pricing in order to develop the market.

55. In GE's study of the economic viability of the proposed MADS system, the basic assumption, therefore, has been that on a middle or long-term basis demand will continue to increase if price is lowered to a level that is competitive with alternative methods by which the potential subscriber may have his message delivered.

56. As we develop further below, promise of a tremendous cost reduction in the transmission of basic record messages is possible through utilization of the MADS concept. Thus, in the proposed Telemail service, it would be possible eventually to transmit messages at 10¢ per 600 word message—with a reduction to approximately 33¢ possible by 1975 and 14¢ by 1980. This, as our examination reveals, represents a cost that is a small fraction of the cost for a similar message transmitted by ordinary teletypewriter on a projected basis.[22] In other words, we are speaking ultimately of rates that are comparable to postal service, but with instant delivery!

Message Service Market:

57. The promise of these dramatic cost reductions arises only because of the availability of space satellite technology and the related operational concepts we have outlined herein. The magnitude of possible cost reduction using satellite transmission is indicated by comparison with current rates for equivalent service.

58. *Table 1* indicates typical rates for transmitting a three-page, 600 word message. The present Telex transmission cost for a message of this sort from New York City to Los Angeles is $6.00. A typical telephone rate, by comparison, between these same locations is $1.75 at the day rate, dropping to $.75 at the night rate.

59. These rates, however, must be viewed not only on a comparable basis but on a projected basis. In this regard the most ambitious projection for a Telex (or equivalent TWX) rate

[22] See *Table 1* at p. 24, *infra*.

for the above-described message, in 1980, that we are aware of is $1.60. In contrast, as depicted in *Table 1,* estimated costs for the equivalent transmission employing the proposed record communication satellite system is an order of magnitude lower in cost.

60. As indicated, the satellite service rates that should be achievable are 33 cents in 1975 with the possibility of 14 cents in 1980, dropping to only 10 cents in 1990. It is evident that reductions in cost of these amounts can bring about a sizable cost benefit to message service subscribers. In turn, rates in the order of cents should stimulate the growth of this entire segment of the record message market.

61. The existing message service market involves record communications such as Telex, TWX, and Private Wire Systems. These services are currently offered by present carriers using

TABLE 1

Comparison of Alternative Services

	Three page, 600 word Message Charges			
Service	1968	1975	1980	1990
Telex: NY-Wash	$1.80			
NY-LA	6.00			
Ave. (100wds)	(.42)			
Telex/TWX			$1.60	
Night Rate Phone				
NY-LA (0000-0700)	.75			
NY-Wash. (0000-0700)	.60			
Day Rate Phone				
NY-LA (0700-1700)	1.75			
NY-Wash (0700-1700)	.80			
Satellite Message Service*		$ .33	$ .14	$ .10

* Unlike charges for existing services listed, the satellite message service would include charges for local loop and subscriber terminal equipment.

TABLE 2

TELEX

Market Data 1960-1968

	60	61	62	63	64	65	66	67	68
No. of Subscribers	218	687	2,872	7,352	9,904	13,566	18,087	23,000	26,000
Total Revenue $-Millions	$ .3	.7	2.5	7.6	13.1	18.4	25.0	32.3	41.0
Average Revenue per Subscriber	$1,375	1,018	870	1,032	1,323	1,357	1,385	1,407	1,580
Total Messages Millions	.3	1	6	15.5	31.5	41.6	51.5	59.6	66.9
Average Messages per Subscriber	1,380	1,460	2,090	2,100	3,180	3,060	2,850	2,590	2,570
Average Revenue per message	$1.00	.70	.42	.49	.42	.44	.49	.54	.61

Source: TEMPO, G.E.'s center for advanced studies.

the terrestrial network. Although market projections of this kind can be made in various ways, historical analysis and reasoned extrapolation form the basis for the approach here used. *Table 2* shows historical data for the Telex service from 1960 to 1968.

62. Projections from the historical data in *Table* 3 indicate the possibility of 500 million Telex messages in 1980—assuming the price remains equally or more attractive than today in relation to alternatives available to the customer.

63. Another important segment of the record market and one experiencing rapid growth is the "private wire" service provided to commercial and government customers. Currently, about two-thirds of this market is in government applications. However, future growth in the commercial sector may well account for the major share of overall growth—contrary to what established trends would suggest.

64. Indicative of the commercial importance of "private wire" are Western Union statistics on 1967 revenues from these two services: $32.3 million from Telex and $106.3 million from private wire. These and other statistics suggest strongly the commercial significance of major customers—whether individual entities or homogeneous groupings of such entities, such as the airline industry.

65. A combined market projection in billions of messages for the Telex, TWX, and Private Wire service is shown in *Table 3*. Also shown for reference purposes is the Telex market projection. It is estimated that the message volume for the combined services will approximately double in ten years, i.e., from about half a billion messages in 1970 to 1 billion in 1980.

TABLE 3

Billions of Messages

	1970	1972	1974	1976	1978	1980
Telex	0.082	0.118	0.168	0.240	0.350	0.500
Telex TWX & Private Wire	0.540	0.590	0.640	0.700	0.790	0.960

Source: TEMPO

66. As described in a prior section, GE also foresees the evolution of an entirely new market and service—one that we have chosen to call "Telemail". In short, "Telemail" would electronically, by satellite, handle much general business-to-business correspondence now delivered by postal facilities. The immediately foreseeable market for Telemail service would probably be confined to this business-oriented usage—and our forecasts are based on that assumption.

67. As we have indicated, the overall volume of business-to-business mail represents currently 26% of all mail. Also, as noted earlier, the segment most amenable to electronic handling

via satellite is the so-called "transaction" mail. The business-to-business segment of this type of mail amounts to 17% of all mail. Thus, while certain limited types of such mail involve financial and legal transactions necessitating certification, etc. (restricting the utility of Telemail to this extent), it is this particular segment of the postal service that would represent the initial market focus of Telemail.

68. Preliminary functional analysis suggests that 93% of transaction mail from business-to-business is of the type not requiring certification. This amounts to nearly 16% of all mail and, in 1967, represented 12.5 billion pieces (or messages).

69. Assuming (1) that the average message length associated with each piece of transaction mail was two minutes at 300 baud (or 3 pages of text) and that (2) the rate charged for a Telemail service would not be higher than the current minimum postal air rate (10 cents per piece), we can reasonably envision that, if such a service were operational in 1967, the maximum market in the mail substitution business would be $1.3 billion. If, in subsequent years, the entity in this market achieved 100% penetration (i.e., 93% of business-to-business transaction mail), it would be handling 16 billion messages in 1975 and 20 billion messages in 1980.

70. As a practical measure of the potentially convertible market, we have assumed a significantly smaller penetration, namely, 1.3 billion messages in 1975, 3.2 billion in 1980, 6.8 billion in 1985, and 21 billion in 1990. These volume projections for business Telemail service amount to only 8% of the total postal market that is potentially accessible through electronic substitution. In actual fact, this market level would be determined by plant investment, rates, customer resistance to change, the extent to which transaction mail can, in fact, be handled electronically, elasticity of demand to qualitative improvements in service offered by Telemail, and other factors. For example, electronic handling of purchase orders (860 million pieces of

mail currently) should be handled with ease. This category by itself amounts approximately to 10% of the total volume of transaction mail (or 1.7% of all mail). Another early target could be intra-company mail amounting currently to 1.3 billion pieces of mail.

71. The findings of a recent study sponsored by the President's Commission on Postal Organization tend to validate these preliminary projections. It has been estimated in this study that 22% of all domestic mail consists of "general correspondence" which is, in part, "telephone substitutable." The business-generated segment of general correspondence amounts, currently, to 2% of all mail. A report on this study provides data indicating that at least 65% of this type of business mail (1.3% of all mail) is highly amenable to substitution by telephone and, therefore, equally amenable to substitution via "Telemail."

72. It is interesting to note that the mail types of immediate interest for the development of a business Telemail service are such that they can be appropriately viewed as natural extensions of today's Telex/TWX message services. It will be recalled that the projected aggregate demand for these conventional message services are considerably lower than the "practical" projections for Telemail. In 1990, they are 1/20th as large.

73. What is most appealing about a Telemail service, to business or other sectors, is that penetrating specialized postal-service markets does not require the creation of *new* demands. Rather, it entails substitutions and extensions of conventional demands—while at the same time offering much greater speed in delivery to the desk of the addressee. Thus, unlike the subsequent projections on computer-related communications demand, projections for business-oriented Telemail services do not have to be predicated on assumptions concerning growth of other sectors of the economy.

Computer-Related Communications Services:

74. In evaluating the market potential and feasibilities of these services, GE sought the assistance of TEMPO, its center for advanced studies. Accordingly, the discussion here substantially reflects the study efforts of TEMPO that have concentrated on this specific area.

75. An important component of future domestic demands for communications services will derive from communications-dependent computer operations, or remote-access computer services (RACS). Time-sharing services, whether provided on a subscription or private basis, are only one aspect of RACS. There are other types of computer uses that do not involve time-sharing but which do depend on communications. These, too, are included in the projections made below.

76. The projections made here for RACS-generated communications demand must of necessity remain fluid, subject to further progress in the delineation of market patterns. The field is simply too new to permit reasonably precise projections by extrapolation. Several assumptions, therefore, had to be made as to growth rate changes, by drawing on our own experience as well as on data made public by IBM, BEMA, ADL and others.

77. It was not until 1965 that computers started becoming dependent on common carrier communications to a significant degree. In that year, the total value of net computer shipments, domestically, was \$1.3 billion.[23] The communications oriented portion was \$0.16 billion (12% total). By 1967, total net shipments had risen to \$2.8 billion and the communications oriented segment to \$.38 billion (21% of total).

78. According to current projections formulated by TEMPO, by 1970 the value of net communications-oriented computer shipments will be \$2.16 billion (\$6.25 billion cumulative).

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[23] In 1965, the revenues from time-sharing services were negligible. Now, they amount to \$75 million per annum.

By 1975 and 1980, these will grow to $6.64 billion ($28.13 billion cumulative) and $18.54 billion ($91.98 billion cumulative), respectively.

79. Operating experience with communications-oriented computer installations (COCI) has not been sufficient to enable reliable estimates on the extent of the RACS dollar spent on communications service provided by common carriers. Based on several assumptions, we have arrived at a tentative projection (*Table* 4) on the distribution of all common carrier revenues estimated to be, cumulatively, $1.28 billion in 1970 and to grow to $17.6 billion by 1980. In *Table* 5, the corresponding long-line revenues to common carriers for the same time period are projected. It is estimated that of these totals, subscription-type RACS will account for $26 million in 1970, $150 million in 1975, and $350 million in 1980. These highly preliminary estimates reflect, implicitly, a number of uncertainties including those concerning:

a. geographic location of RACS and other COCI centers

b. distance between such centers and their respective subscribers

c. elasticity of demand for RACS related to change in communications service rates, and

d. type of RACS offerings (as it affects communications service requirements).

80. These uncertainties are "real", not "statistical", and cannot be reduced significantly except with time.

TABLE 4

ESTIMATED DISTRIBUTION OF COMMUNICATIONS COMMON CARRIER REVENUES FROM COCI BY USER INDUSTRY: 1970 to 1980 *
(BY BILLIONS)

Year	Manufacturing (34%)	Finance (12%)	Services (8%)	Other (8%)	Total Cumulative
1970	0.85	0.2	0.1	0.13	1.28
1972	1.6	0.3	0.14	0.24	2.28
1974	2.9	0.5	0.25	0.43	4.1
1976	4.9	0.9	0.43	0.72	7.0
1978	7.9	1.4	0.7	1.2	11.2
1980	12.5	2.2	1.1	1.8	17.6

* Percentages are current estimates on total annual communications-service costs (expressed as a percent of COCI net shipment value).

TABLE 5

CUMULATIVE LONG-LINE COMMUNICATIONS REVENUES FROM COCI: 1970 to 1980 *
(BY BILLIONS)

Year	Conservative Estimate (25%)	Nominal Estimate (50%)
1970	0.32	0.64
1972	0.57	1.14
1974	1.03	2.05
1976	1.75	3.5
1978	2.8	5.6
1980	4.4	8.8

* Percentages indicate the portion of total communications revenues derived from long-haul service.

81. These revenues to common carriers from COCI would derive in large part from communications between computers and terminals (as opposed to computer-to-computer communication). In 1966 there were 70,000 to 90,000 such terminals, served by 2,500 computer systems. By 1980, these COCI systems are expected to grow to 50-75 thousand, with most being linked to 10-30 terminals. Based on an average of 20 terminals per installation, between 1 and 1.5 million terminals would be in use in 1980.

82. Thus, it is expected that the shared use of computers from remote terminals at users' locations, operating on both a subscription and dedicated basis should become increasingly widespread in the United States (as well as in other countries). This anticipated proliferation of specialized computer/communications networks is motivated and sustained by the potentially large economies of scale and specialization. For example, large efficiencies should accrue from pooling of storage and processing facilities; or from time and job diversity among many subscribers (or internal users) allowing for more efficient peakload smoothing and for potentially major savings in capital expenditures.

83. Over the *near* term, RACS would continue to be motivated principally by the economies that accrue from the time-sharing of "raw" computational power, and confined, typically, to users within a fifty-mile radius, because of relatively high "local-loop" communications costs. However, the principal motivation for RACS over the time period of interest to this discussion would be for sharing high-cost, specialized data bases and "application" software of wide interest—not for the sharing of central processing units. Since such data-sharing and software-sharing RACS would have regional, national and even international geographic coverage, their growth should be enhanced significantly by substantial reductions in long-haul communications costs. Space satellites hold much promise to accomplish this.

Multiple Access Video Service:

84. The proposed domestic communication satellite would have the capability to handle special television service by virtue of the transponders aboard the spacecraft not devoted to the MADS service. These television services are identified as Multiple Access Video Services (MAVS) and have been described in paragraphs 42-48, *supra*.

85. The random assembled network service would include mobile stations to provide desired flexibility. These mobile stations would involve the use of two trailer trucks, one equipped as the studio and the other containing the station equipment. As this service develops as many as seven pairs of these trucks could be operational by 1980. The basic receiving and transmition equipment would be dispersed around the nation in the stations deployed for MADS.[24] Local delivery of the TV signal to the ultimate subscribers of this service would require leasing of local cable facilities as needed—or possibly use of microwave links.

86. The quality of the service envisioned would be "next to being there," with wide-screen color TV and hi-fidelity audio employed. The conferencing service would facilitate audience interaction. Because of the satellite, the rate for the services would be independent of distance, thereby providing an economical alternative to travel for users.

87. The *public* video centers would involve conferencing studios in as many as ten major cities, located in the MADS ground station buildings.[25] On the other hand, one hundred *private* video centers could be accommodated anywhere in the United States should the demand for this service develop as projected.

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[24] See *Figures* 11 and 12 at pp. 65-66 *infra*.

[25] See *Figure* 13 at p. 67 *infra*.

88. We are convinced, therefore, that the demands of contemporary society necessitate the foregoing alternate means of facilitating communications of a personal interaction nature. The market potential for such services is implicit in the inconveniences all of us experience in effectuating social intercourse in terms of time and travel. It also rests with the recognized need for expanding methodologies for instructional and informational purposes. One level of pricing arrived at in the course of structuring the business model for the MAVS services resulted in the following as reasonable estimates:

Half duplex video service	$250/hr.
Duplex video service	$500/hr.
RAN service	$2500/day base plus $400/hr.

These levels, of course, depend upon a reasonable build up of customer service demand and the manner in which cost allocations are made to this portion of the system (see note 21, *supra*).

89. As the Commission will, of course, recognize, the video service market here described is essentially characterized as a growth area. In this respect, therefore, it is difficult to forecast precisely specific future markets and the investment and technical requirements attendent thereto. Accordingly, these factors can reasonably be expected to be subject to modification as the growth pattern of these services more fully develops. For this reason, commensurate with the future market expansion of video service in terms of both demand and capability it may well, for instance, be necessary to make additional investment as well as take into account the necessity for additional or different frequencies.

IV. BASIC TECHNICAL AND OPERATIONAL DESCRIPTION

90. The basic concept developed by GE starts with recognition of the unique characteristics of satellites; the major such characteristic being the ability of a satellite to simultaneously

view a complete geographic area. This permits an entirely new approach to domestic telecommunications. Under existing conditions, a call from Los Angeles to New York via exclusively terrestrial means would, in normal course, pass through approximately ten distinct switching offices. This is shown in *Figure 1.*[26] Thus an originating call in Los Angeles would go from exchange office to the toll center, the call thereupon passed to a primary center, then to a sectional center and from there to a regional center. It would then go to the next regional center, to the sectional center, to the primary center, to the toll center, finally to the New York end office.

91. By contrast, a call via satellite is capable of going directly from the end or local exchange office of the satellite, and down to the end office of the party called. This is demonstrated in *Figure 2.* In our foregoing example, for instance, the call would go from the Los Angeles end office to the satellite and then directly to the New York City end office. By this means only one switching level is required at each end, thereby eliminating eight switching centers and the necessary expense attendent to their use.

92. This highlights, therefore, the significance of utilizing satellites in their most beneficial mode rather them employing them as mere extensions of the present terrestrial switching system. *Figure 3* represents a graphic display of the contrast in the two fundamental approaches.[27]

93. In the simplest terms the system can be described as involving a satellite, earth stations and terminals (connected with the earth stations by a local loop). As is apparent from other sections of this document, the "calls" that we contemplate from location to location would involve non-voice communications. Thus, a subscriber in Los Angeles, under the proposed system,

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[26] p. 36 *infra.*

[27] p. 38 *infra.*

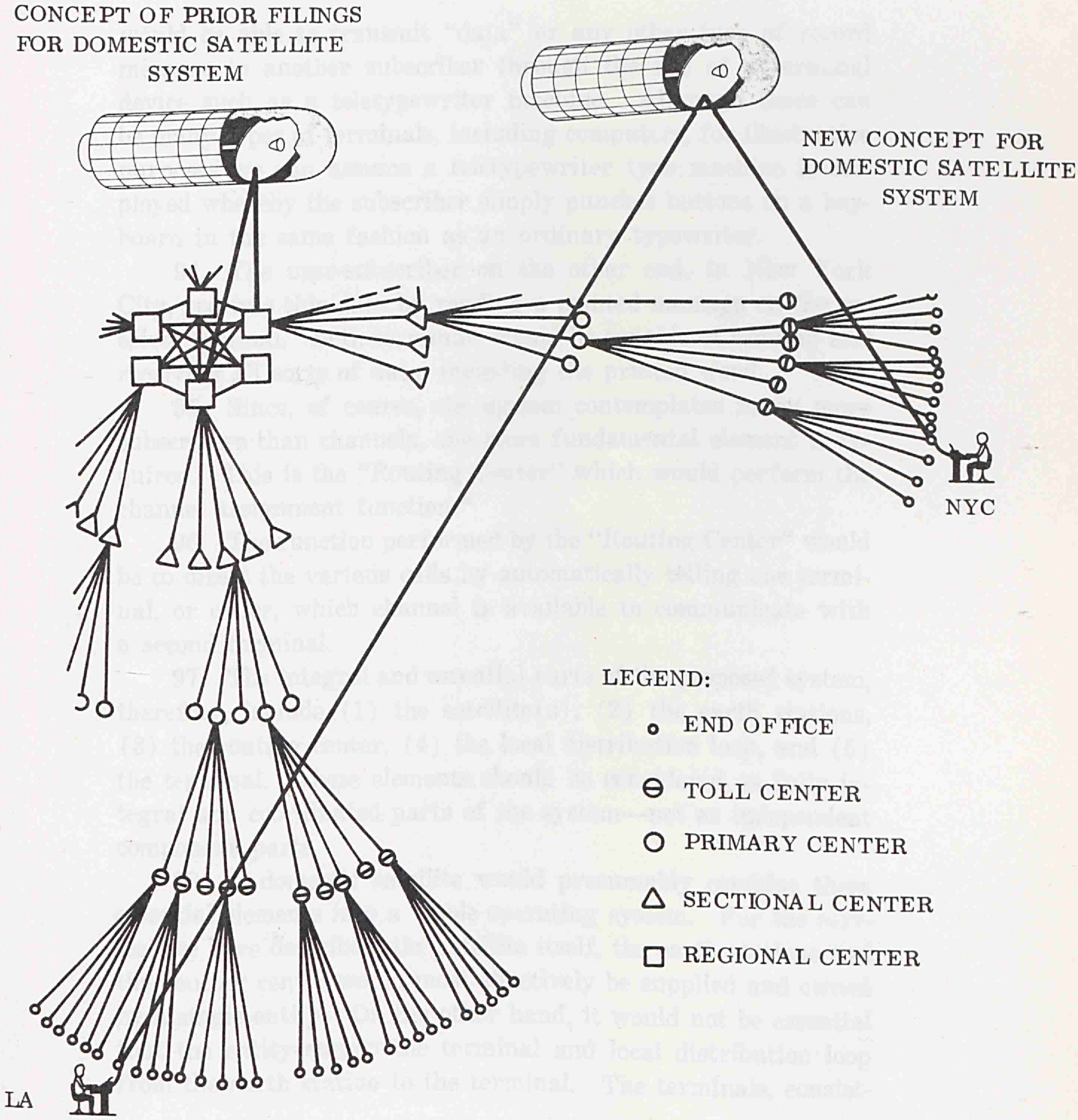

Figure 3. A Graphic Representation of the Difference Between the Prior Filings (Which Eliminate No Switching Centers) and the New Concept (Which Eliminates All Switching Centers Except the End Office)

would be able to transmit "data" or any other type of record message to another subscriber through the use of a terminal device such as a teletypewriter machine. Although there can be many types of terminals, including computers, for illustrative purposes we can assume a teletypewriter type machine is employed whereby the subscriber simply punches buttons on a keyboard in the same fashion as an ordinary typewriter.

94. The user-subscriber on the other end, in New York City, receives this data by reading a printed message on the receive terminal. Both terminals would be capable of sending and receiving all sorts of data, including the printed word.

95. Since, of course, the system contemplates many more subscribers than channels, one more fundamental element is required. This is the "Routing Center" which would perform the channel assignment function.[28]

96. The function performed by the "Routing Center" would be to direct the various calls by automatically telling one terminal, or caller, which channel is available to communicate with a second terminal.

97. The integral and essential parts of the proposed system, therefore, include (1) the satellite(s), (2) the earth stations, (3) the routing center, (4) the local distribution loop, and (5) the terminal. These elements should be considered as fully integral and coordinated parts of the system—not as independent component parts.

98. A domestic satellite would presumably combine these essential elements into a viable operating system. For the services we have described, the satellite itself, the earth stations and the routing center would most effectively be supplied and owned by a single entity. On the other hand, it would not be essential that the entity supply the terminal and local distribution loop from the earth station to the terminal. The terminals, consist-

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[28] See *Figure* 15 at p. 69 *infra*.

would be able to transmit "data" or any other type of record message to another subscriber through the use of a terminal device such as a teletypewriter machine. Although there can be many types of terminals, including computers, for illustrative purposes we can assume a teletypewriter type machine is employed whereby the subscriber simply punches buttons on a keyboard in the same fashion as an ordinary typewriter.

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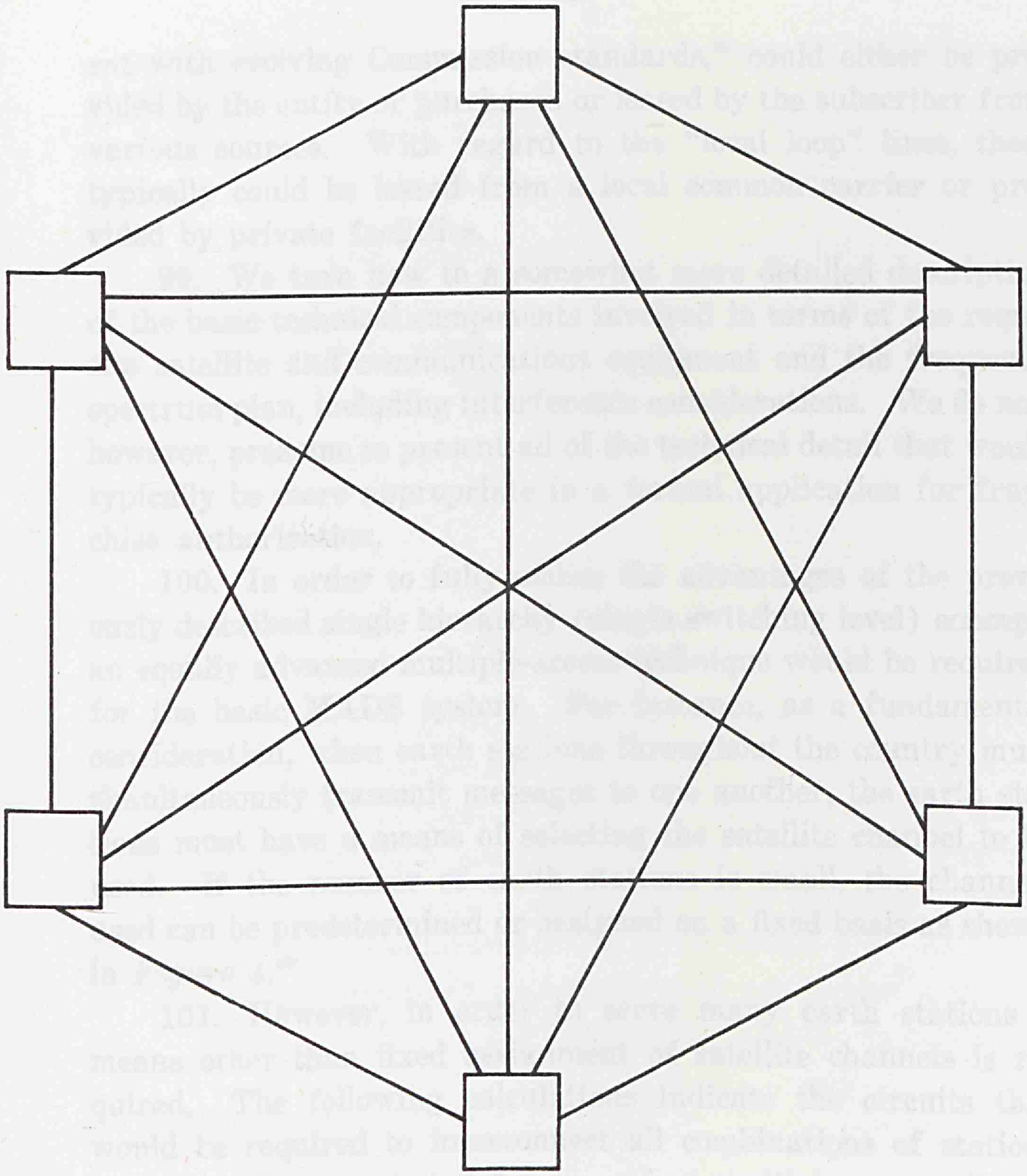
[39] See Figure 15 at p. 69 infra.



LEGEND:
☐ EARTH STATIONS
—— SATELLITE CHANNEL PERMANENTLY INTERCONNECTING TWO EARTH STATIONS

Figure 4. Diagrammatic Representation of Circuits Required to Accommodate Probable Connections Between All Earth Stations

ent with evolving Commission standards,[29] could either be provided by the entity or purchased or leased by the subscriber from various sources. With regard to the "local loop" lines, these typically could be leased from a local common carrier or provided by private facilities.

99. We turn now to a somewhat more detailed description of the basic technical components involved in terms of the requisite satellite and communications equipment and the frequency spectrum plan, including interference considerations. We do not, however, presume to present all of the technical detail that would typically be more appropriate in a formal application for franchise authorization.

100. In order to fully utilize the advantages of the previously described single hierarchy (single switching level) concept, an equally advanced multiple-access technique would be required for the basic MADS system. For instance, as a fundamental consideration, when earth stations throughout the country must simultaneously transmit messages to one another, the earth stations must have a means of selecting the satellite channel to be used. If the number of earth stations is small, the channels used can be predetermined or assigned on a fixed basis as shown in *Figure 4.*[30]

101. However, in order to serve many earth stations a means other than fixed assignment of satellite channels is required. The following calculations indicate the circuits that would be required to interconnect all combinations of stations and subscribers projected for a nominal multiple access digital service (MADS):

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[29] *In re Use of the Cartertone Device in Message Toll Telephone Service* (Carter v. AT&T. Co.), 13 FCC 2d 420, reconsideration denied, 14 FCC 2d 571 (1968).

[30] See p. 40 *supra*.

Number of possible earth station interconnections:

$$I = \frac{E(E-1)}{2}$$

I = Possible Interconnections

E = Number of earth stations

Number of circuits for all interconnections:

$$C = \frac{E(E-1)}{2} S$$

C = Total circuits required in satellites

S = Average number of subscribers at each earth station

Thus for the nominal MADS system, on a fixed assigned basis:

$$C = \frac{175\ (175-1)}{2} \times 1000$$

$$C = 15{,}225{,}000 \text{ circuits}$$

102. If we assume an RF bandwith of 1000 Hz for each circuit, the total RF bandwith required would be 15.225 GHz Since this is significantly more bandwidth than is presently available in satellite service allocations, a different approach to multiple access is clearly required.

103. If a circuit could be made available between any two earth stations at the instant required as shown in *Figure 5*, the maximum circuits required would be:

$$C' = \frac{ES}{2}$$

C′ = number of demand assigned satellite circuits required.

For the same nominal MADS case:

$$C' = \frac{175 \times 1000}{2}$$

$$C' = 87{,}500 \text{ circuits}$$

If we assume an RF bandwith of 1000 Hz for each circuit, the total bandwith required would be 87.5 MHz—less than 20% of the presently available allocation.

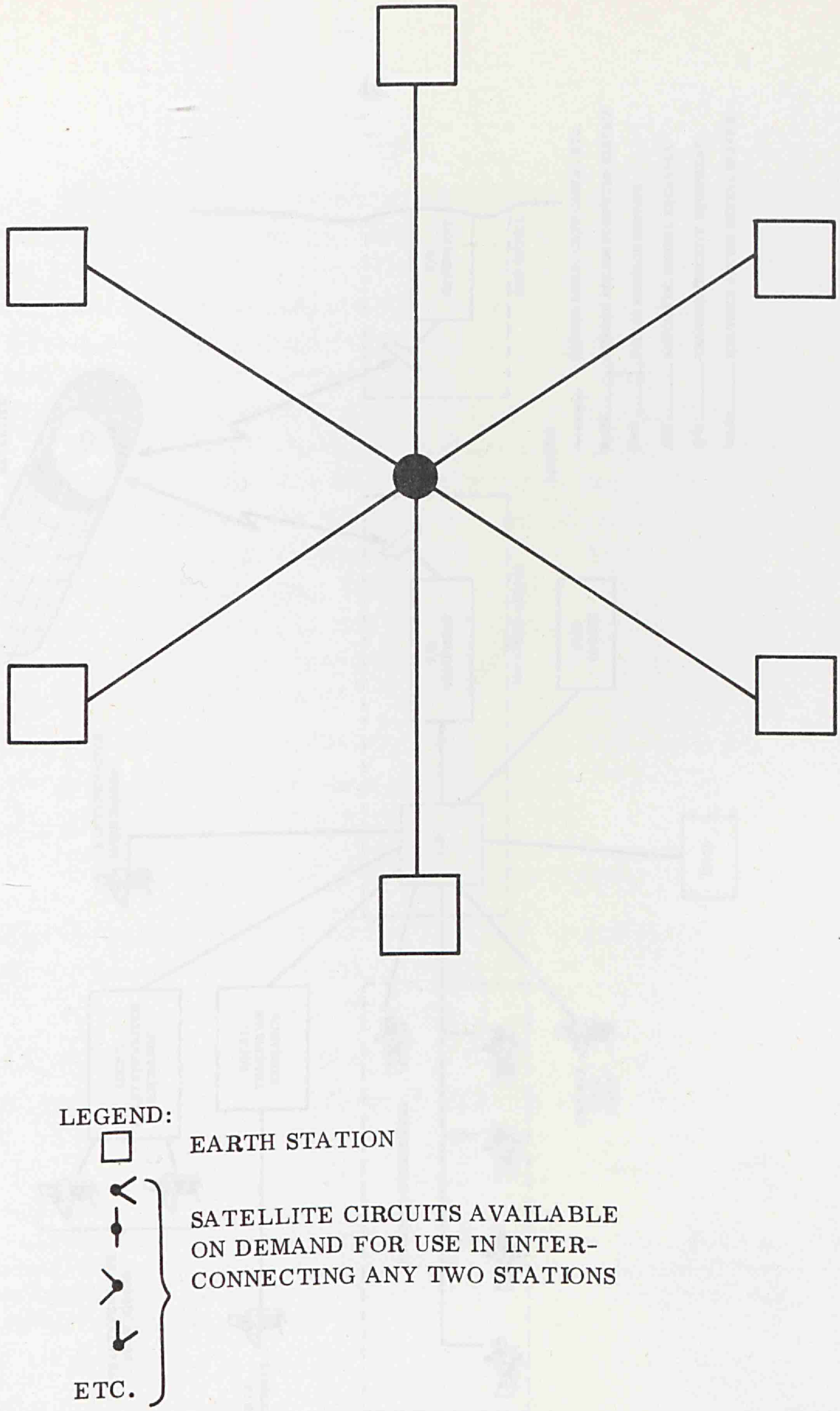

Figure 5. Any Non-Busy Circuit Can Be Used to Establish a Connection Between Any Two Earth Stations

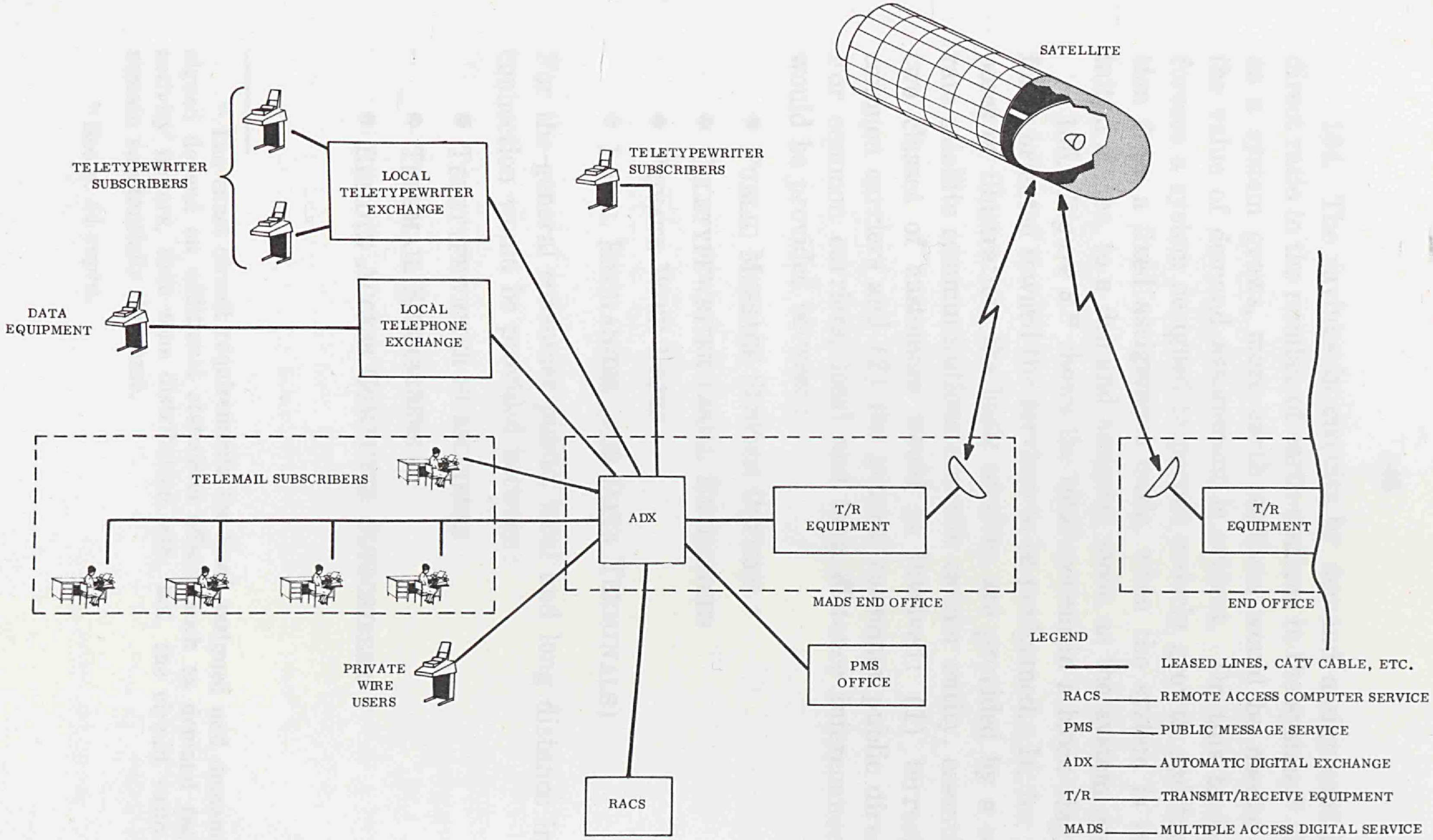

Figure 6. MADS System Block Diagram

104. The savings in circuits by demand assignment is in direct ratio to the number of earth stations in the system.[31] Thus, as a system grows, more earth stations would be needed and the value of demand assignment is evident. On this basis, we foresee a system designed to permit orderly growth and transition from a fixed assignment mode, when the system is in its initial stages, to a demand assigned mode as the system grows.

105. *Figure 6* [32] shows the total system in a block diagram form, oriented toward the services to be performed. If, for purposes of illustration, the basic services are provided by a separate satellite communications common carrier entity, essentially two classes of customers would be involved: (1) terrestrial common carriers and (2) the general consumer public directly. For common carriers, local and long distance interconnection would be provided between:

- Public Message Service Offices
- Teletypewriter Local Exchanges
- Private Wire Users
- Local Exchanges (for Data Terminals)

For the general consumer public, local and long distance interconnection would be provided between:

- Teletypewriter Subscribers
- Telemail Subscribers
- Remote Access Computer Subscribers

[31] The exact circuit requirements for fixed assigned and demand assigned depend on additional statistical effects such as demand factors, activity factors, time zone distribution, etc., but, the circuit ratio will remain substantially the same.

[32] See p. 44 *supra*.

106. In addition to the interconnection function, the following advanced service capability would be provided:

- Variable Bandwidth—On a dial up basis (within limits of the local loop connections at each end)
- Store and Forward
- Automatic Callback
- Automatic Forwarding
- Message Netting
- Multiple Address
- Automatic Format Translation

107. The MADS system to provide the above services can be characterized as Demand Assigned/Time Division Multiple Access (DA/TDMA). Thus the satellite channels would be assigned to end offices as they are needed (Demand Assigned) and the channels in the satellite generated by a time division multiple access technique (TDMA). An engineering prototype of the automatic digital exchange that enables the implementation of the DA/TDMA concept is shown in *Figure 14*.[33]

108. *Figure 7* [34] is a diagramatic representation of the time channels in the satellite. These channels would be temporarily assigned by the routing center *(Figure 8)* as needed to establish connections between stations.[35]

109. The sequence of operation in establishing a connection between two stations is shown in *Figure 9* [36] and would progress in steps as follows:

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[33] See p. 68 *infra.*

[34] See p. 48 *infra.*

[35] See p. 49 *infra.*

[36] See p. 50 *infra.*

(1) a) Los Angeles requests the routing center to designate an open (upper transponder) channel for a connection to Denver.

b) Routing Center searches its file of available (non-busy) channels and designates to Los Angeles the available channel.

(2) Routing Center informs Denver of the call and channel.

(3) Denver acknowledges.

(4) Traffic for Los Angeles/Denver is handled on the assigned channel in the upper transponder.

The routing center would simultaneously make note of the transaction and commence timing for purposes of billing determination. Upon disconnect, a similar sequence to the above would be followed.

110. The basic MADS system, therefore, would be capable of handling many connections simultaneously. In the design tentatively developed, 100,000 data users could be connected at any one instant. Moreover, the total system would have the capability of handling 1.8 million subscribers on each demand assigned (upper) transponder of the satellite. Only one demand assigned and one fixed assigned transponder would be needed to handle the projected data traffic through 1980.[37] Consequently, as noted in other sections, tremendous excess capacity could be built into the system in the form of the availability of the remaining satellite transponders. These, then, might be employed for purposes, on a lease or similar basis, quite apart from the record communications function of the main system.

Frequency Plan:

111. In order to facilitate a timely introduction of the satellite system, priority should be given to the concept of

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[37] Back up facilities would be provided in a second satellite in orbit.

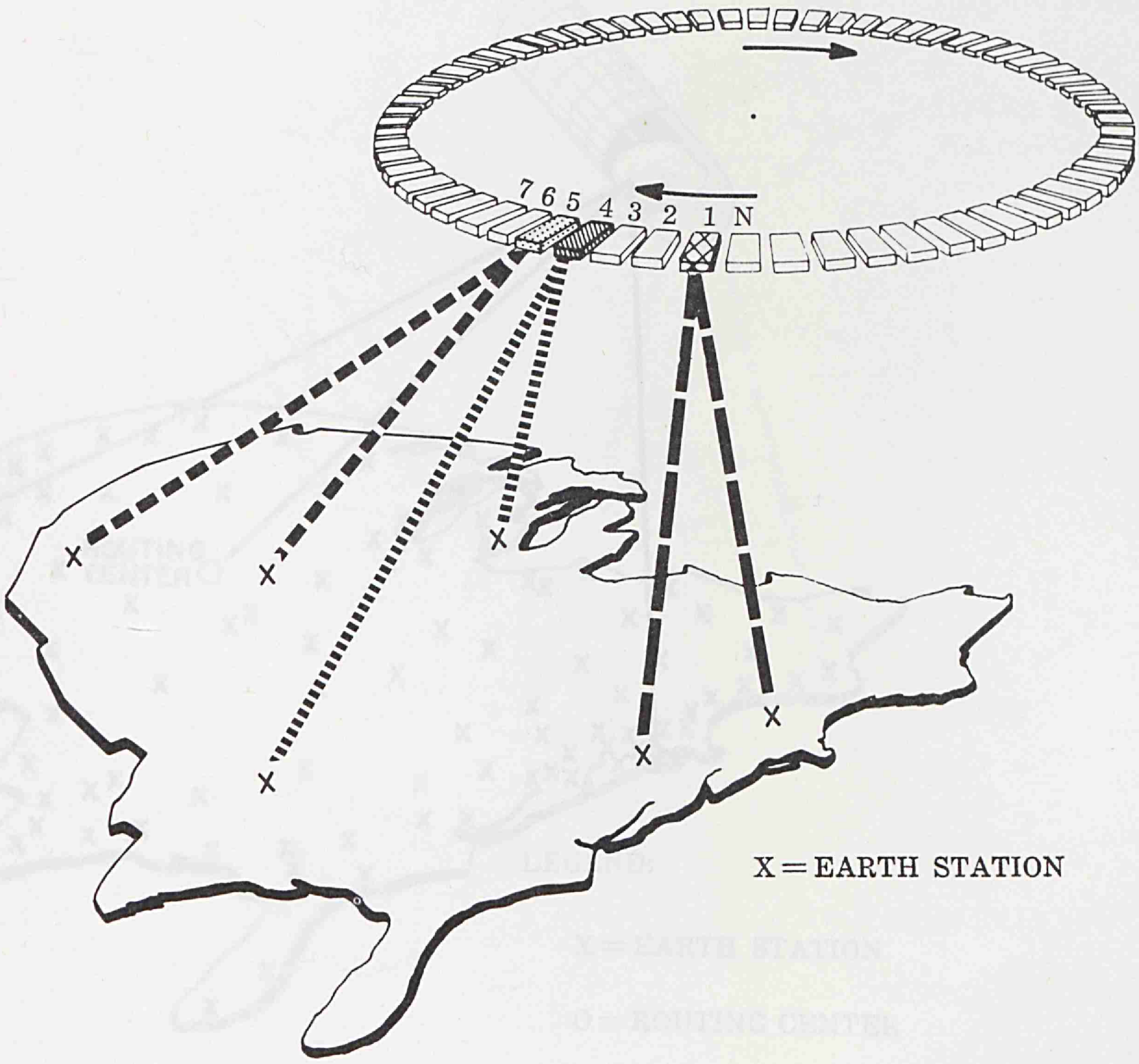


Figure 7. Time Slots (Channels) 1, 4, and 5 Have Been Temporarily Assigned to Connections Between the Earth Stations Illustrated. Channel 1 Connects New York City and Washington, D. C.; Channel 4 Connects Chicago and Dallas; and Channel 5 Connects Los Angeles and Denver

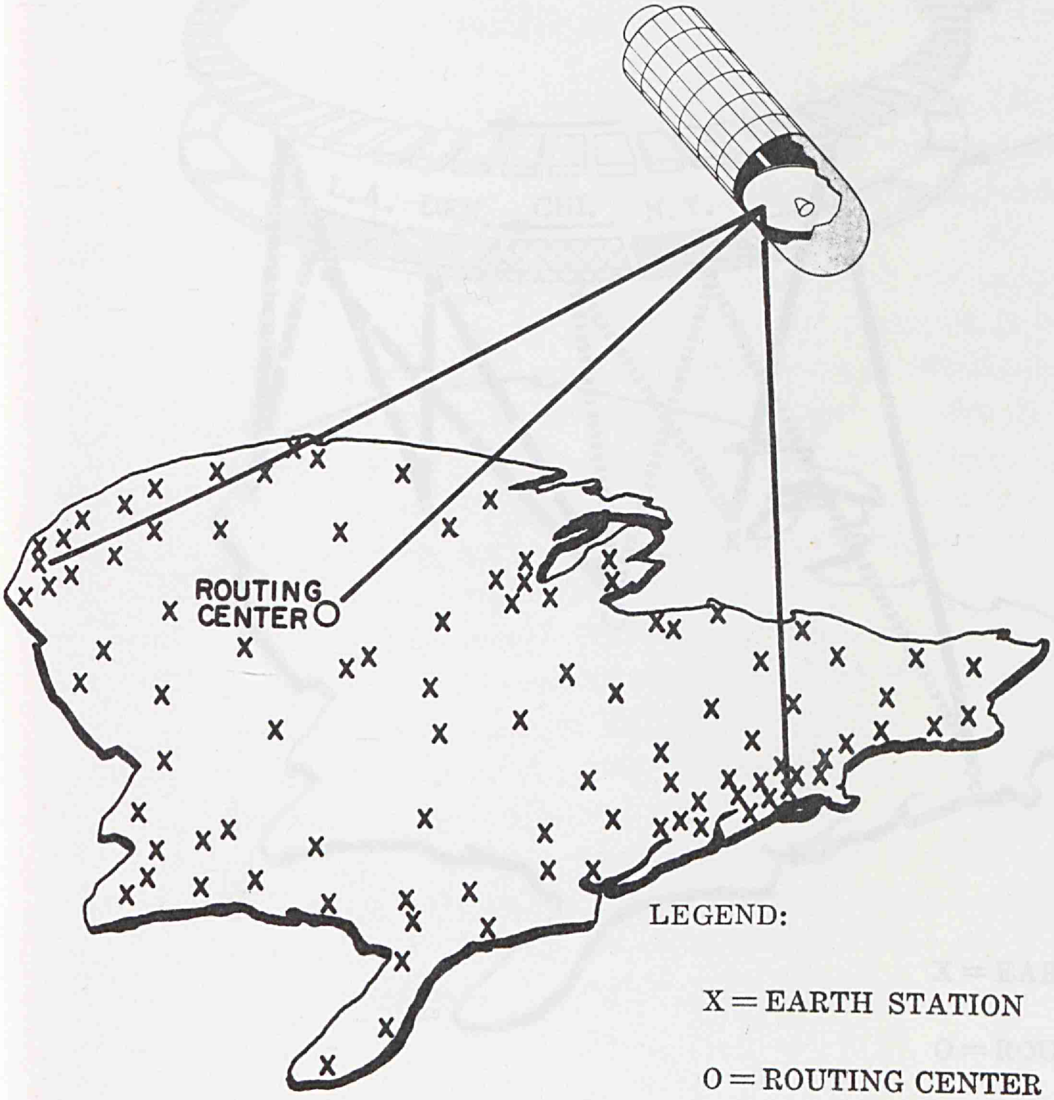


Figure 8. The Routing Center is Used By All Earth Stations as the Director of the System Traffic

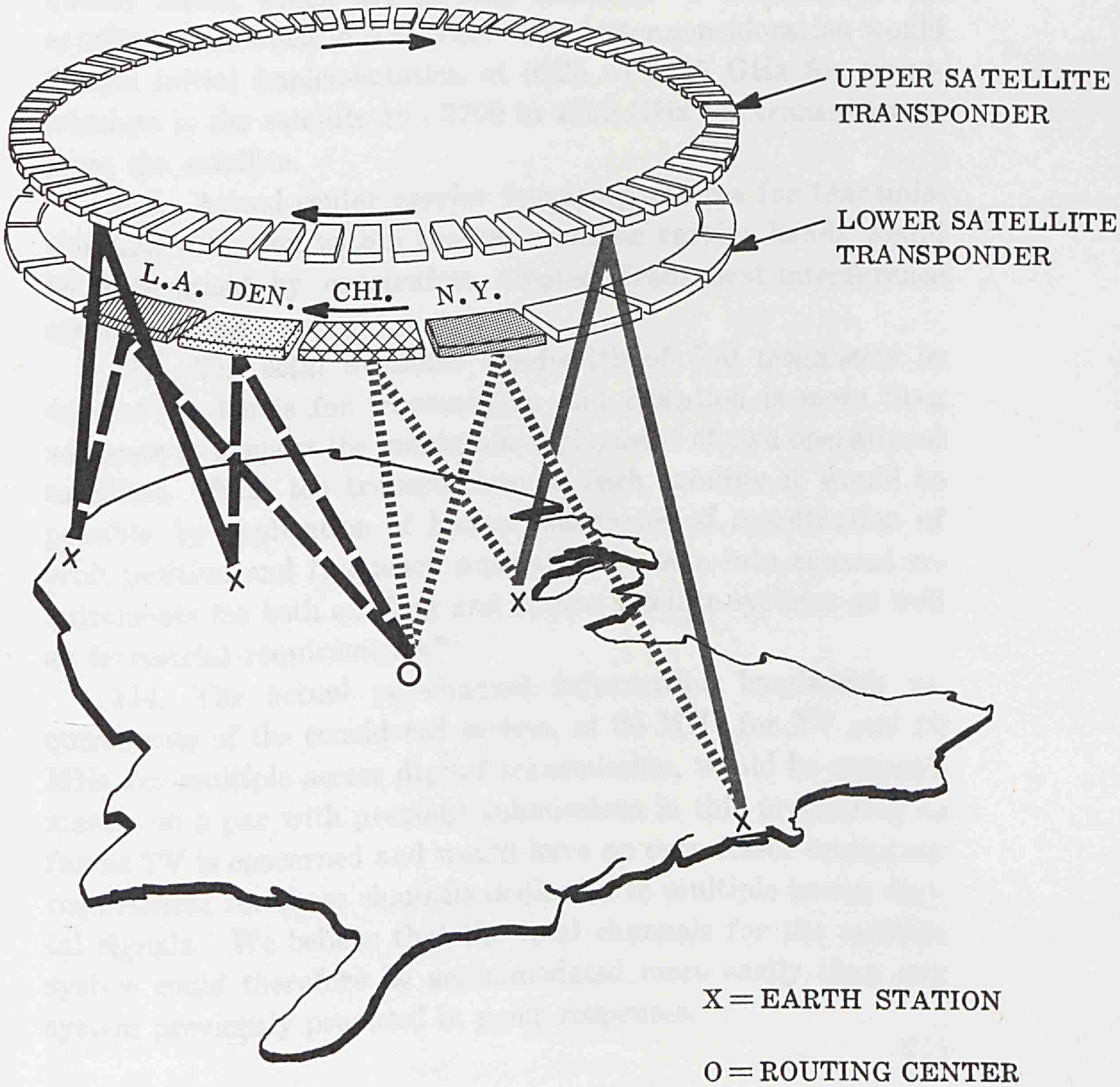


Figure 9. The Lower Transponder is Used on a Fixed Assigned Basis for Conversation Between the Earth Stations and the Routing Center. The Upper Transponder is Used On a Demand Assigned Basis For Traffic Channels Between Earth Stations

state-of-the-art, both in terms of available equipment, and frequency bands which are already allocated to common carrier satellite communications service. This latter consideration would dictate initial implementation at 5925 to 6425 GHz for transmissions to the satellite and 3700 to 4200 GHz for transmissions from the satellite.

112. Actual center carrier frequency choices for transmission and reception within the two common carrier bands would be determined by constraints created from beat-interference considerations.

113. The total available bandwidth of 500 megahertz in each of the bands for transmission and reception is more than adequate to support the maximum deployment of two operational satellites. With ten transponders on each satellite it would be possible, by application of known techniques of coordination of orbit position and frequency separation to take into account requirements for both existing and future satellite systems as well as terrestrial requirements.[38]

114. The actual per-channel information bandwidth requirements of the considered system, at 36 MHz for TV and 20 MHz for multiple access digital transmission, would be approximately on a par with previous submissions in this proceeding as far as TV is concerned and would have an even lesser occupancy requirement for those channels dedicated to multiple access digital signals. We believe that the total channels for the satellite system could therefore be accommodated more easily than any system previously proposed in prior responses.

[38] It must, of course, be reemphasized that certain of the projected services fall within what are essentially growth areas. As such, technical requirements must be subject to the growth and flucuation of specific future markets in terms of the potential necessity for additional or different frequencies as well as additional investment (see para. 89 *supra*).

Interference Considerations:

115. Since immediate implementation plans may preclude consideration of the use of other than the 6 and 4 GHz common carrier frequency assignments, consideration must be given to the problem of coordination with other users in their spectrum area. The other principal users include other satellite systems and terrestrial common carrier microwave users.

116. Other satellite systems at the present time have made no extensive usage of western synchronous equatorial orbit positions which are propitious to domestic coverage of the United States. It is anticipated, however, that eventually these orbit spaces may become a matter of increasing requirement. In order to be certain that efficient space utilization is not precluded, the proposed system should be designed to work effectively from thirty-foot antennas whose beam widths are of the order of three tenths degree. While the actual interference between channels of satellites which are adjacent to one another in orbit is a complex function of radio equipment detection, modulation and other characteristics, previous studies have shown that 30 foot antennas would make the limiting conditions appear in other portions of the system. Consequently, holding antenna diameter to 30 feet should substantially lessen interference between adjacent satellites.

117. The mutual interference problem between satellites and terrestrial facilities is more real, as compared to between satellite systems, in the sense that disruption of actual important existing communications services is involved rather than just a matter of the possible inefficient utilization of natural resources. Much attention has been given to this problem in prior submissions and the potential problems appear to fall into two classes for each of the frequency bands involved.

6 GHz (a) Interference from terrestrial microwave to the satellite receiver.

(b) Interference from the satellite earth station to common carrier terrestrial microwave receiver

4 GHz (a) Interference from the satellite to the terrestrial microwave receiver.

(b) Interference from terrestrial microwave to the satellite earth station receiver.

118. Of these four problems there are two that can be held to inconsequential levels by easily controlled system parameters. First, at 6 GHz the power levels of terrestrial microwave stations, being of the order of 50 dBW EIRP and having a look angle of 30 degrees or more off beam to the satellite, arrive at the satellite at levels in the vicinity of 60 dB below the transmission from the earth station and hence cannot cause interference regardless of quantity.

119. Second, a standard of

$$\left(-152 + \frac{\theta}{15}\right)\frac{\mathrm{dBW}}{\mathrm{m}^2}$$

per 4 KHz of bandwidth has been suggested as the level at which satellite transmission will not create interference with terrestrial systems. The system we have in mind would be equipped for spectrum spreading under absence of modulation to insure that the acceptable level would be maintained at all times. Calculations indicate that the system would not exceed this allowable interference level.

120. The more serious problem of interference to and from satellite earth stations and terrestrial microwave installations can be solved by proper choice of sites but the engineering aspects of these requirements are not as well defined as the satellite to earth facilities case. In order to avoid the local loop transmission expense of excessively remote sites certain new techniques would have to be evaluated. For example in the case of 6 GHz interference from the satellite earth station to terrestrial microwave receivers, by siting the satellite earth station so that it points away from the microwave station, distances of 5 to 10 miles are required with an unshielded antenna. By

locating the earth station in a natural depression, or placing it in a suitable excavation, it may be possible to reduce these distances 2:1 or 3:1 as long as the two beam paths share no common volume in space conducive to rain scatter propagation.

121. Common beam volume rain scatter propagation is a mechanism which also contributes uncertainty as to the required spacing to avoid the last mode of interference, that at the satellite earth station receiver due to terrestrial microwave beams. It appears that the best solution to this problem, as well as the problem of simply being in the microwave beam path, would be to use the computer search method presently used for siting terrestrial microwave. From a data base of all FCC licenses it has been possible to program system gains and azimuths so that the level of interference can be calculated for any known geographical position from all possible sources. This program can be extended to allow common volume predictions to be applicable to the satellite earth station case.

122. In conclusion then, it appears feasible to anticipate and devise suitable solutions so that satellite systems and terrestrial microwave can share the same frequency bands. The elegance of the solution will determine only the economy of the implementation of the system.

System Reliability:

123. The problem of over-all system reliability is really best handled by considering it in two parts, the earth segment and the space segment. In the case of the earth segment a much greater latitude of alternatives is available to insure a reliable system.

124. The available procedures include the ultimate of 100% redundancy with combiners, down through redundant hot or cold standby, switched or alarmed module replacement by operator or service personnel, and even substitution of a complete mobile station for an earth station which has been subject to catastrophic destruction.

125. It is anticipated that the earth stations could be largely unattended and that, while redundancy would be provided at each station for critical elements of the equipment, the prime control on reliability would be an automatic alarm/control routine programmed at the routing center. This alarm/control system could constantly check each station in sequence for a set of major and minor alarms indicating the need for immediate service to prevent or limit outages or routine maintenance to eliminate incipient degradation of the system. This plan is similar to the method used on large commercial microwave systems and the AT&T TD-2 stations in that while they are unattended, personnel make routine inspections and planned replacements, and are also nearby in the event a quick response to a major alarm is required.

126. The space segment can achieve an extraordinarily high degree of reliability through three basic approaches, simplified hardware design with the utmost reliability in components, redundant equipment modules at each critical area of the subsystem, and finally a full backup satellite in orbit.

127. Just as in the earth system, the operational satellite would be monitored at strategic points from information telemetered to the routing center. Decisions would be made on a basis of alarms whether to energize or de-energize the various redundant elements of the total satellite system. In the event of a catastrophic failure, the operational satellite, or portions of it, could be de-energized and the whole traffic or portions of it transferred to the previously de-energized but now energized stand-by satellite. Dual feeds in the ground station would allow total system operation from either satellite without the time consuming effort of antenna pointing.

128. Provisions furthermore should be made to replace the orbiting satellites at regular intervals based upon a conservative estimate of their meantime-to-failure so that a continuing high level of reliability would be maintained for the satellite segment of the system at all times.

Satellite Communication System and Equipment:

129. The following material sets forth in outline fashion additional considerations relative to the technical characteristics of the satellite and communication equipment that might be employed in a system as envisioned. In this respect, a hardware design approach is suggested which could deliberately be kept conservative by using:

(1) Allocated frequency bands
(2) Existing satellite technology
(3) Existing earth station technology

Additionally, digital techniques could be used wherever practical to take advantage of:

(1) Present and future reductions in cost through large scale integration
(2) The amenability of digital techniques to data transmission
(3) Flexibility in implementation by modular digital elements

By adhering to the above philosophy, the system:

(1) Would have no basic technology problems
(2) Would be based on design rather than development, and
(3) Operation would be paced by time to design, fabricate and launch.

Table 6 summarises the technical requirements and status of illustrative system components.

TABLE 6

TECHNICAL REQUIREMENTS AND STATUS

Components	Status	Comments
SATELLITE		
0.2° Attitude System	Similar to Intelsat II	
Spin Stabilized	Similar to Intelsat II	
10WRF Transponders 2 Data 8 Linear-Frequency	Similar to Intelsat IV	
U. S. Coverage	2.8′ Dia. Reflector	
4/6 GHz Band	Common Carrier Band	Sharing
ROUTING CENTER		
Satellite Control Equipment	Similar to NASA and Comsat Designs	
Channel Routing Equipment	GE/ADX Plus Digital Computer	
Software	New	Long Lead Item
GROUND STATION		
30′ Antenna	Commercial Equipment	
RF Eqpt 4/6 GHz	Commercial Equipment	
ADX	GE/ADX	
TV XMT/RCV	Commercial Equipment	

130. The satellites could typically be dual-body spin-stabilized configurations utilizing a despun reflector to obtain U. S. coverage. The specific configuration tentatively selected would minimize the cost per year per transponder and the initial investment. *Table* 7 details the trade-offs.

131. The satellites considered are either in development or scheduled for completion during a reasonably expected deployment period of the system. Projected life of the satellites would be above 5 years and would employ redundancy of critical subsystems to obtain the design objective of a service continuity of 99.99%. The specific satellite selected for illustrative purposes is model MK IIIA which is further detailed in *Table* 8. The system would utilize a minimum of 2 satellites in synchronous orbit to provide the required redundancy. *Table* 9 details the satellite communication capacity.

132. With respect to critical system parameters, certain relevant general system details, leading to possible system link calculations, are shown in *Table* 10. These link calculations are, in turn, depicted in *Table* 11. *Figures* 10 through 16 outline other pertinent system components.

TABLE 7

SUMMARY OF SATELLITE CHARACTERISTICS AND COST

		Transponders					Satellite Unit Costs		10 Year Base		Initial Investment Base		
Model Number	Similar to	MADS Digital 10W 20 MHz (B_{1t})	TV FM or 4∅-PSK 10W 36 MHz (B_{1t})	TV FM HI-PWR 25W 35 MHz (B_{1t})	DC Buss Power, Satellite, Watts	Total Occupied Bandwidth, MHz	Development $ x 10^6	Flight Units $ x 10^6 (Including Boost)	Hot Flight Units Cold Flight Units	Total Cost $ x 10^6	Hot Flight Units Cold Flight Units	Total Cost	First Cost per Year per Transponder $ x 10^6
MK I	Intelsat III ½	2			100	50	8.5	8.0	2 2	40.5	1 1	24.5	2.45
MK II	Intelsat IV	2		5	495	350	21.5	14.5	4 2	108.5	2 1	65.0	0.93
MK IIA	Intelsat IV	2	10		420	500	21.5	14.5	4 2	108.5	1 1	51.0	0.85
MK III	—			4	360	180	15.0	11.0	6 2	103.0	3 1	59.0	0.98
MK IIIA	—	2	8		360	410	15.0	11.0	2 2	59.0	1 1	37.0	0.74
MK IV	—	2		8	760	400	31.0	25.0	2 2	131.0	1 1	81.0	1.62
MK IVA	—	2	12		520	(590)	31.0	25.0	2 2	131.0	1 1	81.0	1.16
MK IVB	—	20			700	500	31.0	25.0	2 2	131.0	1 1	81.0	0.81

TABLE 8

PRELIMINARY DETAILS OF THE MK IIIA SATELLITE

ITEM	DESCRIPTION
Launch Vehicle	Thor—Delta or Equal
Orbit Position	Approximately 100° W
Attitude Stability	± 0.2°
Station Keeping	± 0.1°
Orbit Inclination	± 0.1°
Power Source	Storage Batteries with Solar Array.
Antenna	7½° Beam for Continental U. S. Coverage. Circular Polarization to Reduce Faraday Rotation Losses
Transponders	See Table 9 For Characteristics.
Useful Life	5 Years or Greater

TABLE 9

SATELLITE COMMUNICATION CAPACITY

No. of Transponders	RF Power / Satellite EIRP	Usable Bandwidth	Basic Capability per Transponder	Capacity Total Satellite
2	10 W / 33.8dBW	20 MHz	20 Megabit Digital Stream	● Fixed Assigned, 200,000 subscribers, ● Demand Assigned, 1.8 million Subscribers.
8	10 W / 33.8dBW	36 MHz	(1) FM TV or (1) 4ø PSK TV	(8) TV channels or equivalent

TABLE 10

GENERAL SYSTEM PARAMETERS

ITEM	DESCRIPTION
Earth Station Antenna	30 Foot Diameter Gain: 4 GHz-49 dB 6 GHz-52.5 dB
Satellite Antenna	7.5° Beam Gain 26.8 dB (Beam Center)
TV Baseband	4.5 MHz (Includes audio channel and spreading allowance)
Digital Rates	Data: 20 Mb/s 8 BIT TV: 72 Mb/s
Predetection IF Bandwidth	FM TV: 36 MHz Digital TV: 36 MHz With 4ø PSK Data: 20 MHz With 2ø PSK
Satellite RF Power	10 Watts at Antenna Port
Space Loss	6 GHz: 200 dB 4 GHz: 196.4 dB

TABLE 11

LINK CALCULATIONS

PARAMETER	VALUE		
DOWN LINK 4 GHz			
P_o per channel	10.0 dBW		
Satellite Antenna Gain	26.8 dB		
Off-axis loss allocation	–3.0 dB		
EIRP	33.8 dBW		
Earth Station Antenna Gain	49.0 dB		
Path Loss (Dry Atmosphere)	196.4 dB		
T_r (200° K) Earth Station	23.0 dB		
G/T	26.0 dB/°K		
Received Carrier Level	–113.6 dBW		
	FM - TV	DIGITAL TV	DIGITAL DATA
Receiver Noise Level—dBW	–129.6	–129.6	–131.6
Received Carrier Level—dBW	–113.6	–113.6	–113.6
C/N Ratio —dB	16	16	18
Threshold—dB	14	12	9
Bit Error Rate	—	10^{-12}	10^{-14}
S/N—dB	47.9*	55.0*	—

UP LINK 6 GH$_z$	TV	DATA
Required C/N**	25dB	25 dB
T_r (870°K) Satellite	29.4 dB	29.4 dB
Satellite Antenna Gain	23.8 dB	23.8 dB
G/T	– 5.6 dB/°K	– 5.6 dB/°K
Receiver Noise Level	–123.2 dBW	–125.2 dBW
Received Carrier Level	– 98.2 dBW	–100.2 dBW
Path Loss	200.0 dB	200.0 dB
EIRP (Earth Station)	77.8 dBW	75.8 dBW
Earth Station Antenna Gain	52.5 dB	52.5 dB
P_o Earth Station	25.3 dBW	23.3 dBW
	339 W	214 W

* Unweighted

** Set at 7dB over down-link value for Data and at 9 dB over down-link value for TV to assure system independence from up-link.

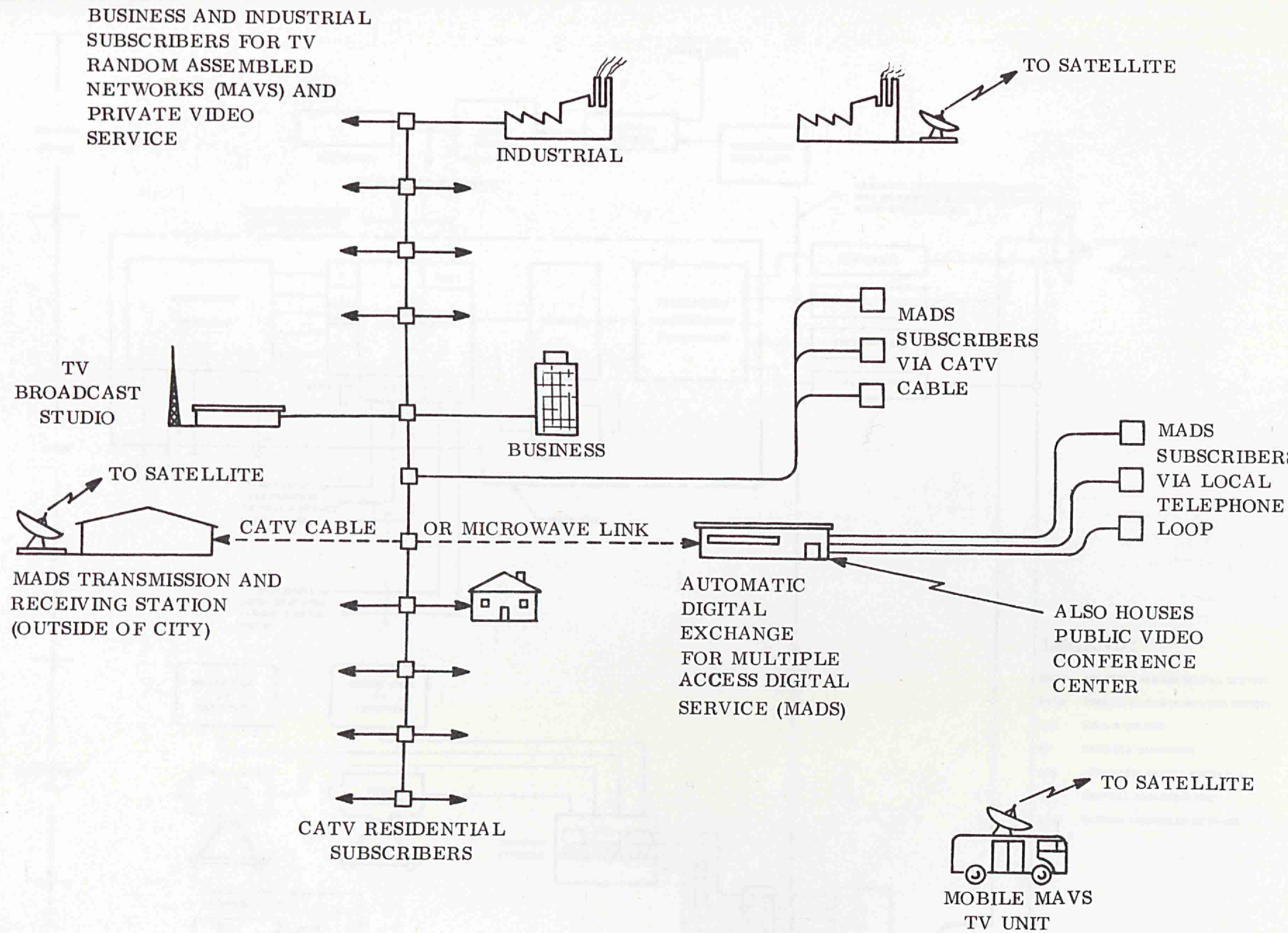


Figure 10. Configuration of Multi-Access Video Service (MAVS) and Multiple Access Digital Service (MADS) Combined Via CATV Cable to Provide Maximum Accessibility and Flexibility By All Users

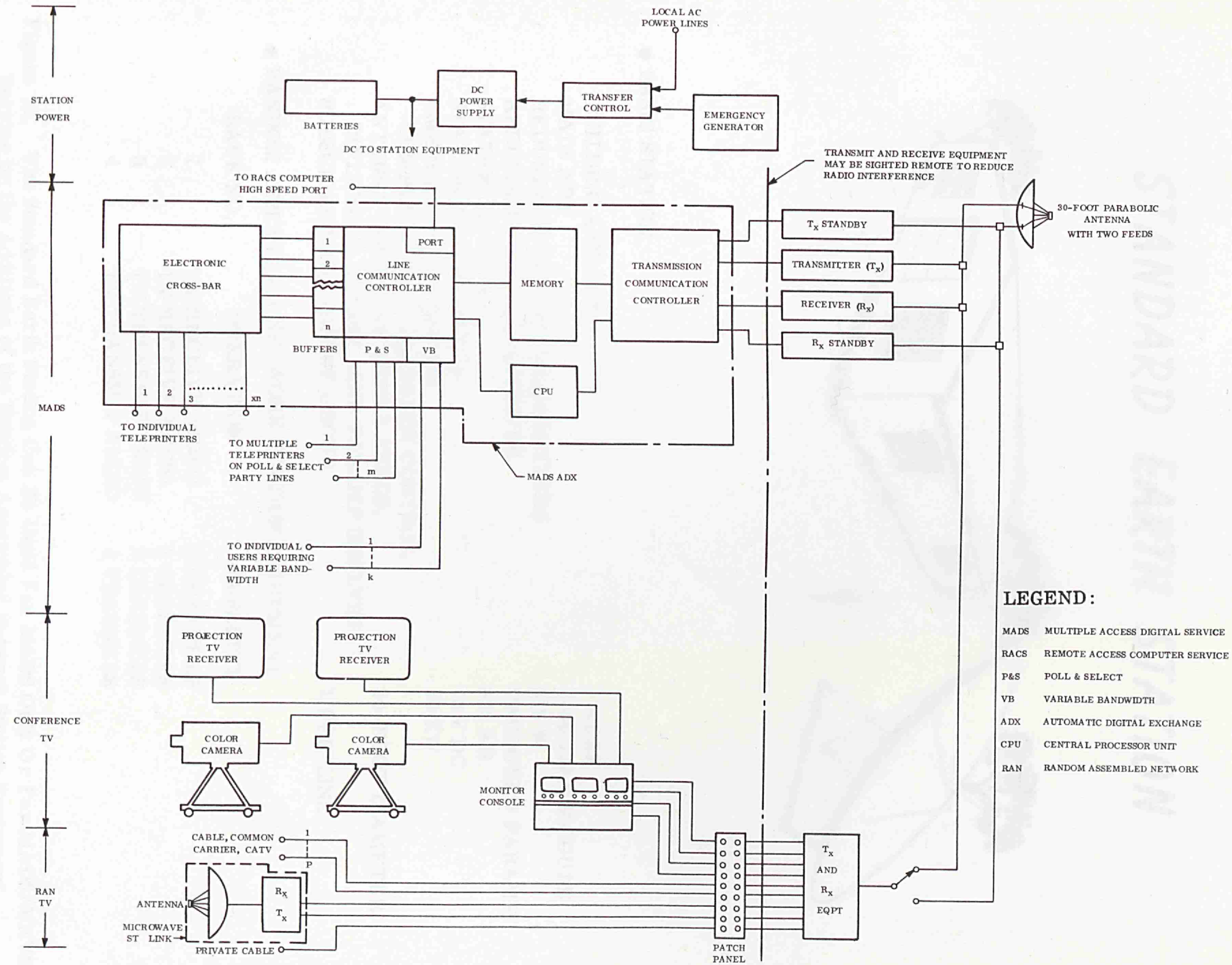
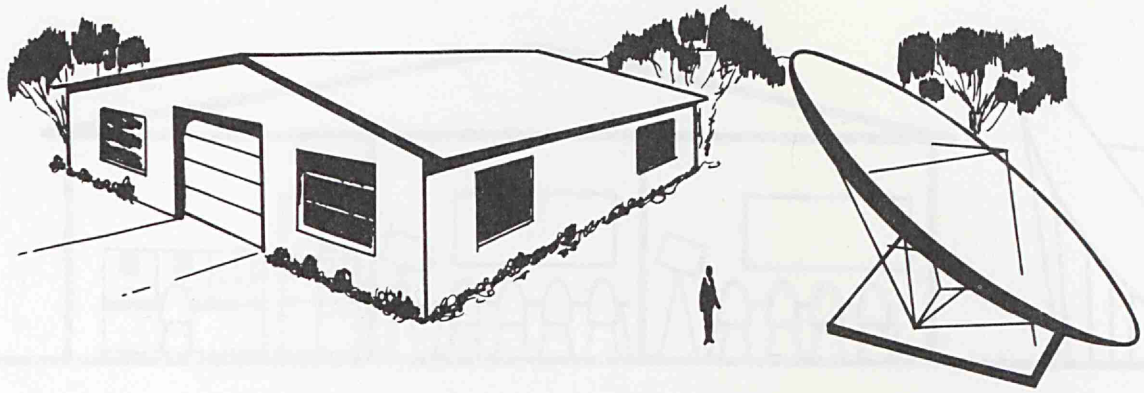


Figure 11. Fixed Service Earth Station Block Diagram Showing Equipment For All Services

STANDARD EARTH STATION



- BASIC STATION

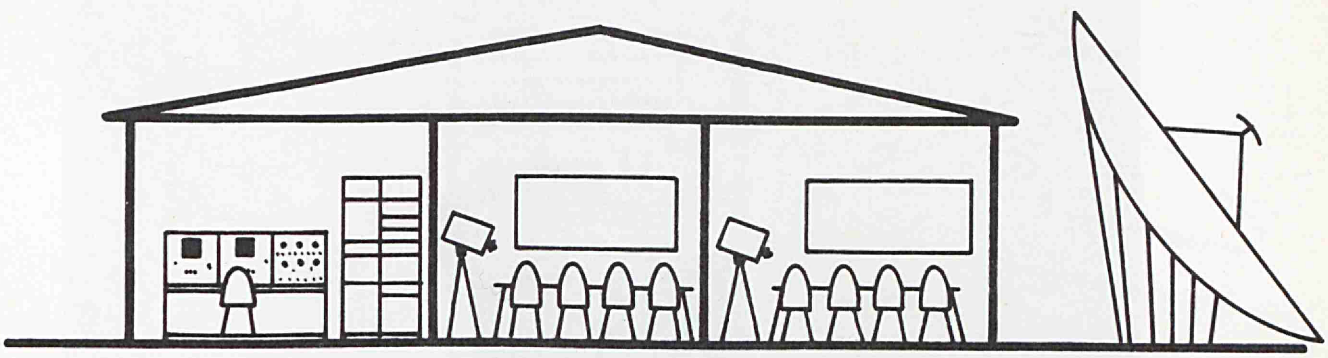
BUILDING AND LAND	1 ACRE
MADS ADX	1000 LINE MODULE
REDUNDANT DIGITAL TRANSMITTERS	215 W
REDUNDANT DIGITAL RECEIVER	UNCOOLED PARAMP
STATION BATTERIES	833 AH
STATION POWER SUPPLY	48 V DC
EMERGENCY GENERATOR COMPLETE WITH TRANSFER CONTROL	10 KW
ANTENNA COMPLETE WITH 2 FEEDS, DIPLEXERS, MOUNT, AND PARAMP SHELVES	30-FOOT DIAMETER
SUBSCRIBER ADX OFFICE GROUP	1 PER LINE

- RANDOM ASSEMBLED NETWORK STATION EQUIPMENT

RACK NO.	OPERATION	CAPACITY
1	TV RECEIVE VIDEO	2 CHANNELS
2	TV RECEIVE AUDIO	3 CHANNELS
3	TV TRANSMIT VIDEO	2 CHANNELS
4	TV TRANSMIT AUDIO	4 CHANNELS

Figure 12. The Standard Earth Station Can Be Used For MADS Only Or For MADS/MAVS Service by the Additions of the Random Assembled Network Station Equipment

MULTIPLE ACCESS VIDEO CONFERENCING STUDIO



DESCRIPTION:

- STUDIO WITH TWO CONFERENCE ROOMS
- LOCATED IN EARTH STATION BUILDING

  2.2 ACRES OF LAND
  30-FOOT ANTENNA
  TV STUDIO EQUIPMENT
  TV XMT/RCV EQUIPMENT
  AUTOMATIC DIGITAL EXCHANGE

- MODULAR

  RF
  ADX MEMORY
  SUBSCRIBER ADX OFFICE

Figure 13. The Maximum Station Configuration Provides Conference Center For Location in Major Cities

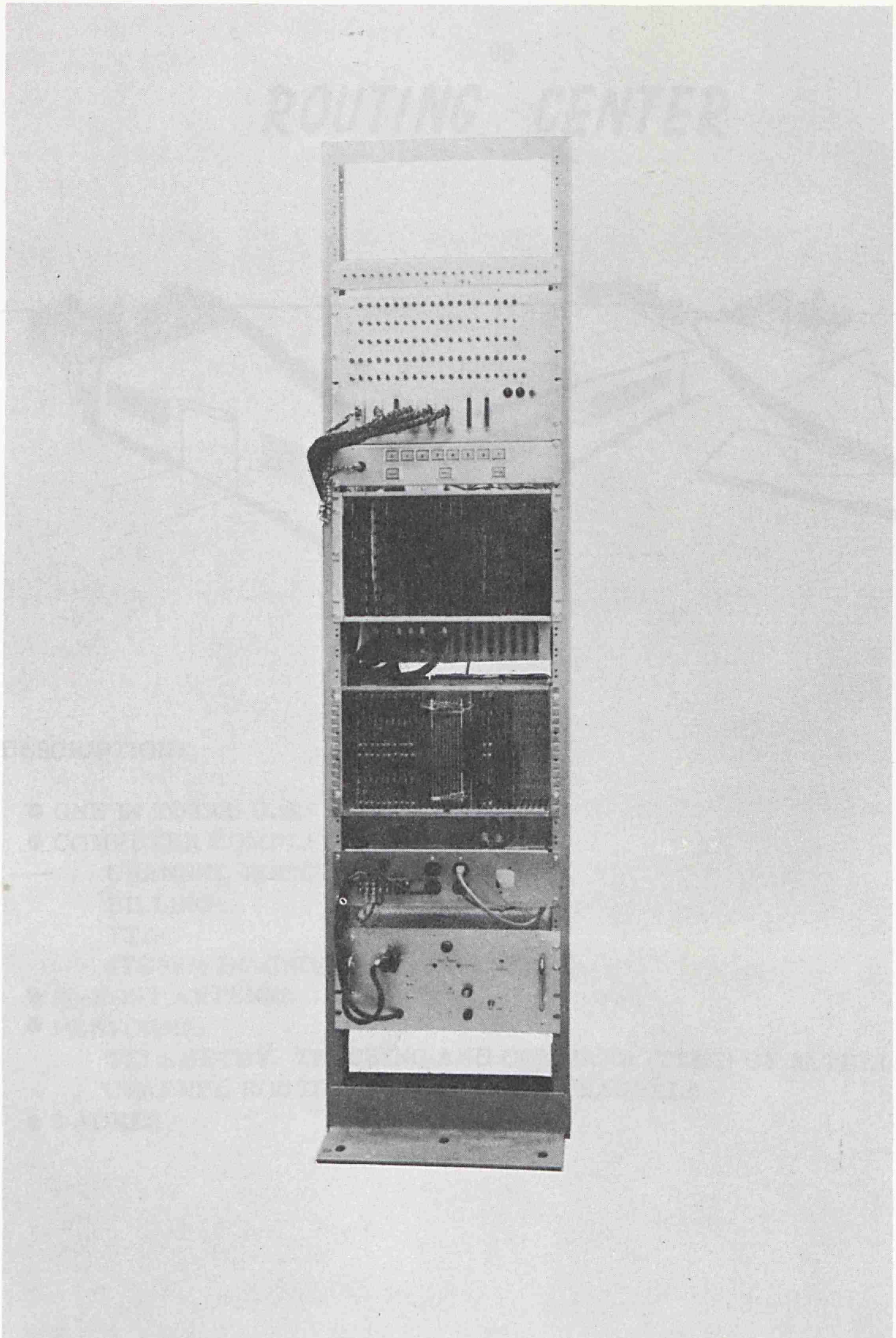
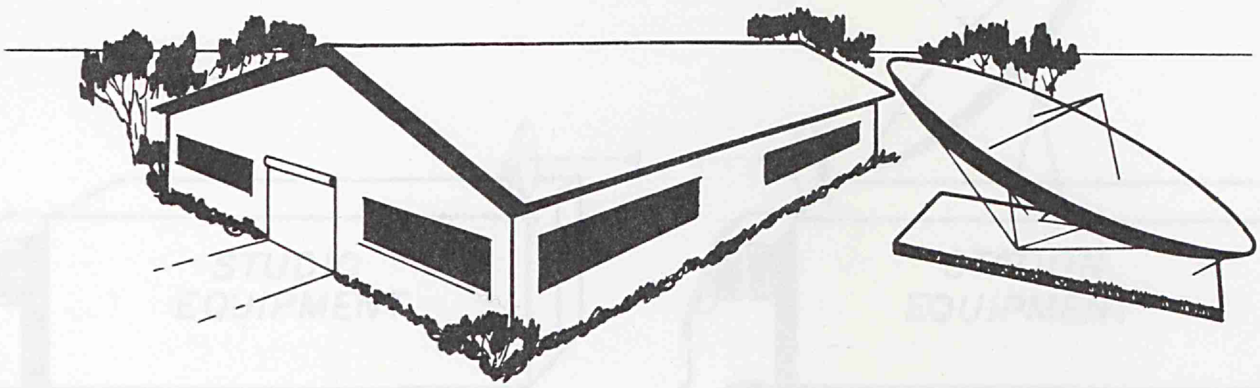


Figure 14. Multiple Access Digital Service (MADS) Automatic Digital Exchange (ADX) Development Unit

ROUTING CENTER

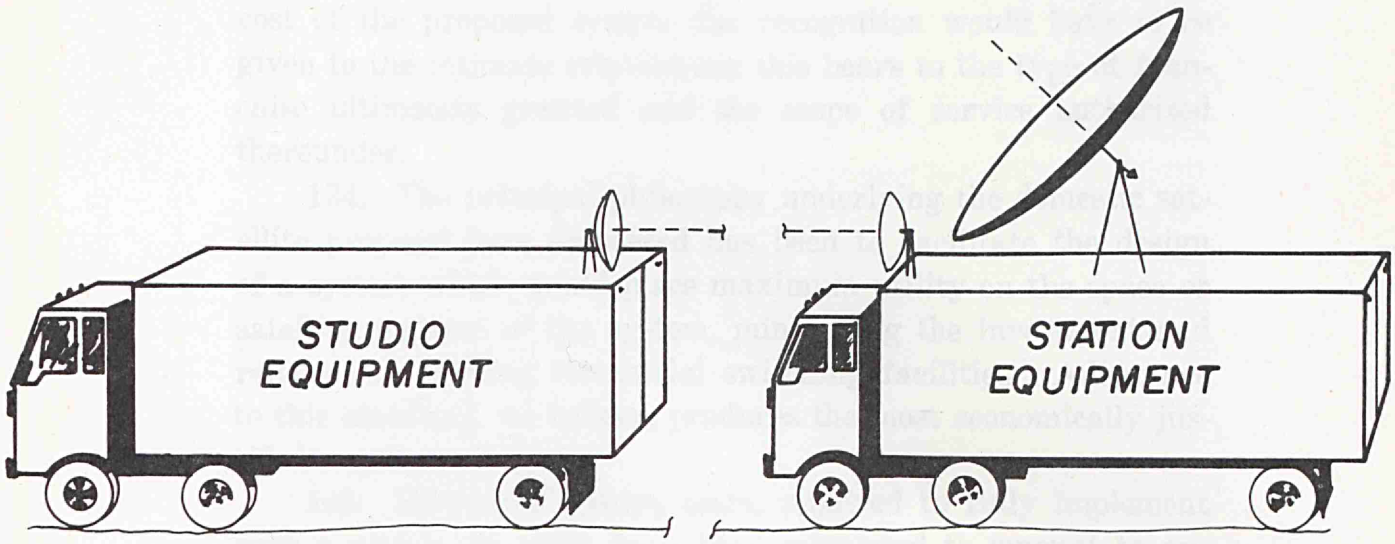


DESCRIPTION:

- ONE IN TOTAL U.S.
- COMPUTER COMPLEX FOR:
  - CHANNEL ROUTING
  - BILLING
  - TT&C
  - SYSTEM DIAGNOSTIC MAINTENANCE
- 30-FOOT ANTENNA
- PERFORMS:
  - TELEMETRY, TRACKING AND COMMAND (TT&C) OF SATELLITE
  - CHANNEL ROUTING FOR MESSAGE CHANNELS
- 2 ACRES

Figure 15. Routing of MADS Channels Plus the TT&C Function Are Both Provided By the Routing Center

MOBILE ACCESS VIDEO STATION



DESCRIPTION:

- ONE TRAILER TRUCK INCLUDING GROUND STATION AND ANTENNA.
- ONE TRAILER TRUCK VIDEO STUDIO EQUIPMENT AND STL LINK.
- EMERGENCY MADS FACILITY IN STATION TRUCK

Figure 16. Mobile Access Video Station

System Cost:

133. In approaching the question of the projected dollar cost of the proposed system due recognition would have to be given to the intimate relationship this bears to the type of franchise ultimately granted and the scope of service authorized thereunder.

134. The principal philosophy underlying the domestic satellite proposal here presented has been to facilitate the design of a system which would place maximum utility on the space or satellite segment of the system, minimizing the investment and reliance on existing terrestrial switching facilities. Adherence to this standard, we believe, produces the most economically justifiable system.

135. Estimated system costs, required to fully implement such a system by 1980, have been calculated to amount to approximately $321 million. As the cost breakdown in *Table 12* reflects, included are such items as the initial research and development cost of both satellite and earth facilities, as well as the continuing research and development costs that would necessarily be expended through 1980.

136. Provision has been made in these estimates for the procurement of five satellites and boosters. This calculation is based on an assumed satellite life of five years with projected expansion of need for transponders to serve MAVS in 1980. Accordingly, at any one time only two satellites would necessarily be operational. The largest single item of investment would be the earth facilities, amounting to approximately $140 million. The latter figure would include the investment in 175 earth stations, one routing center and other administrative facilities. Also included are estimates for land, building and associated electronic equipment.

137. *Table 13* herein takes into account the required investment in terms of personnel. For instance, it is estimated that approximately 4700 people would be required in 1980 to achieve full operational capability. At the time of the initial satellite launch, it is estimated that the venture would engage 1300 people.

138. The system costs and personnel requirements described were estimated by using established cost accounting methods. Briefly, the system costs were developed by examining the cost elements of each system function. Similarly, personnel estimates were developed through a determination of system operational requirements. To further develop confidence in these estimates, the results were weighed against existing common carrier operating statistics available through Commission reports and other published financial data. In this respect, the estimated cost structure developed reflects actual operating practice.

TABLE 12

MADS/MAVS/LEASE—SUMMARY OF INVESTMENT AT 1980

	Total First Cost	% Total
R & D—Total	$ 95.2	29.6
Satellite & Booster	55.0	17.1
Central Admin. Bldg.	10.6	3.3
Ground Station—Land, Bldg, Furniture	18.1	5.6
Ground Station—Equipment	140.4	43.8
Other	1.9	0.6
Total	$321.2	100.0

TABLE 13

NUMBER OF PEOPLE

Year	MADS/MAVS/Lease	MADS Only
1970	565	550
1971	900	875
1972	1,075	1,050
1973	1,300	1,250
1974	1,575	1,500
1975	1,900	1,800
1976	2,300	2,200
1977	2,700	2,600
1978	3,250	3,100
1979	3,950	3,750
1980	4,700	4,500

V. CONSIDERATIONS BEARING ON SELECTION OF A DOMESTIC ENTITY TO UTILIZE SATELLITE TECHNOLOGY

139. It may well be that in the communications field, as in other common carrier fields, certain inherent characteristics, principally those relating to economies of scale and costly and wasteful duplication of facilities, may tend to dictate against sanctioning certain types of direct competitive activity. For example, few would suggest that domestic telephone service should be offered by more than one entity in one locality. On the other hand, however, there is a basic national policy that we have earlier referenced favoring the development of parallel competitive services wherever practical and of benefit to the public. In this regard, we believe that serious consideration should be given to whether domestic satellite common carrier facilities should be provided through existing carriers or whether through authorization of a new entity.

140. It is reasonable to assume that, as they already have in this proceeding, existing communications common carriers will contend with considerable force that their existing facilities, services and experience reasonably dictate that applications for specific satellite authorization be restricted to such entities—at least for the furnishing of common carrier service. This position naturally warrants serious consideration in the Commission's deliberations.

141. Equally worthy of serious consideration is the possible desirability for enhancing the competitive provision of communications services by authorizing an entirely new common carrier entity for the purposes outlined—one not deterred by existing capital or other commitments in the present common carrier system. The potential services described, if they are to be allowed to develop and become available to the public as promptly as possible, would appear to require that they be offered by a type of entity capable of pursuing the stated objectives vigor-

ously. As in other regulatory fields,[39] it can be argued strongly that in domestic common carrier communications this might well be best spurred by vigorous competition between modes of communication.[40]

142. A further matter bearing on the question of ultimate ownership and operation of a system capable of providing these services relates to the question of separation of domestic and international communications. The long-recognized need to separate the activities of U.S. companies engaged in domestic and international communications is a matter of record. Thus the Commission in recommending the consolidation of domestic and international telegraph carriers along separate lines observed:

> "If approval of a consolidation plan should result in the creation of a single domestic telegraph carrier and more than one international carrier, or in the creation of a single international telegraph carrier and more than one domestic carrier, it is obvious that the single carrier controlling its field should have no relation financial or otherwise, with any one of the carriers in the other field."
>
> "It will be the Commission's policy to prevent the opportunity for discrimination which might result from realignment along the lines above referred to." FCC *Supplemental Report on the Telegraph Industry (International Telegraph Service)* Submitted to Senate Comm. on Interstate Commerce—Feb. 1940, p. 150.

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[39] In the land transportation field, for instance, to the extent possible, competition is preserved between modes of transportation, *e.g.*, motor carrier, rail carrier, etc. The National Transportation Policy, 49 U.S.C., note preceding Sec. 1, lays a broad duty upon the Interstate Commerce Commission to administer the Act so as "to recognize and preserve the inherent advantages of each mode of transportation."

[40] Significantly, these considerations were instrumental in the creation of an entirely new entity for international satellite communications and the legislative provisions for competitive dealing with the new entity. See authorities listed at note 8 *supra* and Minority Report in S. Rep. No. 1584, 87th Cong., 2d Sess. (1962) in 1962 *U.S. Code Cong. and Ad. News* 2310-11.

These concerns of the Commission were, of course, embodied in the Domestic Telegraph Merger Act three years later, which (1) prohibited specifically the consolidation or merger of domestic and international telegraph carriers [41] and (2) provided that any merger of domestic telegraph carriers shall be conditioned upon the divestment of the international telegraph operations of any party to the merger.[42] The policy judgment there, contained in the Communications Act, must be given serious consideration in the instant situation.

143. In realistically assessing this matter of who should implement such service offerings, one is faced with the further question of how it should be accomplished. In this context the problem of pilot proposals is squarely raised. GE is aware that the Commission is presently faced with a decision whether or not to authorize an interim system for experimental purposes. These include the Pilot Proposal advanced by Comsat and the recommendation of the Ford Foundation to "test" a domestic satellite system under the direction of the National Aeronautics and Space Administration (NASA).

144. In its third round of comments of April 3, 1967 in this proceeding, Comsat offered to set up a multi-purpose pilot proposal looking "toward establishing a demonstration complex permitting a regional network for educational television and for commercial broadcasting, and permitting transcontinental telephone data, and other communications" (pp. 13-14). In concurrently filed comments the Ford Foundation proposed that NASA, in cooperation with HEW and other federal agencies and

[41] 47 U.S.C. 222(b) (1).

[42] 47 U.S.C. 222(c) (2). The latter provision was added to the Communications Act because of the concern "that the merged company, through ownership of a single remaining nationwide landline telegraph system, would be in a position to control the distribution of outbound international traffic and to favor its own international cable facilities." *Western Union Telegraph Co.* v. *United States*, 267 F 2d 715, 718 (2d Cir. 1959).

interested persons should inaugurate a national test satellite program primarily for network transmission purposes.

145. In this respect, perhaps the most serious question is whether there is a distinct need or desirability for a separate pilot authorization. The feasibility of synchronous satellites for the purposes advanced has long since been established. However, justification of a pilot or demonstration satellite system would seem to depend primarily on the contrary assumption, i.e., that there are major technical uncertainties. In other respects it may have little value. For instance, the principal characteristic of a pilot or interim system is its temporary nature. As such, clouded in uncertainty, it may well be unable effectively and aggressively to advance specific markets. To be of real value in determining "need" data a system of this sort would have to develop and establish new and identifiable markets. The users, therefore, would have to effectuate an alteration in business practices to utilize a pilot system. Sound business judgments of this nature, however, would require a reasonable degree of certainty concerning continuation of the system that would only be associated with a more permanent system.

146. In essence, the essential basic policy determinations confronting the Commission relate to who should own and operate a domestic satellite system(s) and the types of services to be provided. Without at this time arguing for a particular approach, we have sought to point up certain crucial issues which we believe must be taken into account in arriving at final judgments on the entity that should be authorized to provide the type of needed services outlined.

VI. CONCLUDING STATEMENT

147. Accordingly, at this juncture, it would appear reasonable to conclude that a foreseeable and practical alternative, such as we have described, that could have the effect of increasing greatly the availability of an effective alternative record carrier

service, would be strongly favored by the long-established, oft-articulated national policy in this regard. The relevant policy goal is to establish viable competitors in the provision of different common carrier communications services, thus assuring the best, most diversified lowest cost opportunity to the largest number of users to reap the benefits of current communications technology.

148. In preparing this domestic satellite material, GE, quite naturally, has examined with considerable care the question of whether it could and should take affirmative action that would directly, on an investment and operational basis, involve it in an undertaking to bring about the advantages of the satellite services enumerated. In doing so, it has concluded that, for the following reasons, prudent business judgment would not warrant such a commitment.

149. Such business determinations must proceed from an evaluation of total existing and foreseeable commitments, taking into account a multiplicity of factors specific to the company involved and the venture contemplated. In approaching the domestic satellite field it was concluded that there is no realistic way in which to determine, from the standpoint of a potential business commitment, the manner in which the field may develop. For instance, it is entirely possible that the eventual domestic satellite ownership pattern may be so structured as to foreclose or discourage direct investment from private enterprise. The uncertainty of the structuring of a future domestic common carrier satellite system is further clouded when it is recognized that the final product will likely be subject to the actions of not only this Commission, but of Congress, the Executive, and other appropriate authorities.

150. In short, it is impossible to judge with even reasonable certainty the likely nature of the entity ultimately lodged with authority to establish a domestic satellite system or the extent to which, if at all, participation by a company such as General Electric would be possible. Additional critical factors,

of course, relate to the uncertainty of the time that will elapse before such matters are known and the resulting inability to assess the probable nature of GE's total business commitment at that time. It is, however, these very fundamental matters which must be taken into account in any necessary business judgments. Lacking a further delineation of policy the imponderables remain speculative at best.

151. The General Electric Company has, therefore, found that it could not in the exercise of a prudent business judgment propose to undertake commitments of an investment or operational nature. It continues to stand ready, however, to provide technical and other data that may assist the Commission in arriving at the required public policy determinations, and it is in this context that this document has been submitted.

Respectfully submitted,

GENERAL ELECTRIC COMPANY

By JAMES A. MCKENNA, JR.
By JOSEPH M. KITTNER
By CARL R. RAMEY
McKENNA & WILKINSON
1705 DeSales Street, N.W.
Washington, D. C. 20036
Its Attorneys

Of Counsel:

BERNARD H. WHITE
General Electric Company
Missile & Space Division
Valley Forge Space Technology Center
King of Prussia, Pennsylvania 19406

RAYMOND E. BAKER
General Electric Company
Communications Products Department
Mountain View Road
Lynchburg, Virginia 24503

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