NALECOM
SATELLITE USAGE STUDY
FEBRUARY 1975

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12 February 1975

NALECOM Satellite Usage Study

Prepared for Jet Propulsion Laboratory

Under Contract NAS 7-100
EP 37-2146

Prepared By
ROCKWELL INTERNATIONAL
Collins Radio Group
Dallas, Texas

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Section 1

Introduction

1.1 STUDY OBJECTIVES

The objective of this brief study is to investigate applications of satellite communications links of various types for criminal justice usage. The problems of link and ground station security are the major consideration. Emphasis is on identifying potential problems and ways to circumvent these problems. This study has been conducted under the direction of the Jet Propulsion Laboratory.

The study efforts fall into two major efforts. One was the study of the satellite transmission modes and capabilities. The second effort was the investigation of the operational problems/aspects of link and ground station security.

The original statement of work for the satellite transmission mode investigations is as follows:

> Develop estimates of satellite ground station capabilities necessary to support transmission or reception of information using (a) commercial satellites such as WESTAR operating at 6 GHz (uplink) and 4 GHz (downlink), and (b) the potential capabilities of satellites operating at 14 GHz (uplink) and 12 GHz (downlink). Either satellite system shall provide coverage of the continental United States.
>
> Consider requirements for the following information transmission/reception:
>
> (a) Color TV with audio, with received SNR (peak-to-peak picture to weighted RMS noise) equal to or greater than 48 dB.
>
> (b) Digital data transmission at T1 (1.544 Mbps) data rate. In this case, assume one ground transmitter through a single satellite transponder transmitting as many T1 channels as possible with a bit error rate less than or equal to 1×10^{-5}, either uncoded or using convolutional coding, rate 1/2.

> (c) Digital data transmission at 50 Kbps using convolutional coding, rate 1/2. For this case, assume one channel per transmitter with multiple transmitters accessing a single satellite transponder.

The original statement of work for the investigation of the problems/aspects of the link and ground station security is:

> For each transmission/reception mode, determine the following:
>
> (a) Can the ground stations be located within a city? (i.e., at a criminal justice facility,) or must they in most cases be located outside city limits where security is a problem. What security measures are available (and what are the costs) for protecting or monitoring of remote stations?
>
> (b) What is the potential for unwanted monitoring of the uplink or downlink transmissions by unwanted persons? What would be their cost and complexity of hardware? How can these efforts be circumvented, and at what cost and complexity?
>
> (c) Is there any potential for false message injection? If so, what are the costs and complexity of hardware for providing false messages. What techniques can be used to circumvent false message injection and what are the costs and complexity?
>
> (d) What are costs and complexity of hardware to jam (disrupt) communications and for hardware to circumvent potential jamming?
>
> (e) What redundancy in ground stations is necessary to provide average availability of 0.99 for video and 0.995 for digital data transmission?

1.2 Report Summary

This report is the result of a very brief study of several aspects of the transmission of different types of signals via geosynchronous satellites for operation within the Continental United States (CONUS) of America. Three basic types of signal channels were considered:

a) color television with one program (sound) channel
b) 1.544 mbps data rate channels similar to, or identical to the T1 carriers used in the Bell Telephone System
c) 50 Kbps data rate channels.

Five types of satellite transponder models were considered:

a. WESTAR, with uplink at 6 GHz, downlink at 4 GHz with single CONUS beam coverage.
b. Proposed future US. DOMSAT with uplink at 14 GHz, downlink at 12 GHz with multiple spot beam coverage of CONUS.
c. ATS-6 type with uplink at 6 GHz and downlink at 4 GHz with very narrow multiple steerable spot beams.
d. CTS type with uplink at 14 GHz and downlink at 12 GHz with narrow multiple steerable spot beams.
e. ATS-6 type with uplink at 6 GHz and downlink at 2.5-2.6 GHz with multiple spot beams.

For convenience 36-MHz wide transponders were assumed although CTS has wider transponders. Model e) was only used for television transmission studies of the type being conducted by NASA and HEW with the ATS-6. Both ATS-6 and CTS are experimental satellites representing the technology available today if desired. The WESTAR studies represents current lower cost commercially available satellites. The Future Domsat is a hypothetical case which is typical of many commercial 12/14 GHz domestic satellites under consideration by many organizations. The result of using these models is to indicate the wide range of transmission links available within todays communication satellite technology and which may be available for future DOMSAT networks.

Several different techniques of transmitting the three basic signal channels were investigation. Again those investigated are indicative of the range of options available but do not exhaust the possibilities. For color television three basic transmission approaches were investigated:

a. Standard NTSC 525/60 line with one audio subcarrier above video frequency modulated onto a rf carrier.
b. Standard SECAM III 625/50 line with one audio subcarrier above video frequency modulated onto a rf carrier.
c. Same as a. but the sound channel frequency modulated onto a separate rf carrier.
d. Same as b. but the sound channel frequency modulated onto a separate rf carrier.
e. Digital encoding of the TV and sound, phase-shift (QPSK) modulated onto an rf carrier.

In all cases, it was assumed that the TV signal had the entire resources of the transponder available. From previous studies and by means of computer programs for link analysis, the earth station G/T required to give a video peak-to-peak luminance-to-rms weighted noise ratio of 48 dB and a 1 kHz test-tone-to-rms weighted noise ratio of 50 dB for the sound channel was determined for each of the above cases under clear weather conditions, assuming that the earth stations were located at Los Angeles, Chicago and Miami. These locations represent the range of elevation pointing angles and rain attenuation conditions expected for CONUS. Receive only and transmit/receive earth station configurations were selected for the analog and digital TV cases. The difference in link performance between NTSC 525/60 and SECAM III 625/50 version did not justify using significantly different earth stations. The primary basis for selection of the earth station configurations was cost-effectiveness.

However the shortness of the study did not permit ensuring that the configurations selected are optimum. The separate program channel carrier gave better performance than the subcarrier approach. In general SECAM III provided slightly better link performance for the models and assumptions.

DITEC, a COMSAT Laboratory experimental digital television development for satellite links was used as the basis for the digital TV studies. This system required considerable larger earth stations. This is primarily because it is designed for 56 dB signal-to-noise rather than 48 dB. Also in its experimental state it is very expensive. The digital television model used did not fully represent the equipment which will be available for commercial/industrial use in the near future.

It is felt that the digital television performances shown in this study are about 3- to 5-dB short of what may be available in the near future.

Digital TV transmission offers the potential for savings in satellite lease costs by using less than one-half of the satellite resources used by the analog TV signals. Further it is less susceptible to unauthorized monitoring and jamming. SECAM III 625/50 offers greater resolution and true color fidelity than NTSC 525/60. The best combination would be a digital version of SECAM III 625/50.

Two basic transmission approaches for the 1.544 mbps channels were considered. One considered a single earth station transmitting via the satellite in a broadcast mode from 1 to 38 channels. These channels were assumed to be time-division multiplexed (TDM) into one single higher data stream at a rate nx 1.544 mbps in the uncoded case. A case was also considered where each 1.544 mbps channel was coded with a half rate forward error correction coding (FEC) into a 3.1 mbps rate channel. For the coded case the maximum number of channels transmitted was 19, a limit set by the 36-MHz wide transponders and the selection of 4-phase shift (QPSK) modulation. The decoder was assumed to be a Viterbi soft-decision type with a constraint length of 7 which provides a gain advantage to the satellite communication link of 5.1 dB. Receive only and transmit/receive earth station configurations were selected for four out of the five satellite models. The receive only earth stations are reduced in size considerably by the use of codes. However the transmit station size is not reduced by the use of codes. Coding reduces the data throughput, (1/2 in this study) but also decreases the susceptibility to unauthorized monitoring and jamming.

The second approach assumed each 1.544 mbps channel was QPSK modulated onto separate non-overlapping rf carriers in a Frequency Division Multiple Access (FDMA) sharing of the transponder resources. This case can also represent the multiple transmitting earth station case. The number of channels transmitted was between 2 to 32 in the uncoded case. In order to achieve the optimum link performance the satellite transponder must be operated at significantly less than its maximum power. Thus the required transmit earth station radiated power decreases compared to the other case and the receive only station size increases. However if a single high power amplifier is used at the earth station transmitter, its size needs to be as large as in the TDM case. The use of coding changes the optimum operation point of the satellite considerably. In terms of input power backoff, the use of 1/2 rate coding changed

the input backoff level relative to the maximum power point from 9 dB to 4.5 dB. The FDMA case represents a less efficient utilization of the satellite resource but it provides a great deal of flexibility in traffic assignments over the TDM approach. The FDMA case is more susceptible to jamming, unauthorized monitoring and false message injection.

Only the FDMA approach was considered for the 50 Kbps channel cases. Both uncoded and 1/2 rate coding was investigated. The maximum number of channels was 800 based upon the 36-MHz wide bandwidth, use of QPSK modulation and a channel-to-channel spacing designed to keep the adjacent channel interference below the other major noise contributors. In this approach the channel rate over the satellite link was kept at 50 Kbps whether coded or uncoded. Thus in the 1/2 rate coding cases, the channel data throughput is only 25 Kbps. Coding changed the optimum input power backoff point from 13 dB to 4 dB. Because each individual channel is low in power, the 50 Kbps FDMA cases are more susceptible to jamming and false message injection than the 1.544 mbps channel cases.

Figures 1-1 through 1-3 summarize some of the digital transmission capacity studies. In the 50 Kbps FDMA case, the saturation of the capacity of CTS prior to reaching 800 channels was a result of assuming the highest possible gain for the satellite. This results in the smallest receive only earth station size, but does limit the capacity. CTS has lower gain settings which would permit a larger number of channels provided the transmit and receive earth station sizes were also increased.

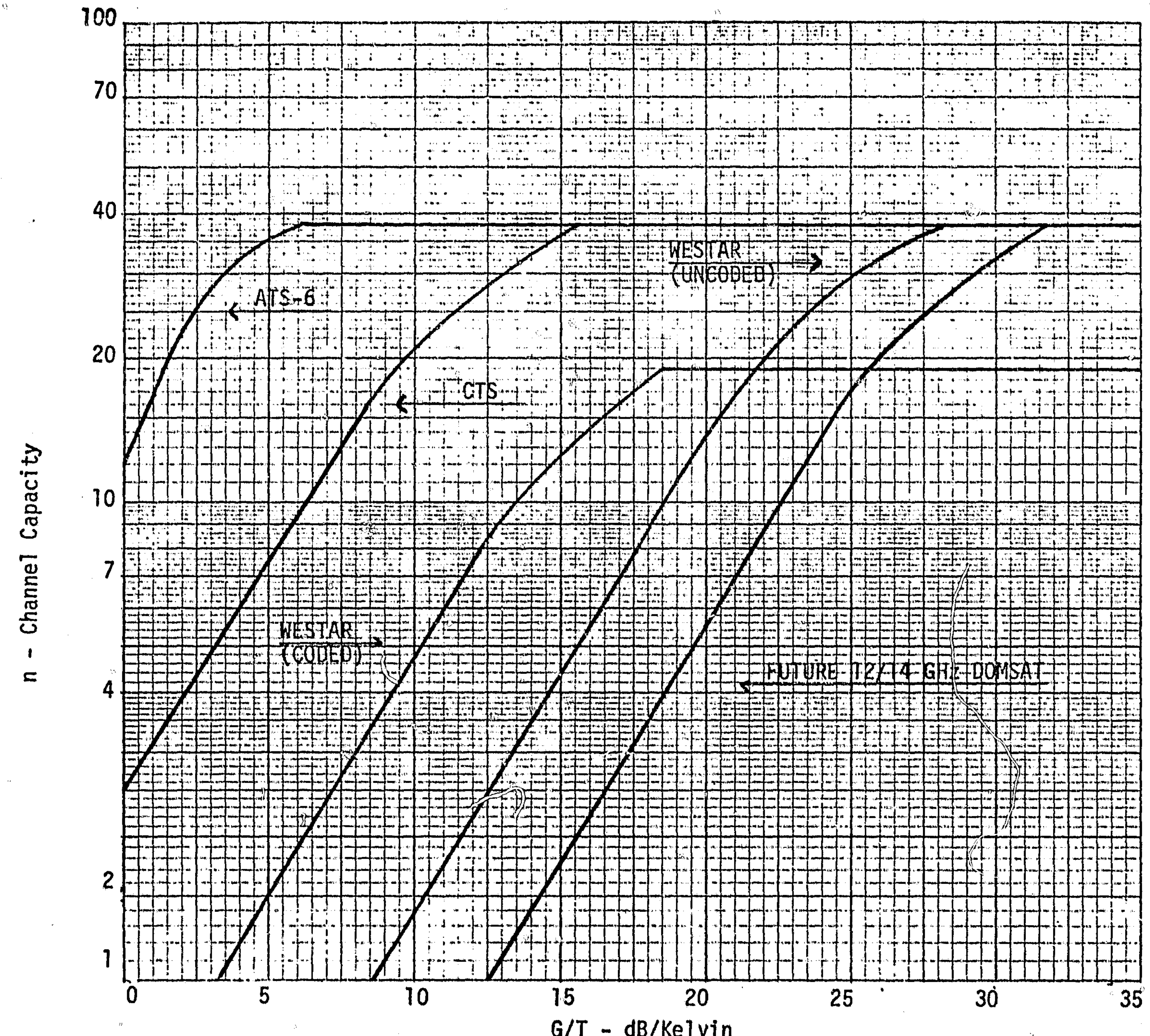

Figure 1-1. Channel Capacity Vs. Earth Station G/T for T1 Carrier TDM Cases.

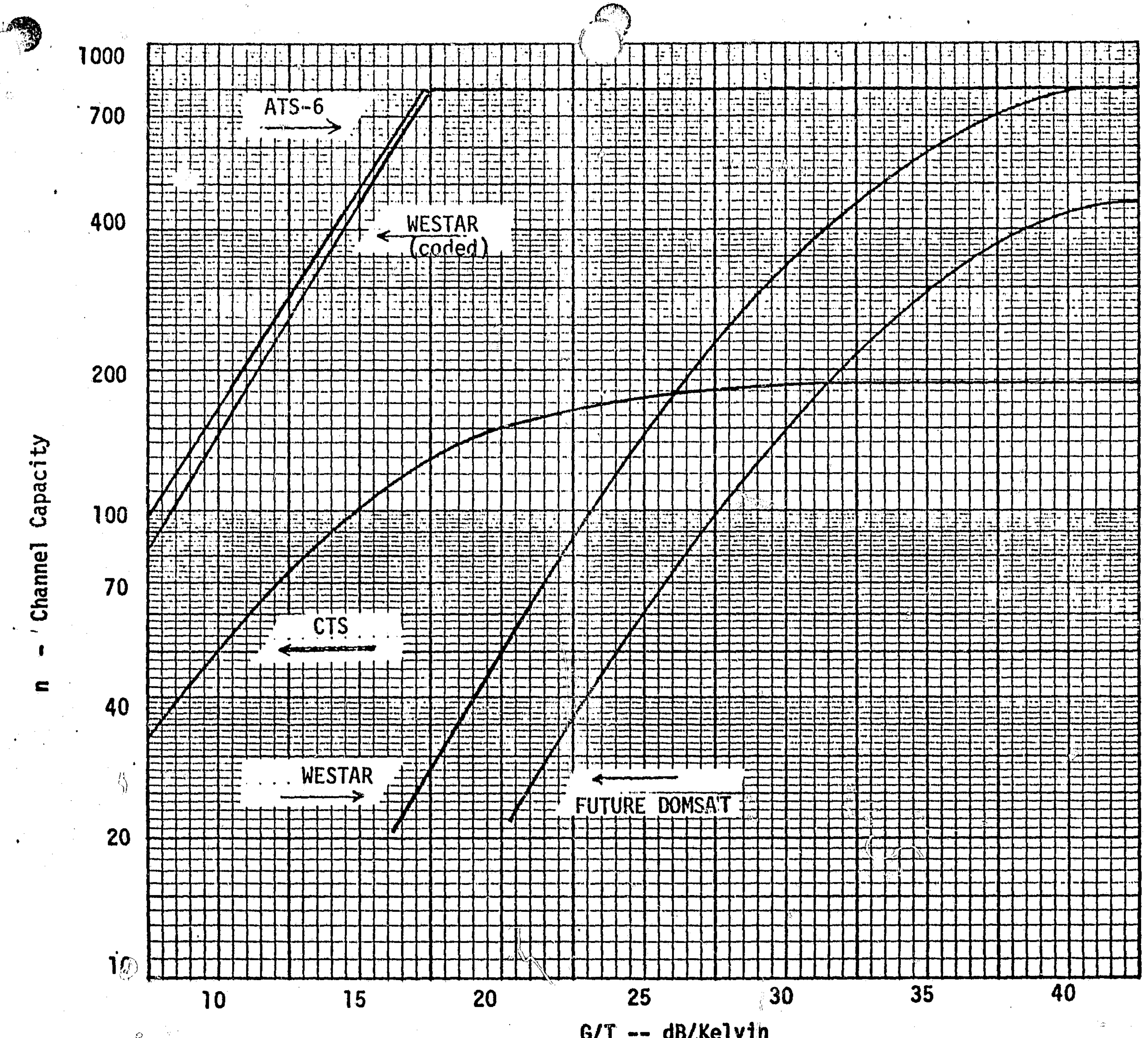

Figure 1-2 . Transponder Channel Capacity as a Function of Earth Station G/T for 50 Kbps FDMA Cases

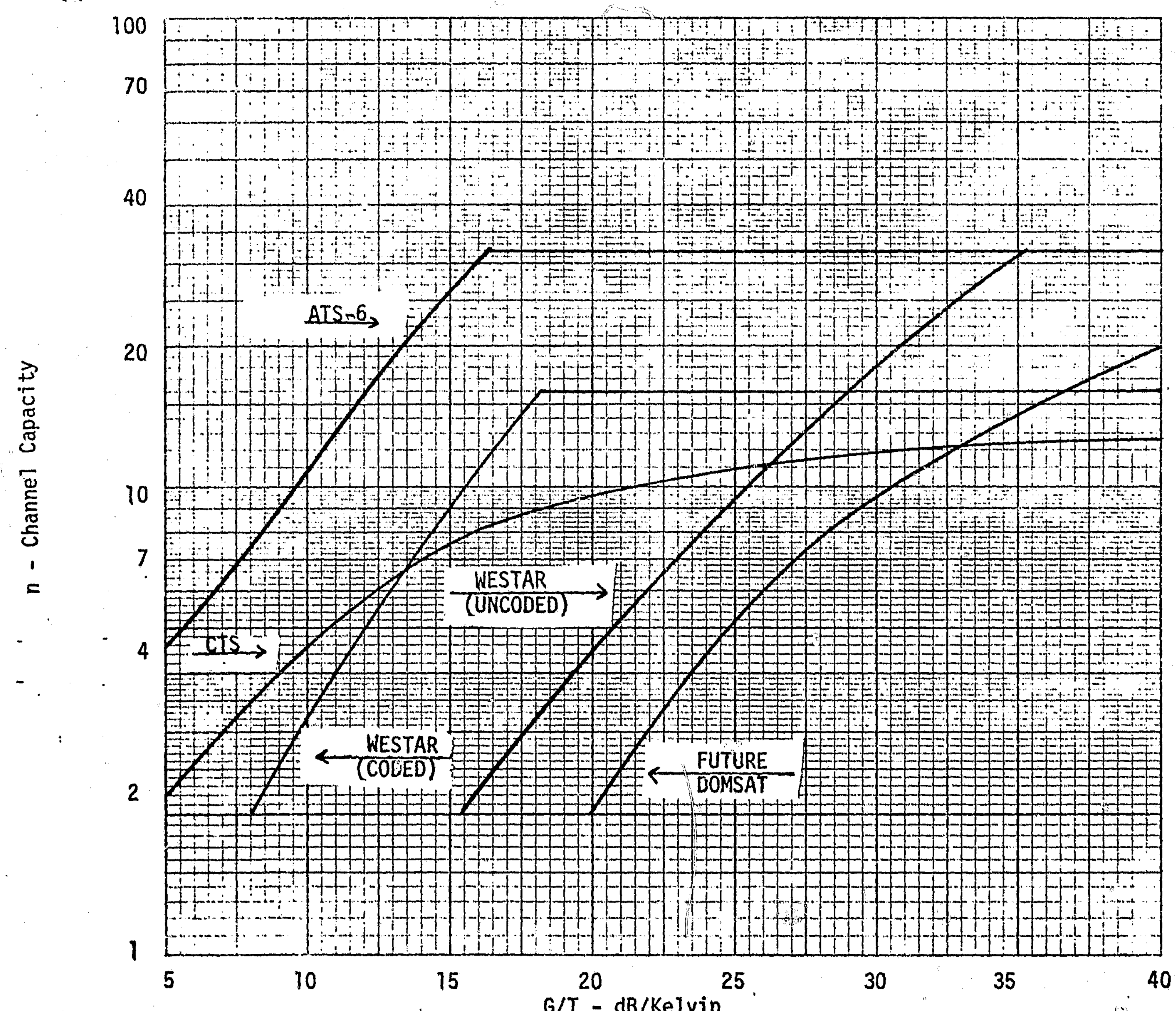

Figure 1-3 Transponder Channel Capacity As A Function of Earth Station G/T for T1 FDMA Cases

This study also briefly considered the availability and earth station redundancy requirements for link availabilities of 0.99 for TV transmissions and 0.995 for data transmissions. For the analog color TV transmissions with submultiplexed audio cases, no redundancy appears to be necessary. In the case of separate audio carrier cases, the receive only stations do not appear to require redundancy, but the transmit portion of the transmit/receive earth station does appear to need redundancy. All of the digital transmission cases appear to be in need of redundancy of the digital transmission equipments. The briefness of the study did not permit the determination of the optimum redundancy configurations for the different transmission cases.

This study also briefly considered general aspects involved in determining the location of an earth station. In general, it is much more difficult to locate a transmit/receive earth station in a city than a receive only earth station. Not only does the receive only earth station tend to be small, there are less FCC restrictions on such stations. For a small receive only terminal, artificial shielding and other techniques such as adaptive phased array antennas can be used to reduce the interferences to an acceptable level. With satellite such as ATS-6 and CTS, which have very high effective radiated power because of their unique designs, the receive only terminals can become very small, in an interference-free environment. For areas with high rain attenuations such as Miami, 12 and 14 GHz frequency earth stations are greatly penalized over 4 and 6 GHz earth stations. Transmit/receive earth stations necessary to overcome the rain attenuation at 14 GHz for such locations become too large to locate in a city. Rather than a single 14 GHz earth station, it appears to be more practical to employ two smaller earth stations separated by several miles to reduce the probability that both stations are simultaneously under heavy rain fall conditions.

This study also briefly considered several aspects of security, namely:

a) physical security of remote earth station
b) unauthorized monitoring of the transmissions
c) disruption of service by jamming the receivers
d) potential for injection of false messages.

The briefness of the study did not permit a very extensive investigation into these aspects. In general, it is relatively easy to physically attack or vandalize a remote earth station. In general, it is relatively easy and inexpensive to monitor or jam an earth station from locations near the earth station. Natural and artificial shielding and other interference rejection techniques can increase the security to some degree but ultimately, the only positive security would be to use message encryption and jam resistant modulation techniques. It is also relatively easy to jam the satellite with a simple pulsed jammer. Monitoring of analog TV transmissions of the satellite is relatively easy. Monitoring of the digital transmissions from the satellite require having essentially the same earth station configurations as an authorized station. The case where the 1.544 mbps are time-division multiplexed together is most resistant to unauthorized monitoring. In any of the multiple digital channel transmission cases, the greater the number of channels, the more difficult it it is to monitor either the earth station or the satellite, because the power per channel is decreased.

In general, where the transmission system maintains separate message channels, it is relatively easy to insert a transmission with message into the system. Where the message channels are multiplexed into larger groupings for transmission in general, it is quite difficult to inject an unauthorized transmission/message into the system without physically controlling the transmission facility portion of the earth station. Cases which maintained separate message channels over the satellite link in this study were:

a) separate analog video and sound rf carriers,
b) separate rf carriers for T1 carriers, i.e., T1-FDMA cases,
c) separate rf carriers for 50 Kbps or 25 Kbps data channels, i.e., 50 Kbps-FDMA case.

Cases which multiplexed the channels into larger groupings were:

a) digital television,
b) time division multiplexed T1 carriers, i.e., T1-TDM.

Tables 1-1 and 1-2 summarize the relative performance of the transmission techniques. The only positive security approach is to encrypt the source messages and to use anti-jam modulation techniques.

Table 1-1. Comparison of Television Transmission Techniques

	Link Performance	Availability of Equipment	Ease of Monitoring	Fidelity
NTSC 525/60 with subcarrier audio	5	1	1	5
NTSC 525/60 with separate audio	2	2	2	4
SECAM IV 625/50 with subcarrier audio	4	3	3	2
SECAM III 625/50 with separate audio	1	4	4	1
Digital video with multiplexed audio	3	5	5	3

Notes 1. Lowest number means most favorable in terms of the column title.

Table 1-2. Comparison of Data Transmission Techniques

	Link Performance	Equipment Complexity	Ease of Monitor	Ease of Jamming	Ease of False Message Injection
T1 - TDM uncoded	2	2	5	6	5
T1 - TDM coded	1	1	6	5	6
T1 - FDMA uncoded	4	4	3	4	3
T1 - FDMA coded	3	3	4	3	4
50 Kbps FDMA uncoded	6	6	1	2	1
50 Kbps FDMA coded	5	5	2	1	2

Notes 1. Lowest number means most favorable in terms of the column title.

2.1 SPACE SEGMENT BASELINES

2.1.1 Introduction

The first baselines to be established for the study were those pertaining to the space segment. The characteristics of the space segment have more impact on the earth station terminal characteristics, location, performance operational aspects, etc. than any other single factor. To indicate the range of this impact, widely different satellite transponder models were considered. To maintain realism existing and currently planned satellite transponders were used for the space segment baselines. Five geosynchronous communication satellite transponder models were selected for the study as follows:

a. WESTAR, with uplink at 6 GHz, downlink at 4 GHz with single CONUS beam coverage.
b. Proposed future vs. DOMSAT satellite with uplink at 14 GHz, downlink at 12 GHz with multiple spot beam coverage of CONUS.
c. ATS-6 type with uplink at 6 GHz and downlink at 4 GHz with very narrow multiple steerable spot beams.
d. CTS type with uplink at 14 GHz and downlink at 12 GHz with very narrow multiple steerable spot beams.
e. ATS-6 type with uplink at 6 GHz and downlink at 2.6 GHz with multiple spot beams (for TV transmission only).

2.1.2 WESTAR 4/6 GHz[1-3]

WESTAR is a Western Union Domestic Communication satellite. WESTAR I, the first domestic commercial satellite, was launched in April 1974 into

1. WESTAR, F-4 Spacecraft Data Handbook, Hughes Aircraft Co., Report HS333A02486, February 1974.
2. S. N. Verma, "WESTAR Communication Characteristics," 1974 National Telecommunications Conference Proceedings, pp 108-113, December 2-4, 1974.
3. S. E. Scrupski, "Users Starting to Hop Aboard U.S. Communication Satellites," Electronics, McGraw-Hill Publishing Co., pp 95-102, October 1974.

geostationary orbit above the equator at 99° west longitude (about directly south of Dallas). All five Western Union earth stations -- located at Glenwood, N. J., Estill Fork, Ala., Lake Geneva, Wis., Steele Valley, Calif., and Cedar Hill, Texas -- are in operation.

The launch of the second satellite, WESTAR II, was successfully accomplished in October, 1974, and is located above the equator at 91° west longitude. WESTAR III will be put into ground storage until traffic or failure on the first two satellites warrants its launching.

The WESTAR I satellite, an HS-333 Hughes Aircraft unit, is a slightly modified version of the Canadian Anik spacecraft. It is a cylinder about 6.3 feet in diameter and 5.1 feet high, with an antenna on top that brings the total height to 11.8 feet. Weight at launch was 1,265 pounds. The surface of the cylinder holds about 20,500 solar cells to provide power, except during the twice-yearly eclipses, when the two batteries take over (during the spring and fall equinoxes, geostationary satellites are shielded by the earth from the sun for a short time around midnight for about a 45-day period; maximum eclipse time is about 70 minutes). The solar cells are designed to supply about 200 watts of electrical power even after seven years in orbit.

The satellite is spin-stabilized -- that is, the body spins to maintain stability in orbit while the antenna is despun to keep it pointing at the earth. The antenna can cover the contiguous 48 states, as well as Alaska and Puerto Rico, while a separate spot beam covers Hawaii. Four feed-horns illuminate the antenna reflector: three of them combine to give the continental U.S. coverage, while the fourth provides Hawaii the spot beam.

The satellite carries 12 amplifiers, or transponders, each with a 36-MHz bandwidth that can carry 1,200 voice channels, one color-TV signal, or data at 50 megabits per second. A wideband receiver covering the full band from 5,927 to 6,403 MHz feeds two multiplexers that split the 12 channels into two groups of six. Traveling-wave-tube amplifiers, one per channel, then amplify the signals, which are remultiplexed before being sent to the antenna for transmission to earth in the band from 3,702 to 4,178 MHz.

The receiver feed network has four inputs, corresponding to the east (E), center (C), west (W), and Hawaii (H) horns, and one output, the 6 GHz receiver interface. The 6 GHz signals, cross-polarized to 4 GHz transmit signals in common waveguides are received by four linear balanced dipoles located inside the waveguides. These three inputs corresponding to E, C and W, then drive a three-to-one power combiner to form the composite receiver signal. The signal received by the Hawaii horn H is directly coupled through an isolator and the coupler. The multiplexed transmit signals at 4 GHz are essentially distributed to the feed horns in the inverse manner. The four feed horn offset feed a common reflector approximately 2m by 1.5 m in size. The coverage of CONUS is thus obtained by a composite of three spot beams. The resultant contours are shown in figures 2-1 and 2-2. The resultant maximum single carrier saturation flux density and minimum G/T for 6 GHz gain contours of 26 dB are -79.6 dBw/m^2 and -7.4 dB, respectively. The minimum single carrier saturated EIRP for 4 GHz contours of 27 dB is 33 dBw. The actual measured values vary somewhat from transponder to transponder as Table 2-1 shows. Glenwood, New Jersey, is at the approximate gain contours of 30 dB at 4 GHz and 28 dB at 6 GHz.

Table 2-1. Measured Flux Density and EIRP for WESTAR I at Glenwood, New Jersey (After Verma[1])

TRANS-PONDER NO.	MEASURED FLUX DENSITY TO SATURATE (dBW/m^2)		MEASURED EIRP (dBW)	
	REC 1	REC 2	REC 1	REC 2
1	82.45	82.73	36.40	36.38
2	82.76	82.47	35.94	35.94
3	83.18	82.55	36.62	36.69
4	82.36	82.11	36.33	36.21
5	82.22	82.37	36.85	36.67
6	82.72	82.37	35.82	35.93
7	82.27	82.35	36.69	36.68
8	82.54	81.88	36.48	36.52
9	82.34	82.51	36.22	36.35
10	82.17	81.83	38.16	36.24
11	81.52	82.14	35.97	36.10
12	81.52	81.29	36.16	36.32

Table 2-2 summarizes the baseline communication characteristics of the WESTAR satellite transponders.

1. Verma, ibid.

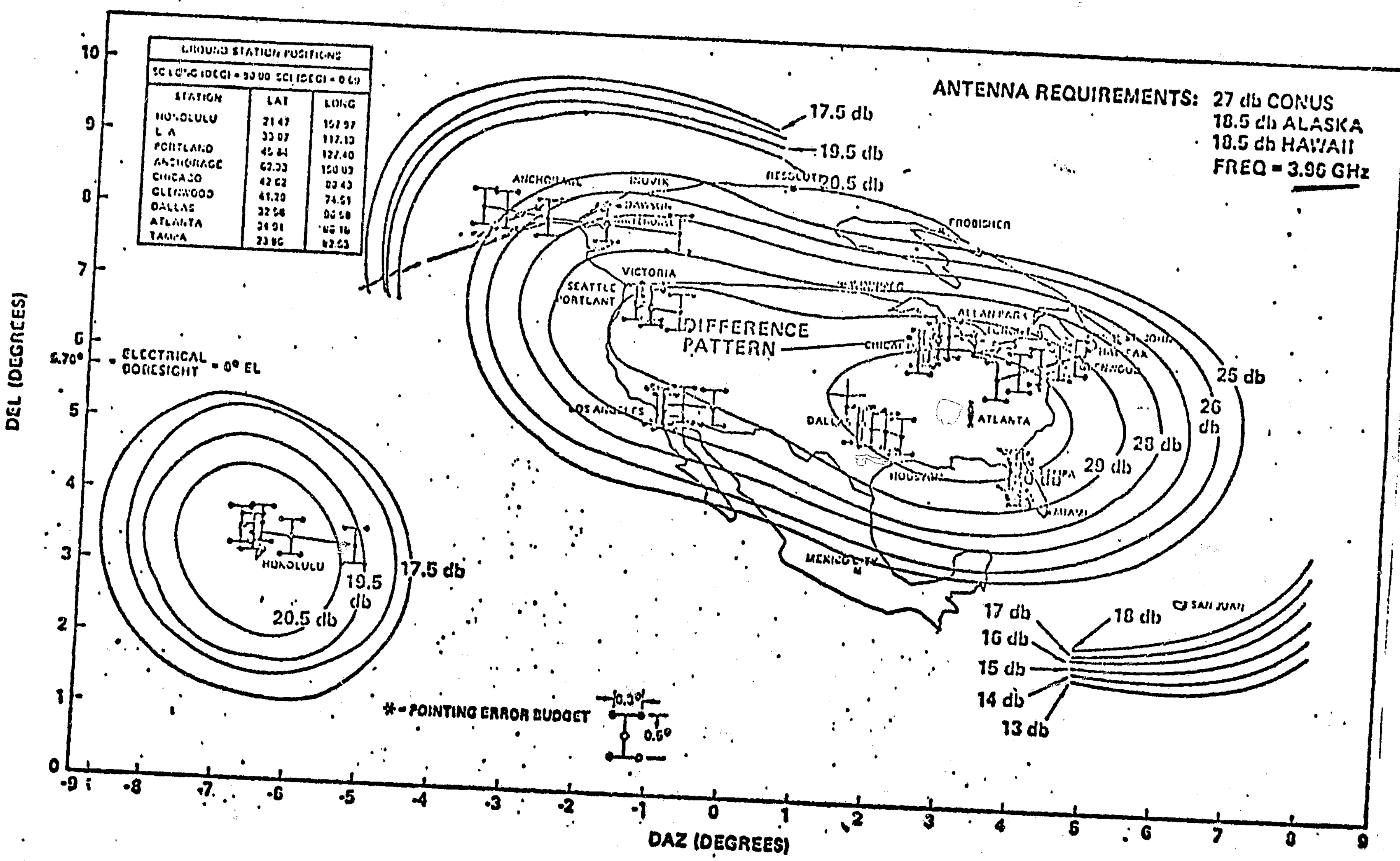

Figure 2-1. WESTAR Downlink Contour Pattern (For 99° West Longitude).

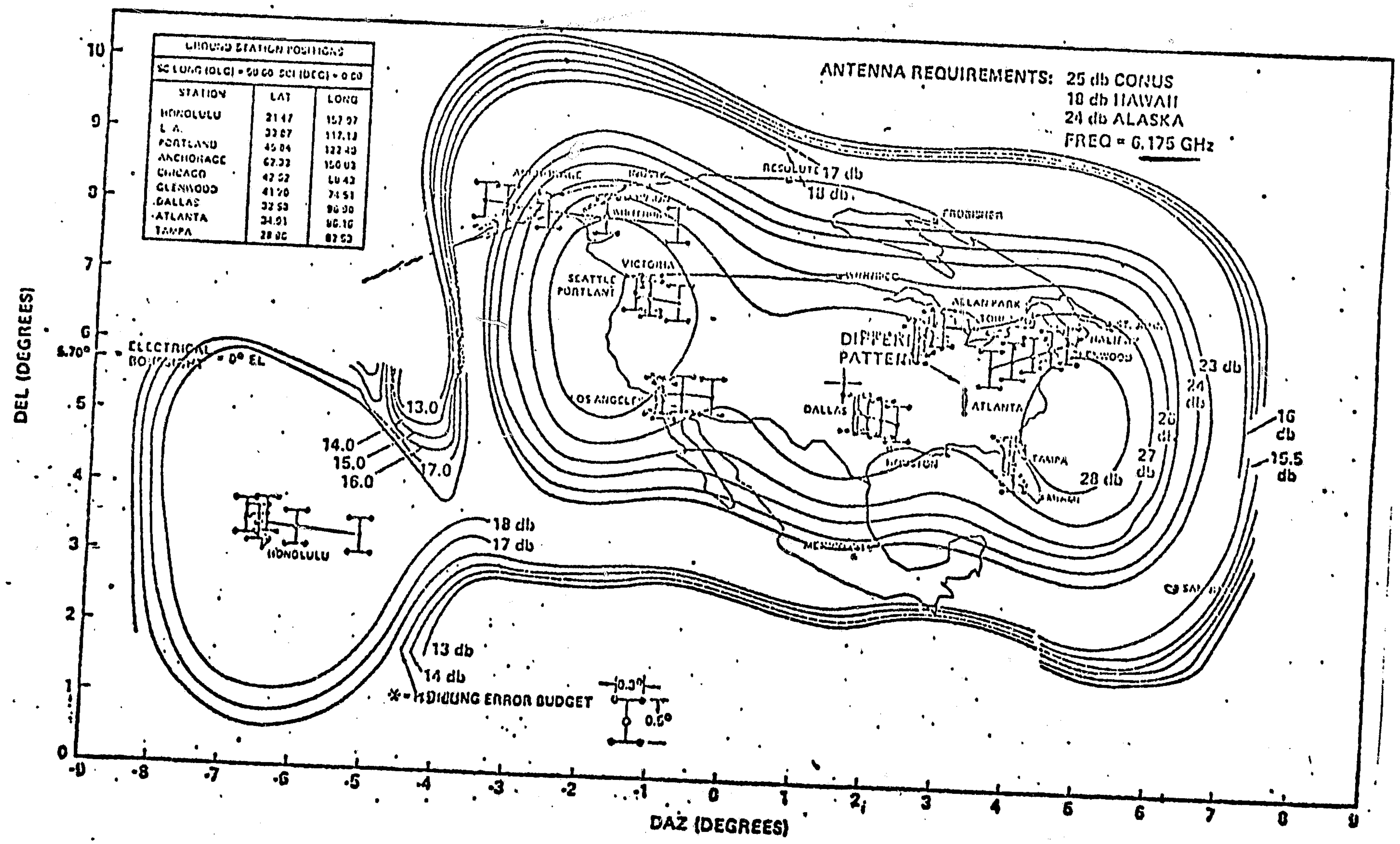

Figure 2-2. WESTAR Uplink Contour Pattern (For 99° West Longitude).

Table 2-2. Baseline WESTAR 4/6 GHz Characteristics.

Uplink Frequency Band	5.925 to 6.425 GHz
Downlink Transmit Band	3.7 to 4.2 GHz
Uplink Beamwidth	3.5° x 9°
Downlink Beamwidth	3.5° x 7°
Maximum Receive Flux Density for Transponder Saturation	-79.6 dBW/m^2 For CONUS (26 dB gain contour).
Receive G/T	Minimum -7.4 dB/°K for CONUS, (26 dB gain contour).
EIRP (Single carrier saturated)	Minimum 33 dBW for CONUS (27 dB gain contour).
Bandwidth	36 MHz
Maximum Group Delay over Passband	62 Nanoseconds at ±18 MHz
Input filter Group delay ripple period	12 MHz
Gain Variation across bandwidth	0.25 dB
Gain Slope across bandwidth	0.01 dB/MHz
Input filter gain slope	
-6 to +6 MHz	0.04 dB/MHz
±6 to ±12 MHz	0.07 dB/MHz
±12 to ±18 MHz	0.5 dB/MHz
Single carrier AM/PM conversation coefficient at -10 dB input	3.3 deg/dB
Output filter gain slope	
-18 to -12 MHz	0.05 dB/MHz
-12 to +12 MHz	0.01 dB/MHz
12 to 18 MHz	0.07 dB/MHz

A very important transponder characteristic is its input/output power transfer linearity. Table 2-3 summarizes the relative output power versus input power for a typical WESTAR transponder. The phase shift as a function of drive level is also an important parameter. Typical relative phase shift from zero drive to saturation drive level for the WESTAR transponder is 40 degrees. Berman and Mahle[1] have shown a convenient model of the phase transfer characteristic for a TWT is:

$$\phi = k_1 \left[1 - \exp\left(-k_2 P_{in}\right)\right] + k_3 P_{in}$$

where

P_{in} = normalized input power

ϕ = relative phase shift, radians,

and the constants, k_1, k_2, and k_3, are evaluated from the characteristics of the individual TWT.

Their mathematical model was tested against experiment results on a very simple basis of equal amplitude, limited number of signals, and very close correlation between results was found when proper constants were used. For this model the slope for zero drive level is given by $k_1 \cdot k_2 + k_3$ and the slope for large input power is given by k_3 only.

For this study the following coefficient values have been selected:

$k_1 = 0.458$,
$k_2 = 4.54$,
$k_3 = 0.24$.

1. Berman, A. L., and Mahle, C. E., "Nonlinear Phase Shift in Traveling-Wave Tubes as Applied to Multiple Access Communications Satellites," IEEE Transactions on Communication Technology, Vol Com 18, No. 1, pp 37-48, February 1970.

Table 2-3. Relative Input/Output Power Transfer Model for Typical WESTAR Transponder

Input Backoff (dB)	Single Carrier Output Backoff (dB)	Multi-Carrier Output Backoff* (dB)
0.0	0.00	1.82
0.5	0.02	1.74
1.0	0.07	1.67
1.5	0.14	1.62
2.0	0.22	1.60
2.5	0.32	1.62
3.0	0.47	1.67
3.5	0.63	1.74
4.0	0.80	1.82
4.5	1.00	2.00
5.0	1.25	2.20
5.5	1.50	2.40
6.0	1.80	2.65
6.5	2.15	2.95
7.0	2.55	3.25
7.5	2.95	3.60
8.0	3.35	3.95
9.0	4.25	4.65
10.0	5.30	5.70
11.0	6.30	6.60
12.0	7.30	7.50
14.0	9.30	9.30

*For multiple carrier input and output power corresponds to total power.

2.1.3 Future 12/14 GHz DOMSAT

In 1971, MCI Lockheed Satellite Corporation presented to the FCC an application for a U.S. Domestic Satellite which would operate at both 4 and 6 GHz (C-Band) and 12 and 13 GHz (K_u-Band) with coverage of CONUS using 3.5° x 7 degree beams.[1] The choice of frequencies was based upon an experimental transponder developed by Thomson-CSF[2] prior to the allocation of the 12 GHz and 14 GHz frequency bands by the World Administrative Radio Conference (WARC) in 1971. With the exception of changing the 12.75-13.25 GHz uplink band to 14.0-14.5 GHz band, the MCI Lockheed transponder has been adopted as the 12/14 GHz transponder baseline having CONUS coverage. Figures 2-3 and 2-4 show the expected coverages at 12 and 14 GHz, respectively.

Table 2-4 summarizes the other transponder characteristics assumed for study purposes. MCI proposed 24 transponders each with 36 MHz bandwidth, 12 on one linear polarization and 12 on the orthogonal polarization to permit frequency reuse. The transponders use double frequency conversion. Each receiver employs a single-stage, uncooled, non-degenerate parametric amplifier for an overall receive G/T of -3 dB at beam edge. It was proposed that each transmitter employ a TWT amplifier having an end-of-life power output of +13 dBw.

2.1.4 ATS-6 Type 4/6 GHz

The sixth of NASA's series of Advanced Technology Satellites is a large advancement in geosynchronous communication satellites.[3] It's most notable feature is a 30-foot diameter reflector and a three-axis body stabilization system using spinning wheels and jets to achieve pointing accuracies of 0.1 degrees and beam slewing rates of slightly greater than

1. Application of MCI Lockheed Satellite Corporation for a Domestic Communications Satellite System, Vol I System Application, Feb 1971.
2. B. Blachier, P. Feve, and W. Koenig, "An 11-13 GHz Satellite Communication Repeater," Paper 72-579, AIAA 4th Communications Satellite Systems Conference, Washington, D. C., April 24-26, 1972.
3. The ATS-F and -G Data Book Revised September 1972, Goddard Space Flight Center.

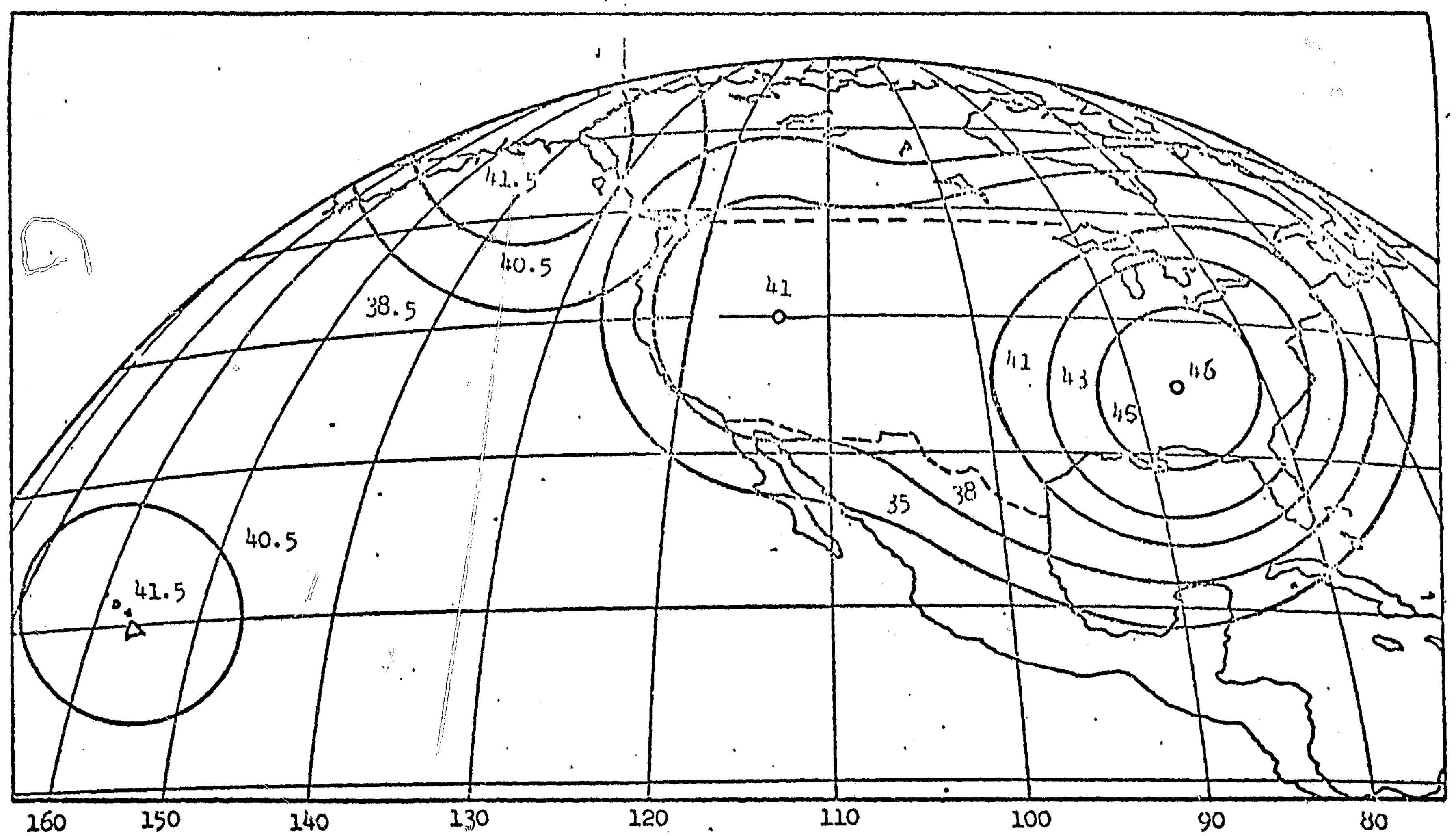

Figure 2-3. 12 GHz EIRP Contours (in dBw)

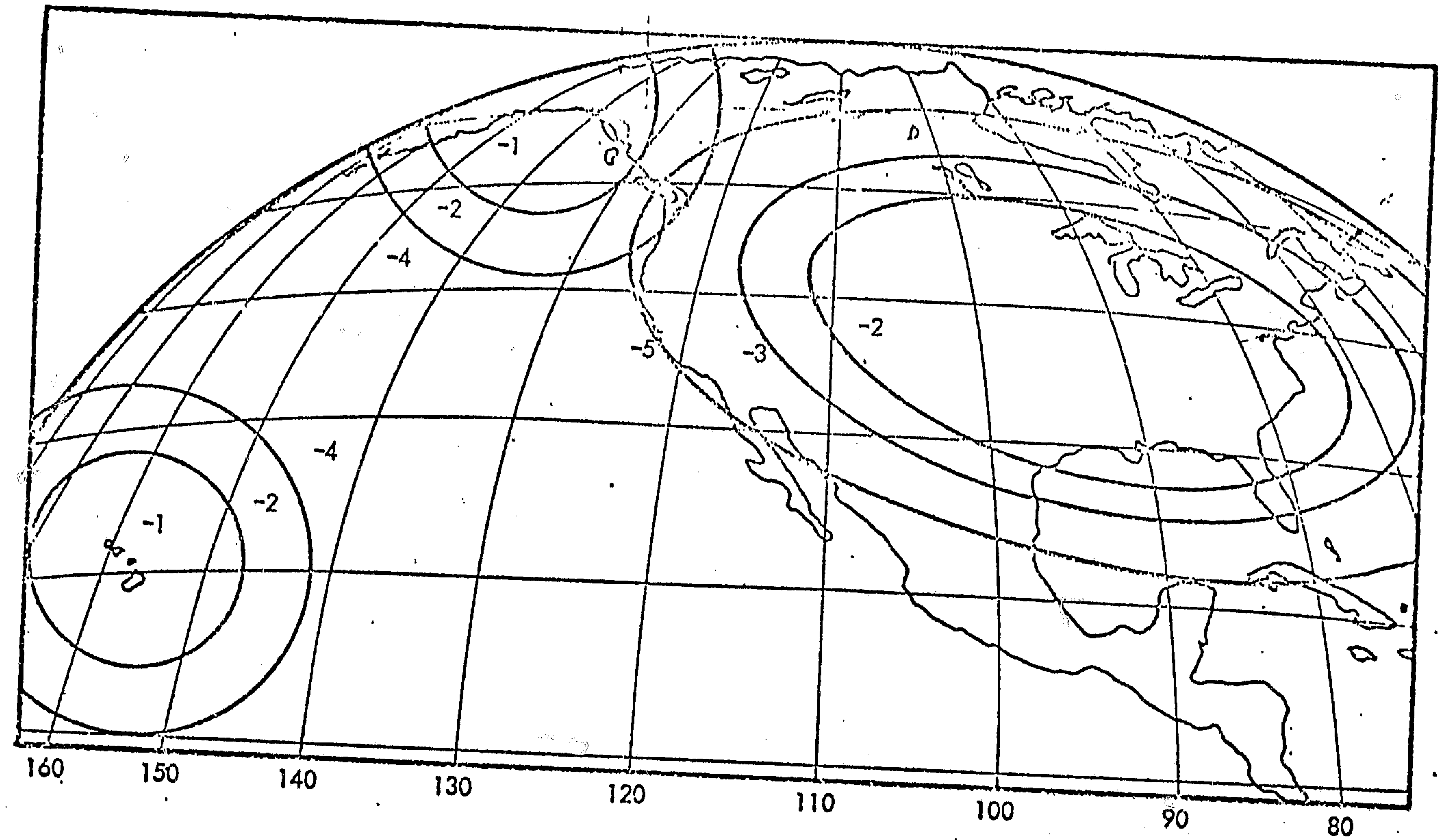

Figure 2-4. 14 GHz Uplink G/T Contours (in dB/°K).

Table 2-4. Baseline Future DOMSAT 12/14 GHz Characteristics.

Uplink Frequency Band	14.0 to 14.5 GHz
Downlink Frequency Band	11.7 to 12.2 GHz
Maximum Receive Flux Density For Transponder Saturation	-79 dBw/m^2 for CONUS (5 dB below peak)
Receive G/T	Minimum -5 dB/°K for CONUS. (5 dB below peak)
EIRP (Single carrier saturated)	Minimum 38 dBw for CONUS (11 dB below peak)
Bandwidth	36 MHz
Maximum Group Delay over Passband	62 Nanoseconds at ±18 MHz
Input Filter Group Delay Ripple Period	12 MHz
Gain Variation Across Bandwidth	0.25 dB
Gain Slope Across Bandwidth	0.01 dB/MHz
Input Filter Gain Slope	
-6 to +6 MHz	0.04 dB/MHz
±6 to ±12 MHz	0.07 dB/MHz
±12 to ±18 MHz	0.5 dB/MHz
Single Carrier AM/PM Conversation Coefficient at -10 dB Input	3.3 deg/dB
Output Filter Gain Slope	
-18 to -12 MHz	0.05 dB/MHz
-12 to +12 MHz	0.01 dB/MHz
+12 to +18 MHz	0.07 dB/MHz

0.5 degrees per minute. The half power beamwidths for the 30-foot diameter antenna are 0.4 degrees and 0.6 degrees, respectively, at 6 GHz (uplink) and at 4 GHz (downlink). At the earth's surface these correspond to spot beam diameters of 180 miles and 270 miles, respectively, at 6 GHz and 4 GHz. Although these beamwidths are not within the study guideline for beamwidths which encompass CONUS, it is believed worthwhile to consider the ATS-6 type of satellite for several reasons:

a. The large antenna gain permits very high downlink EIRP and uplink sensitivity which can in turn significantly reduce the G/T and uplink EIRP requirements and cost of the ground terminals.
b. With the ATS-6 type of satellites small mobile terminals can be considered.
c. The narrow beamwidths permit transfer of information on a more private basis and also can provide large rejection of off-axis sources of jamming or interference.
d. ATS-6 types of satellites have been included in the U.S. DOMSAT filings before the FCC.[1]

The ATS-6 is currently operational in geosynchronous orbit and is being used by NASA for a number of communication satellite and propagation experiments. It is configured with a single 6 GHz to 4 GHz transponder which has a 36 MHz bandwidth. For purposes of this study, the transponder characteristics presented by NASA for ATS-6 will be adopted, except for the nonlinear characteristics which will be assumed to be the same for the WESTAR transponder baseline. Table 2-5 summarizes the transponder characteristics. It will be assumed that 12 multiple uplink and downlink beams, each with steering, can be provided to provide several simultaneous point-to-point transmissions.

1. Application For a Domestic Communication Satellite System, EP-71-501, Fairchild Hiller Corporation, March 1971.

Table 2-5. Baseline ATS-6 Type 4/6 GHz Transponder Characteristics

Uplink Frequency Bands	5.925 to 6.425 GHz
Downlink Frequency Bands	3.7 to 4.2 GHz
Uplink Half Power Beamwidths	0.4 degrees
Downlink Half Power Beamwidths	0.6 degrees
On-Axis Receive Flux Density for Transponder Saturation	-91 dBw/m^2
Receive G/T	Peak 13.5 dB/°K
EIRP (Single Carrier Saturated)	Peak 54.5 dBw
Bandwidth	36 MHz
Maximum Group Delay over Passband	62 Nanoseconds at ±18 MHz
Input Filter Group Delay Ripple Period	12 MHz
Gain Variation Across Bandwidth	0.25 dB
Gain Slope Across Bandwidth	0.01 dB/MHz
Input Filter Gain Slope	
-6 to +6 MHz	0.04 dB/MHz
±6 to ±12 MHz	0.07 dB/MHz
±12 to ±18 MHz	0.5 dB/MHz
Single Carrier AM/PM Conversation Coefficient at -10 dB Input	3.3 deg/dB
Output Filter Gain Slope	
-18 to -12 MHz	0.05 dB/MHz
-12 to +12 MHz	0.01 dB/MHz
+12 to +18 MHz	0.07 dB/MHz

2.1.5 CTS Type 12/14 GHz

ATS-6 does not have a 12/14 GHz transponder. Fairchild-Hiller Corporation had proposed to use an ATS-6 type of satellite for U.S. DOMSAT using a 13 GHz uplink and a 7 GHz downlink; however, they proposed to use a separate smaller 2.8-foot x 1.4-foot antenna for this purpose rather than use the large 30-foot diameter antenna. There are several reasons for not using the larger reflector. First, the half-power beamwidth at 12 GHz would be approximately 0.2 degrees and the pointing accuracy of the ATS-6 is only on the order of ±0.05 to ±0.1 degrees. Second, the ATS-6 large reflector is made out of a fine mesh of metal impregnated cloth, which would begin to lose its reflection properties at 14 GHz. Since the prime purpose of selecting additional satellites was to study the effect of high satellite EIRP on the earth station requirements and operational problems, a viable alternate is the Communication Technology Satellite (CTS).

CTS[1] is a joint program between Canada, United States and the European Space Research Organization (ESRO) to develop and launch a high EIRP, three-axis stabilized, 12/14 GHz communications satellite. The satellite will be launched in 1975 into geostationary orbit by means of a Delta 2914 launch vehicle, and is intended to operate at longitude 116°W for two years. The principal objectives of the program are to 1) demonstrate TV transmission at 12 GHz from a satellite to low-cost ground terminals, 2) demonstrate uplink TV transmission at 14 GHz from transportable terminals, and 3) develop and flight test spacecraft subsystems and components for use in future communications satellites. The major advanced communications subsystems to be flight tested are superefficiency TWT's of novel design having an efficiency greater than 50% at a saturated power output of 200 w at a frequency of 12 GHz. Once the CTS is operational its use for experimental purposes will be shared equally by Canada and the United States.

The transponder has two gimballed 28-inch-diameter antennas with paraboloid reflectors. Each antenna provides a single 2.5 degree beam of circular

1. C. Franklin and E. Davison, "A High-Power Communications Technology Satellite for the 12- and 14-GHz Bands," Paper No. 72-580, AIAA 4th Communications Satellite Systems Conference, April 24-26, 1972.

cross section for the simultaneous transmission and reception of orthogonal linearly polarized signals. Isolation between the two polarizations is expected to be at least 25 dB. The electrical boresight of each antenna can be positioned anywhere within a 14.5 degree cone about the normal to the satellite forward deck. Transmit and receive gains are approximately equal with minimum transmission values of 33.2 dB within the beams and 36.2 dB along the electrical axes. First and second side lobe levels are expected to be -14 dB and -25 dB, respectively. The overall boresight pointing accuracy is ±0.2 degrees. Figure 2-5 shows typical pattern contours projected on to the Northern part of the Western Hemisphere.

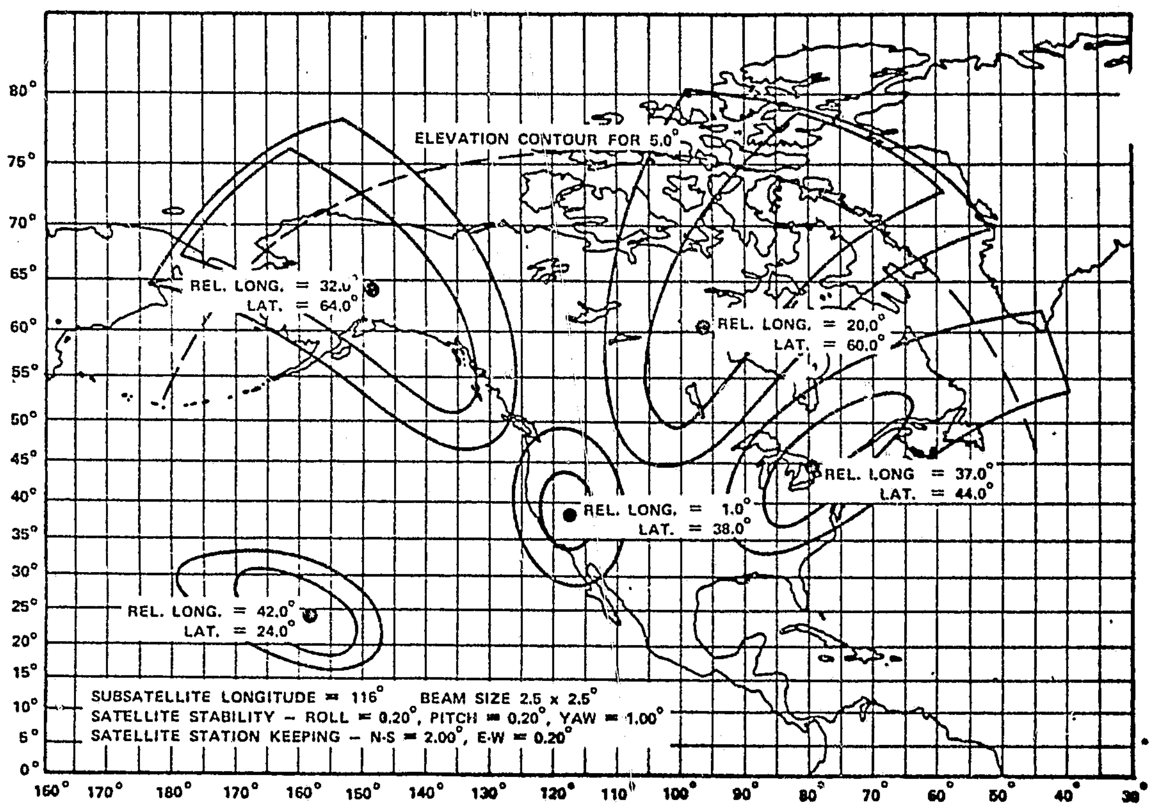

Figure 2-5. 12-GHz Antenna Coverage (3 dB Points) Patterns for CTS at 116°W. (Inner line of each pattern shows reduction in coverage due to spacecraft pointing errors.)

The high value of 60 dBW EIRP comes from the use of a 200 watt TWT high power amplifier. These TWT's employ an advanced multistage depressed collector and are expected to obtain an efficiency in excess of 50 percent.

The communications subsystem consists basically of two steerable antennas, a high-power TWT and power conditioner, driver TWTs, and a high-sensitivity high-gain receiver. The transponder has four 85-MHz passbands, two for transmitting in the 11.7-12.2 GHz band, and two for receiving in the 14.0-14.3 GHz band. In the primary mode, one of two 20-W TWT's is used as an amplifier for the 200-W TWT which drives antenna No. 2. The transponder can simultaneously receive 14 GHz signals via antenna No. 2, amplify and frequency translate to 12 GHz, and them amplify with the 20-W TWT and reradiate the television signals through antenna No. 1. Backup modes permit interchange of the 20-W TWT's or replacement of the 200-W with a 20-W TWT. Redundant preamplifiers consisting of three germanium tunnel diode amplifiers in series provides an overall transponder noise temperature of less than 2000°K. Table 2-6 shows the assumed transponder characteristics except for the nonlinear characteristics which are assumed to be the same as for WESTAR.

2.1.6 ATS-6 Type 2.5/6 GHz

The ATS-6 satellite is equipped with a two-channel TV transmit capability in the 2.5 GHz to 2.69 GHz band for experiments using ITV broadcast to small community terminals. The uplink signals are received at 6 GHz and translated to S-Band. The half-power beamwidth of the downlink transmissions is on the order of 0.9 degrees which corresponds to a diameter of approximately 400 miles. Refer to figure 2-6. The 30-foot diameter antenna is driven by a 12-watt solid state power amplifier for a net peak EIRP of 54 dBW. Table 2-7 summarizes the transponder characteristics assumed for the study. The nonlinear characteristics of input versus output power is of no concern in the case under consideration because only one signal will be present. Further, solid solid state S-Band power amplifiers can be built with a flat saturated output over a wide range of input levels. By operating the amplifiers well into saturation, any downlink perturbation caused by variations in the uplink due to rain, antenna pointing errors, etc., will be eliminated.

Table 2-6. Baseline CTS 12/14 GHz Transponder Characteristics.

Uplink Frequency Band	14.0 to 14.5 GHz
Downlink Frequency Band	11.7 to 12.2 GHz
Uplink Half Power Beamwidth	2.5° (two steerable)
Downlink Half Power Beamwidth	2.5° (two steerable)
On-Axis Receive Flux Density for Transponder Saturation	-91.5 dBw/m^2
Receive G/T	Peak 6.2 dB/°K
EIRP (Single carrier saturated)	Maximum 60 dBw
Bandwidth	36 MHz
Maximum Group Delay over Passband	62 Nanoseconds at ±18 MHz
Input Filter Group Delay Ripple Period	12 MHz
Gain Variation Across Bandwidth	0.25 dB
Gain Slope Across Bandwidth	0.01 dB/MHz
Input Filter Gain Slope	
-6 to +6 MHz	0.04 dB/MHz
±6 to ±12 MHz	0.07 dB/MHz
±12 to ±18 MHz	0.5 dB/MHz
Single Carrier AM/PM Conversation Coefficient at -10 dB Input	3.3 deg/dB
Output Filter Gain Slope	
-18 to -12 MHz	0.05 dB/MHz
-12 to +12 MHz	0.01 dB/MHz
+12 to +18 MHz	0.07 dB/MHz

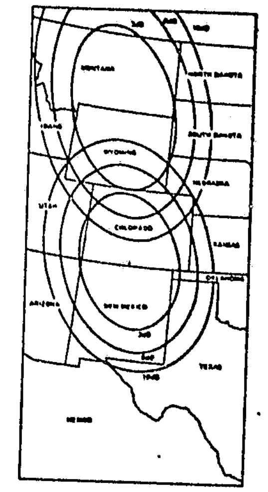

Fig. A. ETV Field of View (Midwest)

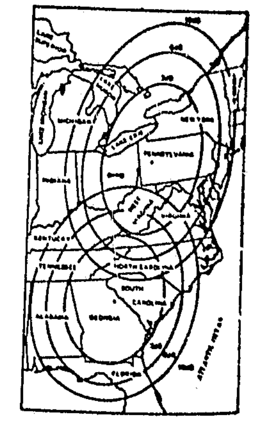

Fig. B. ETV Field of View (Southeast)

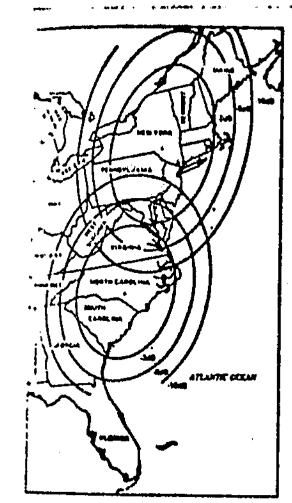

Fig. C. ETV Field of View (Northeast)

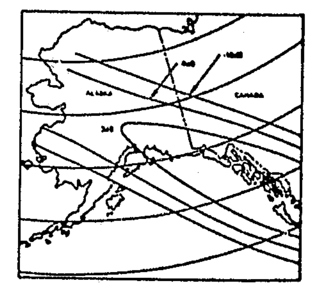

Fig. D. ETV Field of View (Alaska)

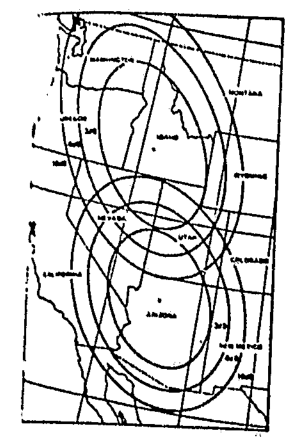

Fig. E. ETV Field of View (West)

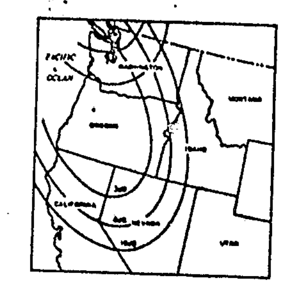

Fig. F. ETV Field of View (Northwest)

Figure 2-6. Typical S-Band Coverage Contours for ATS-6.

Table 2-7. Baseline ATS-6 Type 2.6/6 GHz TV Transponder Characteristics.

Transmit Frequencies	
Channel A Channel B	2569.2 MHz 2670.0 MHz
Receive Frequencies	
Channel A Channel B	6350.0 MHz 6149.2 MHz
Uplink Beamwidth	0.4°
Downlink Beamwidth	0.9°
On-Axis Receive Flux Density for Transponder Saturation	-91 dBw/m^2
Receive G/T	Peak 13.5 dB/°K
EIRP (Single Carrier Saturated)	Peak 53 dBw
Bandwidth	36 MHz
Maximum Group Delay over Passband	62 Nanoseconds at $\pm$18 MHz
Input Filter Group Delay Ripple Period	12 MHz
Gain Variation Across Bandwidth	0.25 dB
Gain Slope Across Bandwidth	0.01 dB/MHz
Input Filter Gain Slope	
-6 to +6 MHz $\pm$6 to $\pm$12 MHz $\pm$12 to $\pm$18 MHz	0.04 dB/MHz 0.07 dB/MHz 0.5 dB/MHz
Single Carrier AM/PM Conversation Coefficient at -10 dB Input	3.3 deg/dB
Output Filter Gain Slope	
-18 to -12 MHz -12 to +12 MHz +12 to +18 MHz	0.05 dB/MHz 0.01 dB/MHz 0.07 dB/MHz

2.2 GENERAL ANALYSIS APPROACH

2.2.1 Introduction

This section presents the general analysis approach for satellite communication links. It also defines the terms and assumptions employed in the performance analysis in sections 3.0 and 4.0. In addition to signal-to-noise analysis, this section also includes a brief discussion of the analysis approach and assumptions employed in the availability and redundancy investigations given in section 4.1.6.

For the transmission studies three measures of signal quality are used

a. for analog video signals the quality is defined as signal-to-noise ratio $(S/N) = \frac{\text{peak-to-peak luminance}}{\text{weighted rms noise}}$

b. for audio sound or telephone channels the quality is defined as output test-tone-to-noise ratio $= \frac{TT}{N} = \frac{\text{test tone}}{\text{weighted rms noise}}$

c. for digital signals the quality is defined in terms of bit error rate $= BER = \frac{\text{number of errors}}{\text{total number of bits}}$.

Where digital signals are used to convey analog information such as analog video or analog sound, it is very difficult to equate BER with S/N or TT/N. This is because the subjective effect of impulse noise caused by bit errors and the quasi-continuous noise of analog transmission systems are quite different. No rigorous attempts to determine this equivalency is made in this study. In all cases the transmission studies assume that the signals put into the transmission system are noise-free.

In the transmission studies the performance analysis relates the signal quality to a signal energy-to-noise energy type of ratio as shown above for the analog cases. In the case of digital transmissions the ratio employed is E_b/N_o where E_b is the energy per bit and N_o is the noise energy per Hertz. In transmission the signal quality is degraded by different types of noise, which may be classified as thermal noise, impulse noise, and waveform distortion caused by non-linearity and interference. In satellite links the thermal noise dominates which explains why satellite links provide excellent data transmission links compared to terrestrial telephone links which are dominated by impulse noise. Generally the available bandwidths on satellites are wide enough that waveform distortion due to bandpass characteristics can be minimized. The principal form of non-linearity is in the power amplifiers of the earth stations and the satellite transponders. The motivation for operating in the non-linear mode is to maximize the signal level for the least cost. However, when operating in such a mode with more than one signal present in the amplifier, intermodulation interference can occur. The balance of these different noises to provide the required signal-to-noise ratios by earth station and satellite transponder parameter selection is the object of a transmission study. Satellite links are also subject to external interference signals which is a function of the specific interference environment of the earth station location. This subject is not as amenable to general analysis as the effects of the other types of noises. In the transmission studies in section 3.0 outside interference is assumed to be absent. Outside interference is treated in general as a separate topic under sections dealing with earth station location and jamming in section 4.0. In general, interference analyses proceed by making assumptions regarding the level of thermal noise required to produce an "equivalent" degradation to that produced by the interference.

In the following subsections basic relationships between the satellite communication link parameters including modulation and multiple access techniques are presented. Also presented are the formulas used for computing the relationship between predetection signal-to-noise ratio C/N and output signal-to-noise SNR. These basic formulas are presented without derivation or proof although they may be in a slightly different form than the reader is accustomed. Also given are tables of assumed parameters, curves and formulas for estimating intermodulation and adjacent channel interference. The exact modulation and link parameters, weight factor assumptions, operating points and margins for the different transmission cases are given in section 3.0.

The boundaries of any space communication problem may be defined in terms of the overall communication requirements and several figures-of-merit that are identified as follows:

a. EIRP - effective radiated power relative to isotropic
b. Q_m - effective receiver/detection processing gain
c. G/T - generalized receive sensitivity factor for earth stations referred to as "G over T".
d. Q_i - ratio of external noise/interference to earth station thermal noise.

Specifically, in the following subsections it will be shown that a solution to a satellite communications problem depends upon the satisfaction of the following expression:

$$\frac{Q_m}{B_{if}\,(1+Q_i)} \geq \frac{SNR_o\, k}{P_d\, L_d} \left(\frac{G}{T_r}\right)^{-1}$$

where

- SNR_o is the required output signal-to-noise ratio in the channel baseband at the receive earth station
- k is Boltzman's constant
- P_d is the down-link EIRP of the satellite allocated to the channel of interest
- L_d is the clear-weather down-link loss between the satellite and the receiving earth station
- B_{if} is the predetection bandwidth.

Note that in general, the required clear-weather SNR_o will be greater than required to satisfy the end user's communications requirements; ie, the clear-weather SNR_o will include a margin for rain attenuation, equipment degradations, and degradations for terrestrial interconnection links with the earth station.

Certain baseline systems/methods considered in this study convert the analog signals to a digital form for transmission and reception over the satellite link. In such cases, the overall received signal quality is more conveniently determined by the bit error rate (BER). The relationship between the BER and the required signal-to-noise ratio (SNR_o) after detection is dependent upon three factors:

a. The type of message modulation employed

b. The nature of the noise/interference

c. The characteristics of the modem.

The relationship between BER and E_b/N_o (ratio of signal energy to noise power spectral density) under the assumption of Gaussian additive noise and ideal modems, has been presented in the literature for many different types of modulation.[1,2] Under the assumption of Gaussian additive noise, the only difference between E/N_o and SNR_o is the information bandwidth, B_{ch}, i.e.,

$$SNR_o = \frac{E}{B_{ch} N_o}$$

where E = total power

N_o = kT_e

k = 1.37×10^{-23} watts/Kelvin/Hertz

T_e is the system noise temperature in Kelvins.

The relationship between BER and E_b/N_o can be altered through the use of various coding techniques. The achievable BER for a given SNR_o will depend upon the particular modulation/demodulation processing equipment, its operating point, and nature of the total noise/interference.

Signal-to-noise ratio after detection is related to the predetection signal-to-noise or called the channel carrier-to-noise prior to detection in an ideal optimum detector simply by the ratio of the predetection bandwidth, B_{if}, to the postdetection bandwidth, B_{ch}, i.e.,

$$SNR_o = \frac{B_{if}}{B_{ch}} \; C/N = (\tau B_{if}) \; C/N$$

where τ = $1/B_{ch}$.

1. A. D. Walen, Detection of Signals in Noise, Academic Press, 1971.
2. Handbook of Telemetry and Remote Control, McGraw-Hill, 1967.

The time-bandwidth product, τB_{if}, is a fundamental concept in detection theory and is sometimes referred to as the modulation/demodulation processing gain.

In practice, even under the assumption of Gaussian additive noise, perfect hardware for matched filter detection is not achieved so that

$$SNR_o = (\eta_d \tau B_{if}) \; SNR_i$$

$$= Q_m \; SNR_i$$

where

η_d is a hardware degradation or implementation factor, and has a value less than unity

Q_m is the demodulation/detection quality factor of figure-of-merit.

2.2.2 Link Equations

The received signal level from the satellite to noise density ratio at the earth station receiver prior to detection is given by the expression:

$$\frac{C}{KT} = \frac{P_d L_d G_r}{kT_r + \frac{N_i}{B_{if}}}$$

where

P_d is the available satellite on-axis down-link EIRP, under the operating conditions

L_d is the downlink signal path loss due to all causes including antenna off-boresight losses

G_r is the earth station receive antenna on-axis gain referred to the input of the low-noise preamplifier

T_r is the earth station receive thermal noise temperature referred to the input of the low-noise preamplifier

N_i is all other thermal noise, nonthermal noise/interference power, etc. received in the predetection bandwidth, B_{if}.

$$L_d = \left(\frac{\lambda_d}{4\pi R_d}\right)^2 \Gamma_d \varepsilon_d$$

where

λ_d is the downlink radio wavelength

R_d is the downlink ray path distance between the satellite and earth station

Γ_d is the downlink signal loss caused by absorption and scattering along the ray path

ε_d is the downlink signal loss caused by antenna off-boresight pointing; i.e., the satellite antenna beam and earth station antennas not pointing directly at each other.

The factor N_i accounts for the fact that even in satellite communications all of the noise presented to the detector is not 100 percent pure thermal Gaussian additive noise. Further, all of the thermal Gaussian additive noise presented to the detector does not originate at the receiving terminal itself. Rather, in satellite communications, a certain amount of thermal noise presented to the detector originates within the satellite transponder and a small, but finite amount originates in the uplink transmitter of the earth station which originates the message signals. In addition, various nonlinearities and mismatches in the communication link cause equivalent colored noise-like distortions such as group/echo delay, intermodulation, and AM-to-PM conversion. Further, there is potential interference from other satellite earth stations, nearby radar systems, and nearby terrestrial radio relay communication systems.

Rearrangement of the above equation leads to

$$\frac{C}{kT} = \frac{P_d L_d}{k(1 + Q_i)} \left(\frac{G}{T}\right)_e$$

where

$$Q_i = \frac{N_i}{kT_r B_{if}}$$

The output signal-to-noise ratio, SNR_o, is given as

$$SNR_o = Q_m \frac{P_d L_d}{kB_{if}(1 + Q_i)} \left(\frac{G}{T}\right)_e$$

In general, for analog signals when nonthermal noise and interference is present, Q_m will be a function of the level and nature of the nonthermal noise and interference. In general, when the analog telephony signals have been converted to digital signals, all nonthermal noise and interference will be treated as equivalent thermal noise.

In the case where SNR_o is specified, the satellite to receive earth station geometry is specified (i.e., L_d), the satellite EIRP per channel is specified, then the required SNR_o is achieved if, and only if,

$$\frac{Q_m}{B_{if}(1 + Q_i)} \left(\frac{G}{T}\right)_e \geq \frac{SNR_o\ k}{L_d P_d} .$$

All of the initially specified/defined factors are typically on the right-hand side of the equations. All of the factors on the left-hand side of the equation are all dependent upon the particular modulation/multiple access technique/configuration and the earth station antenna and receiver. The comparative evaluation of the left-hand factors for different modulation/multiple access methods constitutes a major portion of the analytical portion of this study.

Since satellite links are typically thermal noise limited, it is of interest to know the total signal power to thermal noise that is available in the satellite link. To determine this Q_i is replaced with the uplink thermal noise referenced to the output of the transponder and the link equations are rearranged.

For example

$$\left(\frac{\hat{C}}{T}\right)_{avail} = \frac{\hat{C}_d}{T_e + \hat{T}_u} = \left[\left(\frac{\hat{C}_d}{T_e}\right)^{-1} + \left(\frac{\hat{C}_d}{\hat{T}_u}\right)^{-1}\right]^{-1}$$

where:

$$\hat{C}_d = EIRP_s L_d G_e$$

$EIRP_s$ = effective satellite radiated power in direction of receive station,

and $\hat{T}_u = G_x L_d G_e G_{st} T_s$

where G_x is the transponder electronic gain

G_e is the receiving earth station antenna gain

G_{st} is the satellite antenna transmit gain in the direction of the receiving earth station.

Now $EIRP_s = \hat{C}_u G_x G_{st} = \frac{\hat{C}_d}{L_d G_e}$, thus

$$G_x G_{st} L_d G_e = \frac{\hat{C}_d}{\hat{C}_u}$$

and

$$\left(\frac{\hat{C}}{T}\right)_{avail} = \left[\left(\frac{\hat{C}_d}{T_e}\right)^{-1} + \left(\frac{\hat{C}_u}{T_s}\right)^{-1}\right]^{-1}$$

Redefining

$$\frac{\hat{C}_d}{T_e} = \left(\frac{\hat{C}}{T}\right)_d \quad \text{and} \quad \frac{\hat{C}_u}{T_s} = \left(\frac{\hat{C}}{T}\right)_u$$

The carrier to thermal noise temperature ratio available from the satellite link is the combination of up- and down-link components as given by

$$(\hat{C}/T)_{Avail} = \left\{(\hat{C}/T)_u^{-1} + (\hat{C}/T)_d^{-1}\right\}^{-1} \qquad \text{(dBW/Kelvin)}$$

where the indicated calculation is performed using numerical ratios, not the dB values.

The equation used in section 3.0 to compute the maximum total uplink carrier to effective thermal noise temperature is

$$\max.\ (\hat{C}/T)_u = \Psi + A_i - BO_i + (\hat{G}/T)_s \qquad \text{(dBW/Kelvin)}$$

where

$(\hat{G}/T)_s$ = maximum satellite receive system gain to effective thermal noise temperature ratio (dBi/Kelvin)

Ψ = flux density required at the satellite receive antenna to saturate the output amplifier (dBW/m²)

A_i = $\lambda^2/4\pi$ = capture area of an isotropic antenna at the uplink frequency (dB-m²)

λ = wavelength corresponding to uplink frequency (dB-m)

BO_i = Backoff of transponder input power relative to the level required to saturate the output amplifier (dB).

Both Ψ and $(G/T)_s$ are functions of the satellite antenna uplink patterns. Thus to achieve the max $(\hat{C}/T_u)$ requires that the uplink earth stations be located at the point on the satellite uplink beam where $(G/T)_s$ is maximum. If the total uplink signal power is the sum of a number of earth stations at different locations in the beam, then the effective $(G/T)_s$ will be a weighted sum of the $(G/T)_s$ values corresponding to the earth station locations within the uplink beam.

For a single earth station transmitting $EIRP_e$ the resulting input backoff is

$$BO_i = \Psi + A_i + L_u - EIRP_e$$

where L_u is the uplink losses in dB.

Uplink losses, L_u, include free space loss, rain margin, operating margin, loss due to pointing errors in earth station or satellite antennas, and antenna polarization mismatch losses.

The equation used in section 3.0 to compute the downlink carrier to effective thermal noise temperature ratio is given by,

$$(\hat{C}/T)_d = EIRP_s - L_d + (G/T)_e - BO_o \qquad \text{(dBW/Kelvin)}$$

where

$EIRP_s$ = Equivalent isotropically radiated power from the satellite (dBW)

L_d = Downlink losses (dB)

$(G/T)_e$ = Earth station receive system gain to effective thermal noise temperature ratio (dBi/Kelvin)

BO_o = Backoff of transponder output amplifier power below the saturated level (dB).

2.2.3 Determination of Satellite Capacity

2.2.3.1 General

The term satellite capacity in this report refers to the number of channels or the maximum data rate which can pass simultaneously through the satellite and satisfy the required baseband channel output signal-to-noise ratio at each of the user earth stations. In general, the satellite capacity depends upon the earth station characteristics, the desired output signal-to-noise ratio, and the satellite characteristics as well as the modulation characteristics/parameters. In general, the system capacity of a satellite communication system is referred to as being either bandwidth-limited or power-limited (meaning downlink power limited). Rarely, but sometimes, the capacity can be uplink limited, such as when there is excessive noise in the earth station transmission, or the G/T of the satellite transponder is too low.

Basically, the determination of the satellite capacity is solving the fundamental inequality presented at the beginning of this section. The first step is the determination/specification of the signals to be transmitted and the required transmission quality. The second step is to select a modulation/demodulation technique. If a number of signals are to share the satellite transponder then a satellite accessing technique must be selected which is compatible with the modulation/demodulation technique or vice-versa. The next step is to determine the minimum required predetection carrier-to-total-noise C/N ratio which is required to achieve the desired signal quality. To this is added a reasonable implementation margin or safety factor to account for unanticipated or unknown degradation factors which could reasonably occur over the operational life of the equipments. The result is (C/N) operational.

The next step is to balance all of the thermal and non-thermal noises by earth station and satellite transponder parameter selection to provide the required (C/N) operational for the maximum number of channels or bits.

To compute capacity of a communication satellite it is simplest to assume that all the earth stations and paths are identical. In practice the computation can be reduced to a single transmit earth station with the

average or standard characteristics, an uplink path with average or worst case characteristics depending upon the desired safety factor, a satellite transponder with the maximum, average, or worst case performance expected, and an average or worst case downlink path and earth station characteristics.

For this link the maximum $(\hat{C}/T)$ available is computed. Then the other noise factors applicable to the channels according to their rf bandwidth and location in the frequency spectrum are computed. For capacity determination, either the average or worst case channel can be used according to the amount of margin desired with respect to minimum guaranteed performance.

In terms of the initial generalized formulas

$$Q_i = \frac{N_{IM} + N_{AC} + N_{IN} + N_u}{k B_{if} T_e}$$

where

N_{IM} is the equivalent intermodulation noise due to the nonlinearities in the satellite, and earth station amplifiers

N_{AC} is the equivalent adjacent channel interference noise

N_{IN} is the equivalent interference noise from other sources

N_u is the uplink thermal noise.

The term equivalent noise refers to a thermal noise level in the predetection bandwidth B_{if} which produces the same equivalent level of degradation in the output of the demodulated signal. For sound and video the determination of the equivalent noise level is highly subjective. In this study equivalency was considered to correspond to equal energy levels in the B_{if}.

Q_i can be expressed in terms of channel carrier-to-noise ratios, i.e.,

$$Q_i = \frac{(C/N_{IM})^{-1} + (C/N_{AC})^{-1} + (C/N_{IN})^{-1} + (C/N_u)^{-1}}{(C/N_d)^{-1}}$$

Substituting

$$\frac{\xi L_d P_d}{k B_{if}(1 + Q_i)} \frac{G}{T_e} \geq (C/N)_{operational}$$

where ξ is the fractional part of the downlink power devoted to a channel.

The terms on the left-hand side, L_d, P_d, Q_i and $(G/T)_e$ must be selected or evaluated until equality is achieved. The number of channels, or the maximum data rate corresponding to equality is the satellite capacity.

2.2.3.2 Threshold Carrier-to-Noise Ratios.

A number of modulation processes trade increased occupied bandwidth at rf for reduced predetection signal-to-noise at the input to demodulator. This permits a reduction of the overall transmission gain and permits reduction of the satellite downlink power or, alternatively, a reduction in the earth station antenna gains. Optionally, if the total available satellite power is fixed, the reduced satellite power requirements per channel permit an increase in the number of channels provided some other constraint limit such as the limit on interchannel interference has not been reached.

For digital modulation techniques, the threshold carrier-to-noise power ratio in decibels is given by

$$(C/N)_{Threshold} = (E_b/N_o) - G_c + R_b - B_{if} + M \quad \text{(dB)}$$

where

(E_b/N_o) = Ratio of energy per information (uncoded) bit to noise power density for the required error probability (db-Hz-sec/bit)

G_c = Coding gain (dB)

R_b = Information (uncoded) bit rate (dB-bit/sec)

B_{if} = Predetection noise bandwidth (dB-Hz)

M = Modem implementation margin (dB).

For the purposes of this study, the following relationship is assumed relating R_s and B:

$$B_{if} = 1.2 R_s.$$

This a commonly assumed relationship and several operational digital satellite communication systems (e.g.,the SPADE system) follow this relation, and therefore measured values are available for the implementation margin. In general, required implementation margin increases with increasing bit rate and decreasing error probability. Where possible, implementation margins will be broken down into a modem margin (back-to-back modems at if) and a degradation margin due (primarily) to bandwidth limitations, lack of equalization, and non-linearities in the satellite transponder. Under this assumed relationship between R_s and B, the threshold carrier-to-noise expression becomes

$$(C/N)_{Threshold} = (E_b/N_o) - G_c + 2.2 + 10 \log R_{co} + M \quad \text{(dB)}.$$

where

R_{co} = Coding rate = information bit rate/channel bit rate

G_c = Coding gain

M = Modem implementation margin dB.

The required theoretical E_b/N_o for the required BER is available in many textbooks and tutorial papers.[1,2]

The waveform of a sinusoidal rf carrier frequency modulated by a sinusoidal signal may be expressed as

$$A \cos(\omega_o t + D \sin \omega_m t)$$

where

A = peak amplitude

ω_o = $2\pi f_o$, f_o being the frequency of the rf carrier

ω_m = $2\pi f_m$, f_m being the frequency of the modulating sinusoidal.

D = frequency modulation index.

1. Walen, A.D., Detection of Signals in Noise, Academic Press, 1971
2. Handbook of Telemetry and Remote Control, McGraw-Hill, 1967

The output signal-to-noise ratio for an ideal FM receiver for a sinusoidal modulating signal and a high input carrier-to-noise ratio and rectangular filters is:

$$\frac{S_o}{N_o} = \frac{3}{2} D^2 \frac{C}{N} \left(\frac{B_{if}}{f_m}\right)$$

where

S_o = mean-square of output sinusoidal signal voltage

N_o = mean-square of output noise voltage in the output bandwidth of f_m.

C = mean-square of carrier voltage; $C = \frac{A^2}{2}$

N = total predetection noise in if bandwidth of B_{if}

f_m = frequency of the modulating sinusoid

D = frequency modulation index; $D = \frac{\Delta f}{f_m}$

Δf = peak frequency deviation.

Using Carson's rule the required predetection bandwidth to pass the signal is,

$$B_{if} = 2 (\Delta f + f_m).$$

Neither an audio signal or a video signal represents a sinusoidal waveform. However, audio circuits are set up and tested by using a psophometric weighted 1000 Hz test tone. Performance in this study is derived on the basis of test-tone-to-weighted-noise ratios for the audio signals in which case the above equations apply. Video signals have very little energy at the high frequencies of the baseband, with most of the energy occurring at the low end at the line and frame frequencies. There is a choice in expressing the video signal-to-noise in terms of deviation of the low frequency portion or the high frequency portion. In this report the latter approach will be taken.

The CCIR recommends that the signal-to-noise ratio for TV signals be expressed in terms of the ratio:

$$\frac{\text{Peak-to-Peak Luminance Signal}}{\text{Weighted rms Noise}}$$

Since for a sine-wave the (power) ratio of the peak-to-peak and rms values is eight, and since the peak-to-peak value of the luminance component is 0.707 of the peak-to-peak value of the composite video signal, the above mentioned (power) ratio must be halved. Sinusoidal So/No formulas must be multiplied by a factor of 4 to agree with the CCIR definition of S/N for TV, yielding

$$\frac{\text{Peak-to-peak Luminance Signal}}{\text{Average Noise Power}} = \frac{S_{p-p}}{N} = 6 D^2 \frac{C}{N} \left(\frac{B}{f_v}\right).$$

If pre-emphasis of the video signal is employed, the complementary de-emphasis network will modify the noise spectrum and W will be the weighting improvement after de-emphasis. The term W also includes the weighting improvement due to the relative subjective effects of noise components of varying frequency as specified by the CCIR. Therefore,

$$\frac{\text{Peak-to-Peak Luminance Signal Power}}{\text{Weighted Average Noise Power}} = \frac{S_{p-p}}{N_W} = 6 D^2 \frac{C}{N} \left(\frac{B}{f_v}\right) W.$$

For the case where the audio is frequency modulated onto a subcarrier with the video, the audio rms test tone to noise ratio is

$$\frac{S}{N} = \frac{3}{4} \frac{C}{N} \frac{B_{if}}{f_a} \left(\frac{\Delta F_a}{f_{sc}}\right)^2 \frac{\Delta F_{sc}}{f_a^2} P_1 W_a$$

where

f_{sc} = subcarrier center frequency

ΔF_a = Peak carrier deviation due to audio subcarrier

ΔF_{sc} = Peak subcarrier deviation

f_a = Audio baseband

P_1 = Wideband preemphasis improvement of subcarrier

W_a = Subcarrier preemphasis + noise weighting improvement

In the case of analog television frequency modulated on an rf carrier, the expression used in section 3.0 for the threshold C/N in decibels is,

$$(C/N)_{Threshold} = SNR_{\omega} - 10 \log 6 - 10 \log B_{if} - 20 \log D_v + 30 \log f_v - W_v$$

where

SNR_{ω} = Peak-to-peak luminance signal level to the weighted rms noise level required (dB)

B_{if} = Predetection noise bandwidth (Hz)

D_v = peak video deviation (Hz)

f_v = video bandwidth (Hz)

W_v = Noise improvement factor in dB due to noise weighting and de-emphasis.

B_{if} is given by Carson's rule given previously.

When the sound channel is frequency modulated onto a subcarrier and sub-multiplexed with the video, the ideal predetection noise bandwidth is calculated using Carson's Rule:

$$B_{if} = 2 (D_v + D_{sc} + D_E + f_m + d_a) \text{ Hz.}$$

where D_{sc} = peak deviation of the carrier by a subcarrier

D_E = peak deviation of the carrier by the energy dispersal signal.

f_m = audio subcarrier frequency or f_v if a subcarrier is not used

d_a = deviation of the subcarrier by the audio program material.

When the sound is frequency modulated onto a subcarrier and submultiplexed with the video the subcarrier threshold C/N expressed in decibels is,

$$(C/N)_{threshold} = SNR_{asc} - 10 \log 0.75 - 10 \log B - 20 \log D_{sc} - 20 \log d_a + 20 \log f_{sc} + 30 \log f_a + W_a \text{ (dB)}$$

SNR_{asc} = test-tone to weighted rms noise ratio

where f_p = highest audio frequency in Hz

W_a = noise improvement in dB due to program preemphasis (dB).

When the sound is frequency modulated onto a separate rf carrier the threshold C/N is given by

$$C/N_{threshold} = SNR_a - 10 \log 1.5 - 10 \log B_a - 20 \log d_a + 30 \log f_a - W_a$$

where B_a = IF bandwidth of audio channel

$= 2 (d_a + f_a + f_o)$

f_o = allowance for transmitter and receiver frequency offset.

2.2.3.3 Multiple Access Techniques

Accessing a common satellite transponder by a number of earth stations requires careful consideration if reasonable and/or optimum use of the transponders total communications resources is to be realized. In general, there are three methods of multiple accessing the satellite transponders of the type assumed for this study:

a. Frequency Division Multiple Access (FDMA)
b. Time Division Multiple Access (TDMA)
c. Code Division Multiple Access (CDMA).

In FDMA each earth station, or user channel, is assigned a specific non-overlapping portion of the transponder bandwidth; that is, each up-path radio-frequency carrier occupies a particular frequency allocation. All radio-frequency carriers are amplified simultaneously and translated to a new set of frequencies in the down path. The earth receiving station filters out the desired radio-frequency carrier or carriers prior to demodulation. (It may be necessary in addition to select channels addressed to that station.)

TDMA at radio frequency requires that all participating earth stations transmit periodically in non-overlapping sequence such that the communication repeater in the satellite is only amplifying the signals of one earth station at any instant. Thus, the output signal of the satellite repeater is a constant envelope signal and power backoff loss and intermodulation products are avoided. A particular earth station receiver identifies the desired transmission by observing the information in the periodically distributed time slots associated with the corresponding earth station. It is immaterial whether the same or slightly different radio frequency carriers are used by all earth stations, but minimum system bandwidth is achieved when all use the same radio frequency carrier.

In the common spectrum systems the signals from all of the participating earth stations make common use of the time-frequency domain, and receive processing is employed to detect a wanted signal, in the presence of others. Transmission channels between ground stations are distinguished by means of their characteristic quasi-orthogonal codes which are time-frequency functions that occupy the same spectral bandwidth. By design, two or more signals at the same frequency can exist instantaneously in such systems. Three typical approaches to providing multiple-access capability are: spread spectrum, frequency-time matrix, and frequency-hopping.

In this study only FDMA has been considered to any extent. In a number of cases, only one signal is assumed to use the satellite in a broadcast type of mode.

In the case of equal channel size FDMA, then the available channel power at the earth station is $\hat{C}/n$ where n is the number of channels.

Once the non-thermal noise levels are determined the allowable thermal noise contribution to the channel C/N is given by the relationship,

$$(C/T)_{allow} = \left[(C/N)^{-1}_{op} - \left(\frac{C}{N_{ac}}\right)^{-1} - \left(\frac{C}{N_{IM}}\right)^{-1} + \left(\frac{C}{N_{IN}}\right)^{-1} \right]^{-1}$$

where all addition is in ratios, not dB. In order to support n channels, then,

$$\frac{1}{n}\left(\frac{\hat{C}}{T}\right)_{avail} \geq \left(\frac{C}{T}\right)_{allow} .$$

In decibels, the maximum capacity in number of channels N is obtained when

$$10 \log_{10} [N] \geqq \left(\frac{\hat{C}}{T}\right)_{avail} - \left(\frac{C}{T}\right)_{allow} \quad \text{dB}$$

where [N] indicates the largest integer which satisfies the above inequality.

The maximum value used for carrier to adjacent channel interference ratio in all FDMA cases is 26 dB. This value is based upon an Intelsat analysis of the SPADE system where the spectrum of each transmitted QPSK modulated carrier has the shape

$$G(\omega) = \left[\frac{\sin \frac{\omega T}{2}}{\frac{\omega T}{2}}\right]^2 \left[\frac{1}{1 + \omega^{14}}\right] .$$

In the SPADE system, the approximate relationships between QPSK symbol rate, Rs, noise bandwidth, Bn, and carrier spacing, Δf, are

$$B_n = 1.2 \text{ Rs and } \Delta f = 1.2 B_n .$$

By preserving these relationships and assuming the same composite filter shape for the composite transmit-receive channel filters, the $(\frac{C}{N})AC$ value of 26 dB is also preserved. In some 50 Kbps FDMA cases, the values used are scaled to reflect a larger Δf relative to B_n where available transponder bandwidth permits wider spacing and the adjacent channel interference is reduced.

Where a single high data rate signal occupies the satellite transponder the capacity calculation involves determining the maximum data rate. Two single high data rate carrier cases are analyzed in this study; (1) a time division multiplex of T1 carriers tramsmitted on a single carrier, and (2) a time division multiplex of T1 carriers with 1/2 rate convolutional encoding and soft decision Viterbi decoding.

The threshold carrier-to-noise ratio is calculated from the expression

$$\left(\frac{C}{N}\right)_{threshold} = \frac{E_b}{N_o} - G_c + R - B + M$$

where

$(\frac{C}{N})_{threshold}$ = demodulator threshold carrier-to-noise ratio, in dB, for probability of error of 10^{-5}.

G_c = coding gain, in dB ,

R = information (uncoded) bit rate, in dB

B = predetection noise bandwidth, in dB

M = receiver implementation margin, in dB, As discussed previously, the relationships between information bit rate, R, QPSK symbol rate, Rs, and channel noise bandwidth, B, are

$$B = 1.2\ Rs = 1.2\ (1/2\ R) = 0.6\ R.$$

Furthermore, R is a multiple of the T1 rate of 1.544 mbps, thus

$$R = n(T1) \text{ and } B = 0.6\ n(T1)$$

where

n = number of T1 channels

T1 = 1.544 mbps.

Thus, it follows that

$$\left(\frac{C}{N}\right)_{threshold} = \frac{E_b}{N_o} - G_c - 10 \log 0.6 + M$$

$$= \frac{E_b}{N_o} - G_c + 2.2 + M. \text{ (uncoded)}$$

Total carrier-to-noise ratio is given by the expression

$$\frac{C}{N} = \left\{ \left[\left(\frac{C}{N}\right)_u - M_u \right]^{-1} + \left[\left(\frac{C}{N}\right)_D - M_D \right]^{-1} \right\}^{-1}$$

$$= \left(\frac{C}{N}\right)_{LINK} = \left(\frac{C}{T}\right)_{LINK} - K - B$$

where the terms are as defined in the FDMA section. Note that since only one carrier is present in the TDM cases, the $\left(\frac{C}{N}\right)_{IM}$ term is not included. Also, no adjacent channel interference exists. The maximum bandwidth which may be occupied is computed from the available link carrier-to-noise and the threshold carrier-to-noise by the relation

$$B = \left(\frac{C}{T}\right)_{LINK} - K - \left(\frac{C}{N}\right)_{threshold} \quad \text{(dB - Hz)}$$

where

K = 228.6 dBw/Hz/Kelvin = Boltzmann's Constant

$\left(\frac{C}{T}\right)_{LINK}$ = Carrier to noise temperature of the link, in dBw/Kelvin, as calculated by the link analysis computer program.

Then, the number of T1 channels supported is

$$n = \left[B/(.6)\ (T1) \right] \quad \text{for the uncoded case}$$

$$n = \left[B/(1.2)(T1) \right] \quad \text{for the rate 1/2 coded case}$$

where the brackets [ ] mean truncation to integer.

2.2.4 Intermodulation Analysis

When two or more carriers access a single satellite transponder, non-linear effects in the output amplifier produce intermodulation components. The level and distribution of these products is a function of the number of carriers accessing the transponder, their relative power levels, and carrier spacing, and amplifier operating point. The amplifier operating point is specified, relative to saturation power, by the input backoff BO_i, or the output back BO_o. In this study, it is assumed that the carriers are uniformly spaced in frequency. Under this assumption, the intermodulation noise density approaches a triangular distribution as the number of carriers becomes large (greater than 25 or 30). Thus, a worst case channel exists, and the analysis carried out in later sections applies to this worst case channel. For the 50 kbps (channel rate) FDMA cases, the intermodulation model chosen is based upon analysis of the SPADE system and is shown in Table 2-8. For the T1-rate FDMA cases, a more complicated intermodulation model is required, because fewer carriers are involved, and the intermodulation noise level is a function of the number of carriers. Figure 2-7 has been adopted as the intermodulation model for the T1-rate FDMA cases.

Table 2-8. Intermodulation Versus Satellite Input Backoff for 50 Kbps SCPC FDMA Cases

BO_i - Input Backoff (DB)	(C/N) AM/PM (DB)	(C/N) AM (DB)	(C/N) IM (DB)
0	13.3	9.1	7.7
1	14.2	9.8	8.5
2	15.6	10.6	9.4
3	14.9	11.4	9.8
4	14.8	12.2	10.3
5	14.8	13.0	10.8
6	14.8	14.2	11.5
7	15.0	15.4	12.2
8	15.4	16.8	13.0
9	16.1	18.3	14.1
10	16.9	20.1	15.2
11	18.0	21.8	16.5
12	20.2	23.6	17.9
14	22.7	25.6	20.9
16	27.2	27.6	24.4
18	33.5	29.6	28.1

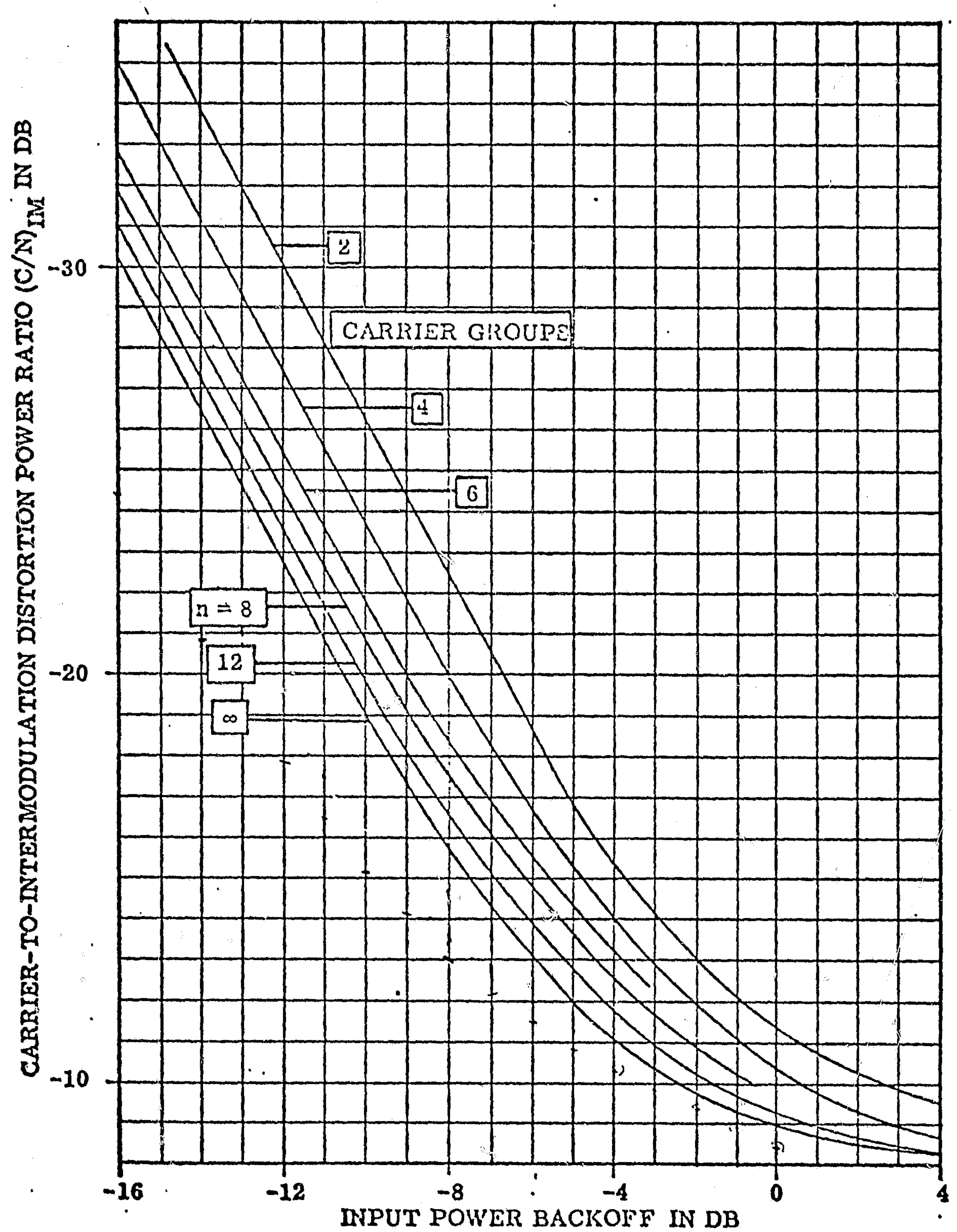

FIGURE 2-7 Approximate Variation in Total Intermodulation Ratio With Input Power for Various Numbers of Carrier Groups, n.

2.2.5 Jamming and Interference Analysis

2.2.5.1 Introduction

Jamming refers to the deliberate radiation of a signal into the receive antennas of a communication system with the intent of degrading the performance of that communication system. The primary difference between jamming and unintentional interference is the intent on the part of transmitting operator. The extent to which a jamming or interference signal degrades the performance is dependent upon many factors. In the case of analog video, and sound the extent of the degradation is a very highly subjective evaluation. A large amount of technology has been developed dealing with jamming. In general, exact analysis is a difficult task because one is not dealing with Gaussian additive noise. Most analyses try to establish upper and lower bounds of degradations for a given interference or jamming situation. General analyses try to establish an equivalent level of thermal noise in the predetection bandwidth which will cause degradation equivalent to the interference or jamming degradation. The simplest approach to estimating the degradation is to estimate the total interferring energy in the predetection bandwidth and simply treat it as thermal noise. Such an estimate can be optimistic or pessimistic according to the actual situation. For simplicity in this brief study, this is the technique adopted in most cases. The accurate analyses can be conducted for simple waveform cases and require accurate knowledge of waveform, relative signal levels, details of the detection process, relative frequency and phase, etc. For complex signals, the most accurate estimates have to resort to extensive experimental data.

In addition to the entry of undesired energy into the predetection bandwidth of the receiver, there is also the possibility of a high level jamming signal changing the operating point of the satellite transponder power amplifiers and the earth station low noise preamplifier from a linear region to a nonlinear region. Thus additional degradation can occur because of the non-linearities. Regardless of whether the satellite transponder is operating in a linear or non-linear region, the presence of a jamming or unauthorized signal reduces the total downlink power available for the desired/authorized signal.

2.2.5.2 CW or Spot-Noise Jamming Without Non-Linear Effects

The objective of this jamming technique is to center a jammer signal on the center frequency of the signal to be obscured. Lacking precise knowledge of this center frequency the jammer can frequency modulate the jammer signal to provide an energy spectrum with a high degree of overlap. The ratio of the desired energy to the jammer energy can be expressed in simple forms although the individual terms can be quite difficult to evaluate. The predetection carrier-to-noise ratio degradation can be expressed as

$$(C/N)_{Wjt} = \frac{C/N}{1 + S_{j/N}}$$

Where

C/N is the carrier-to-noise without jamming

$(C/N)_{Wjt}$ is the carrier-to-noise ratio with jamming

SjN is the ratio of the jammer energy in the predetection bandwidth to the noise energy in absence of jamming.

This can also be expressed as

$$(C/N)_{Wjt} = \frac{C/N}{1 + (C/N)\ (S_j/C)}$$

where: $S_j = \alpha\ P_j\ L_j\ G_{aj}$

$C = P_d\ L_d\ G_e$

where α is a bandwidth overlap factor between 0 and unity

P_j is the EIRP of the jamming source

L_j is the path losses between the jamming source and the antenna of the system under attack

G_{aj} is the antenna gain of the system under attack to the jammer signal

P_d is the EIRP of the desired signal source

L_d is the path losses between the desired signal source and the system under attack

G_e is the antenna gain of the system under attack to the desired signal.

Where both the desired signal source and the jammer signal source have a far-field line-of-sight LOS relationship with the antenna of the system under attack the ratio S_j/C

$$S_j/C = \frac{\alpha P_j R_j^2 G_{aj}}{P_d R_d^2 G_e}$$

where R_j is the distance the jammer antenna is located from the system under attack

R_d is the distance the desired signal is under attack.

For CW jamming of the satellite it is relatively easy for the jammer to locate so to have essentially equal antenna gain advantage. In such a case the distance factors are essentially the same, so

$S_j/c \approx \alpha P_j/Pd$ for satellite jamming.

It is more difficult to locate a jammer in the main beam of the earth station antenna. Therefore, a significant difference in antenna gain can be expected. To achieve the same threat level in the absence of non-linear effects, the jammer must be located much closer to the earth station. In most cases this is required anyway in order to maintain LOS conditions postulated for the distance formulas. Table 2-9 shows the distances which the jammer would have to locate on an LOS basis to achieve the same threat level as jamming the satellite directly in the absence of non-linear effects.

It is of interest to determine the amount of broad band noise jamming (which is the simplest case to analyze) required to induce a minimum signal-to-noise degradation. Assume the jammer noise density to be

N_{jo} at the receiver input.

Table 2-9. Approximate Maximum LOS Distance Between CW Jammer and Receiving Earth Station to Equal Satellite Jamming In Absence of Non-Linearities.

Difference in Antenna Gain (dB)	LOCATION	
	CHICAGO Distance in Miles	MIAMI Distance in Miles
40	235.3	230.0
50	74.4	72.7
60	23.5	23.0
70	7.4	7.3
80	2.35	2.3
90	0.7	0.7
100	0.2	0.2

Notes:

1. Assumes satellite to Chicago distance is 23526 miles and satellite to Miami distance is 23,000 miles.

If the broadband noise jammer operates over a bandwidth B_j the received jammer power is $B_j N_{jo} B_j$. Thus, the amount of jammer energy in the predetection bandwidth B is

$$S_j = B N_{jo}/B_j.$$

2.2.5.3 CW or Spot-Noise Jamming of Satellite with Non-Linear Effects

If the satellite transponder is operating in a non-linear mode and/or if the jammer signal level drives the satellite transponder into a non-linear mode three effects can occur even if the jammer is not overlapping any satellite signal:

a. Downlink power of the desired signal is reduced
b. Additional intermodulation interference is created
c. Backoff point in transponder changed.

An additional effect, of course, can be reduction of signal-to-noise because of the overlapping jamming power. The degree to which these effects occur depend upon the composite signal in the satellite in the absence of jamming, the level and nature of the jamming signal, the characteristics of the transponder power amplifier, etc. Further, because all of these effects can occur simultaneously in a highly non-linear fashion, there are no simple analysis techniques for estimating the result. In this section, each of the three effects above will be discussed briefly as if they were independent only in order to give insight into the effects.

When a jamming signal and one or more desired signals are simultaneously amplified in a common satellite transponder, the desired signals are both distorted by intermodulation more and partially suppressed. Distortion occurs when the jammer and desired signals drive the satellite transponder TWTA into its non-linear operating region generating interferring intermodulation products. The degree to which intermodulation noise interferes with the desired signals is a complex function of the exact TWTA non-linearity.

The downlink power of the desired signal can be reduced in several ways. First, since the satellite TWTA is power limited, presence of the jammer forces the fixed TWTA output power to be divided among all input signals including the jammer in proportion to their relative input amplitudes. Even though the desired signal requires all of the TWTA output power for proper link operation, a jamming signal much larger in amplitude could take most of the TWTA power and thus suppress the desired signal.

A second cause of desired signal suppression can be attributed to "small-signal suppressions" effects in a non-linear TWTA. Presence of a strong jamming signal together with one or more smaller desired signals in a non-linear TWTA will cause the relative power difference between high and low level signals to increase after amplification. Since the TWTA is a power limited device, the increase in the relative power difference comes at the expense of the smaller signals. For example, if the jamming signal strength were 20 dB greater than the desired signal strength at the satellite input, the differential would be greater than 20 dB at the output resulting in further reduction of the smaller signal power. This effect could also occur among desired signals either by design (as in the case of separate carriers for video and audio transmissions) or by improper operational procedures with respect to earth station EIRP level control.

The amount of small signal suppression depends upon the exact satellite TWTA and operating point as well as the relative difference between input signals. Figure 2-8 illustrates the small signal suppression that may be expected for the case of a jammer interferring with a desired signal of sufficient power to operate the TWTA one 1dB below saturation. An interferring jammer would then drive the TWTA into saturation causing small signal suppression.

These curves were obtained using a Collins computer program that simulates the effects of the non-linear transponder on a given set of input signals.

Figure 2-9 shows the satellite non-linearity assumed for both of the TWTA curves of figure 2-8. Figure 2-8 is for a TWTA with the amplitude non-linearity of the WESTAR satellite presented in table 2-3 but extended past saturation as shown. Note that the small signal suppression for this curve increases rapidly as the jamming signal drives the TWTA past saturation. Figure 2-9 also shows the same WESTAR non-linearity extended past saturation by assuming a constant output power. (Case L) The small signal suppression for this case appears to reach a bound at -6 dB.

Since actual satellite TWTA non-linearity curves would probably fall between these two extremes, these two cases bound the small-signal suppression that may be expected.

Figure 2-8 also shows the small signal suppression that would occur if the satellite TWTA were preceded by a hard limiter. Note that small signal

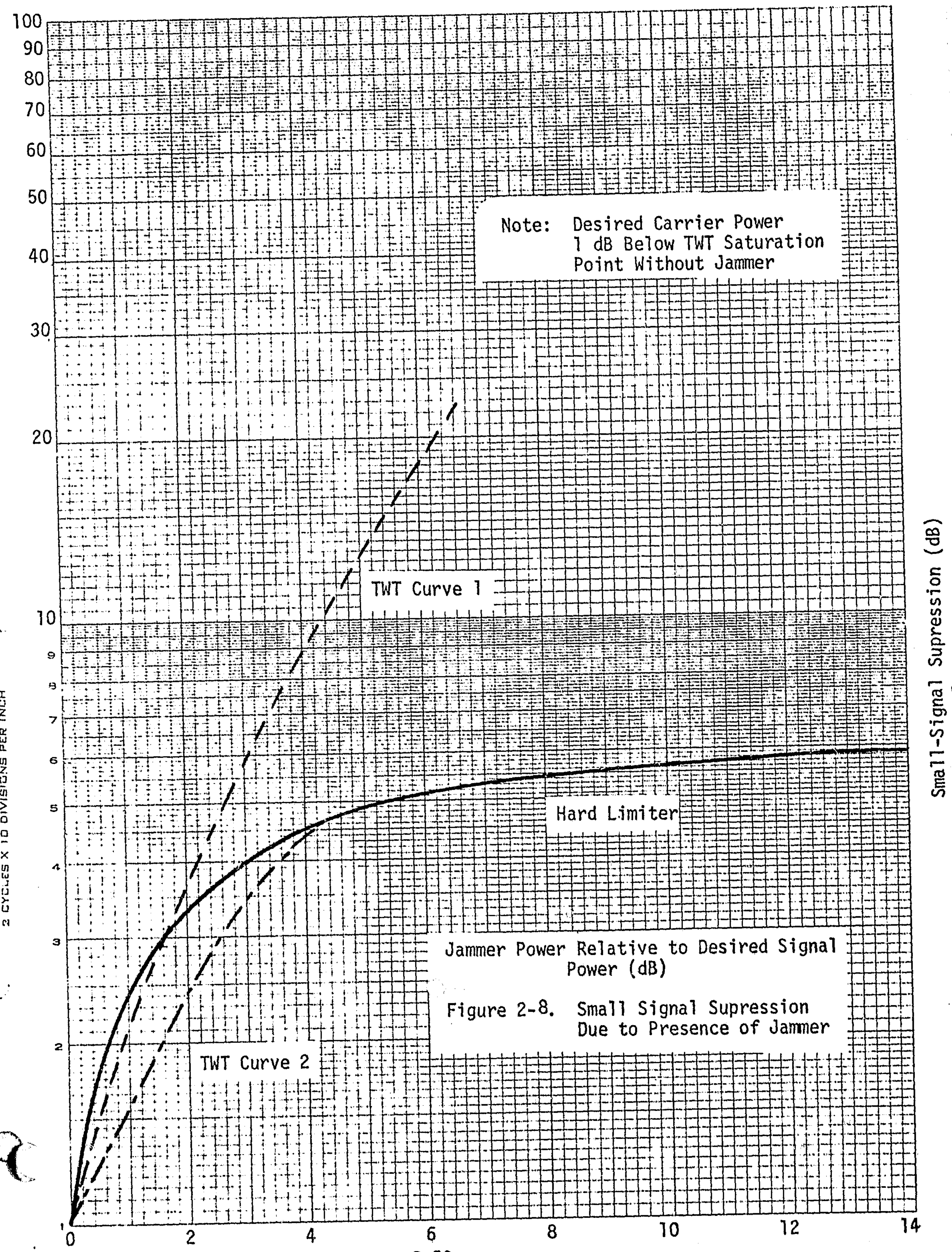

Figure 2-8. Small Signal Supression Due to Presence of Jammer

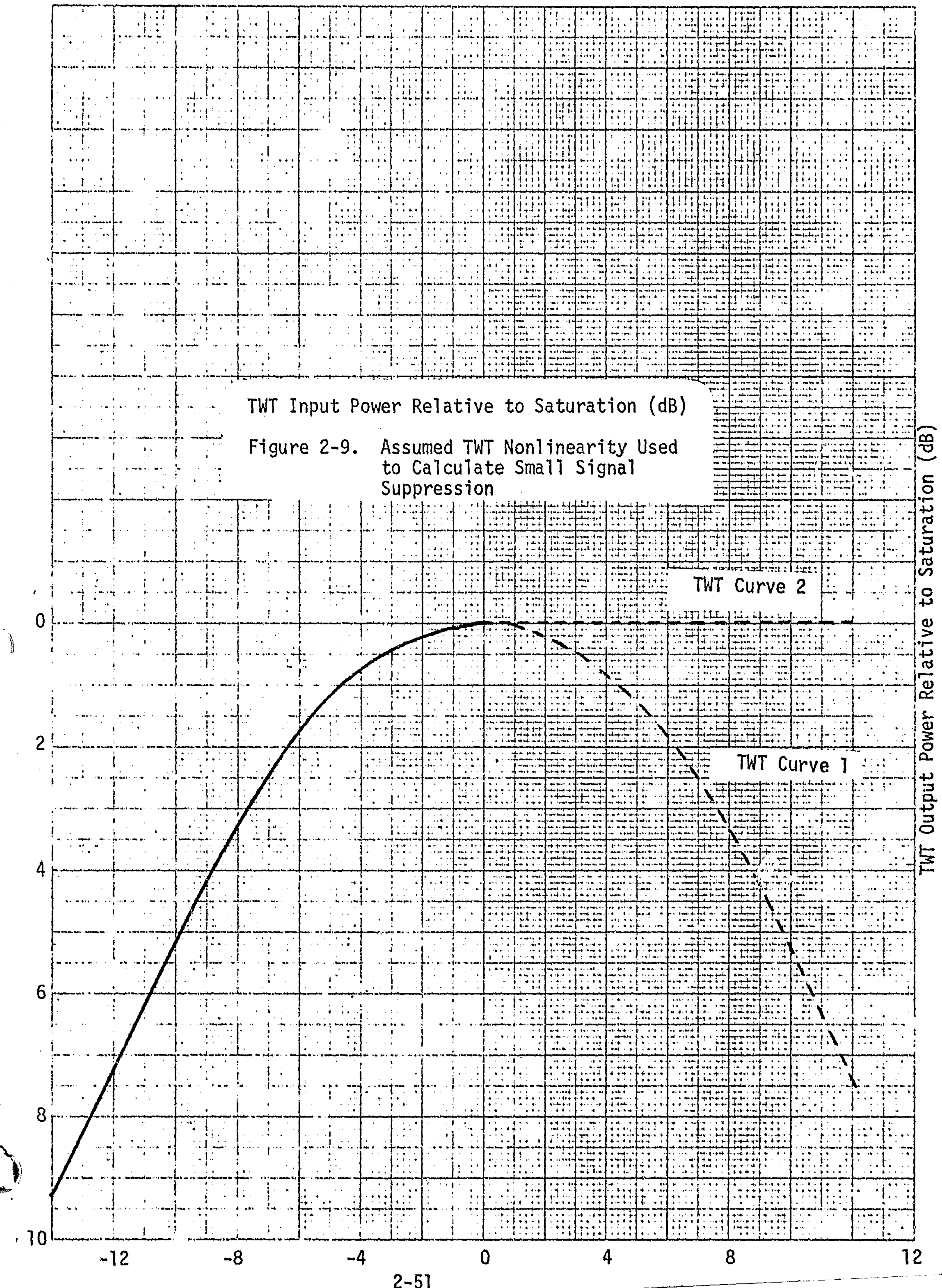

Figure 2-9. Assumed TWT Nonlinearity Used to Calculate Small Signal Suppression

suppression with a hard limiter asymptotically approaches -6 dB as the difference between desired and jamming signals increases. Since the satellite non-linearity shown in figure 2-9 is nearly identical to that of a hard limiter when operated well past saturation, the small signal suppression realized with that TWTA closely approximates that of the hard limiter.

Military satellites frequency utilize hard limiters as a means to limit the small signal suppression a jammer may cause. Although a jammer may still suppress a desired signal due to power splitting considerations discussed earlier, he must pay a much higher price to do it.

The total desired signal suppression due to power splitting and small signal suppression is shown in figure 2-10. A jammer capable of simply saturating the TWT ($\frac{Pj}{Ptv}$ = 1 dB) would suppress the desired signal power by between 5 and 7 dB. Depending upon operating margins, this may be sufficient to reduce the desired signal power below threshold for a discriminator type demodulator. Additional jammer power would ensure that the desired signals are suppressed below the ground receiver demodulator threshold.

In the case where the satellite is not operating near saturation because of the need to suppress the intermodulation effects among FDMA signals, a small jammer signal sufficient to move the backoff point can increase the intermodulation interference level among the desired signals sufficiently to result in unacceptable link performance. For example, refer to table 2-8. Assume that the BO_i is 12 dB in order to achieve the optimum balance point between the satellite intermodulation noise and the rest of the system noise. If the required link C/N to the demodulator is 14 dB, then the C/N in absence of satellite intermodulation noise would be 16.27 dB. A change in the intermodulation to noise level to 12.53 would result in a degradation of the link C/N by 3 dB. From table 2-8, a change in BO_i to about 7.4 dB would achieve this result without considering any additional intermodulation noise introduced by the jammer signal. A BO_i of 7.4 dB is still a considerable way from the saturation point where the small signal suppression and power loss by harmonic generation become totally dominant.

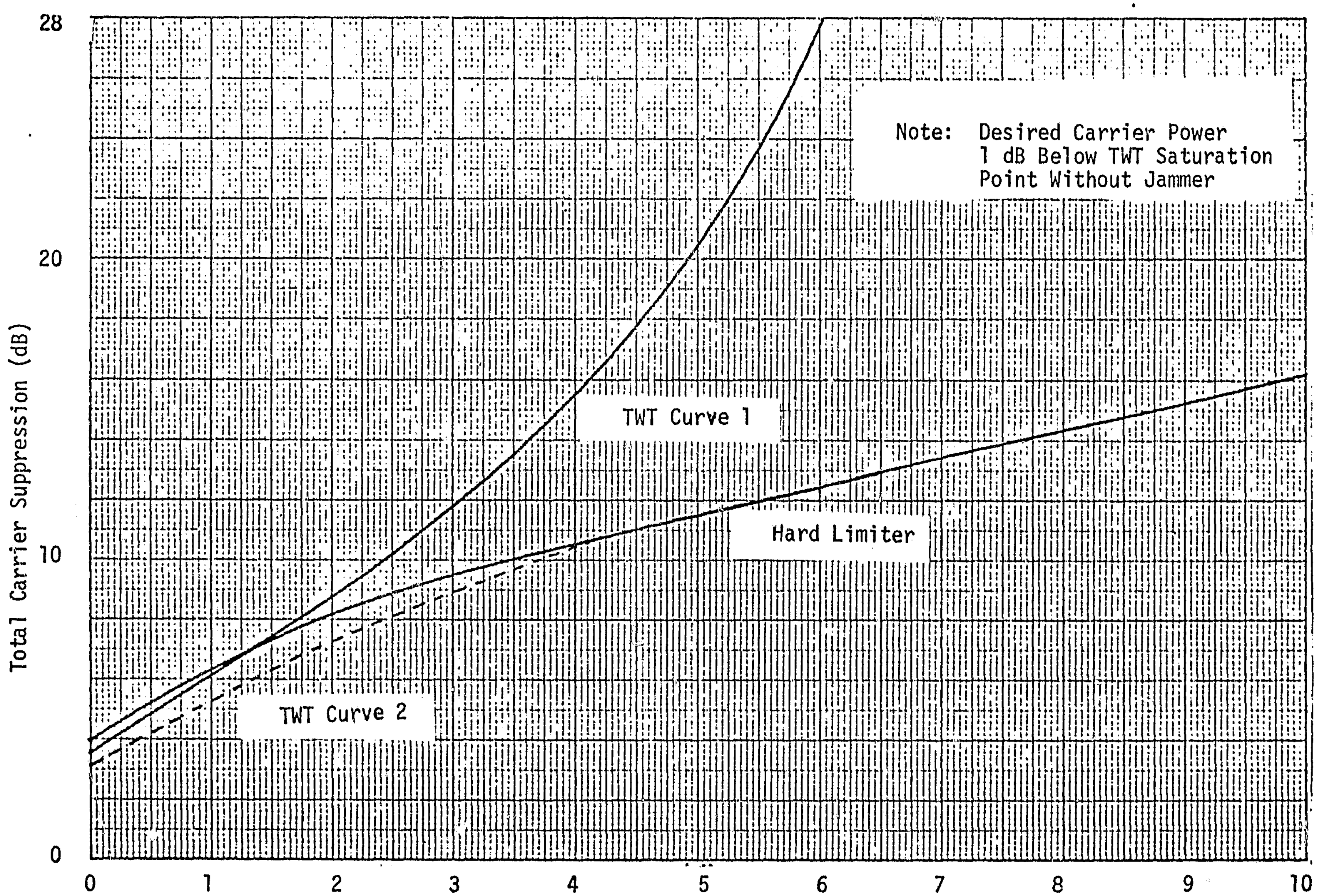

Figure 2-10. Total Desired Carrier Suppression Due to Jamming Signal (dB).

2.2.5.4 Jammer Level Requirements

The exact ratio of jammer level to noise level or to the desired signal level to cause a specific degradation in the case of modulated signals is a complex question which has been dealt with extensively in the literature and is beyond the scope of this brief study. In the transmission studies in section 3.0, two basic types of signal modulations are used: QPSK and FM. Shimbo and Fang[1] of COMSAT Laboratories and others at Bell Telephone Laboratories have treated the effect of interference (jammer) levels on QPSK signals. Numerous individuals have also investigated the effect of interference on FM signals.[2]

1. O. Shimbo and R. Fang, "Effects of Cochannel Interference and Gaussian Noise in M-ary PSK Systems," Comsat Technical Review, Vol 3 No 1, pp 183-206, Spring 1973.
2. E. E. Reinhart, "Radio Relay System Performance in an Interference Environment," Rand Corp. RM 5286-NASA, October 1968.

2.2.6 Availability Analysis

2.2.6.1 General

The objective of the availability analysis in this study is to determine the degree of redundancy in the earth stations to achieve link availabilities of 0.990 and 0.995 respectively, for TV and digital data transmissions.

The availability of an element is defined by:

$$A_i = \frac{\text{Uptime}}{\text{Uptime + Downtime}} = \frac{MTBF_i}{MTBF_i + MTR_i} = \frac{1}{1 + \lambda_i\ MTR_i}$$

Where:

$MTBF_i$ = Mean time between failures,

MTR_i = Mean time to restore to operational status

$= MTTR_i + TT_i + (1.0 - P_i)\ TR_i$

$MTTR_i$ = Mean time to repair/replace faulty module,

TT_i = Travel time required for maintenance personnel to reach the site of failure

P_i = Probability of having a spare module of the failed type on site

TR_i = Time required to obtain a spare from an outside source when no spare is available

$\lambda_i = \frac{1}{MTBF_i}$ = failure rate.

Note availability is not only a function of the speed with which maintenance personnel can restore a station to operational status but also of the travel time and logistics times involved.

The system availability for a system consisting of a series of N non-redundant elements is the product of the element availabilities.

$$A_s = \prod_{i=1}^{n} A_i$$

The availability of a satellite communication link is the product of the satellite availability and the transmit and receive earth station availabilities, as well as the uplink and downlink path availabilities, i.e.,

$$A_s = A_t A_u A_{sat} A_d A_r,$$

where the uplink and downlink path availabilities are the probability that the propagation degradation will not exceed a specified value.

For this study several assumptions have been made to estimate the degree of redundancy required at the earth stations, given that the overall link availability for TV transmissions was to be 0.99 and for digital data transmissions was to be 0.995. First, an availability for the satellite had to be assumed since data was not available on WESTAR or for the other satellite models assumed. In all cases, it is assumed that a 100 percent operational backup satellite exists in geosynchronous orbit and the restoration time is simply the time required to repoint the antenna to the backup satellite.

For commercially operated communication satellite systems at 4 and 6 GHz the availability is quite high. Previous studies of a number of communication satellite links has resulted in the following observed total link availability:[1]

Links	Availability
INTELSAT Atlantic Basin	0.99810
INTELSAT Pacific Basin	0.99842
Telesat-Canada	0.99698

These availabilities include all five link availability factors for 4 and 6 GHz operation. The systems have backup satellites, and redundant earth station equipments. Further, the INTELSAT stations are continuously manned. These availabilities compare favorably to dedicated leased data lines across the United States. For example, the measured availability on a 50 Kbps circuit from Montana to Washington, D.C., leased by the Air Force between October 1971 and October 1972, was 0.98698 including times when the BER was unacceptable for computer processing.[2]

1. COMSAT Corporation Annual Report to President and Congress, 1971.
2. Private conversation with Teledyne Geotech.

For this study, it is assumed that during a 1-year period no more than 4 hours total is lost in repointing the antenna from one satellite to another resulting in an assumed availability for the satellite of 0.9995. Further, it is assumed that the uplink and downlink propagation statistics and the design margins are such as to provide availabilities of 0.9990 and 0.9975 respectively for digital data and TV transmissions. This requires that the availabilities of the transmit and receive portions of the earth stations be at least 0.998745 for digital data transmissions and 0.997735 for TV transmissions. To summarize, the following availabilities will be assumed:

	TV Transmissions	Digital Data Transmissions
A_t	0.997735	0.998746
A_u	0.997500	0.999000
A_{sat}	0.999500	0.999500
A_d	0.997500	0.999000
A_r	0.997735	0.998745
A_s	0.990000	0.995000

For composite transmit and receiver earth stations, their availabilities must be on the order of 0.995475 and 0.997494 respectively, for TV and digital data transmissions depending upon the antenna availability.

Before discussing further the uplink and downlink path availabilities and the earth station equipment availabilities and redundancy requirements, four points should be noted. One is that the networks are somewhat hypothetical and hence the analyses may tend to be optimistic compared to the real world. The second point is that even where existing real-world data was employed, there was not necessarily sufficient data and details available for this study for a rigorous analysis. Third, the factors associated with the reliability and availability are statistical in nature and the numerical values are intended to represent long-term mean values. Fourth, the earth station availability is highly dependent upon the length of time required for the logistics associated with restoration.

2.2.6.2 Uplink and Downlink Path Rain Margins

In this study, only the rain attenuation along the path is considered in any detail. There are other factors which can cause signal degradations such as antenna pointing errors, polarization mismatch, spurious interference, solar thermal noise through a sidelobe, etc. These other factors are assumed to be taken care of by an assigned loss factor for pointing errors and an additional 1 dB pad over and above the C/N thresholds to account for possible unknown degradation factors.

Rain attenuation is highly variable with earth station location and seasons. In general, the higher the instantaneous rain rate and the higher radio frequency along the path, the great the attenuation loss.[1-3] Figure 2-11 shows that, in general, heavy rain conditions are more probably for earth stations located along the Gulf of Mexico and least likely for the West Coast. For this study, three earth station locations were considered to span the range of rain attenuation conditions which can be expected in CONUS: Miami, Chicago and Los Angeles.

Measurements made of rain attenuation on satellite path links at Holmdel, N. J., by Bell Telephone Laboratories were used to estimate the rain attenuation losses.[4,5] Note that in figure 2-11, Northeastern Illinois and New Jersey are in the same probability-of-heavy-rain zone. Bell Telephone Laboratories has also investigated the effect of space diversity earth stations on rain outage statistics and has extended these measurements to Miami where space diversity may be necessary, particularly for radio

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1. Holzer, W., "Atmospheric Attenuation in Satellite Communication Systems," Microwave Journal, p 119, March 1965.
2. Medhurst, R. G., "Rainfall Attenuation of Centimeter Waves: Comparison of Theory and Measurement," IEEE Trans. Antenna and Propagation, p 550, July 1965.
3. Crane, R. K., "Propagation Phenomena Affecting Satellite Communication Systems Operating in the Centimeter and Millimeter Wavelength Bands," Proceedings of the IEEE, Vol 59, No 2, pp 173-188, February 1971.
4. R. W. Wilson, "A Three-Radiometer Path Diversity Experiment," BSTJ Vol 49, p 1239-1242, July/August 1970.
5. H. W. Evans, "Attenuation on Earth Space Paths at Frequencies up to 30 GHz," Proc. International Communication Conference, p 27-31, 1971.

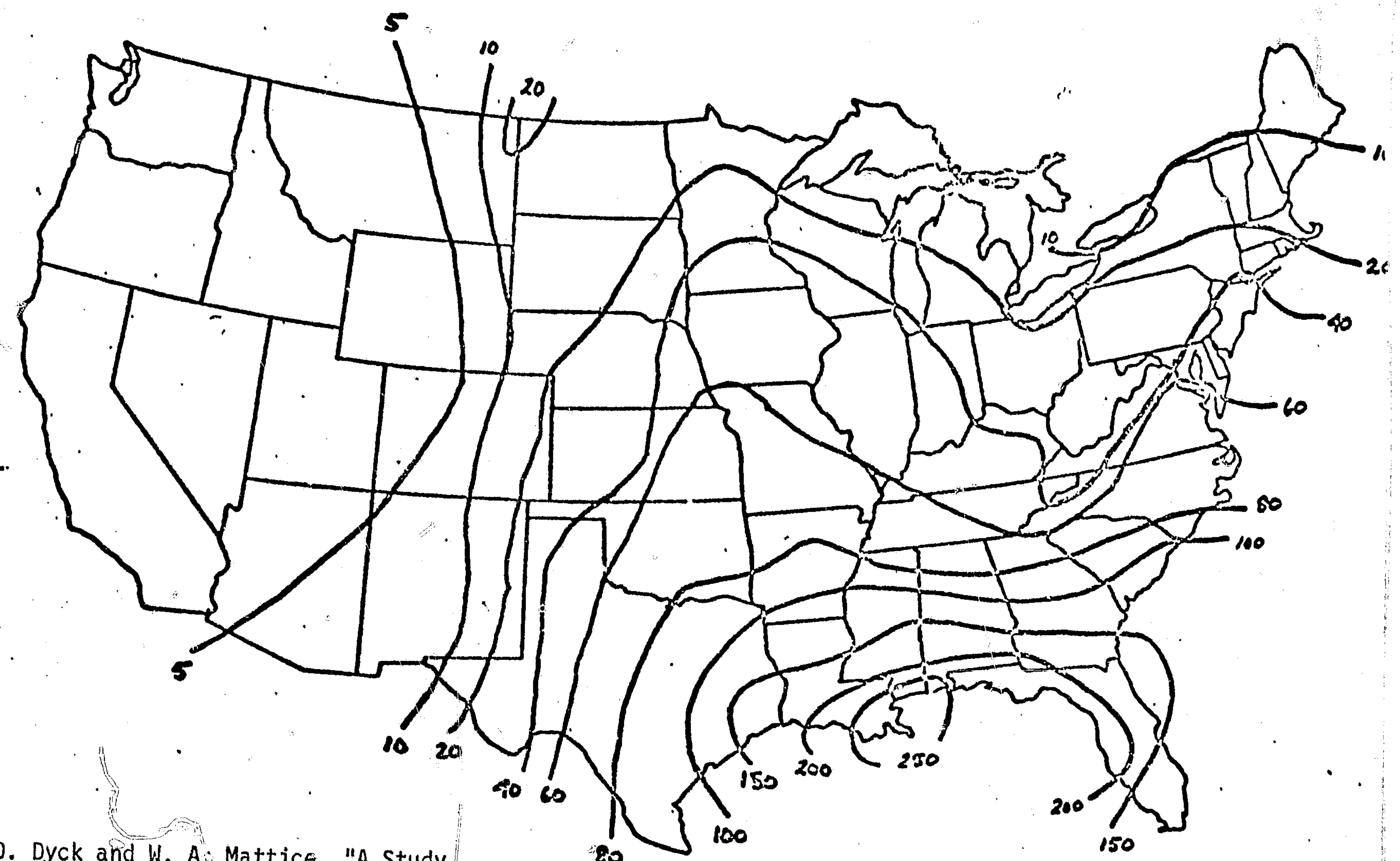

Figure 2-11 Number of Total Occurrences of 1-Inch per Hour or Greater Rainfall Rate for a 30-Year Period.

H. D. Dyck and W. A. Mattice, "A Study of Excessive Rainfall," Monthly Weather Review, Vol 69, pp 293-301, October 1941.

frequencies above C-band. Using these references results in the attenuation estimates shown in tables 2-10 through 2-12. These results have also been extended to Corvalis, Oregon which corresponds to a region where heavy rain is extremely rare.[1] The attenuation values for Corvalis were used to estimate the attenuations for Los Angeles shown in the tables.

In addition to attenuating the signal strength along the path, rain will also cause an increase in the antenna noise temperature of an earth station.[2] The increase in the apparent sky temperature as a function of the path attenuation is shown in figure 2-12. Using this relationship tables 2-13 and 2-14 show the estimated degradation in system noise temperature due to the rain. Note that the higher the clear weather system noise temperature the less is the effect of rain. Tables 2-15 through 2-18 show the effect of using two earth stations 10 Km apart and the reduction in rain margin requirements if the station with the lowest path attenuation is always used. For selection of an uplink rain margin, only the attenuation corresponding to the location, radio frequency and availability are used. For a downlink rain margin, the attenuation corresponding to location, radio frequency and availability must be combined with the system noise temperature degradation which corresponds to the clear weather system noise temperature.

As will be seen in the calcuations in section 3.0, the resulting margins for Miami in order to be able to overcome the rain have a large impact on the earth station requirements, resulting in a station which has much higher EIRP and G/T than needed for clear weather conditions. This results in extra costs. There are several alternatives for stations located on the coast of the Gulf of Mexico:

a. Accept a greater amount of degradation under rain conditions,

b. Do not employ high radio frequencies,

1. COMSAT Corporation, "Multipurpose Domestic Satellite Communications Systems," Filing before FCC, Vol II, p II-67, March 1971.

2. L. J. Ippolitio, "Millimeter Wave Propagation Measurements from the Applications Technology Satellite (ATS-5)," IEEE Trans. Antennas and Propagation, Vol AP-18 No 4, pp 535-552, July 1970.

Table 2-10 - Estimated Rain Attenuation Statistics for Satellite Earth Stations Located near Chicago - Nondiversity.

Values in Decibels

Percent of Time Loss Not Exceeded	Frequency - GHz				
	2.5	4	6	12	14
99.75	0.06	0.12	0.25	0.95	1.60
99.90	0.07	0.15	0.40	1.75	2.90
99.95	0.13	0.25	0.75	4.00	6.00

Table 2-11 - Estimated Rain Attenuation Statistics for Satellite Stations Located Near Miami - Nondiversity.

Values in Decibels

Percent of Time Loss Not Exceeded	Frequency - GHz				
	2.5	4	6	12	14
99.75	0.10	0.20	0.40	2.6	4.40
99.90	0.12	0.25	0.70	11.6	14.40
99.95	0.21	0.40	2.40	19.2	24.30

Table 2-12 - Estimated Rain Attenuation Statistics for Satellite Earth Stations Located Near Los Angeles - Nondiversity.

Values in Decibels

Percent of Time Loss Not Exceeded	Frequency - GHz				
	2.5	4	6	12	14
99.75	0.01	0.02	0.05	0.19	0.32
99.90	0.02	0.03	0.08	0.35	0.58
99.95	0.03	0.05	0.15	0.80	1.20

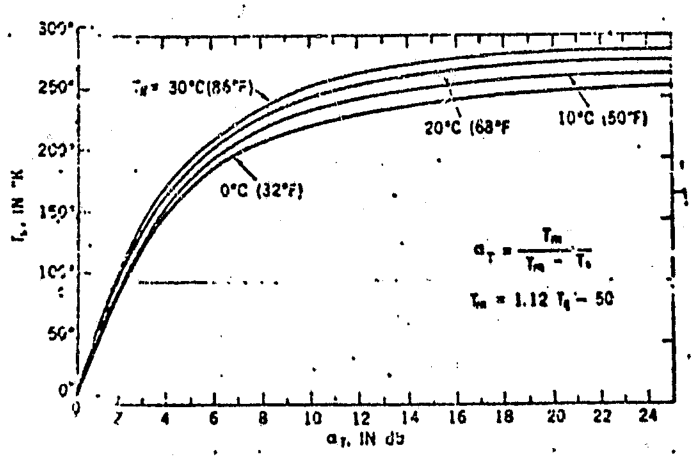

Figure 2-12 Atmospheric Attenuation Predicted from Sky Temperature (After Ippolitio, IEEE Proceedings, February 1971).

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1 OF 5

Table 2-13. Estimated System Noise Temperature Degradation by Rain for Satellite Earth Stations - Values in Decibels Not To Be Exceeded 99.9 Percent of Time. Non-diversity.

Clear Weather System Noise Temperature Kelvins	Los Angeles 4 GHz	Los Angeles 12 GHz	Chicago 4 GHz	Chicago 12 GHz	Miami 4 GHz	Miami 12 GHz
85	0.08	0.81	0.37	3.07	0.60	5.69
100	0.06	0.70	0.31	2.73	0.51	5.19
115	0.06	0.62	0.27	2.46	0.45	4.77
125	0.05	0.57	0.25	2.30	0.41	4.53
150	0.04	0.48	0.21	2.00	0.35	4.03
175	0.04	0.41	0.18	1.76	0.30	3.64
200	0.03	0.36	0.16	1.58	0.26	3.32
250	0.03	0.29	0.13	1.30	0.21	2.83
300	0.02	0.25	0.11	1.11	0.18	2.47
400	0.02	0.19	0.08	0.86	0.13	1.97
500	0.01	0.15	0.06	0.70	0.11	1.64
600	0.01	0.12	0.05	0.59	0.09	1.41
750	0.01	0.10	0.04	0.48	0.07	1.16
900	0.01	0.08	0.04	0.40	0.06	0.99
1100	- -	0.07	0.03	0.33	0.05	0.82
1500	- -	0.05	0.02	0.25	0.04	0.62
2500	- -	0.03	0.01	0.15	0.02	0.38

Table 2-14 Estimated System Noise Temperature Degradation by Rain for Satellite Earth Stations - Values in Decibels Not to be Exceeded 99.75 Percent of the Time. Non-Diversity

Clear Weather System Noise Temperature Kelvins	Los Angeles 4 GHz	Los Angeles 12 GHz	Chicago 4 GHz	Chicago 12 GHz	Miami 4 GHz	Miami 12 GHz
85	0.05	0.46	0.30	1.93	0.48	4.03
100	0.04	0.39	0.25	1.69	0.41	3.62
115	0.04	0.34	0.22	1.50	0.36	3.28
125	0.03	0.32	0.20	1.40	0.33	3.10
150	0.03	0.27	0.17	1.19	0.28	2.71
175	0.02	0.23	0.15	1.04	0.24	2.41
200	0.02	0.20	0.13	0.93	0.21	2.17
250	0.02	0.16	0.10	0.76	0.17	1.82
300	0.01	0.14	0.09	0.64	0.15	1.56
400	0.01	0.10	0.06	0.49	0.11	1.22
500	0.01	0.08	0.05	0.39	0.09	1.00
600	0.01	0.07	0.04	0.33	0.07	0.85
750	0.01	0.05	0.03	0.27	0.05	0.70
900	--	0.05	0.03	0.22	0.05	0.59
1100	--	0.04	0.02	0.18	0.04	0.49
1500	--	0.03	0.02	0.14	0.03	0.36
2500	--	0.02	0.01	0.08	0.02	0.22

Table 2-15 Estimated Rain Attenuation Statistics for Satellite Earth Stations Located near Chicago - 10 KM Diversity Spacing

Values in Decibels

Percent of Time Loss Not Exceeded	Frequency - GHz				
	2.5	4	6	12	14
99.75	0.06	0.11	0.23	0.85	1.40
99.90	0.07	0.14	0.34	1.00	1.70
99.95	0.13	0.20	0.48	1.15	2.10

Table 2-16 Estimated Rain Attenuation Statistics for Satellite Earth Stations Located Near Miami - 10 KM Diversity Spacing

Values In Decibels

Percent of Time Loss Not Exceeded	Frequency - GHz				
	2.5	4	6	12	14
99.75	0.06	0.12	0.34	1.50	2.20
99.90	0.07	0.15	0.40	2.25	3.15
99.95	0.13	0.22	0.75	6.00	9.30

Table 2-17 . Estimated System Noise Temperature Degradation by Rain for Satellite Earth Stations - Values in Decibels Not To Be Exceeded 99.9 Percent of Time - 10 KM Diversity Spacing

Clear Weather System Noise Temperature Kelvins	LOCATION			
	Chicago		Miami	
	4 GHz	12 GHz	4 GHz	12 GHz
85	0.34	2.01	0.37	3.66
100	0.29	1.76	0.31	3.27
115	0.26	1.57	0.27	2.96
125	0.24	1.46	0.25	2.79
150	0.20	1.25	0.21	2.43
175	0.17	1.09	0.18	2.16
200	0.15	0.97	0.16	1.94
250	0.12	0.79	0.13	1.61
300	0.10	0.67	0.11	1.38
400	0.08	0.51	0.08	1.08
500	0.06	0.41	0.06	0.8-
600	0.05	0.35	0.05	0.75
750	0.04	0.28	0.04	0.61
900	0.03	0.23	0.04	0.51
1100	0.03	0.19	0.03	0.42
1500	0.02	0.14	0.02	0.31
2500	0.01	0.09	0.01	0.19

Table 2-18. Estimated System Noise Temperature Degradation By Rain For Satellite Earth Stations - Values in Decibels Not To Be Exceeded 99.75 Percent of Time. 10 KM Diversity Spacing.

Clear Weather System Noise Temperature Kelvins	LOCATION			
	Chicago		Miami	
	4 GHz	12 GHz	4 GHz	12 GHz
85	0.27	1.76	0.37	2.75
100	0.23	1.54	0.31	2.43
115	0.20	1.37	0.27	2.18
125	0.19	1.27	0.25	2.04
150	0.14	1.08	0.21	1.76
175	0.13	0.94	0.18	1.55
200	0.12	0.84	0.16	1.38
250	0.09	0.68	0.13	1.14
300	0.08	0.58	0.11	0.97
400	0.06	0.44	0.08	0.75
500	0.05	0.35	0.06	0.61
600	0.04	0.30	0.05	0.51
750	0.03	0.24	0.04	0.41
900	0.03	0.20	0.04	0.35
1100	0.02	0.16	0.03	0.29
1500	0.02	0.12	0.02	0.21
2500	0.01	0.07	0.01	0.13

c. Place earth stations outside of heavy rain areas and interconnect by terrestrial communication links,

d. Boost the EIRP of the satellite during periods of excess rain.[1]

With respect to item a. above, accepting greater rain degradations can be accomplished in two ways. One is to increase the earth station availability to permit a lower link availability. For example, if the earth stations had an availability of 0.999999, then the link availabilities could be lowered to 0.995236 and 0.997746 respectively, for TV transmissions and digital data transmissions. These changes in the required rain margins can be significant, but the overall cost of improving the earth station availability may not result in a cost-effective solution. The lowest cost alternative would be to accept a lower signal quality under rain conditions.

2.2.6.3 Equipment and Earth Station Availability

For purposes of estimating the degree of redundancy required to achieve the above earth station availabilities, it was assumed that the earth stations were unmanned and that a maintenance technician requires an average of four hours from the time of the failure until he is ready to begin the restoration/repairs. An assessment of predicted system availability figures-of-merit was made on the basis of predicted equipment mean-time-between-failure (MTBF) and mean-time-to-renewal (MTTR). The MTBF for each equipment in the system is based upon MIL-STD-756 procedures utilizing part failure rates contained in MIL-HDBK-217A. In some cases where inadequate information was unavailable from the manufacturer, failure rates were estimated based upon similarity in parts, parts count, and complexity to units whose MTBF and MTTR values were well established. These individual block availabilities were then combined to determine the predicted system availability according to the following formula:

$$\left(\prod_{i=1}^{n} A_{S_i}\right)\left(\prod_{j=1}^{m} A_{P_j}\right)$$

1. C. W. Lundgren and L. D. Spilman, "A Method of Providing Rain Margins for 18/30 GHz Communications Satellites Without Increasing the Solar Power Requirements," International Communications Conference 1974 (Seattle, Wash.), p 12-13 to 12-27, June 11-13, 1973.

where

"A_{S_i}" is the availability of the ith series block, and "A_{P_j}" is the availability of the jth parallel block. A_P for a parallel block consisting of n like units where n-1 units must operate is given by the expression

$$A_P = nA^{n-1} - (n-1)A^n.$$

The availability of the earth stations is first computed for a nonredundant configuration. For those configurations which did not satisfy the required availabilities on a link basis, the degree of redundancy is varied until the desired availabilities were achieved.

2.3 GROUND SEGMENT

2.3.1 Introduction

Figure 2-13 shows the general block diagram of a transmit-receive earth station. Basically the communication satellite link is a long-distance, double hop microwave link with the satellite transponder providing the intermediate repeater. The principle portions of the earth station which distinguishes it from a terrestrial microwave relay station are the larger antenna, more sensitive (lower noise) preamplifier, and usually a higher power amplifier output. These portions of the earth station vary greatly according to the satellite and application.

Typically the frequency up- and down-conversion portions are identical or very similar to those of the superheterodyne radios used for the same frequency bands for terrestrial microwave relay. Generally, the differences, if any, are that the earth station local oscillators have better long-term stability and lower phase noise. Heavy route types of earth stations typically are equipped with frequency agile converters which can be rapidly switched to any satellite transponder frequency band. Frequency agility permits rapid reassignment of satellite resources demanded by traffic changes, or outages. Tables 2-19 and 2-20 show typical specifications. The equalization of the earth station radios is typically more extensive than for a terrestrial microwave radio relay link. This is primarily because the bandwidths of the earth station radios are typically wider than terrestrial microwave radio relay links. Also, in some cases, additional equalization is employed in the earth stations to compensate for non-equalized satellite repeaters. This eliminates the need for equalizers in the satellite and their associated weight.

The modulation and demodulation portions of the typical earth station interface at 70 MHz, which is standard throughout the microwave radio industry. However, the modulation parameters and demodulation techniques differ from the terrestrial microwave links because of the wider bandwidths, different applications and because of the flux density limitations recommended by the CCIR and adopted internationally for radiation from space at the earth's surface. Refer to Tables 2-21 and 2-22. Typically, the modulation/demodulation parameters and techniques are tailored to the earth station application.

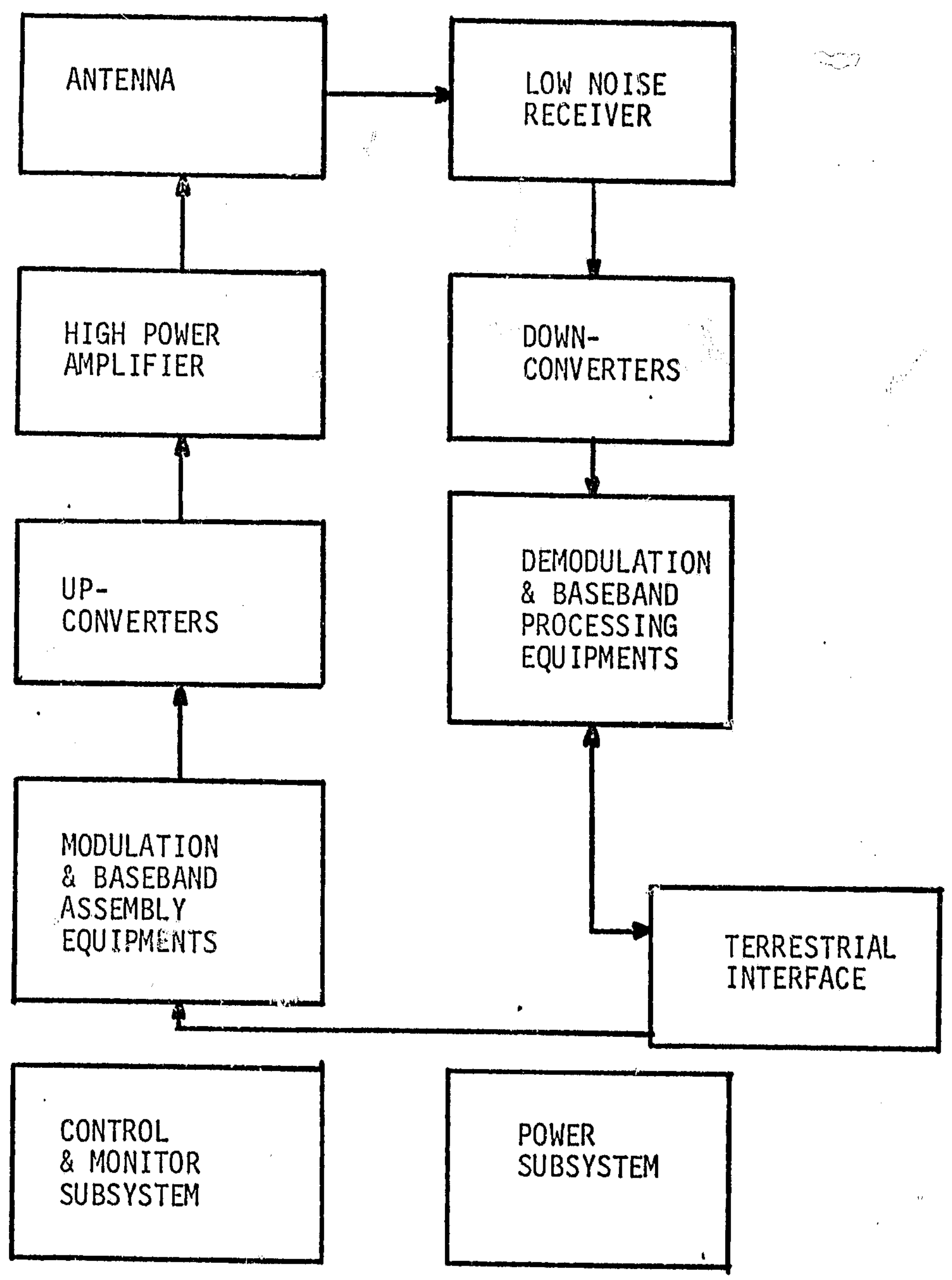

Figure 2-13. General Block Diagram for a Satellite Communication Earth Station.

Table 2-19. Specifications for Typical Single-Conversion Up-Converter and Down-Converter

Up-Converter Specifications	
Output Frequency Range:	40 MHz within the 5.925 to 6.425 GHz range
Output Level:	-10 dBm minimum
Output Impedance:	WR-137 waveguide
Input Frequency:	70 MHz
Input Level:	+13 dBm nominal; -5 dBm minimum
Input Impedance:	75 ohms, return loss ≥ 26 dB
Third Order IM:	More than 45 dB below two -20 dBm carriers spaced 10 MHz apart
Spurious Outputs:	
In-Band	50 dB (CW) below desired output
Out-of-Band	80 dB below desired output
Down-Converter Specifications	
Input Frequency Range:	40 MHz within the 3.700 to 4.200 GHz range
Input Level:	-25 to -60 dBm
Input Impedance:	WR-229
Output Frequency:	70 MHz if baseband
Output Impedance:	75 Ohms
Output Level:	0 ±1 dBm
Noise Figure:	10 dB, maximum
Third Order IM:	More than 45 dB below two -33 dBm input signals
L.O. Image Protection:	80 dB
Spurious Response:	Spurious signals appearing in output are more than 60 dB below desired signal, with input signals of -25 dBm. With reduced levels of input signals, spurious responses rapidly approach 80 dB below primary response.
Selectivity:	Response to frequencies greater than ±70 MHz from center frequency are down more than 80 dB.
Specifications for Both	
Translation Bandwidth (1 dB):	36 ±1 MHz; 2 to 40 MHz available
Frequency Stability:	Standard: ±5 ppm; 0 to +50°C better available
Group Delay (Unequalized):	
Ripple	Less than 1 nsec p-p over any 32 MHz bandwidth
Parabolic	Less than 0.05 nsec/MHz^2 over any 32 MHz bandwidth
Linear	Less than 0.1 nsec/MHz over any 32 MHz bandwidth
Frequency Inversion	Low-side injection in both up- and down-converter mixers

Table 2-20 Typical Specifications for Typical Dual-Conversion Up-Converter and Down-Converter

Up-Converter Specifications	
Output Frequency Range:	5.925 to 6.425 GHz
Output Level:	-10 dBm minimum
Output Impedance:	WR-137 waveguide
Input Frequency:	70 MHz
Input Level:	+13 dBm nominal; -5 dBm minimum
Input Impedance:	75 ohms, return loss ≥ 26 dB
Local Oscillator Frequency:	
First	1.0425 GHz
Second	4.8125 to 5.3125 GHz selectable in 12 equal steps; up to 100 steps available
Third Order IM:	More than 45 dB below two -20 dBm carriers spaced 10 MHz apart
Spurious Outputs:	
In-Band	50 dB (CW) below desired output
Out-of-Band	80 dB below desired output
Down-Converter Specifications	
Input Frequency Range:	3.700 to 4.200 GHz
Input Level:	-25 to -60 dBm
Input Impedance:	WR-229
Output Frequency:	70 MHz if baseband
Output Impedance:	75 Ohms
Output Level:	0 ±1 dBm
Noise Figure:	14 dB, maximum
Third Order IM:	More than 45 dB below two -33 dBm input signals
Local Oscillator Frequency:	
First	4.8125 to 5.3125 GHz selectable in 12 equal steps; up to 100 steps available
Second	1.1825 GHz
Image Protection:	80 dB
Spurious Response:	Spurious signals appearing in output are more than 60 dB below desired signal, with input signals of -25 dBm. With reduced levels of input signals, spurious responses rapidly approach 80 dB below primary response.
Selectivity:	Response to frequencies greater than ±70 MHz from center frequency are down more than 80 dB.
Specifications for Both	
Tunability:	Switching between channels in less than 15 msec
Translation Bandwidth (1 dB):	36 ±1 MHz; 2 to 40 MHz available
First IF:	1.1125 GHz
Frequency Stability:	Standard: ±5 ppm; 0 to +50°C better available
Group Delay (Unequalized):	
Ripple	Less than 1 nsec p-p over any 32 MHz bandwidth
Parabolic	Less than 0.05 nsec/MHz^2 over any 32 MHz bandwidth
Linear	Less than 0.1 nsec/MHz over any 32 MHz bandwidth

Table 2-21. CCIR Limits on Space Radiated Flux Density Values in $dBW/m^2/4$ KHz.

Frequency Band	2.5-2.69 GHz	3.7-4.2 GHz	11.7-12.75 GHz
Angular Region			
$0<\theta\leq 5°$	-152	-152	-148
$5°\leq\theta\leq 25°$	$-152 + \frac{3(\theta-5)}{4}$	$-152 + \frac{(\theta-5)}{2}$	$-148 + \frac{(\theta-5)}{2}$
$\theta>25°$	-137	-142	-138

Notes: 1. International Telecommunication Union Space Conference Recommendation 395-E Rev R. 3, Geneva 1971.

2. θ is the satellite look angle in degrees above the spherical earth horizon.

Table 2-22 Maximum Allowable Geosynchronous Satellite EIRP For Clear Weather Conditions; Values in dBW.

Elevation Angle (Degrees)	2.6 GHz	4 GHz	12 GHz
1	49.3	50.9	58.7
5	49.2	50.8	58.6
20	60.1	58.0	65.7
25	63.8	60.4	68.1
40	63.5	60.1	67.8
50	63.3	59.7	67.6
60	63.2	59.8	67.5
90	63.0	59.6	67.4

Notes:

1. Assumes CCIR flux density limits shown in table 2-14 with signal energy spread uniformly over the bandwidth.
2. Assumes 36 MHz bandwidth transponders for 4 GHz.
3. Assumes 25 MHz bandwidth transponders at 2.6 GHz.
4. Assumes 85 MHz bandwidth transponder for 12 GHz.

Two other subsystems included in a typical earth station are the control and power subsystems. These are also tailored to the earth station application and location.

2.3.2 Earth Station G/T Combinations

The communication capacity of a satellite transponder is primarily a function of the earth station G/T values. This figure-of-merit also indicates the complexity and cost of the earth station, both increasing as G/T increases. G/T is the ratio of the antenna receive gain, G, relative to an isotropic radiator to the system noise temperature, T, both referred to the low noise preamplifier input or some other common point. The preamplifier is usually the reference point because this is a convenient measurement point and the antenna and preamplifiers are often supplied by different manufacturers. The Electronic Industry Association recommends that the input to the low noise preamplifier be adopted as the reference point. G/T is commonly expressed in dB or dB/K by the formula

$$G/T \text{ in dB} = 10 \log_{10} G - 10 \log_{10} K$$

where K is in Kelvins. The receive antenna gain is given by the expression:

$$G = \eta \frac{4\pi A}{\lambda^2} \alpha$$

where

η = efficiency of antenna/feed

A = effective area

λ = wavelength

α = transmission line coefficient between the feed and the input to the preamplifier.

The system noise temperature is given by the general expression:

$$T_{sys}(\theta) = \alpha T_a(\theta) + (1 - \alpha) T_o + T_p + \sum_{n=2}^{N} \frac{T_n}{G_{n-1}}$$

where

- θ = elevation angle above smooth earth horizon
- T_a = antenna noise temperature
- α = transmission line coefficient
- T_o = ambient temperature of transmission line
- T_p = noise temperature of the preamplifier
- T_n = noise temperature of each succeeding receiver element
- G_{n-1} = gain preceding the nth receiver element.

The antenna noise temperature of an antenna is a function of its pointing direction relative to its local environment with the clear overhead sky having the lowest background noise and the ground having the highest background noise. For radio frequencies where rain causes large attenuations the antenna noise temperature can increase significantly under heavy rain conditions. Typically, G/T values are stated, measured, and specified for clear weather conditions at a specific elevation angle above the local horizon. Tables 2-23 and 2-24 show typical clear weather values of antenna noise temperatures for 4 GHz and 12 GHz respectively. These values have been assumed in the G/T calculations for this study.

For U.S. domestic earth stations located in CONUS, the elevation angle relative to a smooth earth ranges from 35 degrees to 55 degrees. Using the above formulas, typical assumptions for transmission line losses, antenna efficiencies, etc., Tables 2-25 and 2-26 show cost effective combinations of antenna size and low-noise preamplifiers as a function of clear weather G/T for elevation angles of 40 degrees.

Table 2-23. Estimated Antenna Noise Temperature at 4 GHz for Subreflector Shaped Cassegrain - f/D = 0.375.

ELEVATION ANGLE (degrees)	T_s (°K)	T_b (°K)	T_{ap} (°K)	T_{ohmic} (°K)	T_a (°K)
90.0	5.8	7.8	13.6	12.4	26.0
80.0	5.8	7.8	13.6	12.4	26.0
70.0	6.0	8.0	14.0	12.3	26.3
60.0	6.2	8.4	14.6	12.3	26.9
50.0	6.6	8.6	15.2	12.3	27.5
45.0	6.8	9.1	15.9	12.3	28.2
40.0	7.2	10.1	17.3	12.3	29.6
30.0	8.2	13.1	21.3	12.1	33.4
25.0	9.3	15.0	24.3	12.0	36.3
20.0	11.0	17.2	28.2	11.8	40.0
15.0	13.5	18.8	32.3	11.6	43.9
10.0	18.0	17.0	35.0	11.5	46.5
7.5	22.5	15.0	37.5	11.4	48.9
5.0	32.0	10.0	42.0	11.3	53.3

Notes:

1. $T_a = T_{ap} + T_{ohmic} = T_s + T_b + T_{ohmic}$
2. $T_{ohmic} = T_{ap}\,\alpha + (1 - \alpha)290°K$
   where α is the ohmic loss. The ohmic loss assumed was 0.20 dB.
3. T_s = sky temperature from NBS - 101 plus 3.5°K for galactic background.
4. T_b = contribution from side-lobe spillover, etc. Values are based upon measured values by BTL at 6 GHz.
5. Resulting temperatures are for clear weather at sea level.

Table 2-24. Estimated Antenna Noise Temperature at 12 GHz for Subreflector Shaped Cassegrain - f/D = 0.375.

ELEVATION ANGLE (degrees)	T_s (°K)	T_b (°K)	T_{ap} (°K)	T_{ohmic} (°K)	T_a (°K)
90.0	8.1	7.8	15.9	12.3	28.2
80.0	8.1	7.8	15.9	12.3	28.2
70.0	8.4	8.0	16.4	12.3	28.7
60.0	8.9	8.4	17.3	12.3	29.6
50.0	9.7	8.6	18.3	12.2	30.5
45.0	10.1	9.1	19.2	12.2	31.4
40.0	10.7	10.1	20.8	12.1	32.9
30.0	12.5	13.1	25.6	11.9	37.5
25.0	13.5	15.0	28.5	11.8	40.3
20.0	16.7	17.2	33.9	11.5	45.4
15.0	20.5	18.8	39.3	11.3	50.6
10.0	27.5	17.0	44.5	11.0	55.5

Notes:

1. $T_a = T_{ap} + T_{ohmic} = T_s + T_b + T_{ohmic}$
2. $T_{ohmic} = T_{ap}\,\alpha + (1 - \alpha)290°K$

   where α is the ohmic loss. The ohmic loss assumed was 0.20 dB
3. T_s = sky temperature from NBS -101 plus 3.5°K for galactic background.
4. T_b = contribution from side-lobe spillover, etc. Values are based upon measured values by BTL at 6 GHz.
5. Resulting temperatures are for clear weather at sea level.

Table 2-25. Cost-Effective Combinations of Antenna Size and Preamplifier No Noise Temperatures at 4 GHz as a Function of G/T.

G/T (dB)	ANTENNA SIZE (feet)	PREAMP TYPE	PREAMP TEMPERATURE (°K)
3.0	4	Transistor	750
3.6	6	None, Mixer	1500
4.3	5	Transistor	870
4.5	4	TDA	520
4.9	5	Transistor	750
5.9	6	Transistor	870
6.5	6	Transistor	750
8.5	8	Transistor	870
9.1	8	Transistor	750
10.6	8	TDA	520
11.0	10	Transistor	750
12.5	10	TDA	520
14.2	12	TDA	520
16.1	15	TDA	520
16.7	16	TDA	520
17.7	18	TDA	520
18.6	20	TDA	520
21.3	16	Paramp	150
22.2	16	Paramp	115
23.2	18	Paramp	115
24.0	20	Paramp	115
25.0	25	Paramp	150
26.1	25	Paramp	105
27.0	32	Paramp	150
28.1	32	Paramp	105
29.5	40	Paramp	115
30.1	40	Paramp	95
31.0	32	Paramp	55
32.0	36	Paramp	55
33.3	42	Paramp	55
33.8	44.3	Paramp	55
34.4	47.6	Paramp	55
35.0	51	Paramp	55

Table 2-26 Cost-Effective Combinations of Antenna Size and Preamplifier Noise Temperatures at 12 GHz as a Function of G/T

G/T (dB/°K)	DIAMETER (Feet)	PREAMP Type	PREAMP TEMPERATURE (°K)
14.3	5	TDA	755
15.0	5	TDA	630
15.9	6	TDA	755
16.6	6	TDA	630
18.4	8	TDA	755
19.1	8	TDA	630
20.4	10	TDA	755
21.1	10	TDA	630
22.1	12	TDA	755
22.7	12	TDA	630
24.0	15	TDA	755
24.7	15	TDA	630
25.3	16	TDA	630
26.3	18	TDA	630
27.1	20	TDA	630
28.2	25	TDA	755
28.9	25	TDA	630
29.2	28	TDA	755
29.9	28	TDA	630
30.5	32	TDA	755
31.0	32	TDA	630
32.0	35	TDA	630
32.5	40	TDA	755
33.0	40	TDA	630
33.5	45	TDA	755
34.0	45	TDA	630
34.5	32	Paramp	300
35.0	35	Paramp	300
35.5	55	TDA	755
36.0	55	TDA	630
36.5	40	Paramp	260
37.0	45	Paramp	300
37.5	45	Paramp	260
38.5	55	Paramp	300
39.0	55	Paramp	260

2.3.3 Earth Station Antennas

The primary purpose of the earth station antenna is to provide for collection of the low level radiation from the satellite. The greater the antenna area and the more efficiently the design uses the area, the greater the energy collected. The power gain formula given in the previous section is the primary figure-of-merit. Note that the same antenna gain at both 4 GHz and 12 GHz typically means that the area of the 4 GHz antenna is 9 times larger than that of the 12 GHz antenna and that the incident flux density at 12 GHz would have to be 9 times larger in order to collect the same amount of energy as at 4 GHz. There are many factors which contribute to the gain efficiency of an antenna.[1,2] Some of the major ones to consider are the, a) intensity of the electromagnetic field strength over the antenna reflector (illumination taper/distribution), b) shadowing of the reflector (aperture blockage), c) reflector surface deviations (surface tolerance), and d) ohmic transmission line losses. All four of these factors also influence the effective thermal noise level of the radiation resistance, i.e., antenna noise temperature, presented to the low-noise receiver.[2,3,4] This is very important when the receiver noise temperature is very low, because the antenna noise temperature will be a large percentage of the total system noise temperature. Because the antenna is pointed towards the sky, the thermal noise pickup from the ground is minimized, and the sky noise temperature is the major contributor to the antenna noise

1 F. G. Doidge, "Antenna Gain As It Applies to Satellite Communication Earth Stations," U.S. Seminar on Satellite Communication Earth Station Technology (Washington, D. C.), May 1960.

2 "Electrical and Mechanical Characteristics of Antennas for Satellite Earth Stations," Electronics Industries Association Standard Proposal No. 1118-B, 2001 Eye Street N.W., Washington, D. C. 20006.

3 A. R. Giddis, "Influence of External Noise on Antenna Temperature," Microwaves, p 16, June 1964.

4 H. R. Reed, "Noise Curves for High Gain Antennas," Microwaves, April 1967.

temperature. The clear weather sky noise temperature at frequencies above 2 GHz is caused by atmospheric water vapor and oxygen, with the temperature increasing as frequency increases. There is also a small galactic cosmic noise background contribution, which is independent of frequency in the 2 to 12 GHz frequency band. Thus, all other things being equal, a 12 GHz antenna would be expected to have a higher noise temperature than a 4 GHz antenna. Refer to tables 2-16 and 2-17.

The most commonly employed design techniques for a high-efficiency, low-noise antenna is the use of a dual shaped reflector antenna with low spillover shaped-beam feed horns. Such designs can achieve antenna gain efficiencies as high as 75 percent for large reflectors, with slightly lower efficiencies for smaller reflectors. Ultimately the net efficiency is highly dependent upon the feed horn design. Many sophisticated and low-cost techniques for improving the efficiency of satellite communication earth station antennas have been developed.[1,2]

An important efficiency factor to consider in large microwave antennas is the surface tolerance. It has been well established that the gain loss due to surface tolerance can be closely estimated by the following simple formula:[3]

$$\Delta G_{dB} = 685.8 \left(\frac{\varepsilon}{\lambda}\right)^2$$

where: ΔG_{dB} is the gain loss in Decibels due to deviations of the reflector surface

ε is the rms of the deviations normal to the aperture plane relative to a best-fit reflector

λ is the radio frequency wavelength.

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1 R. L. Kaiser, "How the Advent of Satellites Has Influenced the Design of Microwave Antennas," Proceedings International Conference on Electronics and Space. (Paris, France), April 10-15, 1967.

2 C. M. Beheler, "Dual Reflector Shaping as Applied to High-Performance Ground Station Antennas," Advanced Aerospace Technology Symposium (Toronto, Canada), March 17-18, 1969.

3 J. Ruze, "Antenna Tolerance Theory - A Review," Proc. of IEEE, Vol. 54, No 4, pp 633-640, April 1966.

The surface tolerance must be kept very small to minimize the gain loss. A loss of 0.1 dB (2.33 percent energy loss) requires rms surface tolerances which are less than 1/16 of the wavelength. This corresponds to rms surface tolerances of 0.065 inch, 0.037 inch, and 0.012 inch respectively, at 2, 4, and 12 GHz. For very large antennas, these surface tolerances are very difficult and costly to achieve, particulary with wind and solar loading effects. Because of the importance of this factor, typical earth station antennas are designed for an rms surface tolerance of 1/12 of the wavelength (0.18 dB gain loss or 4.23 percent energy loss).

The gain value of an antenna is usually stated as the value at the peak of its beam. If the peak of the earth station antenna beam is not pointed at the satellite, its effective loss of area or gain is given, approximately, by the expression,

$$\Delta G_{dB} = 12\left(\frac{\Delta\theta}{\theta_{hp}}\right)^2$$

where: ΔG_{dB} is the gain loss in decibels (up to 12 dB) because of an antenna pointing error,

$\Delta\theta$ is the pointing error angle

θ_{hp} is the half-power (-3 dB) beamwidth of the antenna.

For circular antennas, the half-power beamwidth, θ_{hp}, in radians is given, approximately by the following expression:

$$\theta_{hp} = \frac{1.2\lambda}{D}$$

where: λ is the radio frequency wavelength,

D is the circular antenna diameter.

If the pointing error of the earth station antenna is expected to be greater than $0.1\theta_{hp}$ because of satellite motion, environmental effects (wind, thermal, etc.), automatic or manual means for correction of the antenna pointing should be provided. Typical automatic pointing methods are: programmed pointing, steptrack, conical scan tracking and simultaneous lobing tracking. The last three techniques require the reception of a beacon/carrier signal from the satellite to be tracked. The last two techniques have rapid response times sufficient to partially correct for wind-gust induced pointing errors.

The others do not, and if wind induced pointing errors are a problem, stiffer antenna structures are required. Simultaneous lobing (sometime referred to as passive monopulse) is the most accurate tracking technique, but it is usually considerably more expensive and is not employed by ordinary earth stations. Step-tracking is usually selected as the compromise between cost and performance. Orbit position of geosynchronous satellites are currently being maintained to tolerances which makes it feasible to use lower cost programmed pointing, using shaped contour cams with sidereal clock drives, punched paper tape, microcomputers, etc. to point the antenna. However, these are also subject to the largest pointing errors because of calculation errors, initial alignment, line frequency and others. If the antenna beamwidth is small enough, no pointing corrections are required. For in-between antenna sizes, periodic manual adjustment of the antenna pointing would suffice. Typical geosynchronous satellite motions range from $\pm 0.05°$ to $\pm 0.1°$ daily, to $\pm 0.25°$ to $\pm 0.5°$ over long time intervals.

In some cases, earth stations may be required to operate with more than one satellite either simultaneously or sequentially. A typical occasion for the latter mode is to provide for rapid switching of the earth station from one satellite to another in the event of a satellite outage either because of equipment failure or sun eclipse periods. If the antenna is small enough that relative motions of the satellites will not cause significant pointing error losses, it is possible to employ a dual-beam antenna to operate with two satellites simultaneously. If this is not the case, two separate autotracking types of antennas would probably be required. Changing over from one satellite to another can be very rapid in the case where a dual-beam antenna or two separate antennas are employed. For a one-antenna earth station the change-over time depends upon how rapidly the pointing of the antenna can be changed from one satellite to the other.

The sidelobe characteristics of the antenna are very important. They determine to a degree the antenna noise temperature, but more important, they can affect the radio interference situation between the earth station and any other station which is operating in or near the same radio frequency band.[1]

1. R. L. Kaiser, "Sidelobe Characteristics of Large Antennas from an Interference Point of View," Advanced Aerospace Technology Symposium (Toronto, Canada), March 17-18, 1969.

The FCC requires that beyond one degree off-axis of the antenna that the antenna sidelobes relative to isotropic not exceed the following limits:

SLI in dB $\leq 32 - 25 \log_{10} \theta$ $\qquad 1° \leq \theta \leq 48°$

SLI in dB ≤ -10 dB $\qquad 48° \leq \theta \leq 180°$.

These requirements are very difficult to meet, and some believe that no antenna currently used for earth stations literally satisfies these limits, although they may claim to do so. That is, it is very probable that a complete set of far field patterns for all frequencies, planes and polarization would reveal that some small percentage of the sidelobes would exceed the FCC limits. If the latter claims are true, then strict adherence to the FCC requirements would mean the addition of some sort of shielding around the antenna. One technique which has been employed on several occasions is to place the earth station antenna in an abandoned gravel-pit to obtain a well-shielded antenna.

Most of the emphasis on antenna gain efficiency is put upon achieving a maximum G/T and this generally results in a lower gain efficiency at the transmit frequency band. This stems from the fact that in most occasions the overall link signal quality is limited by the downlink thermal noise as a result of the low satellite EIRP. Since it is easier to increase the uplink EIRP on the ground than it is to increase the satellite EIRP, the received gain of the earth station antenna is often maximized with the transmit gain falling where it will. In a balanced satellite and earth station network configuration this will normally result in a cost effective solution. However, when a general purpose satellite is being used for a wide range of user earth stations unbalanced situations can occur where it is more cost-effective for the ground station to maximize the transmit gain efficiency of the antenna rather than the receive gain efficiency. In the final analysis, each earth station and/or network configuration must be optimized according to its specific application, location and other applicable restrictions. Tables 2-27 and 2-28 show typical cost-effective combinations of antenna and HPA sizes for transmit earth stations.

Table 2-27. Cost Effective Combinations of Antenna and HPA Sizes at 6 GHz.

UPLINK EIRP (dBW)	ANTENNA DIAMETER (Feet)	HPA P_{sat} (kW)
75.93	15	1.0
76.49	16	1.0
77.51	18	1.0
78.43	20	1.0
80.34	25	1.0
80.70	15	3.0
81.26	16	3.0
82.28	18	3.0
83.20	20	3.0
85.11	25	3.0
86.98	32	3.0
87.72	35	3.0
88.73	40	3.0
89.63	45	3.0
90.72	51	3.0
91.14	55	3.0

Table 2-28. Cost-Effective Combinations of Antenna and HPA Sizes at 14 GHz.

UPLINK EIRP (dBW)	ANTENNA DIAMETER (feet)	HPA PSAT (Watts)
64.5	8	50
67.5	8	100
70.5	8	200
72.3	8	300
74.0	8	450
75.9	10	450
77.5	12	450
79.4	15	450
81.0	18	450
81.9	20	450
83.8	25	450
84.8	28	450
85.9	32	450
86.8	35	450
87.9	40	450
88.9	45	450
91.4	40	1000
92.4	45	1000
94.2	55	1000
97.2	55	2000

2.3.4 Low-Noise Amplifiers

Low-noise amplifiers (LNA's) are required for systems in which the threshold of sensitivity is primarily limited by the thermal noise component such as those systems used in satellite communications.

The general satellite system ground station functional requirements on the LNA's are that they supply low noise temperatures so as not to degrade the received signal quality, consistent with the antenna and system noise requirements, and that they supply adequate gain to the signal to drive the receiving equipment and the associated interconnecting waveguide. These requirements must be met under a variety of environmental and communications conditions, and do it over a channel bandwidth and with low distortion of the amplified signals. In addition, they should perform in an efficient and cost-effective manner with good reliability over the life of the ground station.

The generic types of LNA's best fitting these requirements and most commonly used in various satellite communication ground terminal systems are:

a. Parametric amplifiers (Paramp's)

b. Tunnel diode amplifiers (TDA's)

c. Traveling wave tube amplifiers (TWTA's)

d. Transistor amplifiers.

These can be used alone or in a mixture of the types to modify different performance/cost parameters. In general, as the noise temperature performance areas improves, the cost and complexity of the LNA rise rapidly. In some cases, other parameter performance areas suffer (such as reliability) when the noise temperature performance area is stressed to a high degree.

In the application of LNA's to the low-noise receiver front end requirements of small ground terminals, the recognized need is for LNA's that are inexpensive and yet provide relatively high performance.

The LNA candidates most applicable to the small earth terminal requirements are the parametric amplifier (both cooled and uncooled), the tunnel diode amplifier, and the transistor amplifier. The latter two LNA types are suitable for use with larger antenna systems or systems requiring less sensitivity and/or very low cost. This is due to their inherently high noise performance and, in the case of transistors, their frequency limitations.

The parametric amplifier in either its cooled or uncooled form, provides both relatively high performance with relatively low cost over a wide range of frequencies and configurations. The noise temperature performance of paramps depends upon the ambient physical temperature environment provided for the individual amplifier stages. The cooled version uses a refrigerator machine which maintains a stable cryogenic temperature (usually around 15 Kelvins but sometimes as high as 80 Kelvins) at the amplifier stage. The uncooled version actually includes types which may cool the amplifier stage as low as 220 Kelvins or heat it as high as 320 Kelvins. All types, of course, must maintain their design operating temperature in a very stable manner. Because the cooled version requires special refrigeration-type support equipment, its complexity and cost (both initial and maintenance) are increased while its reliability is decreased when compared to the uncooled version. Therefore, the cooled type parametric amplifier should only be considered for use in systems requiring the additional performance margin and where the additional cost and complexity can be tolerated. The uncooled parametric amplifier is the primary choice for LNA use in the widest possible range of earth stations.

Figure 2-14 presents the noise figure variations as a function of frequency for the TDA, the transistor amplifier, and both cooled and uncooled parametric amplifiers. The range of values shown for each device represents both present capability and projected future capability. Approximately the upper half of each range represents current capability either in production or in the laboratory with near-term potential for production. Approximately the lower half of each range represents projected capability under the same conditions for the 1980 to 1985 time frame. The device variation over frequency does not represent the same device parameters or performance but rather, typical devices, characteristic of the frequency band, required to achieve the performance levels.

2.3.5 Earth Station High Power Amplifiers

The output carrier power level of the high power amplifier (HPA) required for the satellite communication link is given by the expression

$$P_{out} = EIRP - G_t - L_t$$

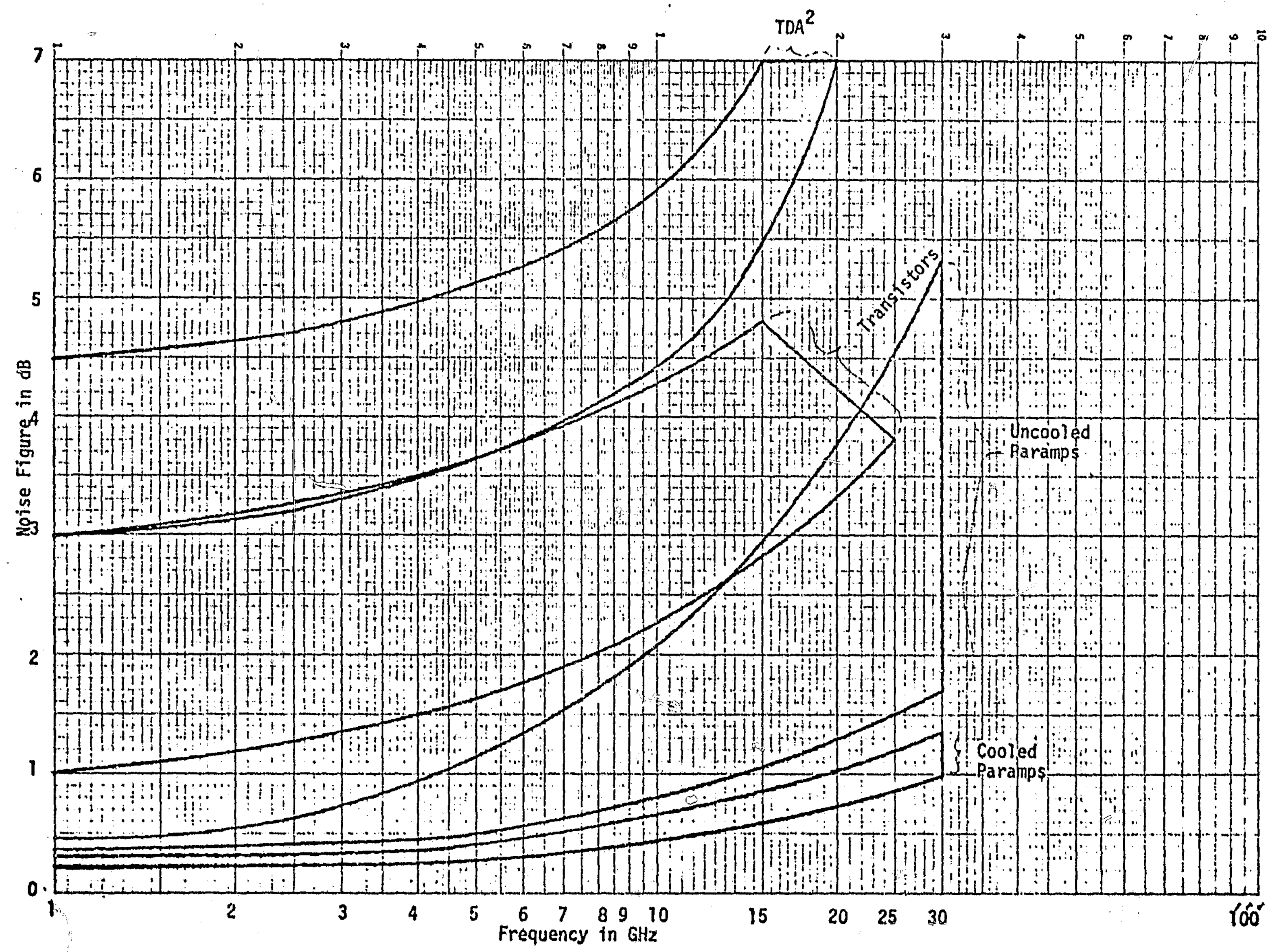

Figure 2-14. Noise Figure Variations of Low Noise Preamplifiers.

where

EIRP is the required uplink radiated power in dBW

G_t is the transmit antenna gain in dB

L_t is the transmission line losses in dB between the output of the HPA and input to the antenna.

The output saturation level of the earth station HPA depends upon several factors. The cost and complexity of an HPA is a function of its saturated output power level. If the HPA is only required to transmit a single signal at a time, then the saturation output power level need not be greater than the power required to meet the maximum uplink EIRP requirement. However, if the HPA is simultaneously amplifying more than one signal, intermodulation interference signals can occur. Refer to section 2.2.4. To prevent this undesirable effect, the amplifier must be operated in a quasi-linear mode which requires operating the amplifier below its saturation level. Thus the required HPA saturation level is given by the expression

$$P_{sat} = EIRP - G_t - L_t + BO_o$$

where

BO_o is the output backoff from saturation in dB.

For earth stations HPA's typically employ klystron tubes or traveling wave tubes for the final amplification stage. In general, the power levels are too high for solid state power amplifiers to be cost effective. The relative input power versus output power characteristics of the klystrons and TWT's are very similar. For purposes of this study the same relative characteristics will be assumed for the earth station HPA's as for the satellite transponders. From section 2.2.4 the required input backoff to satisfy a carrier-to-intermodulation ratio of 28 dB for a large number of equal-level rf carriers is approximately 18.0 dB. Referring to table 2-2, this corresponds approximately to 13 dB. This total power allowable out of the HPA would be 5 percent of its saturation power capability. This mode of operation is very costly. On the other hand, the use of separate amplifiers and using power combiners is usually even more costly because of the transmission losses and costs associated with the power combiners. For purposes of this study single HPA's will be assumed for multiple signal transmissions from earth stations.

In general, klystrons are significantly less costly than TWT's, but have narrower bandwidth (15 percent). TWT's have octave bandwidths and thus a single amplifier can operate without retuning anywhere in an entire 500 MHz bandwidth allocated for satellite communications. For this reason, TWT amplifiers are more apt to encounter multiple signal transmission requirements than klystrons. Klystrons are available with pretuned cavity tuning, pushbutton selection, and features for up to 12 different frequencies. This permits a klystron to be rapidly tuned to any transponder within the 500 MHz bandwidth allocated for satellite communications. Either the water-cooled klystrons or TWT's are significantly more costly than air-cooled units. Typically water-cooling is required for power levels above a few kilowatts. The additional complexity of the water-cooled units must be considered in the reliability and maintenance aspects. The water must be free of foreign particles and undesirable ions which requires a small water filter/treatment unit. For locations subject to freezing, special ethyl compounds are usually added to the cooling water. The heat load and the noise levels produced by the HPA's and their cooling equipments must be considered in the earth station location and design. The power plant and regulation required for HPA's is a significant factor. The HPA power supplies employ very high dc voltage levels. Hence proper grounding and personnel safety techniques must be employed. All things considered, the HPA portion of a small earth station can easily become one of the most costly items. Except for where extremely high EIRP is required to overcome high rain attenuation air-cooled klystron power amplifiers will be assumed for the earth station configurations considered in this study.

The proper backoff point on the satellite transponder power amplifier is for multiple signals and is also an important parameter for determining the intermodulation interference/noise levels in the downlink signal. In most satellites, the only control of this backoff point is the combined uplink power level received at the satellite from all of the earth stations sharing the same transponder. Thus it becomes very important that the uplink EIRP of the earth station be controlled very closely. Usually the links are designed to tolerate uplink EIRP on the order of ± 0.5 dB due to antenna pointing variations.

Variations on the order of ±1.0 dB usually will start to become noticeable. Thus it is sometimes required that the output level of the earth station HPA be held to ±0.25 dB, leaving some variation for light rain and other causes. If the HPA is only required to transmit a single rf signal, then the tube beam voltage could be adjusted downward to the point where the HPA is in saturation and thus would not pass on any variations in the driver level. It would still be subject to power supply voltage perturbations. The alternative is to use an output level sensor and a control loop to the input of the driver to maintain the output of the HPA at a fixed level. In general, this is required when multiple signals are being transmitted. This would automatically adjust for any change in the number or level of carriers.

It was shown in section 2.2.6 that in some cases (i.e., Miami) rain attenuation causes a large amount of loss on the uplink. In order to maintain the link availability, it becomes necessary for such locations to be able to increase the earth station EIRP. In the case of Miami, this increase can be significant; so significant, in fact, that a two HPA configuration could be the best operational solution, with one sized for clear weather and other sized for high rain conditions. The second HPA could also provide a backup for clear weather conditions. However, too much increase could be as bad as not enough as far as controlling the satellite transponder backoff point. Thus, a means for increasing the uplink EIRP during rainy conditions must be accompanied with a means of determining how much rain attenuation is occurring. For attenuations on the order of a few decibels, a system noise temperature sensor could be used for this purpose.[1] This is also a valuable check on the condition of the earth station LNR's. However, it also cannot distinguish between an LNR failure, sun in the sidelobes, etc. Further, it cannot measure accurately large amounts of attenuation. Thus a combination of system noise temperature monitor and a satellite downlink monitor would be required to make proper adjustments to the uplink EIRP during heavy rain conditions.

1. Ippolitio, IEEE Proceedings, February 1971, ibid.

3.1 INTRODUCTION

This section presents summary details for estimating the earth station requirements for color TV transmission and for digital data transmission via the different satellites assumed in section 2.1. Three locations for the earth stations are considered: Los Angeles, Chicago and Miami, to show the impact on the earth station requirements. All five geosynchronous satellite transponder models (i.e., WESTAR 4/6 GHz, ATS-6 4/6 GHz, CTS 12/14 GHz, Future DOMSAT 12/14 GHz and ATS-6 2/6 GHz) were studied for color TV transmissions. Three basic transmission systems were considered: NTSC 525/60 line, SECAM III 625/50 line and a relatively new digital television system. In the case of the analog baseband signals frequency modulation was assumed with and without the FM sound channel submultiplexed with the video. In the latter case, the sound is transmitted via a separate rf carrier through the transponder in a two-carrier FDMA case. Only the submultiplexed audio form of NTSC 525/60 line was studied in conjunction with ATS-6 2/6 GHz transponder. The digital TV signal was a time division multiplex of the digitally encoded sound and picture signal, modulated on the rf carrier by QPSK techniques.

Excluding the ATS-6 2/6 GHz transponder model several FDMA cases were studied for digital data transmissions. In these cases the object of the study was to determine the satellite capacity as a function of earth station G/T for the other four satellites and different data channels. The data channels considered were:

a. 50 Kbps uncoded channels
b. 25 Kbps half-rate coded channels (rf rate of 50 Kbps)
c. 1.544 Mbps (T1-carrier) uncoded channels
d. 1.544 Mbps half-rate coded channels (rf rate 3.088 Mbps).

QPSK modulation was assumed in all cases. Another digital transmission case was studied to determine the maximum data rate as a function of earth station G/T for a single signal using QPSK. For this portion of the study the baseband data stream was assumed to consist of time division multiplexed T1 carriers (1.544 Mbps each). Both uncoded and half-rate coding was assumed.

In this study TDMA was not considered other than for an example of sharing the WESTAR transponder with two high data rate digital signals such as Telesat-Canada is currently doing with their ANIK satellites. For this example two digital TV signals were assumed. CDMA was not considered in the transmission studies.

In general, the link calculations are presented in power budget table form. The downlink calculations for determining the required earth station G/T are shown in separate tables from the uplink calculations for determining the required uplink EIRP. Based upon tables supplied in section 2.3, the G/T values are converted to an antenna size and preamplifier noise temperature which would be suitable for receive only (R.O.) earth stations. Where the required G/T values fall between the tabulated values in section 2.3, the combination tabulated just above the required G/T is usually selected. In some cases, an antenna and preamplifier combination which appears to be a more cost-effective match to the tabulated combinations was selected. No claims are made that the combinations picked are the optimum combination. The briefness of the study did not permit optimization. Many of the combinations reflect cost-effective combinations from previous studies. However, manufacturer's offerings are constantly varying and inflation is not always a predictable factor. Thus, the combinations selected are to be taken as representative of reasonable choices. The optimum combination can only be selected after the application and network has been specified, studied in more detail and the most recent manufacturer's offerings investigated in detail.

The same applies to the selected combinations of antenna size and the size of the high power amplifiers. For earth stations which both transmit and receive (T/R) a combination of antenna size, HPA size and preamplifier noise temperature needs to be selected which satisfies the G/T

and the EIRP requirements simultaneously. In general, this combination uses a larger antenna size and higher preamplifier noise temperatures than the R.O. stations. The primary reasons for this may be several. In this study, the smallest antenna size assumed for transmitting is 15-feet in diameter and 7-feet in diameter for 6 GHz and 14 GHz respectively. This is based upon anticipated lower limits on transmit antenna sizes under consideration by the FCC. In general, air-cooled HPA's are more costly than uncooled parametric amplifiers. Thus, the economics often favor increasing the antenna size to keep the size and cost of the HPA down. Similar reasons prevail for going to space diversity at 14 GHz for the Miami earth stations. Because of the large HPA power capability to overcome the large rain attenuation, the costs for a single earth station become impractical. In general, the need to use space diversity for the uplink will result in using space diversity for the downlink as well, even though a single R.O. station may be able to provide the required link G/T margin at less cost.

3.2 COLOR TELEVISION TRANSMISSION

3.2.1 General

This section summarizes the results of the color television transmission studies. In all cases, it was assumed that the TV signal consisted of a video signal and one audio sound signal and that the entire resources of the transponder was available within the flux density and interference limits set by the FCC. It was assumed that the signals into the transmit earth station were essentially noise-free.

The encoding/modulation cases investigated were as follows;

a. Standard NTSC 525/60 line with one audio subcarrier above video frequency modulated onto a rf carrier.

b. Standard SECAM III 625/50 line with one audio subcarrier above video frequency modulated onto a rf carrier.

c. Same as a. but the video and sound channel frequency modulated onto separate rf carriers.

d. Same as b. but the video and sound channel frequency modulated onto separate rf carrier.

e. DITEC a digital encoding of the video and sound, multiplexed and phase-shift (QPSK) modulated onto an rf carrier.

In cases a, b and e, intermodulation products in the transponder and earth station were assumed to be negligible. In c and d cases the intermodulation level between the video rf carrier and the sound rf carrier was taken from previous in-house studies.

From in-house studies and by means of in-house computer programs for link analysis, the earth station G/T required to give a video peak-to-peak luminance-to-rms weighted noise ratio of 48 dB and a 1 kHz test-tone-to-rms weighted noise ratio of 50 dB for the sound channel was determined for each of the above cases under clear weather conditions, assuming that the earth stations are located at Los Angeles, Chicago and Miami. All five satellite transponder models were considered, i.e.,

a. WESTAR - 4-6 GHz down and 6 GHz up,
b. ATS-6 - 4 GHz down and 6 GHz up,
c. CTS - 12 GHz down and 14 GHz up,
d. Future DOMSAT - 12 GHz down and 14 GHz up,
e. ATS-6 - 2.6 GHz down and 6 GHz up.

Only the NTSC 525/60 line video and audio subcarrier multiplexed case was considered for case e, i.e., ATS-6 2.6/6 GHz. All of the encoding/modulation cases were analyzed for the other four satellite transponder models. NTSC 525/60 color TV was included because it is the standard transmission form in the United States of America and test equipments and receiving sets are readily available. SECAM III 625/50 color TV was considered because of four factors:

a. Test equipments and receiving sets not readily available in USA,
b. Highest color fidelity,
c. High resolution,
d. Highly resistant to transmission degradations.

Factors b) and c) could be important factors in law enforcement, and justice activities. In the USA, SECAM III or equivalent system PAL is used for closed circuit TV in hospitals and medical institutions where factors b) and c) are important. SECAM III home receivers do not normally have front control knobs for color balance, hue, etc., because they are normally not needed. Factors a) and d) could also be positive factors from a security viewpoint. Although factor a) means slightly higher costs to the authorized user it is also an

effective deterrent to casual monitoring by the unauthorized. Factor d) is important to the extent that b) and c) are important under conditions of transmission difficulties due to equipment problems, inadvertent interference, heavy rain conditions, jamming, etc.

Digital TV transmission was considered for two reasons:

a. It is expected to become the standard transmission technique for satellite communications in the next few years,
b. It offers the greatest potential for security.

Properly implemented digital TV will significantly reduce the cost of the satellite portion of the link because of the lower power and bandwidth requirements. The DITEC (Digital Television Communications) implementation technique developed by COMSAT Laboratories, Inc. was used as the model for the transmission analysis. This implementation has demonstrated the ability to simultaneously transmit two TV signals of broadcast studio-quality through a single 36 MHz wide transponder using FDMA with earth stations which normally can only transmit a single standard analog NTSC 525/60 TV signal through a single 36 MHz wide transponder. DITEC is already obsolete in terms of bandwidth reduction and satellite power requirements. Improved equipments for commercial use will be introduced into the USA shortly. For illustration purposes, a transmission case involving sharing of a single WESTAR 36 MHz transponder by two DITEC signals using TDMA techniques is shown. Further investigations of digital TV should be based upon the newest equipment currently in the process of being introduced to the USA industry.

Because of the digital nature of the signals, unauthorized monitoring is discouraged for all but the most determined. Further, the nature of digital transmission is such that a key-operated scrambler can be easily implemented of any sophistication required to prevent unauthorized monitoring. Also there are transmission techniques which are easily implemented for digital transmissions which preserves the signal quality in the presence of hostile jamming or unintentional interference. Digital equipments in large quantity productions are highly amenable to economical automatic mass production procedures. Digital equipments can also be developed with simple reprogrammable features which permits optimum adaptive equalization, and flexibility for changing conditions.

3.2.2 NTSC 525/60 Color Television Transmission Studies

3.2.2.1 General

A color video signal consists of two basic signals, the luminance and the chrominance. The chrominance is modulated onto a subcarrier in the luminance band. The luminance band for standard 525 lines per frame color video is approximately 0 to 4.1 MHz and the chrominance band is approximately 2.1 to 4.1 MHz. The TV signal does not have a flat spectrum but rather most of the energy falls around the low frequency region at the frame and line frequencies. Such a spectrum in frequency modulated transmission systems lends itself to preemphasis and noise weighting improvements. However, the gain and phase characteristics of the top end of the baseband are critical to ensure minimum degradation of the chrominance signal. For FM transmission over satellite links an energy dispersal modulation waveform (usually triangular) which provides a 1 MHz peak-to-peak carrier deviation is added to satisfy the CCIR and FCC requirements regarding radiated flux density during picture blanking periods.

For the transmission analysis, two ways of transmitting the analog sound channels were considered. One employs a FM subcarrier above the video baseband. The other employs a completely separate FM rf carrier. For these analyses a single audio sound channel is assumed, although some systems employ up to 4 channels with the additional ones being used for cueing, service channels, second language, etc. TV program sound channel bandwidths typically range from 8 to 15 kHz, and the addition of three additional subcarriers above the video baseband becomes a little difficult, particularly if each channel is 15 kHz wide. In such a case a recent approach is to use a 13-level PCM code A/D conversion, time division multiplex the four channels together and QPSK modulate a single subcarrier.[1] Tests show that this works quite well and that it is possible to put an entire T1 carrier (1.544 Mbps) on this subcarrier without degrading the video.

When the audio is multiplexed with the video the allowable bandwidth occupancy depends upon how well the passband characteristics can be equalized in the transponder or on the ground. The allowable bandwidth typically varies from 32 to 34 MHz. In the case of WESTAR, which does not employ equalizers in the satellite, the allowable bandwidth is about 32 MHz.

1. R.E. Wetmore, "DATE: A Digital Audio System for Television," Journal of the SMPTE, Vol. 83, pp. 180-185, March, 1974.

When separate rf carriers are used for the video and sound channels, it has been customary to employ about 30 MHz of the transponder bandwidth for video. The remaining portion is used for sound carriers. Typically two sound channels spaced 2.5 MHz apart are provided with the second channel being used for cueing, service channel, talk-back channel for ETV, second language, etc. In this study only one sound carrier is assumed. With separate carriers there is a power sharing problem as well as a frequency sharing problem. However, the power requirements for sound channels are so small compared to the video channel that there would be very little difference between one or two channels. To add more sound channels and/or to reduce the intermodulation products introduced with separate carriers, the bandwidth of the video channel can be reduced. INTELSAT sometimes uses a "demi-transponder" mode wherein the video channel/carrier occupies 17.5 MHz. This reduces the FM advantage and was not employed for this study.

The modulation parameters that are used in the transmission studies are listed below in Table 3-1. The values for f_v and W_v are generally used for NTSC video performance calculations, and the audio bandwidth and weighting factors are typical for a high-quality program channel with 75 microsecond preemphasis.

Table 3-1. 525/60 Color TV and Audio Modulation Parameters.

Parameter	Symbol	Value
Peak deviation of energy-dispersal signal	D_E	0.5 MHz
Highest video frequency	f_v	4.2 MHz
Video noise improvement factor	W_v	13 dB
Video signal-to-noise ratio	SNR_v	48 dB
Highest audio frequency	f_a	15 kHz
Audio deemphasis improvement factor	W_a	13.2 dB
Audio test tone-to-noise ratio	SNR_a	50 dB

3.2.2.2 NTSC 525/60 With Audio Subcarrier

In addition to the parameters in Table 3-1, a subcarrier frequency of 6.2 MHz, which provides nearly optimum signal-to-noise performance,* and a video-to-subcarrier deviation ratio (D_v / D_{sc}) of 20 dB will be used in the analysis. Substituting these values in the equations given in Section 2.2, the threshold carrier-to-noise ratio is

$$(C/N)_{threshold} = 45.9 - 10 \log B - 20 \log D_v \quad (dB)$$

where B and D_v are respectively, the if (predetection) noise bandwidth and peak video deviation in MHz.

$$B = 2.2\, D_v + 0.002\, d_a + 13.4 \quad (MHz)$$

where d_a is the deviation of the audio subcarrier in kHz. Substituting and rearranging

$$(C/N)_{threshold} = 79.2 - 10 \log B - 20 \log D_v - 20 \log d_a \quad (dB)$$

Since the two carrier-to-noise equations must yield identical results, they may be equated and solved for the subcarrier program deviation

$$d_a = 10^{(79.2 - 45.9)/20} = 46.2 \text{ kHz}$$

Substituting this value in the equations above gives

$$B = 2.2\, D_v + 13.49 \text{ MHz}$$

and $$(C/N)_{threshold} = 42.9 - 10 \log (1.1\, D_v + 6.75) - 20 \log D_v \text{ dB}$$

Table 3-2 shows the video $(C/N)_{threshold}$ as a function of the video deviation using Carson's Rule bandwidths. The video and audio performance

*K. G. Johannsen, F. L. Paulsen and J. E. Morton, "Television Sound Subcarrier Transmission in Space Communication", IEEE Trans. on Broadcasting, Vol. BC-20, No. 3, pp 42-48, Sept., 1974.

Table 3-2. C/N_t for NTSC 525/60 Color TV as Function of Modulation Parameters for Video with Subcarrier Deviation of 46.2 kHz.

D_v (MHz)	B_{IF} (MHz)	$(C/N)_{threshold}$ (dB)
8.0	31.1	12.9
8.5	32.2	12.2
9.0	33.3	11.6
9.3	34	11.2
9.5	34.4	11.0
10.0	35.5	10.4

objectives can be achieved in a 34 MHz bandwidth with a carrier-to-noise ratio of 11.2 dB.

However because of the unequalized transponder characteristics in the case of WESTAR it was decided for computational purposes to restrict the bandwidth to 32.2 MHz. A $(C/N)_{operational}$ of 13.2 dB was used and BO_i was set for 1 dB to minimize potential of oversaturation of the satellite transponder due to antenna pointing errors. Tables 3-3 through 3-11 show the earth station G/T_e and $EIRP_e$ requirements for locations at Chicago, Los Angeles and Miami for the five satellite transponder models given in Section 2.1.

Using the tables in Section 2.3 the G/T_e values were converted into receive only station antenna sizes and preamplifier noise temperatures. Non-diversity earth stations were assumed. This conversion is an iterative process in that a change of the receiver noise temperature changes the required downlink rain margins. The downlink rain margins were determined from section 2.2.7 where a path loss and a noise temperature degradation are combined. Path availabilities of 0.9975 were assumed. Approximately 40°K at 4 GHz and 50°K at 12 GHz were allowed for the antenna noise temperature. Also on the basis of the data in the tables in section 2.3, the uplink $EIRP_e$ values were converted into transmit antenna sizes and HPA sizes. In general this resulted in a larger antenna size and permitted a reduction of the preamplifier noise temperature. Time did not permit this process to be interated until the most cost-effective combination was determined.

Table 3-3 4 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Submultiplexed Audio Through WESTAR.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.5 dB
Uplink C/N	28.0 dB	28.0 dB	28.0 dB
Required C/N_{op} [2]	13.2 dB	13.2 dB	13.2 dB
Required Downlink C/N_D	13.4 dB	13.7 dB	13.9 dB
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	22.1 dB/°K	21.4 dB/°K	21.9 dB/°K
Preamp Noise Temperature	115°K	150°K	115°K
Required Antenna Size	16 feet	15 feet	15 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-4 HPA Vs. Antenna Sizes Required For 6 GHz Transmit Stations For NTSC TV With Submultiplexed Audio Through WESTAR

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m^2	-81.8 dBW/m^2	-81.8 dBW/m^2
Maximum Required EIRP	82.2 dBW	82.6 dBW	82.6 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Net Clear C/N_u	28.0 dB	28.5 dB	28.5 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	4266W	4678W	4678W
b) 18-ft. Diameter	2951W	3236W	3236W
c) 20-ft. Diameter	2399W	2630W	2630W
d) 30-ft. Diameter	1066W	1169W	1169W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	4169W	4365W	4266W
b) 18-ft. Diameter	2884W	3020W	2951W
c) 20-ft. Diameter	2344W	2454W	2399W
d) 30-ft. Diameter	1042W	1091W	1066W

Notes:

1. Uplink rain margin is for 99.75 percent link availability for non-diversity stations.

Table 3-5 4 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Submultiplexed Audio Through ATS-6.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	51.4 dBW	51.4 dBW	51.4 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.3 dB
Uplink C/N	38.0 dB	38.0 dB	38.0 dB
Required C/N_{op} [2]	13.2 dB	13.2 dB	13.2 dB
Required Downlink C/N_D	13.3 dB	13.4 dB	13.6 dB
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	6.0 dB/°K	6.1 dB/°K	6.1 dB/°K
Preamp Noise Temperature	750°K	750°K	750°K
Required Antenna Size	6 feet	6 feet	6 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-6 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for NTSC TV With Submultiplexed Audio Through ATS-6

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss (6 GHz)	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	1.0 dB	1.0 dB	1.0 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-89.0 dBW/m^2	-89.0 dBW/m^2	-89.0 dBW/m^2
Maximum Required EIRP	75.7 dBW	75.9 dBW	75.9 dBW
Clear Weather EIRP	75.6 dBW	75.6 dBW	75.5 dBW
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	10.5 dB/K	10.5 dB/K	10.5 dB/K
Net Clear Weather C/N_u	38.0 dB	38.0 dB	38.0 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	970W	1016W	1016W
b) 18-ft. Diameter	674W	704W	704W
c) 20-ft. Diameter	546W	570W	570W
d) 25-ft. Diameter	349W	364W	364W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	948W	948W	927W
b) 18-ft. Diameter	657W	657W	644W
c) 20-ft. Diameter	532W	532W	521W
d) 25-ft. Diameter	340W	340W	333W

Notes:

1. Uplink rain margin is for 0.9975 link availability for non-diversity stations.

Table 3-7 12 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Submultiplexed Audio Through Future DOMSAT

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	37.9 dBW	43.9 dBW	38.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.2 dB	1.2 dB	3.2 dB
Uplink C/N	24.0 dB	24.0 dB	24.0 dB
Required C/N_{op} ²	13.2 dB	13.2 dB	13.2 dB
Required Downlink C/N_D	13.8 dB	14.8 dB	15.8 dB
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	29.5 dB/°K	24.5 dB/°K	30.3 dB/°K
Preamp Noise Temperature	630°K	630°K	755°K
Required Antenna Size	28 feet	15 feet	32 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-8 HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for NTSC TV With Submultiplexed Audio Through Future DOMSAT.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-80.5 dBW/m^2	-81.5 dBW/m^2	-80.3 dBW/m^2
Maximum Required EIRP	84.3 dBW	84.6 dBW	88.4 dBW
Clear Weather EIRP	84.0 dBW	83.0 dBW	84.0 dBW
Noise Bandwidth	75.5 dB-Hz	75.5 dB-Hz	75.5 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-5.0 dB/K	-1.0 dB/K	-5.2 dB/K
Clear Weather C/N_u	23.6 dB	26.6 dB	23.6 dB
Maximum Required HPA Output for:			
a) 18-ft. Diameter	962W	1031W	2473W
b) 25-ft. Diameter	498W	533W	1281W
c) 28-ft. Diameter	398W	426W	1022W
d) 32-ft. Diameter	304W	327W	782W
Clear Weather HPA Output for:			
a) 18-ft. Diameter	898W	713W	898W
b) 25-ft. Diameter	465W	369W	465W
c) 28-ft. Diameter	371W	295W	371W
d) 32-ft. Diameter	284W	226W	284W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

Table 3-9 12 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Submultiplexed Audio Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	59.2 dBW	59.0 dBW	56.9 dBW
S/C Pointing Error	0.7 dB	0.7 dB	0.7 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.3 dB	1.3 dB	3.6 dB
Uplink C/N	22.3 dB	22.3 dB	22.3 dB
Required C/N_{op} [2]	13.2 dB	13.2 dB	13.2 dB
Required Downlink C/N_D	14.1 dB	15.1 dB	17.4 dB
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	8.5 dB/°K	9.9 dB/°K	14.1 dB/°K
Preamp Noise Temperature	870°K	520°K	520°K
Required Antenna Size	8 feet	8 feet	12 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-10 HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for NTSC TV With Submultiplexed Audio Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-92.3 dBW/m^2	-92.1 dBW/m^2	-90.0 dBW/m^2
Maximum Required EIRP	72.5 dBW	74.0 dBW	78.7 dBW
Clear Weather EIRP	72.2 dBW	72.4 dBW	74.3 dBW
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 DBW/Hz/K
Satellite G/T	5.5 dB/K	5.3 dB/K	3.2 dB/K
Clear Weather C/N_u	22.3 dB	22.3 dB	22.3 dB
Maximum Required HPA Output for:			
a) 8-ft. Diameter	323W	455W	1340W
b) 10-ft. Diameter	207W	293W	857W
c) 12-ft. Diameter	144W	202W	596W
d) 15-ft. Diameter	92W	130W	383W
Clear Weather HPA Output for:			
a) 8-ft. Diameter	301W	315W	308W
b) 10-ft. Diameter	193W	202W	197W
c) 12-ft. Diameter	134W	140W	137W
d) 15-ft. Diameter	86W	90W	88W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

Table 3-11 2 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Submultiplexed Audio Through ATS-6

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	192.4 dB	192.4 dB	192.2 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	44.4 dBW	49.5 dBW	44.5 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.0 dB	0.0 dB	0.1 dB
Uplink C/N	28.0 dB	28.0 dB	28.0 dB
Required C/N_{top} 2)	13.2 dB	13.2 dB	13.2 dB
Required Downlink C/N_D	13.3 dB	13.3 dB	13.4 dB
Noise Bandwidth	75.1 dB-Hz	75.1 dB-Hz	75.1 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	9.3 dB/°K	4.2 dB/°K	9.1 dB/°K
Preamp Noise Temperature	650°K	650°K	650°K
Required Antenna Size	14 feet	8 feet	14 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

3.2.2.3 NTSC 525/60 Color TV With Separate Audio Carrier

For the video carrier, substitution of the video parameters in Table 3-1 into the equations in Section 2.2 gives

$$(C/N)_{threshold} = 45.9 - 10 \log B - 20 \log D_v \quad (dB)$$

and

$$B_v = 2 D_v + 9.4 \quad (MHz)$$

where B_v and D_v are, respectively, the video if noise bandwidth and peak deviation in MHz. Substitution of the bandwidth equation into the carrier-to-noise equation gives

$$(C/N)_{threshold} = 42.9 - 10 \log (D_v + 4.7) - 20 \log D_v \quad (dB)$$

The effect of video deviation on threshold carrier-to-noise ratio is shown in Table 3-12.

Table 3-12 C/N_t for NTSC 525/60 Color TV As A Function of Video Deviation

D_v (MHz)	B_{if} (MHz)	$(C/N)_{threshold}$ dB
9.0	27.4	12.4
9.5	28.4	11.8
10.0	29.4	11.2
10.5	30.4	10.7

It is standard to keep the video rf bandwidth to 30 MHz in order to leave frequency space for the FM sound carrier. From Table 3-12 this requires a deviation of 10.25 MHz using Carson's Rule and results in a $(C/N)_{threshold}$ of 11.0 dB for a 48 dB video signal-to-noise.

As mentioned previously the video spectrum energy is primarily at the low frequency end. Consequently, the inclusion of a pre-emphasis network results in signal components at high baseband frequencies having large deviations. It is thus possible, provided pre-emphasis is used, to raise the deviation considerably above the value predicted by the above bandwidth while distorting only the top end of the baseband. Because there is little signal energy in this region, the subjective effect of the distortion can be negligible compared with the S/N improvement resulting from the increased deviation. However, because the chrominance is located at the high end of the video band excessive deviation will result in loss of color fidelity.

If the signal were to be relayed over many hops, such as in a long terrestrial microwave relay, each modulation/demodulation step would result in additional loss of color fidelity and any over deviation would be unacceptable. However, on a satellite communication link the modulation/demodulation process only occurs once. Since a conventional FM discriminator has a threshold value of 10 dB, this represents another limitation on the amount of overdeviation improvement which can be achieved.

To reduce the $(C/N)_{threshold}$ as low as possible (10.2 dB) in a 30 MHz bandwidth would require a peak deviation of 11.25 MHz which is only an over-deviation of 0.8 dB compared to 3 or 4 dB over deviation which can be tolerated on a satellite link. A peak deviation of 11.25 MHz and i.f. bandwidth of 30 MHz will be selected for the link calculations.

Substitution of the audio parameters in Table 3-1 into the audio equations in Section 2.2 gives

$$(C/N)_a = 70.3 - 10 \log B_a - 20 \log d_a \quad \text{(dB)}$$

and

$$B_a = 2\,(d_a + 15\ \text{kHz})$$

where B_a and d_a are, respectively, the audio if bandwidth and peak deviation in kHz.

Substitution of the bandwidth equation into the carrier-to-noise equation gives the $(C/N)_{threshold}$ for the separate audio

$$(C/N)_a = 67.3 - 10 \log (d_a + 15) - 20 \log d_a \quad \text{(dB)}$$

The audio carrier-to-noise performance is tabulated as a function of audio deviation in Table 3-13.

Table 3-13 $(C/N_a)_{Threshold}$ For Separate Audio FM Carrier

da (kHz)	B_a (kHz)	C/N_a (dB)
65	180	12
70	190	11.1
75	200	10.3

For the calculations to follow a deviation of 75 kHz will be assumed. A frequency offset for the audio subcarrier of ± 10 kHz was added to the rf bandwidth in the receiver end of the link.

When separate carriers are used, intermodulation products occur. To achieve the required $(C/N)_{threshold}$ with the lowest cost receiving earth station, the video signal requires virtually all of the satellite power available.

All things being equal the amount of power allocated to the audio sound channel would be less than that allocated to the video channel by ratio of the rf bandwidths, i.e., about 22dB. However, it is also desirable to operate as close to transponder saturation as possible without over saturation. This results in the classical small signal suppression effect which results in suppression of the audio carrier power by about 7 dB to 7.5 dB at the output. (Refer to Section 2.2.5.). Thus either the audio carrier needs to be increased in power or additional advantage must be given to the audio carrier such as use of compandor techniques. TV program channel compandors are commercial available with S/N advantages of 10 to 18 dB. This technique is not selected for the calculations to follow. Rather the audio carrier will be operated at a level of 13.0 dB below the video carrier level.

In the link calculations shown, some of the additional assumptions were

a) $C/N_{op} = C/N_t + 1$ dB
b) Rain margins based on 99.75 percent path availability requirements
c) The input backoff point in the satellite is 1 dB. The 1 dB input backoff point is approximately the operating point for the best balance between satellite intermodulation and maximum $(C/T)_d$.

The G/T_e and $EIRP_e$ requirement calculations for each station are shown in Tables 3-14 through 3-23 for four of the satellite transponder models assumed in Section 2.1. The ATS-6-GHz up and 2-GHz down case was not considered. The sound carrier calculations are only shown for WESTAR for illustration purposes. If the earth station has sufficient $(G/T)_e$ to satisfy the video requirements, there is no problem in satisfying the audio requirements.

Table 3-14 4 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With A Separate Audio Carrier Through WESTAR.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.[illegible] dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.5 dB
Uplink C/N	28.0 dB	28.0 dB	28.0 dB
Satellite IM	23.0 dB	23.0 dB	23.0 dB
Required C/N_{op} 2)	11.2 dB	11.2 dB	11.2 dB
Required Downlink C/N_D	11.7 dB	11.8 dB	12.1 dB
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	20.1 dB/°K	19.2 dB/°K	19.8 dB/°K
Preamp Noise Temperature	200°K	250°K	200°K
Required Antenna Size	15 feet	15 feet	15 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-15 HPA Vs. Antenna Sizes Required For 6 GHz Transmit Stations For NTSC TV With Separate Audio Carriers Through WESTAR

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m²	-81.8 dBW/m²	-81.8 dBW/m²
Maximum Required EIRP	82.2 dBW	82.6 dBW	82.6 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Net Clear C/N_u	28.3 dB	28.8 dB	28.8 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	4266W	4678W	4678W
b) 18-ft. Diameter	2951W	3236W	3236W
c) 20-ft. Diameter	2399W	2630W	2630W
d) 30-ft. Diameter	1066W	1169W	1169W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	4169W	4365W	4266W
b) 18-ft. Diameter	2884W	3020W	2951W
c) 20-ft. Diameter	2344W	2454W	2399W
d) 30-ft. Diameter	1042W	1091W	1066W

NOTES:

1. Uplink rain margin is for 99.75 percent link availability for non-diversity stations.

Table 3-16. 4 GHz Receive Only Earth Station Downlink Calculations for NTSC TV with a Separate Audio Carrier Through WESTAR - Sound Channel.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	20.0 dB	20.0 dB	20.0 dB
EIRP	15.5 dBW	16.5 dBW	16.0 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.5 dB
Uplink C/N	38.0 dB	38.0 dB	38.0 dB
Satellite IM	30.6 dB	30.6 dB	30.6 dB
Required C/N_{op}^{2}	11.3 dB	11.3 dB	11.3 dB
Required Downlink C/N_D	11.4 dB	11.5 dB	11.8 dB
Noise Bandwidth	53.0 dB/Hz	53.0 dB/Hz	53.0 dB/Hz
Boltzman's constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	17.9 dB/°K	17.2 dB/°K	17.6 dB/°K

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 50 dB test-tone-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-17. HPA Vs. Antenna Sizes Required for 6 GHz Transmit Station for NTSC TV with Separate Audio Carriers Through WESTAR - Sound Channel.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	14.2 dB	14.2 dB	14.2 dB
Required Flux Density	-95.2 dBW/m²	-95.0 dBW/m²	-95.0 dBW/m²
Maximum Required EIRP	69.0 dBW	69.4 dBW	69.4 dBW
Clear Weather EIRP	68.9 dBW	59.1 dBW	69.0 dBW
Noise Bandwidth	53.0 dB-Hz	53.0 dB-Hz	53.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Net Clear C/N_u	39.4 dB	39.9 dB	39.9 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	204W	224W	224W
b) 18-ft. Diameter	141W	155W	155W
c) 20-ft. Diameter	115W	126W	126W
d) 30-ft. Diameter	51W	56W	56W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	200W	209W	204W
b) 18-ft. Diameter	138W	145W	141W
c) 20-ft. Diameter	112W	117W	115W
d) 30-ft. Diameter	50W	52W	51W

Notes:

1. Uplink rain margin is for 99.75 percent link availability for non-diversity stations.

Table 3-18 12 GHz Receive Only Earth Station Downlink Calculations for NTSC TV with Separate Audio Carrier Through Future DOMSAT

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	37.9 dBW	43.9 dBW	38.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.2 dB	1.2 dB	3.3 dB
Uplink C/N	24.0 dB	24.0 dB	24.0 dB
Satellite IM	23.0 dB	23.0 dB	23.0 dB
Required C/N_{op} 2)	11.2 dB	11.2 dB	11.2 dB
Required Downlink C/N_D	11.9 dB	12.9 dB	14.9 dB
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	27.3 dB/°K	22.3 dB/°K	29.1 dB/°K
Preamp Noise Temperature	755°K	755°K	630°K
Required Antenna Size	25 feet	12 feet	28 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-19 HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for NTSC TV With Separate Audio Carriers Through Future DOMSAT.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-80.5 dBW/m^2	-81.5 dBW/m^2	-80.3 dBW/m^2
Maximum Required EIRP	84.3 dBW	84.6 dBW	88.4 dBW
Clear Weather EIRP	84.0 dBW	83.0 dBW	84.0 dBW
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-5.0 dB/K	-1.0 dB/K	-5.2 dB/K
Clear Weather C/N_u	23.9 dB	26.9 dB	23.9 dB
Maximum Required HPA Output for:			
a) 18-ft. Diameter	962W	1031W	2473W
b) 25-ft. Diameter	498W	533W	1281W
c) 28-ft. Diameter	398W	426W	1022W
d) 32-ft. Diameter	304W	327W	782W
Clear Weather HPA Output for:			
a) 18-ft. Diameter	898W	713W	898W
b) 25-ft. Diameter	465W	369W	465W
c) 28-ft. Diameter	371W	295W	371W
d) 32-ft. Diameter	284W	226W	284W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

Table 3-20 4 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Separate Audio Carrier Through ATS-6.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	51.4 dBW	51.4 dBW	51.4 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.3 dB
Uplink C/N	36.0 dB	36.0 dB	36.0 dB
Satellite IM	23.0 dB	23.0 dB	23.0 dB
Required C/N_{op} 2)	11.2 dB	11.2 dB	11.2 dB
Required Downlink C/N_D	11.6 dB	11.7 dB	11.9 dB
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	4.0 dB/°K	3.9 dB/°K	4.1 dB/°K
Preamp Noise Temperature	870°K	870°K	870°K
Required Antenna Size	5 feet	5 feet	5 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-21 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for NTSC TV With Separate Audio Carrier Through ATS-6

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss (6 GHz)	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	1.0 dB	1.0 dB	1.0 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-89.0 dBW/m²	-89.0 dBW/m²	-89.0 dBW/m²
Maximum Required EIRP	75.7 dBW	75.9 dBW	75.9 dBW
Clear Weather EIRP	75.6 dBW	75.6 dBW	75.5 dBW
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	10.5 dB/K	10.5 dB/K	10.5 dB/K
Net Clear Weather C/N_u	38.3 dB	38.3 dB	38.3 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	970W	1016W	1016W
b) 18-ft. Diameter	674W	704W	704W
c) 20-ft. Diameter	546W	570W	570W
d) 25-ft. Diameter	349W	364W	364W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	948W	948W	927W
b) 18-ft. Diameter	657W	657W	644W
c) 20-ft. Diameter	532W	532W	521W
d) 25-ft. Diameter	340W	340W	333W

Notes:

1. Uplink rain margin is for 0.9975 link availability for non-diversity stations.

Table 3-22 12 GHz Receive Only Earth Station Downlink Calculations for NTSC TV With Separate Audio Carrier Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	59.2 dBW	59.0 dBW	56.9 dBW
S/C Pointing Error	0.7 dB	0.7 dB	0.7 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.3 dB	1.2 dB	3.3 dB
Uplink C/N	23.0 dB	23.0 dB	23.0 dB
Satellite IM	23.0 dB	23.0 dB	23.0 dB
Required C/N_{op} 2)	11.2 dB	11.2 dB	11.2 dB
Required Downlink C/N_D	12.1 dB	13.0 dB	15.1 dB
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	6.2 dB/°K	7.5 dB/°K	11.5 dB/°K
Preamp Noise Temperature	755°K	755°K	755°K
Required Antenna Size	2 feet	2.5 feet	4 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to **ensure** operating point above demodulator threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3- 23 HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for NTSC TV With Separate Audio Carrier Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-92.3 dBW/m^2	-92.1 dBW/m^2	-90.0 dBW/m^2
Maximum Required EIRP	72.5 dBW	74.0 dBW	78.7 dBW
Clear Weather EIRP	72.2 dBW	72.4 dBW	74.3 dBW
Noise Bandwidth	74.8 dB-Hz	74.8 dB-Hz	74.8 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	5.5 dB/K	5.3 dB/K	3.2 dB/K
Clear Weather C/N_u	22.6 dB	22.6 dB.	22.6 dB
Maximum Required HPA Output for:			
a) 8-ft. Diameter	323W	455W	1340W
b) 10-ft. Diameter	207W	293W	857W
c) 12-ft. Diameter	144W	202W	596W
d) 15-ft. Diameter	92W	130W	383W
Clear Weather HPA Output for:			
a) 8-ft. Diameter	301W	315W	308W
b) 10-ft. Diameter	193W	202W	197W
c) 12-ft. Diameter	134W	140W	137W
d) 15-ft. Diameter	86W	90W	88W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

3.2.3 SECAM 625/50 Color Television Transmission Studies

3.2.3.1 General

The luminance band for 625 lines per frame color video is approximately 0 to 5 MHz, and the frequency band occupied by the chrominance subcarrier is approximately 3.5 to 5 MHz. The analysis procedures are the same as those used for the NTSC 525/60 analysis, and the parameters in Table 3-1 apply except for the highest video frequency which is changed to 5.2 MHz and the video noise weighting factor which is increased to 18.2 dB. A single audio channel will be assumed also.

3.2.3.2 SECAM 625/50 Color TV with Audio Subcarrier

The audio subcarrier will be assumed to be at 6.2 MHz for this analysis. Although the IM distortion will increase somewhat because the frequency separation between the chrominance and audio subcarriers has decreased, the curves presented by Johannsen, et al.[1] for NTSC parameters indicate the degradation to the audio signal-to-total noise ratio will be small.

Repeating the equations and analyses corresponding to those in Section 3.2.2.2 as before,

$$(C/N)_{threshold} = 43.5 - 10 \log B - 20 \log D_v \quad \text{(dB)}$$
$$B = 2.2\, D_v + 0.002\, D_a + 13.4 \quad \text{(MHz)}$$
and $$(C/N)_{threshold} = 79.2 - 10 \log B - 20 \log D_v - 20 \log D_a.$$

Equating the carrier-to-noise equations and solving for the subcarrier program deviation gives

$$D_a = 10^{(79.2 - 43.5)/20} = 61 \text{ kHz}$$

and the resulting carrier-to-noise equation is

$$(C/N)_{threshold} = 43.5 - 10 \log (2.2D_v + 13.52) - 20 \log D_v \text{ (dB)},$$
and $B = 2.2\, D_v + 13.52$.

The threshold carrier-to-noise is tabulated in Table 3-24 as a function of video deviation. When a video deviation of 8.2 MHz is used, the performance objectives can be net with a $(C/N)_{threshold}$ of 10.2 dB in a 31.6 MHz bandwidth. Since these values are essentially the same as for NTSC 525/60 cases, separate calculations were not performed.

[1] K. G. Johannsen, et. al., loc. cit.

Table 3-24 SECAM 625/50 C/N_t as Function of Video Deviation With Subcarrier Deviation of 61 kHz

D_v (MHz)	B_{if} (MHz)	$(C/N)_{threshold}$ (dB)
6.0	26.7	13.7
6.5	27.8	12.8
7.0	28.9	12.0
7.5	30.0	11.2
8.0	31.1	10.5
8.2	31.6	10.2
8.5	32.2	9.8

3.2.3.3 SECAM 625/50 Color TV Performance with Separate Audio Carrier

The audio subcarrier parameters are the same as those in Section 3.2.2.3. The corresponding video equations are

$$(C/N)_{threshold} = 43.5 - 10 \log B - 20 \log D_v \quad \text{(dB)}$$
$$B = 2\, D_v + 11.4 \quad \text{(MHz)}$$
and $$(C/N)_{threshold} = 40.5 - 10 \log (D_v + 5.7) - 20 \log D_v \text{ (MHz)}.$$

The video threshold carrier-to-noise ratio is presented in Table 3-25 as a function of the video deviation. The video performance objectives can be met with an $(C/N)_{threshold}$ of 10.2 dB in a 28.7 MHz bandwidth.

Table 3-25 C/N_f for SECAM 625/50 Color TV With Separate Audio Carrier

D_v (MHz)	B_{if} (MHz)	$(C/N)_{threshold}$ (dB)
6.0	23.4	14.3
6.5	24.4	13.4
7.0	25.4	12.5
7.5	26.4	11.8
8.0	27.4	11.1
8.5	28.4	10.4
8.65	28.7	10.2

If the same earth stations were used for the 625/50 Color TV transmission and reception as used for the NTSC 525/60 Color TV, the signal-to-noise would be approximately 0.2 dB better than for the NTSC 525/60. This difference is probably less than the accuracy of the estimations, and is imperceptible to a television viewer. Hence link performance tables are not shown for the 625/50 Color TV cases.

Experiments have shown that SECAM III 625/50 Color video can tolerate about 6 dB overdeviation compared to about 3 to 4 dB overdeviation tolerable for NTSC 525/60 Color video. This could be used to an advantage in several ways:

a) Reducing susceptibility to jamming or interference
b) Reducing bandwidth and power required from the satellite to permit other traffic to share the transponder
c) Reducing G/T requirements for earth station.

It should be noted that in a TV system being developed for an African Nation, the b) advantage has been used to add a significant number of telephone, TTY and data channels to the transponder simultaneously with the TV transmissions.

3.2.4 Digital TV Transmission Studies

3.2.4.1 System Description

In the transmission of television signals via satellite communication links, the use of digital techniques can offer significant advantages in terms of satellite power and bandwidth efficiency. An additional factor, which is especially significant in the context of this study, is the possibility of the easy addition of cryptographic equipment to a digital system in order to make the transmitted video and sound channels secure from unauthorized monitoring. Even without cryptographic techniques, digital video is more secure than analog video. Many alternatives exist in digitizing a TV signal.[1,2,3] This report considers the DITEC system developed for Intelsat, since it currently is in the most developed state for use on satellite links.[4,5]

In the DITEC system, 525/60 NTSC color analog TV signals are converted to a 33.6 Mbit per second digital bit stream. The luminance channel, in-phase chrominance channel, quadrature-phase chrominance channel, and audio channel are all sampled individually, at rates determined by the characteristics of the individual signals, as shown in table 3-26.

TABLE 3-26
COMPONENT BIT RATES FOR DITEC

VIDEO SIGNAL	SAMPLING FREQUENCY (MHZ)	NUMBER OF BITS PER SAMPLE	BIT RATE FOR SIGNAL (MBPS)
Y	6.02	5	25.1
I	1.77	4	3.0
Q	0.668	4	1.1
AUDIO	0.01575	12	0.2

1) "Real Time Image Redundancy Reduction Using Transform Coding Techniques", A. Habibi, W. K. Pratt, G. Robinson, R. Means, H. Whitehouse, J. Speiser, Proceedings of the 1974 International Communications Conference, pp. 18A-1 to 18A-8.

2) "Entropy Encoded Differential Pulse Code Modulation Systems for Television", S. K. Goyal and J. B. O'Neal, Jr., Proceedings of the 1974 National Telecommunications Conference, pp. 72-76, December 2-4, 1974.

3) "A Real Time Hadamard Transform Video Compression System Using Frame-to-Frame Differencing", J. A. Heller, Proceedings of the 1974 National Telecommunications Conference, pp. 77-82, December 2-4, 1974.

4) "DITEC - A Digital Television Communications System for Satellite Links", L. S. Golding, The 2nd International Conference on Digital Satellite Communications Proceedings, Paris, France, Nov. 28-30, 1972, pp. 384-397.

A rate 7/8 convolutional codec is used to obtain the final bit rate of 33.6 Mbps. The A/D codec used is basically a differential pulse code modulation type. However, a technique called edge coding is employed wherein the DPCM quantization noise is increased at sharp edges in the picture in exchange for the ability to follow these transitions more closely. Figure 3-1 shows the results of subjective tests to determine the equivalent S/N performance of DITEC. About 56% of the 60 observers rated DITEC equal to or better than an analog signal having 56 dB S/N and 90% better than 48 dB S/N.[1]

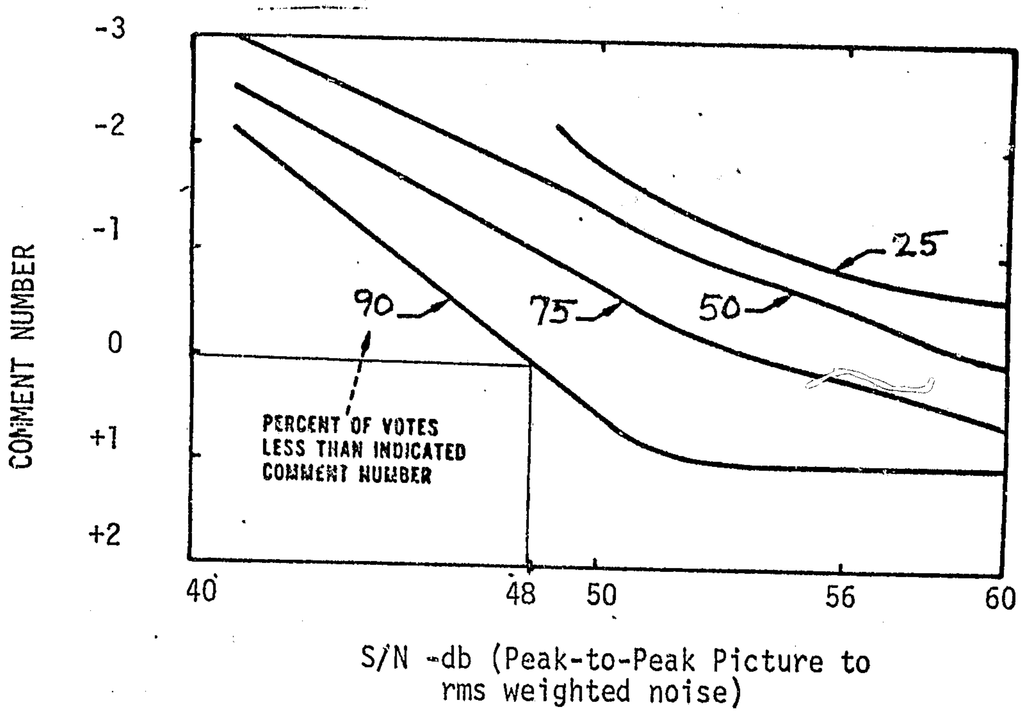

Figure 3-1. Subjective test results for A-B comparison tests to measure signal-to-noise ratio performance for DPCM codec.

1) "Frequency Interleaved Sampling of a Color Television Signal", L. S. Golding and R. K. Garlow, IEEE Transactions on Communication Technology, vol. COM-19, No. 6, Part I, Dec. 1971, pp. 972-979.

The threshold carrier-to-noise ratio for DITEC is given by

$$\left(\frac{C}{N}\right)_{Threshold} = \frac{Eb}{No} - G_c + R_b - B + M \qquad (dB)$$

where

$\frac{Eb}{No}$ = energy per information (uncoded) bit to noise density ratio for an error probability of 10^{-8} (dB)

G_c = coding gain of 7/8 rate codec (dB)

R_b = information bit rate (dB)

B = noise bandwidth of channel (dB)

M = implementation margin (dB).

For a rate 7/8 coded system the channel bit rate, R_c is

$$R_c = \frac{8}{7} R_b$$

For a practical QPSK modem, it is realistic to assume that the implementation margin, M, is 4 dB, and that the bandwidth, B, is related to the symbol rate R_s and channel bit rate R_c by

$$B = 1.2 R_s = .6 R_c .$$

Therefore,

$$\left(\frac{C}{N}\right)_{Threshold} = \frac{Eb}{No} - G_c + 2.2 + M \qquad (dB)$$

$$= 12 - 4 + 2.2 + 4 = 16 \text{ dB}$$

$$B = 0.6 R_c = (0.6)(33.6) = 20.16 \text{ MHz.}$$

In the Intelsat IV satellites, where DITEC was intended for use, the transponder passband is quite flat out to the full 36 MHz. This allowed for two DITEC channels to be squeezed through using TDMA or even FDMA, in conjunction with carefully designed transmit and receive channel filters. Recently, the required bit rate has been reduced somewhat, to about 32 Mbit/sec, which makes it less difficult to pass two DITEC channels through a single transponder. The primary difference in applying DITEC to DOMSAT satellites such as Westar, is that where the Intelsat IV satellites had on board equalizazation, the WESTAR transponders do not. This factor is taken into account in the implementation margins in the link analysis.

One of the problems with DITEC is its high cost, on the order of $200K per terminal. Several development efforts are currently underway, with the aim of reducing both the cost and the required bit rate for digital TV.

Commercial systems providing "industrial quality" (e.g., 48 dB S/N) digital TV are expected to be available in the near future. These terminals should have data rates under 10 Mbits/sec and cost in the neighborhood of $20-$40K per terminal. As these new techniques are proven viable, TV transmission via satellite will become increasingly attractive economically.

Figure 3-2 and 3-3 show the block diagrams for the baseband to 70 MHz portions of the earth station required for DITEC.

3.2.4.2 Digital TV Transmission Studies

Since DITEC as configured is in reality a 56 dB video signal-to-noise system, it is of interest to consider a digital TV system which is basically equivalent to the analog video configurations considered which were 48 dB signal-to-noise configurations. There was insufficient data available for this study on the effect of link BER on DITEC's picture quality to establish the BER required for equivalent performance to a 48 dB signal-to-noise. This relationship is highly subjective and also nonlinear because of the coding and data compression scheme. DITEC is probably more sensitive to BER than the more recently developed industrial quality systems soon to be introduced in the USA. Unfortunately, insufficient information was available from the manufacturers of this new system, also.

For this study, three cases were considered for the WESTAR satellite. One case assumes a $(C/N)_{threshold}$ of 16 dB, i.e. DITEC which really corresponds to a 56 dB signal-to-noise case. The results are shown in tables 3-27 and 3-28. The second case assumes a $(C/N)_{threshold}$ of 14.2 dB which corresponds to a BER of 10^{-6} assuming a coding gain of 3.7 dB for the DITEC type of encoding as follows:

$$\left(\frac{C}{N}\right)_{threshold} = \frac{E_b}{N_o} - G_c + 2.2 + M$$

$$= 10.2 - 3.7 + 2.2 + 4 = 14.2 \text{ dB.}$$

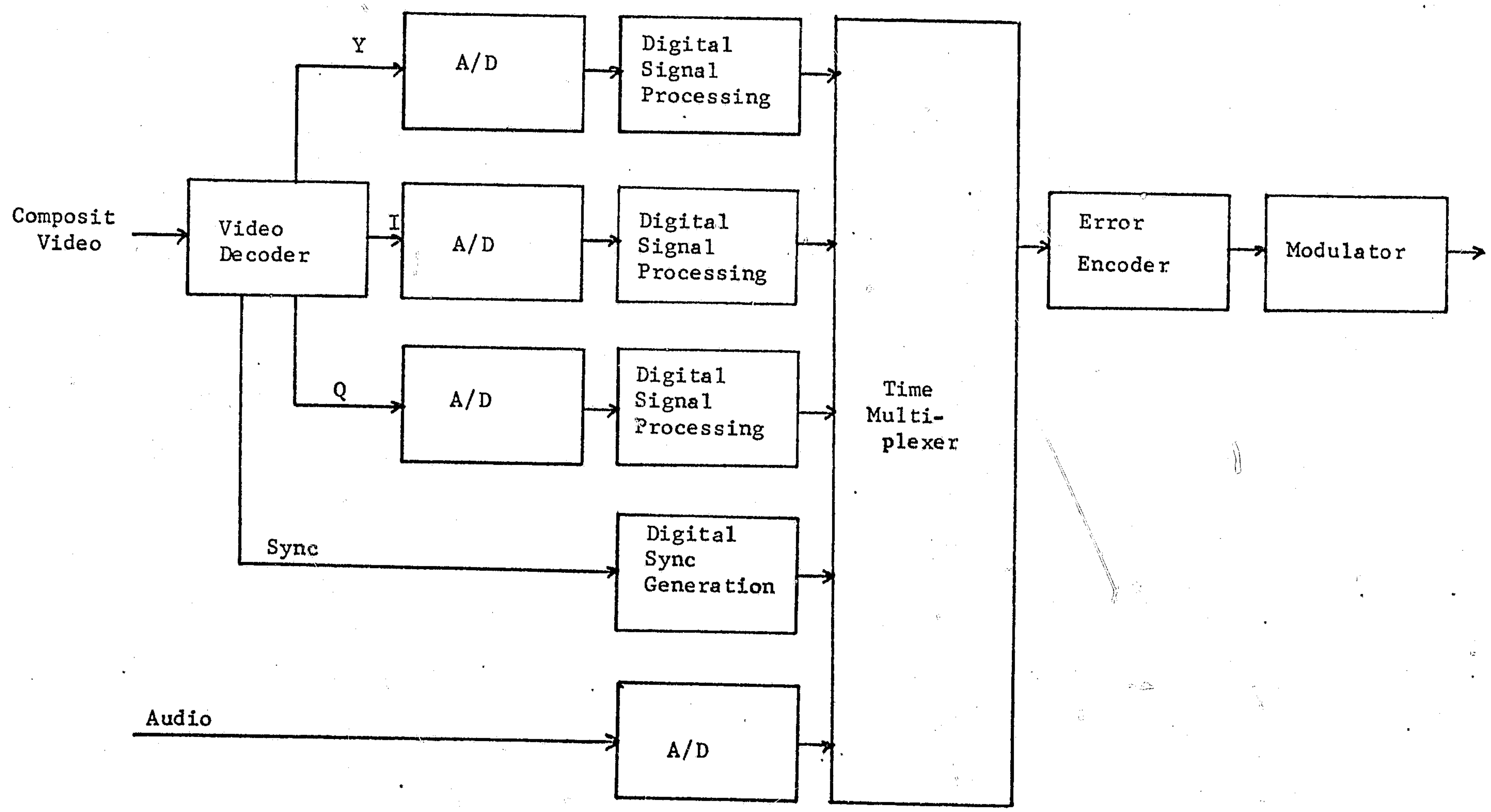

Figure 3-2 DIGITAL TELEVISION (DITEC) TRANSMIT BASEBAND PROCESSING AND MODULATION

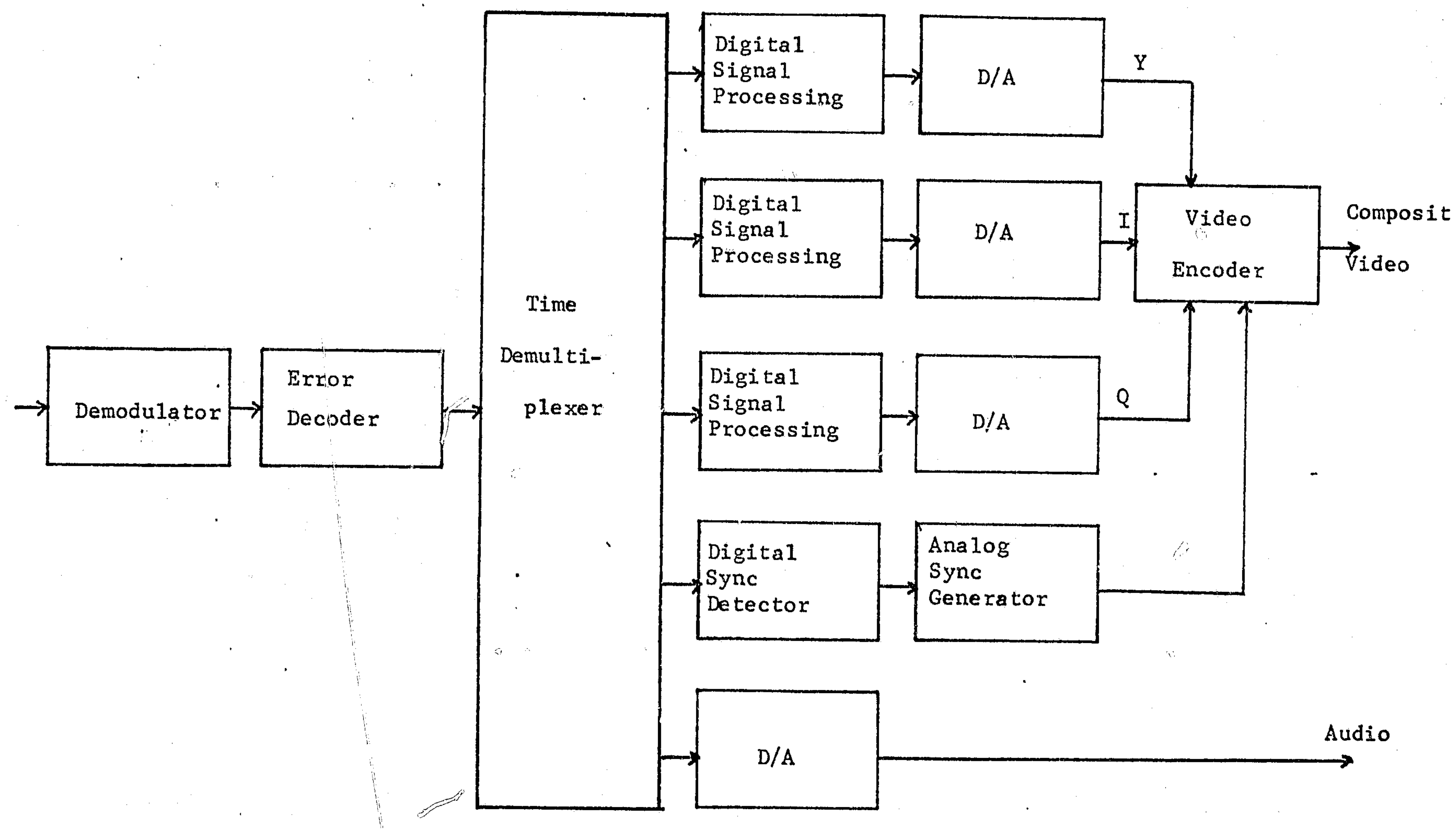

Figure 3-3 DIGITAL TELEVISION (DITEC) RECEIVE BASEBAND PROCESSING AND DEMODULATION

Table 3-27. 4 GHz Receive Only Earth Station Downlink Calculations for a Single DITEC Channel Through WESTAR.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.5 dB
Uplink C/N	28.6 dB	28.6 dB	28.6 dB
Required C/N_t	17.0 dB	17.0 dB	17.0 dB
Required Downlink C/N_D	17.4 dB	17.6 dB	17.8 dB
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	24.0 dB/°K	23.2 dB/°K	23.7 dB/°K
Preamp Noise Temperature	115°K	115°K	115°K
Required Antenna Size	20 feet	18 feet	20 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 56 dB signal-to-noise plus 1 dB link margin to ensure operating point above BER threshold 99.75 percent of time.
3. Assumes DITEC data rate of 33.6 Mbps.

Table 3-28. HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for Single DITEC Channel Through WESTAR

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m²	-81.8 dBW/m²	-81.8 dBW/m²
Maximum Required EIRP	82.2 dBW	82.6 dBW	82.6 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	30.1 dB	30.6 dB	30.6 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	4266W	4678W	4678W
b) 18-ft. Diameter	2951W	3236W	3236W
c) 20-ft. Diameter	2399W	2630W	2630W
d) 30-ft. Diameter	1066W	1169W	1169W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	4169W	4365W	4266W
b) 18-ft. Diameter	2884W	3020W	2951W
c) 20-ft. Diameter	2344W	2454W	2399W
d) 30-ft. Diameter	1042W	1091W	1066W

Notes:

1. Assumes DITEC data rate of 33.6 mbps.
2. Uplink rain margin for 0.9975 link availability for non-diversity stations.

This system is probably closer to equivalent 50 dB video signal-to-noise than a 48 dB signal-to-noise based strictly on the writer's opinion. The G/T calculations are shown for WESTAR in Table 3-29. The EIRP requirements are the same as for a DITEC case.

An alternative configuration, offering duplex DITEC channel (or broadcast mode from two different locations) via single WESTAR transponder, is a two-access TDMA system. Refer to figure 3-4. Link calculations for this system are presented in tables 3-30 and 3-31. The assumed TDMA system has the following parameters:

Frame Rate	1 kHz
Interburst Guard Time	20 QPSK Symbols
Burst Pre-ample Time	40 QPSK Symbols
QPSK Burst Rate	64.12 Mbps
Noise Bandwidth	35.3 MHz
Frame Efficiency	99.8%
DITEC Bit Rate	32 Mbps.

A TDMA "frame" contains one transmitted burst from each accessing earth station. Each station's burst contains an interburst guard time, a preamble time for receiver synchronization, and the DITEC information burst. Frame efficiency is the ratio of information burst time to the sum of guard, preamble, and information burst times.

Finally, the cases where $C/N_{threshold}$ corresponds to a BER of 10^{-6} was computed for three additional satellite models as shown in tables 3-32 through 3-37.

Table 3-29. 4 GHz Receive Only Earth Station Downlink Calculations for a Single Ditital TV Channel Through WESTAR.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.5 dB
Uplink C/N	30.6 dB	30.6 dB	30.6 dB
Required C/N_t	15.2 dB	15.2 dB	15.2 dB
Required Downlink C/N_D	15.4 dB	15.5 dB	15.9 dB
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	22.0 dB/°K	21.1 dB/°K	22.0 dB/°K
Preamp Noise Temperature	115°K	150°K	115°K
Required Antenna Size	16 feet	16 feet	16 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 48 dB signal-to-noise plus 1 dB link margin to ensure operating point above BER threshold 99.75 percent of time.
3. Assumes DITEC data rate of 33.6 Mbps.

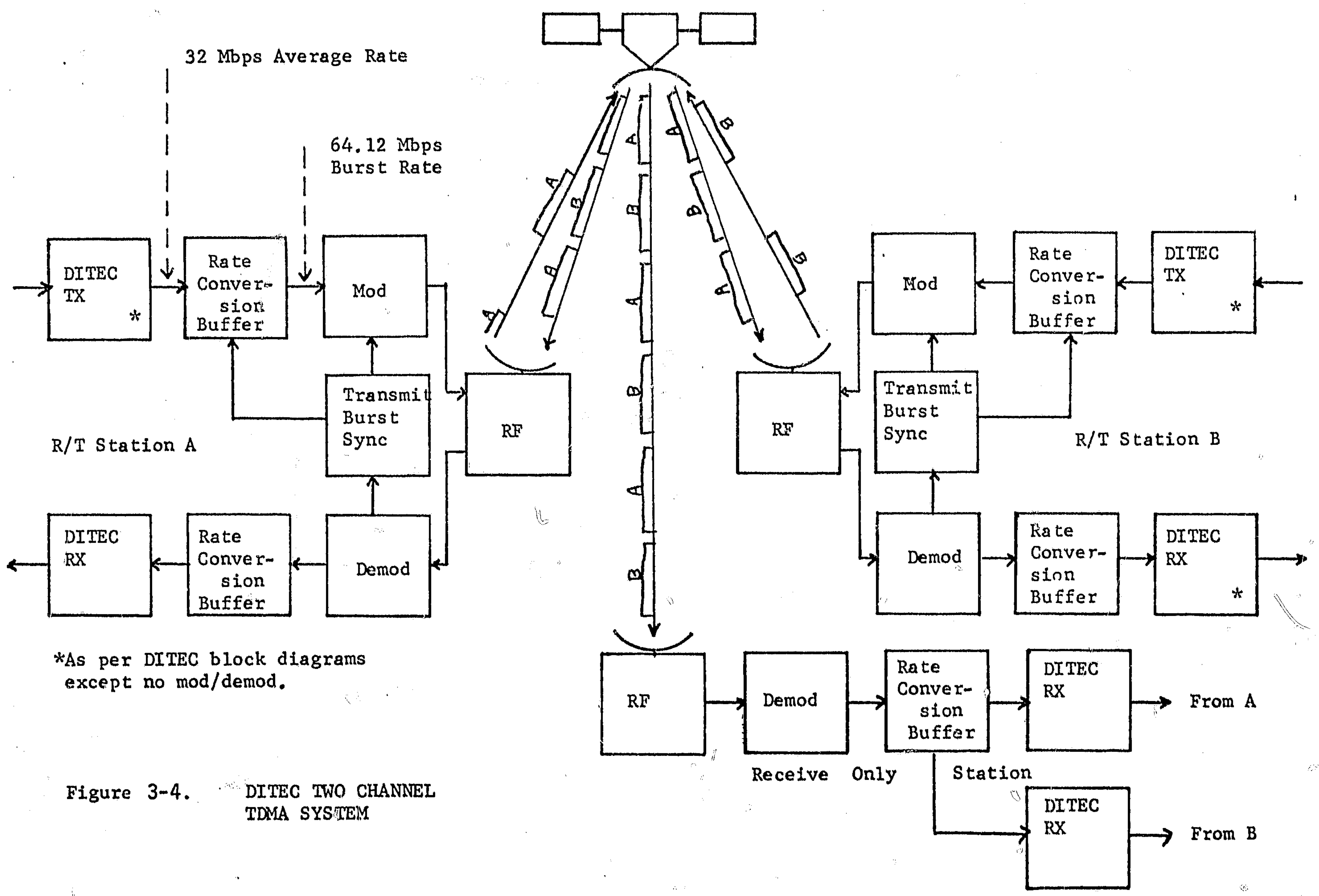

Figure 3-4. DITEC TWO CHANNEL
TDMA SYSTEM

Table 3-30. 4 GHz Receive Only Earth Station Downlink Calculations for Two DITEC TDMA Channels Through WESTAR.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.5 dB
Uplink C/N	27.6 dB	27.6 dB	27.6 dB
Required $C/N_{op}^{2)}$	19.0 dB	19.0 dB	19.0 dB
Required Downlink C/N_D	19.8 dB	20.0 dB	20.2 dB
Noise Bandwidth	75.5 dB-Hz	75.5 dB-Hz	75.5 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	28.9 dB/°K	28.1 dB/°K	28.6 dB/°K
Preamp Noise Temperature	115°K	115°K	115°K
Required Antenna Size	40 feet	36 feet	40 feet

NOTES:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 56 dB signal-to-noise plus 1 dB link margin to ensure operating point above 10^{-8} BER threshold 99.75 percent of time.
3. Implementation margin budgets 1.5 dB to receiver and 4.5 dB to trandponder degradation.
4. Assumes improved DITEC bit rate of 32 Mbps.
5. Assumes two access TDMA system: 99.8% frame efficiency, 1 kHz frame rate, 20 QPSK symbol guard time, 40 QPSK symbol pre-amble, burst rate 64.12 Mbps, noise bandwidth 35.3 MHz.

Table 3-31. HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for Two DITEC TDMA Channels Through WESTAR

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m^2	-81.8 dBW/m^2	-81.8 dBW/m^2
Maximum Required EIRP	82.2 dBW	82.6 dBW	82.6 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	75.5 dB-Hz	75.5 dB-Hz	75.5 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	27.6 dB	28.1 dB	28.1 dB
Maximum Required HPA Output for:			
a) 30-ft. Diameter	1066W	1169W	1169W
b) 32-ft. Diameter	937W	1027W	1027W
c) 36-ft. Diameter	740W	812W	812W
d) 40-ft. Diameter	600W	658W	658W
Clear Weather HPA Output for:			
a) 30-ft. Diameter	1042W	1091W	1066W
b) 32-ft. Diameter	916W	959W	937W
c) 36-ft. Diameter	724W	758W	740W
d) 40-ft. Diameter	586W	614W	600W

Notes:

1. Assumes data rate of 64 Mbps
2. Uplink rain margin for 0.9975 link availability for non-diversity stations.

Table 3-32. 4 GHz Receive Only Earth Station Downlink Calculations for Single Digital TV Channel Through ATS-6.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	51.4 dBW	51.4 dBW	51.4 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.3 dB
Uplink C/N	40.0 dB	40.0 dB	40.0 dB
Required C/N_t	15.2 dB	15.2 dB	15.2 dB
Required Downlink C/N_D	15.3 dB	15.4 dB	15.5 dB
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	5.9 dB/°K	6.0 dB/°K	5.9 dB/°K
Preamp Noise	870°K	750°K	870°K
Required Antenna Size	6 feet	6 feet	6 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-6} BER threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-33. HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for Single Digital TV Channel Through ATS-6.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss (6 GHz)	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	1.0 dB	1.0 dB	1.0 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.4 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-89.0 dBW/m^2	-89.0 dBW/m^2	-89.0 dBW/m^2
Maximum Required EIRP	75.7 dBW	75.9 dBW	75.9 dBW
Clear Weather EIRP	75.6 dBW	75.6 dBW	75.5 dBW
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	10.5 dB/K	10.5 dB/K	10.5 dB/K
Net Clear Weather C/N_u	40.1 dB	40.1 dB	40.1 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	970W	1016W	1016W
b) 18-ft. Diameter	674W	704W	704W
c) 20-ft. Diameter	546W	570W	570W
d) 25-ft. Diameter	349W	364W	364W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	948W	948W	927W
b) 18-ft. Diameter	657W	657W	644W
c) 20-ft. Diameter	532W	532W	521W
d) 25-ft. Diameter	340W	340W	333W

Notes:

1. Uplink rain margin is for 0.9975 link availability for non-diversity stations.

Table 3-34. 12 GHz Receive Only Earth Station Downlink Calculations Single Digital TV Channel Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	59.2 dBW	59.0 dBW	56.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.3 dB	1.2 dB	3.3 dB
Uplink C/N	24.0 dB	24.0 dB	24.0 dB
Required C/N_{op} [2]	15.2 dB	15.2 dB	15.2 dB
Required Downlink C/N_D	16.1 dB	17.0 dB	19.1 dB
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	8.4 dB/°K	9.5 dB/°K	13.5 dB/°K
Preamp Noise Temperature	755°K	755°K	755°K
Required Antenna Size	3 feet	3 feet	5 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-6} BER threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-35. HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for Single Digital TV Channel Through CTS.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-92.3 dBW/m^2	-92.1 dBW/m^2	-90.0 dBW/m^2
Maximum Required EIRP	72.5 dBW	74.0 dBW	78.7 dBW
Clear Weather EIRP	72.2 dBW	72.4 dBW	74.3 dBW
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	5.5 dB/K	5.3 dB/K	3.2 dB/K
Clear Weather C/N_u	24.4 dB	24.4 dB	24.4 dB
Maximum Required HPA Output for:			
a) 8-ft. Diameter	323W	455W	1340W
b) 10-ft. Diameter	207W	293W	857W
c) 12-ft. Diameter	144W	202W	596W
d) 15-ft. Diameter	92W	130W	383W
Clear Weather HPA Output for:			
a) 8-ft. Diameter	301W	315W	308W
b) 10-ft. Diameter	193W	202W	197W
c) 12-ft. Diameter	134W	140W	137W
d) 15-ft. Diameter	86W	90W	88W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

Table 3-36. 12 GHz Receive Only Earth Station Downlink Calculations for Single Digital TV Channel Through Future DOMSAT

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	37.9 dBW	43.9 dBW	38.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.2 dB	1.3 dB	3.1 dB
Uplink C/N	25.0 dB	25.0 dB	25.0 dB
Required C/N_{op} [2]	15.2 dB	15.2 dB	15.2 dB
Required Downlink C/N_D	15.7 dB	16.8 dB	17.6 dB
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	29.3 dB/°K	24.4 dB/°K	30.0 dB/°K
Preamp Noise Temperature	755°K	630°K	755°K
Required Antenna Size	28 feet	15 feet	32 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_T to give plus 1 dB link margin to ensure operating point above 10^{-6} BER threshold 99.75 percent of time.
3. Assumes non-diversity stations.

Table 3-37. HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations for Single Digital TV Channel Through Future DOMSAT

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.3 dB	1.6 dB	4.4 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-80.5 dBW/m^2	-81.5 dBW/m^2	-80.3 dBW/m^2
Maximum Required EIRP	84.3 dBW	84.6 dBW	88.4 dBW
Clear Weather EIRP	84.0 dBW	83.0 dBW	84.0 dBW
Noise Bandwidth	73.0 dB-Hz	73.0 dB-Hz	73.0 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-5.0 dB/K	-1.0 dB/K	-5.2 dB/K
Clear Weather C/N_u	25.7 dB	28.7 dB	25.7 dB
Maximum Required HPA Output for:			
a) 18-ft. Diameter	962W	1031W	2473W
b) 25-ft. Diameter	498W	533W	1281W
c) 28-ft. Diameter	398W	426W	1022W
d) 32-ft. Diameter	304W	327W	782W
Clear Weather HPA Output for:			
a) 18-ft. Diameter	898W	713W	898W
b) 25-ft. Diameter	465W	369W	465W
c) 28-ft. Diameter	371W	295W	371W
d) 32-ft. Diameter	284W	226W	284W

Notes:

1. Uplink rain margin for 0.9975 link availability for non-diversity stations.

3.2.5 Comparison of Color TV Cases

Tables 3-38 through 3-43 summarize the earth station configurations for the different TV transmission cases. The sizes selected are highly dependent upon the assumptions regarding the satellite and the link margins. They also only represent one combination out of many which would suffice. The combinations selected are not necessarily the optimum because of limited effort spent in this study. If the calculations assumed a worst case combination of high rain fall environment and an unfavorable location in the satellite beam, then the sizes required will be larger than the average. An example of such a case located at Miami. A wide range of satellite models and earth station locations was deliberately picked to produce a wide range of illustrative cases. However, some effort was taken to ensure that the range of cases was realistic.

The largest antenna sizes shown in the summary tables were for CTS and a Miami earth station. A 2 dB satellite beam disadvantage and heavy rain attenuations at 12 and 14 GHz make space diversity very attractive for such a case. At the other extreme the smallest antenna sizes selected for the receive only (R.O.) earth stations were also for the CTS cases. For the CTS case the sizes in the tables range from 2 feet to 8 feet in diameter for Los Angeles which was assumed to have a favorable position in the satellite beam. The smallest sizes are perhaps impractical when local interference is taken into consideration. All of the calculations were assumed to be for interference-free environments.

In general a cost effective transmit/receive earth station required a larger antenna than a receive only earth station. In some cases a smaller diameter 15-feet for 6-GHz antennas and 7 feet for 14-GHz antennas was assumed as an FCC requirement.

In all cases the BO_i for the satellite was 1 to 1.5 dB below saturation, so the EIRP requirements were independent of modulation approach. Rather, they depended more on satellite model and earth station location assumptions. For the receive only earth stations the case using separate video and audio

Table 3-38. Earth Station Configurations for Analog Color TV with Submultiplexed Audio Transmission and Reception

Satellite Case	Required G/T (dB/K)	R.O. Antenna Size (feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR (4/6 GHz)							
Los Angeles	22.1	16	115	82.2	18	3	150
Chicago	21.4	15	150	82.6	20	3	300
Miami	21.9	15	115	82.6	20	3	200
ATS-6 (2.6/6 GHz)							
Los Angeles	9.3	14	650	75.7	15	3	650
Chicago	4.2	8	650	75.9	15	3	2000
Miami	9.1	14	650	75.9	15	3	650
ATS-6 (4/6 GHz)							
Los Angeles	6.0	6	750	75.7	15	1	260
Chicago	6.1	6	750	75.9	15	1	260
Miami	6.1	6	750	75.9	15	1	260

CONTINUED

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Table 3-39. 12 and 14 GHz Earth Station Configurations for Analog Color TV With Submultiplexed Audio Transmission and Reception.

Case	Required G/T (dB/K)	R.O. Antenna Size(feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
FUTURE DOMSAT							
Los Angeles	29.5	28	630	84.3	28	450	630
Chicago	24.5	15	630	84.6	28	460	2200
Miami:							
Non-Diversity	30.3	2	755	88.4	4	450	630
Diversity	29.2	28	755	86.2	35	450	1200
CTS							
Los Angeles	8.5	8	870	72.5	8	300	870
Chicago	9.9	8	520	74.0	8	450	520
Miami:							
Non-Diversity	14.1	12	520	78.7	15	450	630
Diversity	13.0	10	520	76.5	12	450	520

Table 3-40. 4 and 6 GHz Earth Station Configurations for Analog Color TV With Separate Audio Carrier Transmission and Reception.

Case	Required G/T (dB/K)	R.O. Antenna Size(feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR							
Los Angeles	20.1	15	200	82.2	18	3	115
Chicago	19.2	15	250	82.6	20	3	125
Miami	19.8	15	200	82.6	20	3	200
ATS-6							
Los Angeles	4.0	5	870	75.7	15	1	2600
Chicago	3.9	5	870	75.9	15	1	2600
Miami	4.1	5	870	75.9	15	1	2600

Table 3-41. 12 and 14 GHz Earth Station Configurations for Analog Color TV With Separate Audio Carrier Transmission and Reception.

Case	Required G/T (dB/K)	R.O. Antenna Size(feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
CTS							
Los Angeles	6.2	2	755	72.5	8	300	2600
Chicago	7.5	2.5	755	74.0	8	450	2600
Miami:							
Non-Diversity	11.5	4	755	78.7	15	450	2600
Diversity	10.4	3.5	755	76.5	12	450	2600
FUTURE DOMSAT							
Los Angeles	27.3	25	755	84.3	28	450	630
Chicago	22.3	12	755	84.6	28	450	630
Miami:							
Non-Diversity	29.1	28	755	88.4	45	450	2000
Diversity	28.0	25	755	86.2	35	450	1100

Table 3-42. 4 and 6 GHz Earth Station Configurations for Digital TV Transmission and Reception

Case	Required G/T (dB/K)	R.O. Antenna Size(feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR DITEC 10^{-8} BER							
Los Angeles	24.0	20	115	82.2	18	3	115
Chicago	23.2	18	115	82.6	20	3	125
Miami	23.7	20	115	82.6	20	3	200
WESTAR DITEC 10^{-6} BER							
Los Angeles	22.0	16	115	82.2	18	3	2600
Chicago	21.1	16	150	82.6	20	3	2600
Miami	22.0	16	115	82.6	20	3	2600
WESTAR DUAL DITEC TDMA							
Los Angeles	28.9	40	115	82.2	18	3	870
Chicago	28.1	36	115	82.6	20	3	870
Miami	28.6	40	115	82.6	20	3	870
ATS-6 DITEC 10^{-6}							
Los Angeles	5.9	6	870	75.7	15	1	
Chicago	6.0	6	750	75.9	15	1	
Miami	5.9	6	870	75.9	15	1	

Table 3-43. 12 and 14 GHz Earth Station Configurations for Digital TV Carrier Transmission and Reception.

Case	Required G/T (dB/K)	R.O. Antenna Size(feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
CTS							
Los Angeles	8.4	3	755	72.5	8	300	6400
Chicago	9.5	3	755	74.0	8	450	6400
Miami:							
Non-Diversity	13.5	4.5	755	78.7	15	450	8300
Diversity	12.4	4	755	76.5	12	450	7200
FUTURE DOMSAT							
Los Angeles	29.3	28	755	84.3	28	450	755
Chicago	24.4	15	630	84.6	28	450	2300
Miami:							
Non-Diversity	30.0	32	755	88.4	45	450	1500
Diverstiy	28.9	25	630	86.2	35	450	1250

carriers resulted in significantly lower G/T values. However, this advantage is generally not as significant in a T/R earth station because of the shift of the cost optimization point. In general, it appeared the SECAM III 625/50 color TV would permit even smaller G/T values for R.O. earth stations, particularly if full advantage is taken of the overdeviation possibilities. SECAM III 625/50 also offers better resolution and color fidelity than NTSC 525/60 color TV. The 10^{-6} BER digital TV case selected required G/T vales on the same order as the analog video with submultiplexed audio. It is believed that the performance of the digital TV can be improved to the point that it is comparable in performance to SECAM III 625/60.

However, if the input to the digital encoder is a conventional analog NTSC 525/60 input, it will not have the resolution and color fidelity inherent in SECAM III 625/50. In general, the digital TV versions will be the most costly and the most secure both from monitoring and jamming.

3.3 T-1 CARRIER TRANSMISSION STUDIES

3.3.1 Introduction

This section summarizes the results of data transmission channels studies using the T-1 (1.544 Mbps) carrier data rates. For these studies a single ground station was assumed to be transmitting a number of data channels in a broadcast mode through a single transponder.

A link analysis to determine satellite channel capacity as a function of receiving earth station G/T was carried out for each of the satellite baselines in Section 2.1 except the ATS-6 (2.6/6) TV-only case. The majority of the cases examined assume uncoded operation and an earth station located at Chicago, Illinois, Miami, Florida, and Los Angeles, California. Some cases using a 1/2 rate forward error correction code were considered. For these cases the rf channel data rates were doubled, i.e., 3.088 Mbps.

Two multiplexing and satellite accessing techniques were investigated. One assumed that all of the transmitted T-1 channels were time division multiplexed in to higher data rate rf channels.

The rf channel rate is assume to be n X 1.544 Mbps where n is the number of channels - in the uncoded case and n X 3.088 Mbps in the coded case. The second case assumed the use of FDMA with each 1.544 Mbps (or 3.088 Mbps in the coded case) modulating a separate rf carrier for the transmission through the satellite.

In all cases QPSK modulation was assumed. n - T-1-TDM cases truly represents a broadcast case with a single transmitting earth station. This case is the simplest to calculate because only one signal is present in the satellite. For this study 36 - MHz wide transponders were considered for simplicity even though bandwidths of 50 and 80 MHz wide transponders will be available when CTS is launched.

The T-1 FDMA cases represent either a single transmitting earth or multiple transmitting earth station case. For this case adjacent channel interference and intermodulation products must be considered.

3.3.2 T 1 Carrier TDM Transmission Studies

3.3.2.1 System Description

In the T 1 carrier TDM System, it is assumed that only one carrier is present in the transponder. The carrier is QPSK modulated by a number of time division multiplexed T 1 carriers. In terms of the link analysis and channel capacity calculation, this is the simplest digital transmission case considered, since for single carrier operation, transponder non-linearities do not produce in-band intermodulation products as in the FDMA cases.

For each of the satellite baseline systems described in Section 2.1, except for the ATS-6 (6/2.6) TV-only case, calculations were performed to determine the number of time division multiplexed T 1 channels which could be transmitted through the transponder on a single carrier at an error rate of 10^{-5} as a function of earth station G/T and EIRP. The calculations were carried out assuming that the earth stations were located at Chicago, Illinois; Miami, Florida; and Los Angeles, California, in order to demonstrate the effects of geographic location on critical parameters such as rain margin, satellite EIRP and G/T contours, etc. In addition, for the WESTAR satellite, the effects of forward error correction coding were also considered.

Figure 3-5 is a block diagram of a typical baseband/modulation portion of a T 1-TDM earth terminal. The transmit side consists of a digital multiplexer, an optional forward error correcting (FEC) encoder, and a quadrature (four phase) phase shift keying (QPSK) modulator. The modulator interfaces with the earth station frequency conversion equipment at if. On the receive side, the down converted if. signal feeds the QPSK demodulator, which is followed by an optional FEC decoder, and the digital de-multiplexer.

The FEC codec is assume to be a rate 1/2, constraint length 7, convolutional encoder and 3-bit soft decision Viterbi decoder. Commercial units of this description are available for data rates up to 10 Mbps. In general, as data rate requirements increase, decoder implementation is accomplished by increased parallel processing. For the type of code assumed in this study, codecs for use above 10 Mbps data rate could be realized by parallel implementation.[1)]

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1) "Time Division Multiple Access for the Defense Satellite Communication System," W. E. Coffrin & G. U. Goubeaud, Proceedings of 1973 IEEE International Convention, Paper 5-4.

A second significant aspect of using the FEC coding, is the impact on the QPSK modem. Soft decision requires that the hard quantizing bit sampler of the modem be replaced by a sampler/3-bit A/D converter. Also, the modem must be able to properly operate at the lower C/N level used during coded operation. For example, the carrier recovery loop must be designed for lower C/N operation.

Several details of an actual implementation have not been considered in the channel capacity calculations. The first involves selection of a method of carrier phase ambiguity resolution in the QPSK demodulator. Two common methods of ambiquity resolution are differential encoding and insertion of synchronization/ambiguity resolution words in the composite bit stream. Use of differential encoding, for example, increases the required Eb/No by less than 0.2 dB at the assumed error rate of 10^{-5}. It is worth noting that in the coded case, the convolutional code can be designed to provide the phase ambiguity resolution in addition to the 5.1 dB coding gain above coherent QPSK. A second issue is the synchronization required for the multiplexing and de-multiplexing of the T 1 carriers to and from the composit transmitted bit stream. For example, a typical T 3 multiplex of 28 T 1 carriers contains about 3% overhead bits for synchronization. This small effect has been neglected in the channel capacity calculations.

3.3.2.2 Threshold Carrier to Noise Power Ratios

Threshold carrier to noise power ratios for the T1-TDM cases were computed using the formulas presented in Section 2.2. Results of this calculation are summarized in Tables 3-44 and 3-45. The TDM cases differ from the FDMA cases in that the implementation margin is a function of the number channels. The reason for this is primarily the added degradation of performance caused by the transponder as the occupied bandwidth is increased to utilize the imperfectly equalized edge portions of the transponder. For example, in the two access TDMA system operated by Telesat Canada, measured performance of the 61 Mbps QPSK modem indicates a required margin of 1.5 dB in an if back-to-back test and an additional 4 to 4.5 dB margin for operation through the ANIK satellite. The assumed margins for if. loop and satellite loop are broken out separately in Tables 3-44 and 3-45. For the coded cases, a rate 1/2, constraint length 7, convolutional encoder with 3-bit soft decision Viterbi decoder is assumed to provide a 5.1 dB coding gain at an error rate of one in 10^5. This performance is based on published data for the Linkabit LV-series codecs.

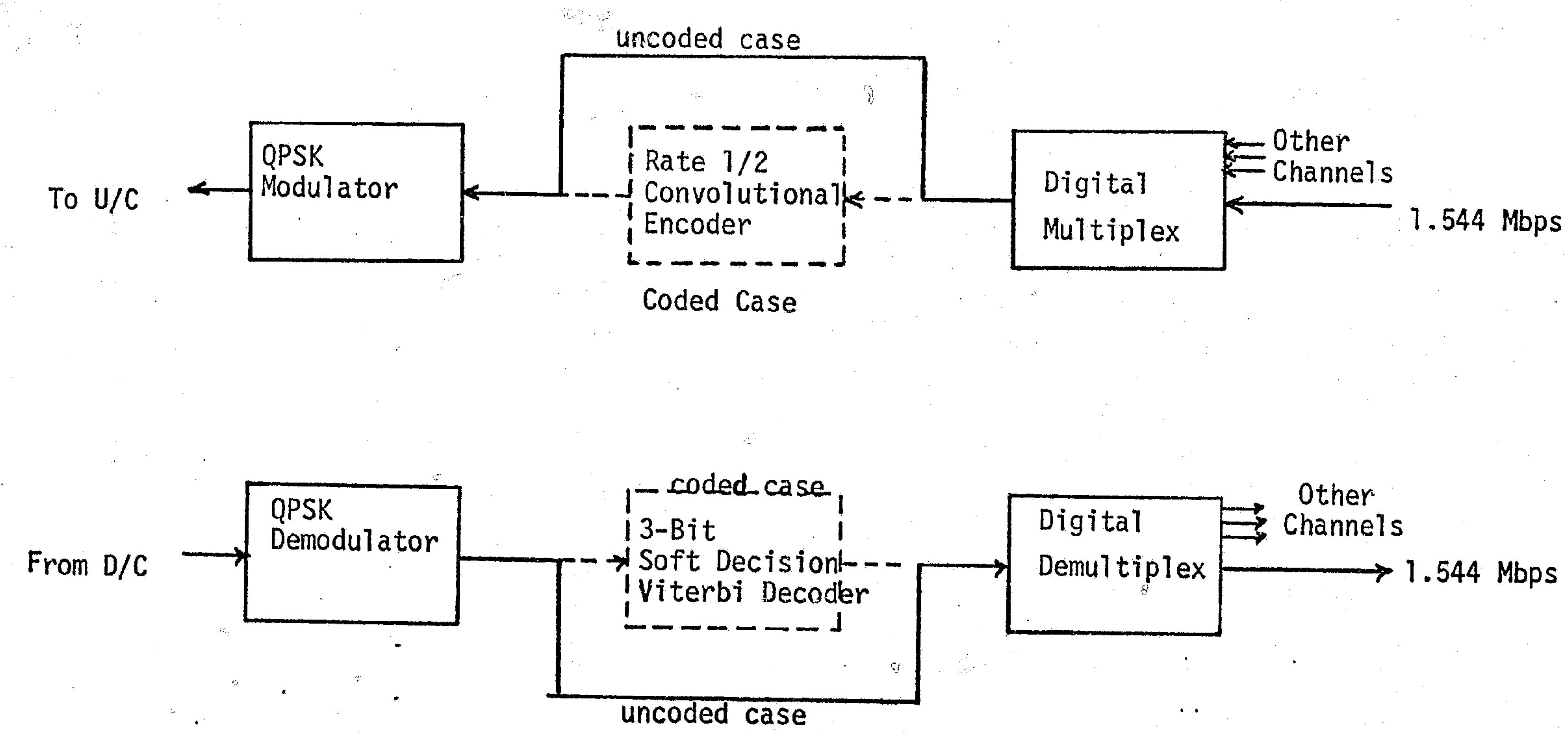

Figure 3-5. Block Diagram for T1 Carrier TDM Cases

Table 3-44 Calculation of Threshold Carrier to Noise-Uncoded T1 TDM Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	Eb/No	9.6 dB
2.	Probability of Error	Pe	10^{-5}
3.	Coding Gain	Gc	0
4.	Code Rate	Rco	1
5.	Information bit rate	Rb	nx1.544 Mbps
6.	Channel bit rate	Rch = Rb/Rco	nx1.544 Mbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	1/2nx1.544 Mbps
8.	Noise Bandwidth	B = 1.2 Rs	0.6xnx1.544 Mbps
9.	Implementation Margin	M	3 dB*
10.	Threshold Carrier to Noise ratio	$\left(\frac{C}{N}\right)$Threshold = $\frac{Eb}{No} - Gc + R_b - B + M$	14.8 dB

(n = number of T1 channels)

* Notes:

1. For n less than 16 Implementation Margin Includes 1.5 dB for modem, 1.5 dB for transponder.
2. For n of 32 Implementation Margin Includes 1.5 dB for modem, 3.5 dB for transponder.
3. For n of 38 Implementation Margin includes 1.5 dB for modem, 4.0 dB for transponder.

Table 3-45 Calculation of Threshold Carrier to Noise Coded T1 TDM Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	E_b/No	9.6 dB
2.	Probability of error	Pe	10^{-5}
3.	Coding Gain	Gc	5.1
4.	Code Rate	Rco	1/2
5.	Information bit rate	Rb	nx1.544 Mbps
6.	Channel bit rate	Rch = Rb/Rco	2xnx1.544 Mbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	nx1.544 Mbps
8.	Noise Bandwidth	B = 1.2 Rs	1.2xnx1.544 Mbps
9.	Implementation Margin	M	3 dB*
10.	Threshold Carrier to noise ratio	$\frac{C}{N}$ Threshold = $\frac{Eb}{No} - Gc + R_b - B + M$	7.7 dB

(n = number of T1 channels)

*Notes:

1. For n less than 16 Implementation Margin Includes 1.5 dB for modem, 1.5 dB for transponder
2. For n of 32 Implementation Margin Includes 1.5 dB for modem, 3.5 dB for transponder.
3. For n of 38 Implementation Margin includes 1.5 dB for modem, 4.0 dB for transponder.

3.3.2.3 Channel Capacity Calculations

The general equations for channel capacity calculation were presented in Section 2.2. In this section, these equations are presented in the form used in computing channel capacity versus earth station G/T for the T1-TDM cases. The following parameters are assumed known (See Section 2.2 for definitions): Ψ, A_i, L_u, L_d, $(G/T)_s$, $EIRP_s$, $(C/N)_{Threshold}$ as a function of channel bit rate, BO_o versus BO_i, $(C/N)_{AC}$ assumed zero, $(C/N)_{IM}$ assumed zero.

In order to avoid the potential of oversaturating due to beam pointing errors BO_i was picked as 1 dB. The following gives a step-by-step flow of the procedure used to compute the required $(G/T)_e$ for the different cases considered.

1. Pick value for n (number of T1 carriers)
2. Compute $B = 10 \log (.6)\ (1.544 \text{ Mbps}) - 10 \log R_{co} + 10 \log n$ (db-Hz)
3. Compute $EIRP_e = \Psi + A_i + L_u$ (dBw)
4. Compute $(C/N)_u = \Psi + A_i + (G/T)_s - K - B$ (dB)
5. Determine $(C/N)_{Threshold}$ from relationship with B and add 1 dB for (C/N) sub-operational.
6. Compute $(C/N)_d = \{(C/N)^{-1}_{operational} - (C/N)^{-1}_u\}^{-1}$
7. Compute $(G/T)_e = (C/N)_d + K + B - EIRP_s + L_d$ (dB)
8. Go to step 1 and repeat for other desired n.

3.3.2.4 Summary And Earth Station Requirements

Tables 3-46 through 3-55 show the results of the link calculations to determine the required earth station G/T and EIRP for the case where 8 T1-channels are multiplexed together. Table 3-56 and 3-57 shows the tabular results for larger and smaller number of T1-channels up to 38 for earth stations located at Chicago. Tables 3-58 and 3-59 show possible antenna, preamp and HPS sizes for these earth stations.

Since a single carrier is being transmitted there need be no concern about operating the earth station HPA and satellite transponder near saturation. This minimizes the earth stations costs. This also makes the uplink $EIRP_e$ independent of the number of T1-carriers. Rather it is dependent upon location and the satellite uplink beampointing. However the required earth station G/T increases as the number of T1 carriers increase.

The tabular results are plotted in Figure 3-6. All of the curves shown in Figure 3-6 ultimately reach the bandwidth limited situation. This is in contrast to the FDMA cases where, for some of the satellite baselines, bandwidth limiting is never achieved, due to uplink limiting resulting from the required operating point as determined by intermodulation considerations. Note that the slope of each curve in Figure 3-6 decreases somewhat as the band limiting case is approached. This effect is caused by the requirement for increased implementation margin as the poorly equalized portions of the transponder passband begin to be utilized at higher channel capacities.

Table 3-46 4 GHz Receive Only Earth Station Downlink Calculations for 8 T1-TDM Channels Through WESTAR - Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.4 dB
Uplink C/N	26.0 dB	26.0 dB	26.0 dB
Required C/N_{op} (Note 2)	15.8 dB	15.8 dB	15.8 dB
Required Downlink C/N_D	16.3 dB	16.4 dB	16.6 dB
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	18.6 dB/°K	17.7 dB/°K	18.7 dB/°K
Preamp Noise Temperature	520°K	520°K	520°K
Required Antenna Size	20 feet	20 feet	20 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.

Table 3-47: HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for 8 T1-TDM Channels Through WESTAR - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m^2	-81.8 dBW/m^2	-81.8 dBW/m^2
Maximum Required EIRP	82.2 dBW	82.7 dBW	82.9 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	34.5 dB	34.9 dB	34.9 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	4266W	4786W	5012W
b) 18-ft. Diameter	2951W	3311W	3467W
c) 20-ft. Diameter	2399W	2691W	2819W
d) 30-ft. Diameter	1066W	1196W	1252W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	4169W	4365W	4266W
b) 18-ft. Diameter	2884W	3020W	2951W
c) 20-ft. Diameter	2344W	2454W	2399W
d) 30-ft. Diameter	1042W	1091W	1066W

Notes:

1. Uplink rain margins for .999 link availability for non-diversity stations.

Table 3-48 4 GHz Receive Only Earth Station Downlink Calculations for 8 T1-TDM Channels Through WESTAR - Coded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	35.4 dBW	36.4 dBW	35.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.4 dB
Uplink C/N	32.0 dB	32.0 dB	32.0 dB
Required C/N_{op} (Note 2)	7.7 dB	7.7 dB	7.7 dB
Required Downlink C/N_D	7.8 dB	7.9 dB	8.1 dB
Noise Bandwidth	71.7 dB-Hz	71.7 dB-Hz	71.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	13.1 dB/°K	12.2 dB/°K	12.7 dB/°K
Preamp Noise Temperature	520°K	520°K	520°K
Required Antenna Size	12 feet	12 feet	12 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.

Table 3-49: HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for 8 T1-TDM Channels Through WESTAR - Coded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-82.0 dBW/m²	-81.8 dBW/m²	-81.8 dBW/m²
Maximum Required EIRP	82.2 dBW	82.7 dBW	82.9 dBW
Clear Weather EIRP	82.1 dBW	82.3 dBW	82.2 dBW
Noise Bandwidth	71.7 dB-Hz	71.7 dB-Hz	71.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	31.5 dB	31.9 dB	31.9 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	4266W	4786W	5012W
b) 18-ft. Diameter	2951W	3311W	3467W
c) 20-ft. Diameter	2399W	2691W	2819W
d) 30-ft. Diameter	1066W	1196W	1252W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	4169W	4365W	4266W
b) 18-ft. Diameter	2884W	3020W	2951W
c) 20-ft. Diameter	2344W	2454W	2399W
d) 30-ft. Diameter	1042W	1091W	1066W

Notes:

1. Uplink rain margins for .999 link availability for non-diversity stations.

Table 3-50 4 GHz Receive Only Earth Station Downlink Calculations for 8 T1-TDM Carriers Through ATS-6 - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	51.4 dBW	51.4 dBW	51.4 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.3 dB
Uplink C/N	40.0 dB	40.0 dB	40.0 dB
Required C/N_{op} (Note 2)	15.8 dB	15.8 dB	15.8 dB
Required Downlink C/N_D	15.9 dB	16.0 dB	16.1 dB
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	-2.2 dB/°K	-2.1 dB/°K	-2.2 dB/°K
Preamp Noise Temperature	2500°K	2500°K	2500°K
Required Antenna Size	4 feet	4 feet	4 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.

Table 3-51 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations 8 T1-TDM Carriers Through ATS-6 - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss (6 GHz)	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	1.0 dB	1.0 dB	1.0 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	1.0 dB	1.0 dB	1.0 dB
Required Flux Density	-89.0 dBW/m²	-89.0 dBW/m²	-89.0 dBW/m²
Maximum Required EIRP	75.7 dBW	76.0 dBW	76.2 dBW
Clear Weather EIRP	75.6 dBW	75.6 dBW	75.5 dBW
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	10.5 dB/K	10.5 dB/K	10.5 dB/K
Net Clear Weather C/N_u	44.4 dB	44.4 dB	44.4 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	970W	1040W	1089W
b) 18-ft. Diameter	674W	722W	757W
c) 20-ft. Diameter	546W	585W	612W
d) 25-ft. Diameter	349W	374W	391W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	948W	948W	927W
b) 18-ft. Diameter	657W	659W	644W
c) 20-ft. Diameter	532W	534W	521W
d) 25-ft. Diameter	340W	342W	333W

Notes:

1. Uplink rain margin is for 0.999 link availability.

Table 3-52 12 GHz Receive Only Earth Station Downlink Calculations for 8 T1-TDM Carriers Through Future DOMSAT - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	37.9 dBW	43.9 dBW	38.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	0.8 dB
Rain Margin	0.5 dB	2.2 dB	14.0 dB
Uplink C/N	26.0 dB	26.0 dB	26.0 dB
Required C/N_{op} (Note 2)	15.8 dB	15.8 dB	15.8 dB
Required Downlink C/N_D	16.7 dB	18.3 dB	29.4 dB
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	26.0 dB/°K	21.6 dB/°K	37.5 dB/°K
Preamp Noise Temperature	630°K	755°K	260°K
Required Antenna Size	18 feet	12 feet	45 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.

Table 3-53 HPA Vs. Antenna Sizes Required For 14 GHz Transmit Stations For 8-T1-TDM Carriers Through Future DOMSAT - Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.6 dB	2.9 dB	3.2 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-80.5 dBW/m²	-81.5 dBW/m²	-80.3 dBW/m²
Maximum Required EIRP	84.6 dBW	85.9 dBW	87.2 dBW
Clear Weather EIRP	84.0 dBW	83.0 dBW	84.0 dBW
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-5.0 dB/K	-1.0 dB/K	-5.2 dB/K
Clear Weather C/N_u	30.1 dB	33.1 dB	30.1 dB
Maximum Required HPA Output for:			
a) 25-ft. Diameter	546W	737W	993W
b) 28-ft. Diameter	436W	588W	793W
c) 35-ft. Diameter	279W	376W	507W
d) 55-ft. Diameter	113W	152W	206W
Clear Weather HPA Output for:			
a) 25-ft. Diameter	927W	378W	927W
b) 28-ft. Diameter	740W	301W	740W
c) 35-ft. Diameter	473W	193W	473W
d) 55-ft. Diameter	192W	78W	192W

NOTES:

1. Uplink rain margin for 0.999 link availability.
2. Assumes 10 Km space diversity for Miami.

Table 3-54 12 GHz Receive Only Earth Station Downlink Calculations for 8 T1-TDM Channels Through CTS-Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	0.1 dB	0.1 dB	0.1 dB
EIRP	59.2 dBW	59.0 dBW	56.9 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.4 dB	2.9 dB	12.7 dB
Uplink C/N	26.0 dB	26.0 dB	26.0 dB
Required C/N_{op} (Note 2)	15.8 dB	15.8 dB	15.8 dB
Required Downlink C/N_D	16.4 dB	18.8 dB	28.3 dB
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	4.6 dB/°K	7.2 dB/°K	19.0 dB/°K
Preamp Noise Temperature	2600°K	2600°K	755°K
Required Antenna Size	2.5 feet	4.0 feet	10 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t to give 10^{-5} BER plus 1 dB margin to ensure operating point above threshold BER 99.9% of time.
3. Assumes non-diversity stations

Table 3-55 HPA Vs. Antenna Sizes Required for 14 GHz Transmit Stations 8 T1-TDM Carriers Through CTS - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.6 dB	2.9 dB	3.2 dB
Satellite Input Backoff	1.5 dB	1.5 dB	1.5 dB
Required Flux Density	-91.8 dBW/m²	-91.6 dBW/m²	-89.5 dBW/m²
Maximum Required EIRP	72.8 dBW	75.3 dBW	77.5 dBW
Clear Weather EIRP	72.2 dBW	72.4 dBW	74.3 dBW
Noise Bandwidth	68.7 dB-Hz	68.7 dB-Hz	68.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	5.5 dB/K	5.3 dB/K	3.2 dB/K
Clear Weather C/N_u	28.7 dB	28.7 dB	28.7 dB
Maximum Required HPA Output for:			
a) 18-ft. Diameter	566W	1006W	1053W
b) 20-ft. Diameter	458W	815W	852W
c) 25-ft. Diameter	294W	523W	547W
d) 32-ft. Diameter	179W	318W	334W
Clear Weather HPA Output for:			
a) 18-ft. Diameter	493W	516W	504W
b) 20-ft. Diameter	300W	418W	408W
c) 25-ft. Diameter	256W	268W	262W
d) 32-ft. Diameter	156W	163W	160W

Notes:

1. Uplink rain margin is for 0.999 link availability.
2. Assumes 10 KM space diversity for Miami.

Table 3-56 EIRP and G/T Requiremnts as a Function of Satellite Type and Number Of channels for TI-TDM Cases for WESTAR and Chicago Earth Stations

	Number of Channels	Bandwidth (M Hz)	C/N_u (dB)	C/N (dB)	C/N_{op} (dB)	Peak EIRP (dBW)	G/T (dB/K)
Case WESTAR Uncoded (4/6)	1	0.93	46.9	16.4	15.8	82.7	8.6
	2	1.85	43.9	16.4	15.8	82.7	11.7
	4	3.71	40.9	16.4	15.8	82.7	14.6
	8	7.41	37.9	16.4	15.8	82.7	17.7
	16	14.82	34.9	16.4	15.8	82.7	20.8
	32	29.65	31.9	18.6	17.8	82.7	25.9
	38	35.23	31.2	19.2	18.3	82.7	27.2
WESTAR (5.1 dB Coding Gain)	1	1.85	43.9	7.9	17.7	82.7	3.6
	2	3.71	40.9	7.9	1 .7	82.7	6.6
	4	7.41	37.9	7.9	1..7	82.7	9.7
	8	14.82	34.9	7.9	1 .7	82.7	6.2
	16	29.65	31.9	9.9	1 .7	82.7	17.7
	19	35.23	31.2	10.4	10.2	82.7	19.0

Table 3-57 EIRP and G/T Requirements as a Function of Satellite Type and Number of Channels for TI-TDM Cases for Chicago Earth Stations

Case	Number of Channels	Bandwidth (MHz)	C/N_u (dB)	C/N (dB)	C/N_{op} (dB)	Peak EIRP (dBW)	G/T (dB/K)
ATS-6 Uncoded (4/6)	1	0.93	53.4	16.0	15.8	76.0	-11.1
	2	1.83	50.4	16.0	15.8	76.0	-8.1
	4	3.71	47.4	16.0	15.8	76.0	-5.1
	8	7.41	44.4	16.0	15.8	76.0	-2.1
	16	14.82	41.4	16.0	15.8	76.0	0.9
	32	29.65	38.4	18.0	17.8	76.0	5.9
	38	35.23	37.6	18.5	18.3	76.0	7.2
Future DOMSAT Uncoded (12/14)	1	0.93	42.1	18.3	15.8	85.9	12.5
	2	1.85	39.1	18.3	15.8	85.9	15.5
	4	3.71	36.1	18.3	15.8	85.9	18.5
	8	7.41	33.1	18.3	15.8	85.9	21.6
	16	14.82	30.1	18.4	15.8	85.9	24.7
	32	29.65	27.1	20.9	17.8	85.9	30.2
	38	35.23	26.3	21.6	18.3	85.9	31.7
CTS Uncoded (12/14)	1	0.93	37.3	16.7	15.8	75.3	- 1.7
	2	1.85	34.7	16.7	15.8	75.3	1.3
	4	3.71	31.7	16.8	15.8	75.3	4.3
	8	7.41	28.7	16.9	15.8	75.3	7.4
	16	14.82	25.7	17.3	15.8	75.3	10.9
	32	29.65	22.7	19.7	17.8	75.3	16.3
	38	35.23	21.9	20.6	18.3	75.3	18.0

Table 3-58 4 and 6 GHz Earth Station Configurations for 8-T1-TDM Carrier Transmission And Reception

Case	Required G/T (dB/K)	R.O Antenna Size (feet)	R.O Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR Uncoded							
Los Angeles	18.6	20	520	82.2	20	3	520
Chicago	17.7	20	520	82.7	20	3	520
Miami	18.7	20	520	82.9	20	3	520
WESTAR Coded							
Los Angeles	13.5	12	520	82.2	18	3	1200
Chicago	12.7	12	520	82.7	20	3	1500
Miami	13.4	12	520	82.9	20	3	1500
ATS-6 Uncoded							
Los Angeles	-2.2	4	2500	75.7	15	1	2500
Chicago	-2.1	4	2500	76.0	16	1	2500
Miami	-2.1	4	2500	76.2	16	1	2500

Table 3-59 12 and 14 GHz Earth Station Configuration for 8 T1-TDM Carrier Transmission and Reception

Case	Required G/T (dB/K)	R.O Antenna Size (Feet)	R.O Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (Feet)	HPA Size (W)	T/R Preamp Noise Temp (°K)
CTS Uncoded							
Los Angeles	4.6	2.5	2600	72.8	20	450	2600
Chicago	7.2	4	2600	75.3	28	450	2600
Miami:							
Non-Diversity	19.0	10	755	88.8	40	1000	2600
Diversity	10.1	6	755	77.5	28	450	2600
Future DOMSAT Uncoded							
Los Angeles	26.0	18	630	84.6	28	1000	1500
Chicago	21.6	12	755	85.9	28	1000	2600
Miami:							
Non-Diversity	37.5	45	260	98.5	68	3000	755
Diversity	28.2	25	755	87.2	32	1000	1500

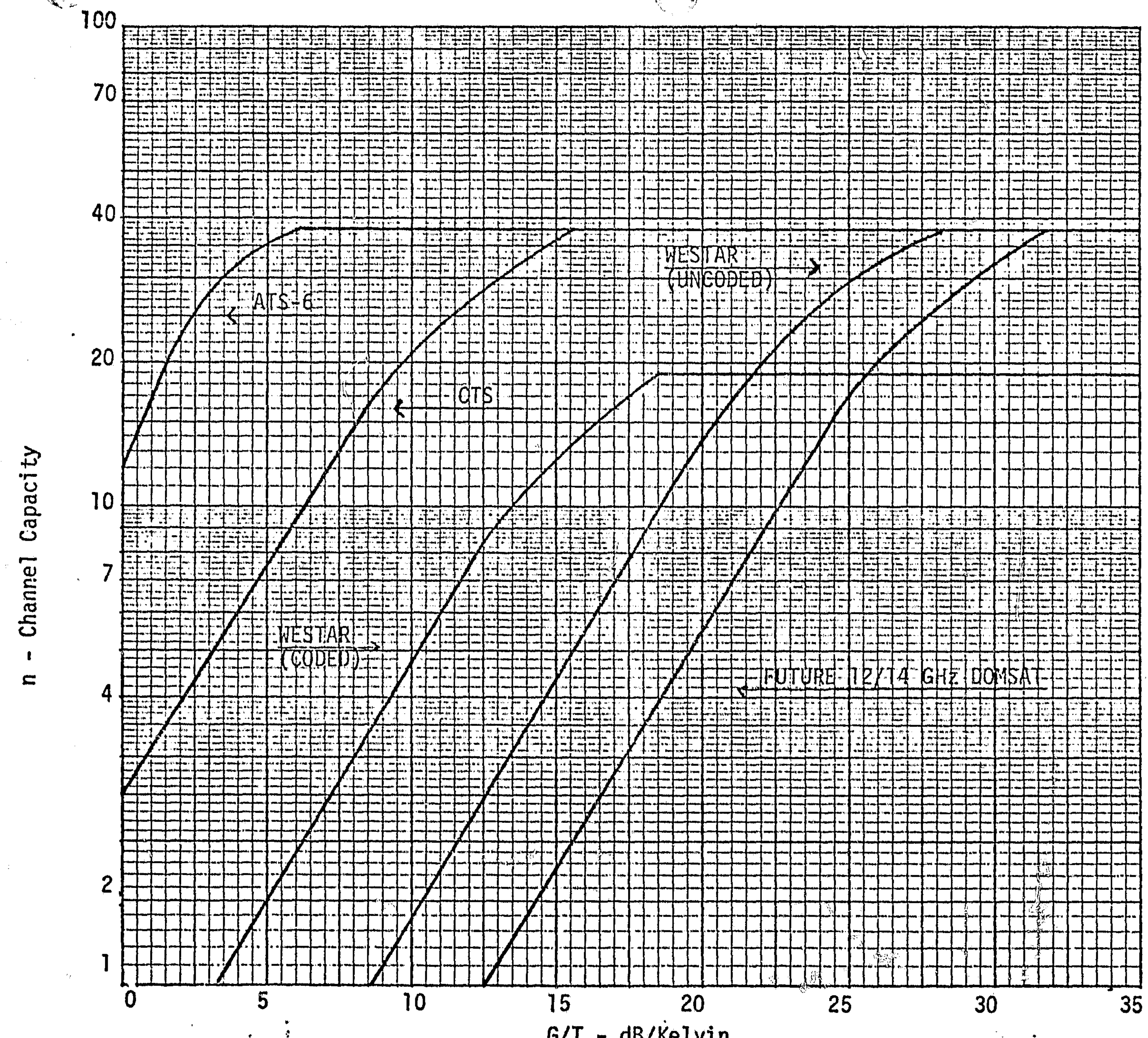

Figure 3-6 . Channel Capacity Vs. Earth Station G/T for Multiple TT-TDM Cases.

3.3.3 T_1 Carrier FDMA Transmission Studies

3.3.3.1 System Description

In the T1 Carrier FDMA System, several rf carriers simultaneously occupy the transponder in non-overlapping frequency bands. Each carrier is QPSK modulated by a T1 rate (1.544 Mbps) bit stream. The T1/FDMA system requires the most complex intermodulation model of the three digital data systems considered, since for the range of two to 32 rf carriers considered, the carrier to inter-modulation noise ratio is a function of both transponder backoff and the number of carriers.

A link analysis to determine satellite channel capacity as a function of earth station G/T and EIRP has been carried out for each of the satellite baselines, except the ATS-6 (6/2.6) TV-only case. The majority of the cases examined assume uncoded operation and an earth station located at Chicago, Illinois. Additional selected cases have been extended to include analyses for earth stations at Miami, Florida, and Los Angeles, California, and for forward error correction coding. The analyses for the alternate earth station locations illustrate performance variations due to varying climatic conditions (e.g., different rain margin requirements) and geographic locations (e.g., different satellite EIRP and G/T contours).

Figure 3-7 is a block diagram for a typical T1/FDMA earth station, showing the baseband processing and modulation portion of the equipment. The transmit portion is simply an optional FEC encoder and a 1.544 Mbps (3.088 Mbps in the coded case) QPSK modulator. The receive portion is the mirror image of the transmit side. A synthesizer is shown as providing a "channel select" L.O. frequency. If the transmit and receive frequency pairs for all modems have the same frequency separation, it is possible to use a common select synthesizer. If transmit and receive frequencies must be selected independently, two synthesizers will be required.

The FEC codec is composed of a rate ½, constraint length 7, convolutional encoder, and a 3-bit soft decision Viterbi decoder. Commercially available codecs of this description are available with data rates of 1.8 Mbps, which is suitable for the application considered. When coding is employed, the modem must be equiped with a 3-bit A/D encoder to provide the "soft decision" data to the FEC codec. In addition, the carrier recovery loop of the modem must be capable of operation at

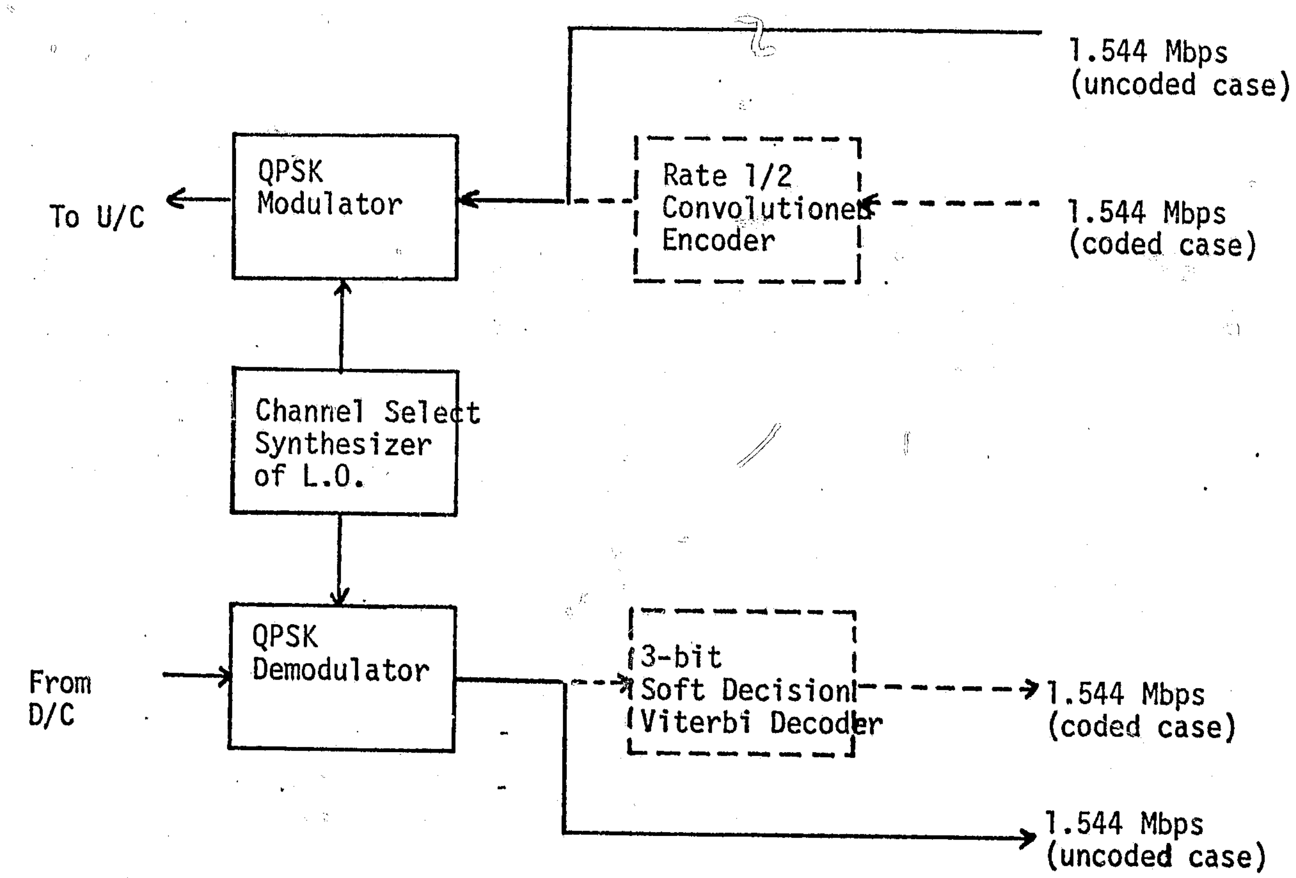

Figure 3-7 . Block Diagram for T1 Carrier FDMA Cases.

the lower C/N values used in coded operation. One further benefit of the FEC codec is its ability to provide the carrier phase ambiquity resolution for the QPSK demodulator. This feature can be made integral to the FEC codec by proper choice of code and implementation. For the uncoded case, techniques of ambiquity resolution such as differential encoding or unique word insertion are available, at a slight cost in Eb/No (about 0.2 dB) or usable bit rate. For the channel capacity calculations performed, this small degradation has not been considered.

3.3.3.2 Threshold Carrier-to-Noise Power Ratios

Threshold carrier-to-noise ratio calculations are presented in tables 3-60 and 3-61 for the coded and uncoded T1 FDMA cases. An implementation margin of 2 dB has been used. This margin has been increased slightly over the 50 Kbps modem case to allow for degradation due to lack of transponder equalization, an effect which may be particularly noticeable for those FDMA channels near the transponder band edge. In addition to the phase non-linearity near the transponder band edge, the amplitude roll-off causes asymmetry in the FDMA channel which results in crosstalk interference between the in-phase and quadrature-phase components of the QPSK modulated carrier. As in the other digital cases, a rate 1/2, constraint length 7, convolutional encoder and 3-bit soft decision Viterbi decoder are assumed to provide a 5.1 dB coding gain in the coded cases considered.

3.3.3.3 Channel Capacity Calculations

In this section, the general equations of section 2.2 are rearranged and presented in the form used to calculate channel capacity versus $(G/T)_e$ in the T1-FDMA cases. The procedure differs from the 50 Kbps FDMA case in that since fewer carriers are involved, the $(C/N)_{IM}$ versus BO_i model changes significantly with n. Consequently, it is found desirable to assume a value of n (thus fixing the intermodulation model) and then find the minimum $(G/T)_e$ as a function of BO_i. The parameters (see section 2.2) assumed known are Ψ, A_t, $(G/T)_s$, $EIRP_s$, $(C/N)_{Threshold}$, $(C/N)_{AC}$, B, n, L_d, L_u, $(C/N)_{IM}$ versus BO_i and n, and BO_o versus BO_i.

The procedure is as follows:

1. Assume a value for n
2. Assume a value for BO_i
3. Determine $(C/N)_{IM}$ for assumed BO_i and n
4. Determine BO_o for assumed BO_i
5. Compute $(C/N)_{Allow} = \left\{(C/N)^{-1}_{operational} - (C/N)^{-1}_{AC} - (C/N)^{-1}_{IM}\right\}^{-1}$
6. Compute $(C/T)_{Allow} = (C/N)_{Req} + B + K$
7. Compute $(C/T)_{Avail} = 10 \log n + (C/T)_{Req}$

Table 3-60 . Calculation of Threshold Carrier to Noise - Uncoded T1 - FDMA Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	Eb/No	9,6 dB
2.	Probability of Error	Pe	10^{-5}
3.	Coding Gain	Gc	0
4.	Code Rate	Rco	1
5.	Information bit rate	Rb	1.544 Mbps = 61.9 dB
6.	Channel bit rate	Rch = Rb/Rco	1.544 Mbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	772 kbps
8.	Noise Bandwidth	B = 1,2 Rs	926 KHz = 59.7 dB-Hz
9.	Implementation Margin	M	2 dB
10.	Threshold Carrier to noise ratio	$\left(\frac{C}{N}\right)$Threshold = $\frac{Eb}{No}$ - Gc+R-B+M	13,8 dB

Table 3-61 . Calculation of Threshold Carrier to Noise - Coded T1 FDMA Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	Eb/No	9.6 dB
2.	Probability of Error	Pe	10^{-5}
3.	Coding Gain	Gc	5.1 dB
4.	Code Rate	Rco	1/2
5.	Information bit rate	Rb	1.544 Mbps - 61.9 dB
6.	Channel bit rate	Rch = Rb/Rco	3.088 Mbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	1.544 Mbps
8.	Noise Bandwidth	B = 1.2 Rs	1.823 MHz = 62,7 dB
9.	Implementation Margin	M	2 dB
10.	Threshold Carrier to noise ratio	$\left(\frac{C}{N}\right)$ Threshold = $\frac{Eb}{No}$ - Gc+R-B+M	5,7 dB

8. Compute $(C/T)_u = \Psi + A_i + (G/T)_s - BO_i$

9. Compute $(C/T) = \left\{(C/T)^{-1}_{Allow} - (C/T)^{-1}_u\right\}^{-1}$

10. Compute $(G/T)_e = (C/T)_d - EIRP_s + L_d + BO_o$

11. Go back to Step 2 and iterate BO_i to minimize $(G/T)_e$

12. Compute $EIRP_e$ (per channel) $= L_u + \Psi + A_i - BO_i - 10 \log n$

13. Go back to Step 1 to repeat for other desired n

Table 3-62 provides a numerical example of the above outlined procedure.

3.3.3.4 Computational Results and Discussion

The calculations outlined in section 3.3.3.3 were carried out for each of the satellite baselines of section 2.1. The results of these calculations are presented in tables 3-63 through 3-72 for the 8 channel cases.

Tables 3-73 and figure 3-8 summarize the transponder channel capacity as a function of earth station G/T. Four of the cases plotted, corresponding to the ATS-6 (4/6), CTS (12/14), WESTAR (4/6), and WESTAR (4/6)-Coded, show two distinct regions corresponding to bandlimited (constant n) and power limited conditions. Note that on the power limited portions of these curves, the relationship between n and $(G/T)_e$ is not dB for dB as it is in the 50 Kbps FDMA cases. The reason that n increases less rapidly with $(G/T)_e$ is that since the intermodulation model changes with n in the present case, the optimum back off value and resulting relative contributions of up and downlink C/T also changes. Thus, even in a downlink limited situation, the relationship between n and $(G/T)_e$ is more complex than in the constant intermodulation model 50 Kbps cases. Also noteworthy in figure 3-8 is the uplink limited situation encountered in the future DOMSAT (11/14) system. In order to achieve bandwidth limited operation for this system, it would be necessary to decrease the transponder gain. If this change is made, and the satellite G/T is not significantly degraded, then a higher uplink power level will maintain the same transponder output level at a higher uplink C/T. Some satellites, such as INTELSAT IV, are capable of varying transponder gain by commands from the ground, and can thus optimize system capacity as indicated above. Tables 3-74 and 3-75 show possible earth stations for the 8 channel cases.

TABLE 3-62 LINK CAPACITY CALCULATION - CASE OF 8 UNCODED T1/FDMA CHANNELS VIA CTS 12/14 GHz TRANSPONDER

CTS 12/14 GHZ T1/FDMA/UNCODED CASES

PARAMETERS:

8 = NUMBER OF CARRIERS
39.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.25 = DOWNLINK RAIN MARGIN (DB)
13.80 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	EARTH STATION G/T (DB/K)	UPLINK PER CHAN EIRP (DBW)
7.00	3.25	-138.20	-116.52	-138.23	16.10	-147.26	37.08	59.57
7.50	3.60	-138.70	-133.64	-139.88	16.70	-148.91	20.31	59.07
8.00	3.95	-139.20	-136.53	-141.08	17.40	-150.11	17.77	58.57
8.50	4.26	-139.70	-138.21	-142.03	18.25	-151.06	16.40	58.07
9.00	4.65	-140.20	-139.06	-142.68	19.10	-151.71	15.94	57.57
9.50	5.19	-140.70	-139.47	-143.14	19.92	-152.17	16.07	57.07
10.00	5.70	-141.20	-139.65	-143.50	20.80	-152.53	16.40	56.57
10.50	6.15	-141.70	-139.64	-143.80	21.76	-152.83	16.86	56.07
11.00	6.60	-142.20	-139.38	-144.02	22.70	-153.06	17.57	55.57
11.50	7.05	-142.70	-138.82	-144.19	23.60	-153.22	18.58	55.07
12.00	7.50	-143.20	-137.88	-144.32	24.50	-153.35	19.97	54.57
12.50	7.93	-143.70	-136.26	-144.42	25.39	-153.45	22.02	54.07
13.00	8.37	-144.20	-132.76	-144.50	26.29	-153.53	25.97	53.57

Table 3-63 4 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Carriers Through WESTAR- Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	4.7 dB	4.7 dB	4.7 dB
EIRP/Channel	21.7 dBW	22.7 dBW	22.2 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.3 dB	0.5 dB
Uplink C/N	24.2 dB	24.2 dB	24.2 dB
Satellite IM	19.1 dB	19.8 dB	19.1 dB
Required C/N_{op} (Note 2)	14.8 dB	14.8 dB	14.8 dB
Required Downlink C/N_D	17.8 dB	18.1 dB	18.2 dB
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	24.8 dB/°K	24.0 dB/°K	24.5 dB/°K
Preamp Noise Temperature	150°K	150°K	150°K
Required Antenna Size	25 feet	25 feet	25 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_{op} plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Uplink C/N includes worse case C/N_u due to satellite G/T_s and 28 dB C/N_{IM} from earth station HPA.

Table 3-64 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for 8 TI-FDMA Channels Through WESTAR - Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	196.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	9.0 dB	9.0 dB	9.0 dB
Required Flux Density	-90.0 dBW/m^2	-89.8 dBw/m^2	-88.8 dBw/m^2
Maximum Required EIRP	74.2 dBW	74.7 dBW	74.9 dBW
Clear Weather EIRP	74.1 dBW	74.3 dBW	74.2 dBW
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	26.5 dB	30.1 dB	33.3 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	676W	759W	794W
b) 18-ft. Diameter	463W	525W	549W
c) 20-ft. Diameter	380W	427W	447W
d) 25-ft. Diameter	243W	273W	286W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	661W	691W	676W
b) 18-ft. Diameter	457W	478W	468W
c) 20-ft. Diameter	371W	389W	380W
d) 25-ft. Diameter	238W	249W	243W

Notes:

1. Uplink rain margins for .999 link availability for non-diversity stations.
2. HPA saturated level must be approximately 9.5 times greater than levels shown.

Table 3-65 4 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Channels Through WESTAR - Coded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9dB
Output Backoff	2.0 dB	2.0 dB	2.0 dB
EIRP/ Channel	24.5 dBW	25.5 dBW	25.0 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.4 dB
Uplink C/N	26.0 dB	26.0 dB	26.0 dB
Satellite IM	13.2 dB	13.2 dB	13.2 dB
Required C/N_{op} (Note 2)	6.7 dB	6.7 dB	6.7 dB
Required Downlink C/N_D	8.0 dB	8.2 dB	8.3 dB
Noise Bandwidth	62.7 dB-Hz	62.7 dB-Hz	62.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	15.0 dB/°K	14.4 dB/°K	14.8 dB/°K
Preamp Noise Temperature	520°K	520°K	520°K
Required Antenna Size	15 feet	15 feet	15 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.
4. Uplink C/N includes worse case C/N_u due to satellite G/T_s and 28 dB C/N_{IM} from earth station HPA.

Table 3-66 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for 8 TI-FDMA Channels Through WESTAR - Coded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	4.5 dB	4.5 dB	4.5 dB
Required Flux Density	-85.5 dBW/m^2	-85.3 dBW/m^2	-84.3 dBW/m^2
Maximum Required EIRP	78.7 dBW	79.2 dBW	79.4 dBW
Clear Weather EIRP	78.6 dBW	78.8 dBW	78.7 dBW
Noise Bandwidth	62.7 dB-Hz	62.7 dB-Hz	62.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	28.0 dB	31.4 dB	28.4 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	1905W	2137W	2238W
b) 18-ft. Diameter	1318W	1479W	1548W
c) 20-ft. Diameter	1071W	1202W	1259W
d) 25-ft. Diameter	686W	770W	806W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	1863W	1950W	1905W
b) 18-ft. Diameter	1288W	1349W	1318W
c) 20-ft. Diameter	1046W	1095W	1071W
d) 25-ft. Diameter	670W	701W	686W

Notes:

1. Uplink rain margins for .999 link availability for non-diversity stations.

Table 3-65 4 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Channels Through WESTAR - Coded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9dB
Output Backoff	2.0 dB	2.0 dB	2.0 dB
EIRP/ Channel	24.5 dBW	25.5 dBW	25.0 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.4 dB
Uplink C/N	26.0 dB	26.0 dB	26.0 dB
Satellite IM	13.2 dB	13.2 dB	13.2 dB
Required C/N_{op} (Note 2)	6.7 dB	6.7 dB	6.7 dB
Required Downlink C/N_D	8.0 dB	8.2 dB	8.3 dB
Noise Bandwidth	62.7 dB-Hz	62.7 dB-Hz	62.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	15.0 dB/°K	14.4 dB/°K	14.8 dB/°K
Preamp Noise Temperature	520°K	520°K	520°K
Required Antenna Size	15 feet	15 feet	15 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.
4. Uplink C/N includes worse case C/N_u due to satellite G/T_s and 28 dB C/N_{IM} from earth station HPA.

Table 3-66 HPA Vs. Antenna Sizes Required for 6 GHz Transmit Stations for 8 TI-FDMA Channels Through WESTAR - Coded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	4.5 dB	4.5 dB	4.5 dB
Required Flux Density	-85.5 dBW/m^2	-85.3 dBW/m^2	-84.3 dBW/m^2
Maximum Required EIRP	78.7 dBW	79.2 dBW	79.4 dBW
Clear Weather EIRP	78.6 dBW	78.8 dBW	78.7 dBW
Noise Bandwidth	62.7 dB-Hz	62.7 dB-Hz	62.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-6.4 dB/K	-6.2 dB/K	-6.2 dB/K
Clear Weather C/N_u	28.0 dB	31.4 dB	28.4 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	1905W	2137W	2238W
b) 18-ft. Diameter	1318W	1479W	1548W
c) 20-ft. Diameter	1071W	1202W	1259W
d) 25-ft. Diameter	686W	770W	806W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	1863W	1950W	1905W
b) 18-ft. Diameter	1288W	1349W	1318W
c) 20-ft. Diameter	1046W	1095W	1071W
d) 25-ft. Diameter	670W	701W	686W

Notes:

1. Uplink rain margins for .999 link availability for non-diversity stations.

Table 3-67 4 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Carriers Through ATS-6- Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	196.1 dB	196.1 dB	195.9 dB
Output Backoff	4.7 dB	4.7 dB	4.7 dB
EIRP/Channel	37.8 dBW	37.8 dBW	37.8 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.2 dB	0.3 dB
Uplink C/N	25.7 dB	25.7 dB	25.7 dB
Satellite IM	19.1 dB	19.1 dB	19.1 dB
Required C/N_{op} (Note 2)	14.8 dB	14.8 dB	14.8 dB
Required Downlink C/N_D	17.3 dB	17.4 dB	17.5 dB
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	8.2 dB/°K	8.4 dB/°K	8.3 dB/°K
Preamp Noise Temperature	750°K	750°K	750°K
Required Antenna Size	8 feet	8 feet	8 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_t plus 1 dB link margin to ensure operating point above 10^{-5} BER Threshold 99.9 percent of time.
3. Assumes non-diversity stations.
4. Uplink C/N includes C/N_u due to satellite G/T_S plus 28 dB C/N_{IM} due to earth station HPA.

Table 3-68 HPA Vs Antenna Sizes Required for 6 GHz Transmit Stations 8 TI-FDMA Carriers Through ATS-6- Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss (6 GHz)	199.6 dB	199.6 dB	199.5 dB
S/C Pointing Error	1.0 dB	1.0 dB	1.0 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.1 dB	0.4 dB	0.7 dB
Satellite Input Backoff	9.0 dB	9.0 dB	9.0 dB
Required Flux Density	$-97.0\ dBW/m^2$	$-97.0\ dBW/m^2$	$-97.0\ dBW/m^2$
Maximum Required EIRP	67.7 dBW	68.0 dBW	68.2 dBW
Clear Weather EIRP	67.6 dBW	67.6 dBW	67.5 dBW
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	10.5 dB/K	10.5 dB/K	10.5 dB/K
Net Clear Weather C/N_u	29.5 dB	29.5 dB	29.5 dB
Maximum Required HPA Outfut for:			
a) 8-ft. Diameter	540W	580W	607W
b) 10-ft. Diameter	346W	371W	388W
c) 12-ft. Diameter	240W	258W	269W
d) 15-ft. Diameter	154W	165W	172W
Clear Weather HPA Output for:			
a) 8-ft. Diameter	526W	526W	517W
b) 10-ft. Diameter	337W	337W	331W
c) 12-ft. Diameter	234W	234W	230W
d) 15-ft. Diameter	150W	150W	147W

Notes:

1. Uplink rain margin is for 0.999 link availability.
2. HPA saturation levels must be approximately 9.5 times greater than levels shown.

Table 3-69. 12 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Channels Through CTS-Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	4.7 dB	4.7 dB	4.7 dB
EIRP/Channel	45.5 dBW	45.3 dBW	43.2 dBW
S/C Pointing Error	0.7 dB	0.7 dB	0.7 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	1.0 dB
Rain Margin	0.4 dB	2.2 dB	12.9 dB
Uplink C/N	21.2 dB	21.2 dB	21.2 dB
Satellite IM	19.1 dB	19.1 dB	19.1 dB
Required C/N_{op} 2	14.8 dB	14.8 dB	14.8 dB
Required Downlink C/N_D	19.5 dB	21.0 dB	31.9 dB
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	12.5 dB/°K	14.1 dB/°K	26.8 dB/°K
Preamp Noise Temperature	1100°K	755 °K	630°K
Required Antenna Size	5.0 feet	5.0 feet	18 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N to give 10^{-5} BER plus 1 dB margin to ensure operating point above threshold BER 99.9% of time.
3. Assumes non-diversity stations
4. Uplink C/N includes C/N_u due to satellite G/T_s and 28 dB C/N_{IM} due to earth station HPA.

Table 3-70. HPA Vs. Antenna Sizes Required for 14 Ghz Transmit Stations 8 TI-FDMA Carriers Through CTS - Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.6 dB	2.9 dB	3.2 dB
Satellite Input Backoff	.0 dB	.0 dB	.0 dB
Required Flux Density	-98.3 dBW/m^2	-98.1 dBW/m^2	-96.0 dBW/m^2
Maximum Required EIRP	66.3 dBW	68.8 dBW	71.0 dBW
Clear Weather EIRP	65.7 dBW	65.9 dBW	67.8 dBW
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	5.5 dB/K	5.3 dB/K	3.2 dB/K
Clear Weather C/N_u	22.2 dB	22.2 dB	22.2 dB
Maximum Required HPA Output for:			
a) 8-ft. Diameter	704W	1248W	1309W
b) 10-ft. Diameter	451W	799W	838W
c) 12-ft. Diameter	312W	555W	583W
d) 15-ft. Diameter	200W	355W	373W
Clear Weather HPA Output for:			
a) 8-ft. Diameter	611W	642W	565W
b) 10-ft. Diameter	392W	410W	403W
c) 12-ft. Diameter	272W	286W	279W
d) 15-ft. Diameter	174W	183W	179W

Notes:

1. Uplink rain margin is for 0.999 link availability.
2. Assumes 10 kM space diversity for Miami.
3. HPA saturation level must be approximately 9.5 times larger than levels shown.

Table 3-71. 12 GHz Receive Only Earth Station Downlink Calculations for 8 TI-FDMA Carriers Through Future DOMSAT - Uncoded.

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Path Loss	205.6 dB	205.6 dB	205.4 dB
Output Backoff	4.7 dB	4.7 dB	4.7 dB
EIRP/Channel	24.3 dBW	30.3 dBW	25.3 dBW
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.0 dB	1.0 dB	0.8 dB
Rain Margin	0.5 dB	2.2 dB	14. dB
Uplink C/N	22.2 dB	22.2 dB	22.2 dB
Satellite IM	19.1 dB	19.1 dB	19.1 dB
Required C/N_{op} [2]	14.8 dB	14.8 dB	14.8 dB
Required Downlink C/N_D	18.8 dB	21.0 dB	33.2 dB
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K	-228.6 dBW/Hz/°K
Required G/T	32.7 dB/°K	28.9 dB/°K	45.7 dB/°K
Preamp Noise Temperature	630°K	630°K	160°K
Required Antenna Size	40 feet	25 feet	108 feet

Notes:

1. Assumes satellite located at 99° west longitude.
2. Required C/N_{op} plus 1 dB margin to ensure operating point above 10^{-5}. BER threshold 99.9 percent of time.
3. Assumes non-diversity stations.
4. Uplink C/N includes C/N_u due to satellite G/T_S and 28 dB C/N_{IM} due to earth station HPA.

Table 3-72. HPA Vs. Antenna Sizes Required For 14 GHz Transmit Stations For 8-TI-FDMA Carriers Through Future DOMSAT - Uncoded

LOCATION	LOS ANGELES	CHICAGO	MIAMI
Elevation Angle	40°	39°	51°
Clear Weather Path Loss	206.9 dB	206.9 dB	206.7 dB
S/C Pointing Error	0.5 dB	0.5 dB	0.5 dB
Ground Antenna Pointing Error	1.5 dB	1.5 dB	1.5 dB
Rain Margin	0.6 dB	2.9 dB	3.2 dB
Satellite Input Backoff	9.0 dB	9.0 dB	9.0 dB
Required Flux Density	-88.0 dBW/m^2	-89.0 dBW/m^2	-87.8 dBW/m^2
Maximum Required EIRP	77.1 dBW	78.4 dBW	79.7 dBW
Clear Weather EIRP	76.5 dBW	75.5 dBW	76.5 dBW
Noise Bandwidth	59.7 dB-Hz	59.7 dB-Hz	59.7 dB-Hz
Boltzman's Constant	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K	-228.6 dBW/Hz/K
Satellite G/T	-5.0 dB/K	-1.0 dB/K	-5.2 dB/K
Clear Weather C/N_u	23.5 dB	26.5 dB	23.5 dB
Maximum Required HPA Output for:			
a) 15-ft. Diameter	536W	722W	972W
b) 18-ft. Diameter	373W	502W	675W
c) 25-ft. Diameter	193W	260W	350W
d) 35-ft. Diameter	98W	133W	179W
Clear Weather HPA Output for:			
a) 15-ft. Diameter	467W	369W	467W
b) 18-ft. Diameter	324W	257W	324W
c) 25-ft. Diameter	168W	133W	168W
d) 35-ft. Diameter	86W	68W	86W

NOTES:

1. Uplink rain margin for 0.999 link availability.
2. Assumes 10 km space diversity for Miami.

Table 3-73 Earth Station EIRP And G/T Requirements As A Function Of Satellite Type And Transponder Channel Capacity For T1 FDMA Cases.

Case	Number of Channels	BO_i (dB)	G/T_e (dB/K)	Downlink Rain Margin (dB)	Uplink $EIRP_e$ Per Channel (dBW)	Uplink Rain Margin (dB)
WESTAR	4	8.5	19.25	0.2	69.18	0.4
WESTAR	8	9.0	24.07	0.4	65.67	0.4
WESTAR	32	10.5	35.29	0.5	58.15	0.4
WESTAR (Coded)	4	4.0	11.00	0.2	73.68	0.4
WESTAR (Coded)	8	4.5	14.43	0.2	70.17	0.4
WESTAR (Coded)	16	5.0	18.13	0.3	66.66	0.4
ATS (4/6)	4	8.5	4.07	0.17	61.48	0.4
ATS (4/6)	8	9.0	8.44	0.2	57.97	0.4
ATS (4/6)	32	11.5	16.29	0.2	49.95	0.4
FUTURE DOMSAT (12/14)	4	8.5	23.40	2.25	72.48	2.9
FUTURE DOMSAT (12/14)	8	9.0	28.3	2.35	68.97	2.9
FUTURE DOMSAT (12/14)	32	10.5	48.59	4.48	61.45	2.9
CTS (12/14)	4	8.5	9.02	2.25	61.08	2.9
CTS (12/14)	8	9.0	15.94	2.25	57.57	2.9
CTS (12/14)	12	10.0	31.14	2.25	54.81	2.9

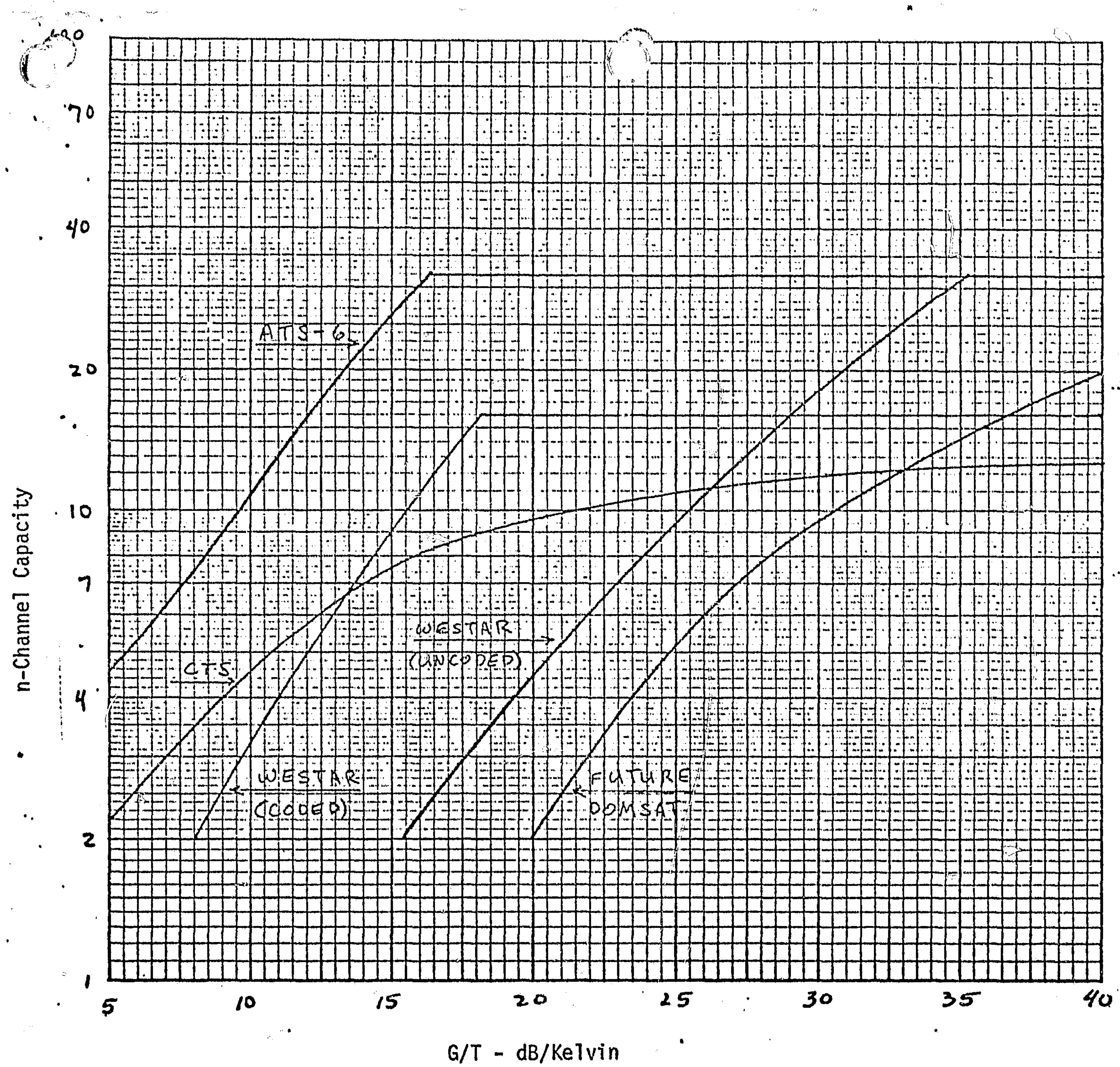

Figure 3-8 Transponder Channel Capacity As A Function of Earth Station G/T for T1 FDMA Cases (Earth Station near Chicago.)

Table 3-74. 4 and 6 GHz Earth Station Configurations for 8-T1-FDMA Carrier Transmission And Reception

Case	Required G/T (dB/K)	R.O Antenna Size (feet)	R.O Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR Uncoded							
Los Angeles	24.8	25	150	74.2	25	3	150
Chicago	24.0	25	150	74.7	25	3	150
Miami	24.5	25	150	74.9	25	3	150
WESTAR Coded							
Los Angeles	15.0	15	520	78.7	45	3	2600
Chicago	14.4	15	520	79.2	45	3	2600
Miami	14.8	15	520	79.4	55	3	2600
ATS-6							
Los Angeles	8.2	8	750	67.7	15	1.5	1500
Chicago	8.4	8	750	68.0	15	2.0	1500
Miami	8.3	8	750	68.2	15	2.0	1500

Table 3-75. 12 and 14 GHz Earth Station Configurations for 8 T1-FDMA Carrier Transmission and Reception

Case	Required G/T (dB/K)	R.O. Antenna Size (feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
CTS Uncoded							
Los Angeles	12.5	5	1100	66.3	10	450	2600
Chicago	14.1	5	755	68.8	12	450	2600
Miami:							
Non-Diversity	26.8	18	630	82.3	40	1000	2600
Diversity	17.5	8	755	71.0	15	450	2600
Future DOMSAT Uncoded							
Los Angeles	32.7	40	630	77.1	40	450	630
Chicago	28.9	25	630	78.4	40	450	1500
Miami:							
Non-Diversity	45.7	108	160	91.0	108	1500	160
Diversity	33.6	45	630	79.7	45	1000	2600

3.4 QPSK/FDMA - 50 Kbps Case

3.4.1 Introduction

In the 50 Kbps QPSK/FDMA cases considered, the satellite transponder is simultaneously occupied by a large number of small rf signal carriers. These carriers may originate at and/or be received by a few or many earth stations. The allocation of the carriers among earth stations may be varied as desired. The carriers are assumed to be uniformly spaced in the transponder bandwidth. For each of the satellite baselines described in section 2.1, except for the TV-only ATS-6 case, the relationship is shown between major earth station parameters (G/T and EIRP) and the maximum number of 50 Kbps channels which may be transmitted over the satellite link with a bit error probability of 10^{-5}. Also for the WESTAR satellite, the effects of employing a half-rate forward error correction coding (FEC) are examined. With FEC, the throughput data rate per channel is reduced to 25 Kbps.

3.4.2 Digital Subsystem Description

A block diagram of a typical 50 Kbps QPSK/FDMA earth station terminal is shown in figure 3-9. The diagram interfaces at if. to the earth station frequency translation equipment and at baseband to the user digital data interface. The transmit side consists of an optional forward error correction encoder, a quadrature (four-phase) phase shift keying (QPSK) modulator, and an if. power combiner. If the station was only transmitting one 50 Kbps channel, the power combiner would be omitted. The forward error correction (FEC) encoder is assumed to be a rate 1/2, constraint length 7, convolutional encoder, similar to commercially available units. Note that when coding is employed, the data rate available to the user is decreased from 50 Kbps to 25 Kbps. The rate delivered to the modulator is 50 Kbps in both the coded and uncoded cases. In the block diagram, a synthesizer is shown as providing the "carrier select" frequency. Typically, this synthesizer would provide a large number of if carrier frequencies centered at 70 or 116 MHz and covering a range of $\pm$18 MHz (for a 36 MHz transponder bandwidth) in small increments. Typical carrier spacings range from 22.5 to 100 kHz. In this study, 45 kHz spacing has assumed which permits a maximum of 800 carriers within a 36 MHz bandwidth. Within the network it is necessary for a designated station to send a pilot centered in the transponder to permit all

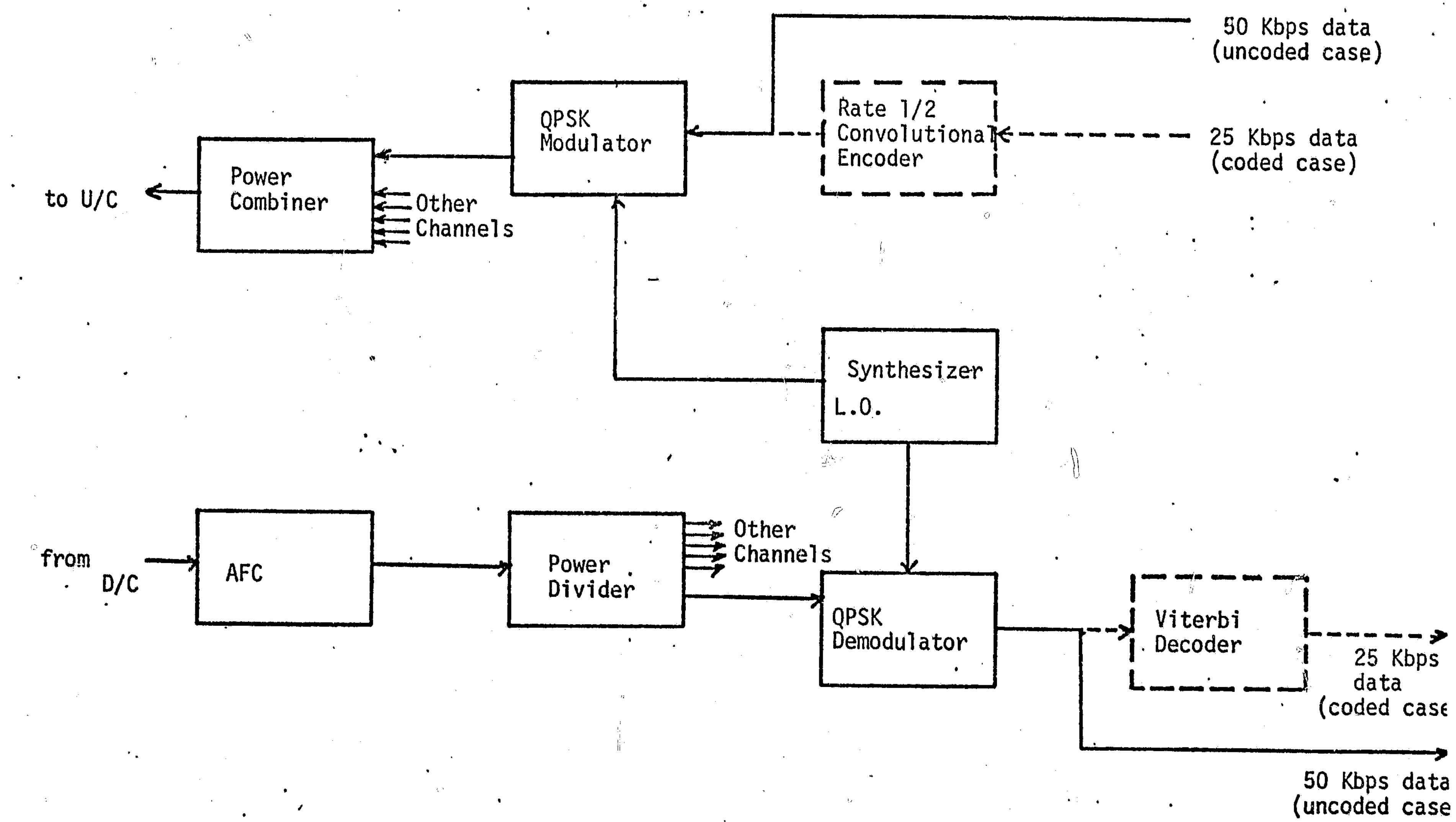

Figure 3-9. Block Diagram for 50 Kbit (Channel Rate) FDMA Cases.

other stations to maintain proper carrier frequency control.

On the receive side, the entire spectrum of carriers from the received transponder band is down-converted and passed through an automatic frequency control (AFC) loop to center the received spectrum with the aid of the pilot. This procedure is necessary because the frequency uncertainty (long term drift) of the satellite transponder frequency translation equipment can be on the order of ± 30 KHz or more. If the AFC loop is not used, the narrow spectra of the received carriers could fall out of the receive channel filter bandwidth, and performance would be degraded at best. Following the AFC loop, a power divider distributes the received spectrum to the channel demodulators. For the case of a one channel station, no power divider is required. The QPSK demodulator coherently detects the selected received carrier. As in the transmit side, a synthesizer referenced to the pilot provides the appropriate local oscillator frequency for channel selection. If the transmit and receive frequency pairs are always selected to be spaced by the same frequency difference, it is only necessary to have one synthesizer for a transmit-receive channel modem. For variable spacing two synthesizers are required. In existing systems, the method of synthesizer frequency selection ranges from hard-wired selection, thumbwheel switch selection, to remote BCD digital selection. The final receive chain component is the optional FEC decoder. This unit is assumed to be a 3-bit soft decision Viterbi decoder similar to commercially available units. These units provide a coding gain of 5.1 dB at a 10^{-5} error probability. Because soft decisions are assumed, use of the FEC codec has a hardware impact on the QPSK modem. Specifically, the modem must be equipped with a 3-bit A/D converter in place of the sampler/hard limiter used for hard (0 or 1) decisions. In addition, the modem must be capable of working at the lower C/N used in a coded system. Carrier recovery loops in particular must be designed for the lower C/N.

An additional important equipment issue is the method used in resolving the phase ambiguity in the recovered carrier in the modem. One method is to employ differential encoding, which results in less then 0.2 dB degradation of E_b/N_o performance at a 10^{-5} error probability. A second technique is to periodically send "unique words" with correlation properties necessary for phase ambiguity resolution. This method results in a slightly lower "user available" bit rate. In the coded case, commercially available FEC codecs

employ codes which inherently have the ability to resolve carrier phase ambiguity. For the purposes of this study, the small degradation due to differential encoding is included in the modem implementation margin.

3.4.3 Threshold Carrier-to-Noise Power Ratios

Threshold carrier-to-noise power ratio calculations are presented in tables 3-76 and 3-77 using the formulas given in section 2.2. The implementation margin used is based on that required for SPADE channel modems, but is reduced slightly to account for the added margin required in the SPADE system due to voice activation. In the coded case, the channel bit rate is maintained at 50 Kbps, as in the uncoded case, so that the information rate has been halved to 25 Kbps. A rate ½, constraint length 7, convolutional code is assumed. Using a soft decision (3-bits) Viterbi decoder[1], a coding gain of 5.1 dB can be expected at an information bit error probability of 10^{-5}.

3.4.4 Channel Capacity Calculations

The general equations necessary for channel capacity calculations were presented in section 2.2. In this section, these equations are presented in the form most suitable for calculating channel capacity in the 50 Kbps FDMA cases. For convenience of computation it is assumed that the link consists of a single transmit earth station and a single receive earth station both located at Chicago. For purposes of computation a single HPA was assumed with a $(C/N)_{IM}$ of 28 dB. The following parameters are assumed known (see section 2.2): Ψ, Ai, $(G/T)_s$, $EIRP_s$, $(C/N)_{Operational}$, $(C/N)_{AC}$, B, L_u, L_d, $(C/N)_{IM}$ of satellite versus BO_i, BO_o versus BO_i. The transponder channel capacity, n, is to be determined as a function of $(G/T)_e$. Once n is determined, the per-channel $EIRP_e$ is calculated.

The calculation procedure is as follows:

1. Determine $(C/N)_{Operational} = (C/N)_{Threshold} + 1$ dB.
2. Assume a value for $(G/T)_e$ and associated downlink rain margin.
3. Assume a value for BO_i
4. Calculate $(\hat{C}/T)_u = \Psi + Ai + (G/T)_s - BO_i$
5. Determine BO_o from BO_o versus BO_i relationship

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1. J. A. Heller, "Performance and Implementation of the Viterbi Decoding Algorithm for Satellite and Space Communication," Proceedings of 1974 International Communications Conference (IEEE), paper 37A.

Table 3-76. Calculation of Threshold Carrier to Noise - Coded 50 Kbps QPSK/FDMA Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	Eb/No	9.6 dB
2.	Probability of Error	Pe	10^{-5}
3.	Coding Gain	Gc	5.1 dB
4.	Code Rate	Rco	1/2
5.	Information bit rate	Rb	25 Kbps = 44.0 dB
6.	Channel bit rate	Rch = Rb/Rco	50 Kbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	25 Kbps
8.	Noise Bandwidth	B = 1.2 Rs	30 KHz = 44.8 dB-Hz
9.	Implementation Margin	M	1.8 dB
10.	Threshold Carrier to noise ratio	$\left(\frac{C}{N}\right)$ Threshold = $\frac{Eb}{No}$ -Gc+R_b-B+M	5.5 dB

Table 3-77. Calculation of Threshold Carrier to Noise - Uncoded 50 Kbps QPSK/ FDMA Case

	Parameter	Symbol	Value
1.	Energy per information bit to noise density ratio	Eb/No	9.6 dB
2.	Probability of Error	Pe	10^{-5}
3.	Coding Gain	Gc	0
4.	Code Rate	Rco	1
5.	Information bit rate	Rb	50 Kbps = 47.0 dB
6.	Channel bit rate	Rch = Rb/Rco	50 Kbps
7.	QPSK Symbol rate	Rs = 1/2 Rch	25 Kbps
8.	Noise Bandwidth	B = 1.2 Rs	30 KHz = 44.8 dB-Hz
9.	Implementation Margin	M	1.8 dB
10.	Threshold Carrier to noise Ratio	$\left(\frac{C}{N}\right)$ Threshold = $\frac{Eb}{No}$ -Gc+R_b-B+M	13.6 dB

6. Compute $(\hat{C}/T)_d = EIRP_s - L_d + (G/T)_e - BO_o$

7. Compute $(\hat{C}/T)_{Avail} = \left\{(\hat{C}/T)_d^{-1} + (\hat{C}/T)_u^{-1}\right\}^{-1}$

8. Determine $(C/N)_{IM}$ from $(C/N)_{IM}$ versus BO_i relationship

9. Combine with HPA $(C/N)_{IM}$ to get total $(\hat{C}/N)_{IM} = \left[(C/N_{IM})_{sat}^{-1} + (C/N_{IM})_{HPA}^{-1}\right]^{-1}$

10. Compute $(C/N)_{allow} = \left\{(C/N)_{operational}^{-1} - (C/N)_{AC}^{-1} - (\hat{C}/N)_{IM}^{-1}\right\}^{-1}$

11. Compute $(C/T)_{allow} = (C/N)_{allow} + B + K$ (dB)

12. Compute n from $10 \log(n) = (\hat{C}/T)_{avail} - (C/T)_{allow}$ (dB)

13. Go back to Step 2, and iterate until maximum for n is located.

14. Compute $EIRP_e$ (per channel) $= L_u + \Psi_s + A_i - BO_i - 10 \log(n)$ using (0 dB) maximum n and corresponding BO_i

15. Go back to step 1, iterate on $(G/T)_e$ until desired range of n is covered.

Table 3-78 provides a numerical example of the procedure outlined above. Notice that for G/T_e fixed and the earth station locations fixed there is an optimum value of BO_i in terms of maximizing the total number of channels. Further Tables 3-78 through 3-92show that as the G/T_e is increased the number of channels increase.

3.4.5 Summary of Results and Earth Station Requirements

The calculational procedure outlined in section 3.4.4 has been carried out for several satellite baselines described in section 2.1. Tables 3-93 through 3-96 show the assumptions used for the satellites.

The curves of channel capacity versus earth station G/T are presented in figure 3-10. For the ATS-6 (4/6), WESTAR (4/6) and WESTAR (4/6)-coded cases, the curves show two distinct regions: a bandlimited region where channel capacity is a constant 800 channels, and a power limited region where capacity increases with G/T. In the power limited region of the curves, channel capacity varies with G/T in essentially a dB for dB relationship. The reason for this behavior is the downlink limited condition of the system, i.e., the link C/T is dominated by the downlink component.

Figure 3-78. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Future 12/14 GHz Domsat - Uncoded

27.00 = EARTH STATION G/T (DB/K)
41.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.35 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-135.90	-144.25	-144.84	15.20	-158.29	22	63.58
10.50	6.15	-136.40	-144.70	-145.30	15.84	-162.21	49	59.60
11.00	6.60	-136.90	-145.15	-145.76	16.50	-164.06	67	57.74
11.50	7.05	-137.40	-145.60	-146.21	17.19	-165.24	79	56.52
12.00	7.50	-137.90	-146.05	-146.67	17.90	-166.05	86	55.66
12.50	7.93	-138.40	-146.48	-147.11	18.60	-166.64	89	55.01
13.00	8.37	-138.90	-146.92	-147.56	19.34	-167.10	89	54.51
13.50	8.83	-139.40	-147.38	-148.02	20.10	-167.46	87	54.10
14.00	9.30	-139.90	-147.85	-148.50	20.90	-167.76	84	53.76
14.50	9.80	-140.40	-148.35	-149.00	21.76	-168.01	79	53.52
15.00	10.30	-140.90	-148.85	-149.50	22.63	-168.20	74	53.31
15.50	10.80	-141.40	-149.35	-150.00	23.51	-168.36	68	53.17
16.00	11.30	-141.90	-149.85	-150.50	24.40	-168.48	62	53.08
16.50	11.80	-142.40	-150.35	-151.00	25.31	-168.58	57	52.94
17.00	12.30	-142.90	-150.85	-151.50	26.23	-168.66	52	52.84

Table 3-79. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Future 12/14 GHz Domsat - Uncoded

36.00 = EARTH STATION G/T (DB/K)
26.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.35 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-135.90	-135.25	-138.60	15.20	-149.57	12	66.21
10.50	6.15	-136.40	-135.70	-139.07	15.84	-160.33	133	55.26
11.00	6.60	-136.90	-136.15	-139.55	16.50	-162.93	217	52.64
11.50	7.05	-137.40	-136.60	-140.03	17.19	-164.40	273	51.14
12.00	7.50	-137.90	-137.05	-140.51	17.90	-165.37	306	50.14
12.50	7.93	-138.40	-137.48	-140.98	18.60	-166.05	321	49.43
13.00	8.37	-138.90	-137.92	-141.45	19.34	-166.57	325	48.88
13.50	8.83	-139.40	-138.38	-141.93	20.10	-166.98	320	48.45
14.00	9.30	-139.90	-138.85	-142.42	20.90	-167.31	308	48.11
14.50	9.80	-140.40	-139.35	-142.92	21.76	-167.58	292	47.85
15.00	10.30	-140.90	-139.85	-143.42	22.63	-167.80	274	47.62
15.50	10.80	-141.40	-140.35	-143.92	23.51	-167.97	254	47.45
16.00	11.30	-141.90	-140.85	-144.42	24.40	-168.10	233	47.33
16.50	11.80	-142.40	-141.35	-144.92	25.31	-168.21	213	47.22
17.00	12.30	-142.90	-141.85	-145.42	26.23	-168.30	194	47.12

Table 3-80. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Future 12/14 GHz Domsat - Uncoded

42.00 = EARTH STATION G/T (DB/K)
26.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
3.75 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-135.90	-130.65	-137.03	15.20	-149.57	17	64.70
10.50	6.15	-136.40	-131.10	-137.52	15.84	-160.33	190	53.71
11.00	6.60	-136.90	-131.55	-138.01	16.50	-162.93	310	51.09
11.50	7.05	-137.40	-132.00	-138.50	17.19	-164.40	389	49.60
12.00	7.50	-137.90	-132.45	-138.99	17.90	-165.37	434	48.63
12.50	7.93	-138.40	-132.88	-139.47	18.60	-166.05	454	47.93
13.00	8.37	-138.90	-133.32	-139.96	19.34	-166.57	458	47.39
13.50	8.83	-139.40	-133.78	-140.45	20.10	-166.98	449	46.98
14.00	9.30	-139.90	-134.25	-140.95	20.90	-167.31	433	46.64
14.50	9.80	-140.40	-134.75	-141.45	21.76	-167.58	411	46.36
15.00	10.30	-140.90	-135.25	-141.95	22.63	-167.80	384	46.16
15.50	10.80	-141.40	-135.75	-142.45	23.51	-167.97	356	45.99
16.00	11.30	-141.90	-136.25	-142.95	24.40	-168.10	328	45.84
16.50	11.80	-142.40	-136.75	-143.45	25.31	-168.21	299	45.74
17.00	12.30	-142.90	-137.25	-143.95	26.23	-168.30	272	45.65

Table 3-81. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through CTS - Uncoded

9.00 = EARTH STATION G/T (DB/K)
48.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.35 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-141.20	-147.15	-148.13	15.20	-158.38	10	55.60
10.50	6.15	-141.70	-147.60	-148.59	15.84	-162.25	23	51.48
11.00	6.60	-142.20	-148.05	-149.05	16.50	-164.09	31	49.69
11.50	7.05	-142.70	-148.50	-149.51	17.19	-165.26	37	48.42
12.00	7.50	-143.20	-148.95	-149.97	17.90	-166.07	40	47.58
12.50	7.93	-143.70	-149.38	-150.42	18.60	-166.65	41	46.97
13.00	8.37	-144.20	-149.82	-150.88	19.34	-167.11	42	46.37
13.50	8.83	-144.70	-150.28	-151.34	20.10	-167.47	41	45.97
14.00	9.30	-145.20	-150.75	-151.82	20.90	-167.77	39	45.69
14.50	9.80	-145.70	-151.25	-152.32	21.76	-168.02	37	45.42
15.00	10.30	-146.20	-151.75	-152.82	22.63	-168.21	34	45.29
15.50	10.80	-146.70	-152.25	-153.32	23.51	-168.37	31	45.19
16.00	11.30	-147.20	-152.75	-153.82	24.40	-168.49	29	44.98
16.50	11.80	-147.70	-153.25	-154.32	25.31	-168.59	26	44.95
17.00	12.30	-148.20	-153.75	-154.82	26.23	-168.67	24	44.80

Table 3-82. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through CTS - Uncoded

15.00 = EARTH STATION G/T (DB/K)
39.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.35 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-141.20	-141.15	-144.19	15.20	-158.21	25	51.62
10.50	6.15	-141.70	-141.60	-144.66	15.84	-162.18	56	47.62
11.00	6.60	-142.20	-142.05	-145.14	16.50	-164.04	77	45.74
11.50	7.05	-142.70	-142.50	-145.61	17.19	-165.22	91	44.51
12.00	7.50	-143.20	-142.95	-146.09	17.90	-166.04	98	43.69
12.50	7.93	-143.70	-143.38	-146.55	18.60	-166.63	101	43.06
13.00	8.37	-144.20	-143.82	-147.03	19.34	-167.09	101	42.56
13.50	8.83	-144.70	-144.28	-147.51	20.10	-167.45	98	42.19
14.00	9.30	-145.20	-144.75	-147.99	20.90	-167.75	94	41.87
14.50	9.80	-145.70	-145.25	-148.49	21.76	-168.00	89	41.61
15.00	10.30	-146.20	-145.75	-148.99	22.63	-168.19	83	41.41
15.50	10.80	-146.70	-146.25	-149.49	23.51	-168.35	76	41.29
16.00	11.30	-147.20	-146.75	-149.99	24.40	-168.47	70	41.15
16.50	11.80	-147.70	-147.25	-150.49	25.31	-168.57	64	41.04
17.00	12.30	-148.20	-147.75	-150.99	26.23	-168.65	[illegible]	40.97

Table 3-83. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through CTS - Uncoded

21.00 = EARTH STATION G/T (DB/K)
34.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
2.35 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-141.20	-135.15	-142.16	15.20	-157.76	36	50.04
10.50	6.15	-141.70	-135.60	-142.65	15.84	-162.00	86	45.76
11.00	6.60	-142.20	-136.05	-143.14	16.50	-163.93	119	43.84
11.50	7.05	-142.70	-136.50	-143.63	17.19	-165.14	141	42.61
12.00	7.50	-143.20	-136.95	-144.12	17.90	-165.97	152	41.78
12.50	7.93	-143.70	-137.38	-144.61	18.60	-166.56	156	41.17
13.00	8.37	-144.20	-137.82	-145.10	19.34	-167.03	155	40.70
13.50	8.83	-144.70	-138.28	-145.59	20.10	-167.40	151	40.31
14.00	9.30	-145.20	-138.75	-146.09	20.90	-167.70	145	39.99
14.50	9.80	-145.70	-139.25	-146.59	21.76	-167.95	136	39.76
15.00	10.30	-146.20	-139.75	-147.09	22.63	-168.15	127	39.56
15.50	10.80	-146.70	-140.25	-147.59	23.51	-168.31	118	39.38
16.00	11.30	-147.20	-140.75	-148.09	24.40	-168.43	108	39.27
16.50	11.80	-147.70	-141.25	-148.59	25.31	-168.53	98	39.19
17.00	12.30	-148.20	-141.75	-149.09	26.23	-168.62	89	39.11

Table 3-84. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Uncoded

21.00 = EARTH STATION G/T (DB/K)
48.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.30 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-134.00	-146.20	-146.45	15.20	-158.38	15	61.94
10.50	6.15	-134.50	-146.65	-146.91	15.84	-162.25	34	57.89
11.00	6.60	-135.00	-147.10	-147.36	16.50	-164.09	47	55.98
11.50	7.05	-135.50	-147.55	-147.81	17.19	-165.26	55	54.80
12.00	7.50	-136.00	-148.00	-148.27	17.90	-166.07	60	53.92
12.50	7.93	-136.50	-148.43	-148.70	18.60	-166.65	62	53.28
13.00	8.37	-137.00	-148.87	-149.15	19.34	-167.11	62	52.78
13.50	8.83	-137.50	-149.33	-149.61	20.10	-167.47	61	52.35
14.00	9.30	-138.00	-149.80	-150.08	20.90	-167.77	58	52.07
14.50	9.80	-138.50	-150.30	-150.58	21.76	-168.02	55	51.80
15.00	10.30	-139.00	-150.80	-151.08	22.63	-168.21	51	51.62
15.50	10.80	-139.50	-151.30	-151.58	23.51	-168.37	47	51.48
16.00	11.30	-140.00	-151.80	-152.08	24.40	-168.49	43	51.37
16.50	11.80	-140.50	-152.30	-152.58	25.31	-168.59	39	51.29
17.00	12.30	-141.00	-152.80	-153.08	26.23	-168.67	36	51.14

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Table 3-85. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Uncoded

27.00 = EARTH STATION G/T (DB/K)
38.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.30 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-134.00	-140.20	-141.13	15.20	-158.16	50	56.71
10.50	6.15	-134.50	-140.65	-141.59	15.84	-162.16	113	52.67
11.00	6.60	-135.00	-141.10	-142.05	16.50	-164.03	157	50.74
11.50	7.05	-135.50	-141.55	-142.51	17.19	-165.21	186	49.50
12.00	7.50	-136.00	-142.00	-142.97	17.90	-166.03	202	48.65
12.50	7.93	-136.50	-142.43	-143.42	18.60	-166.62	208	48.02
13.00	8.37	-137.00	-142.87	-143.87	19.34	-167.08	209	47.50
13.50	8.83	-137.50	-143.33	-144.34	20.10	-167.45	204	47.10
14.00	9.30	-138.00	-143.80	-144.81	20.90	-167.74	196	46.78
14.50	9.80	-138.50	-144.30	-145.31	21.76	-167.99	185	46.53
15.00	10.30	-139.00	-144.80	-145.81	22.63	-168.19	172	46.34
15.50	10.80	-139.50	-145.30	-146.31	23.51	-168.34	159	46.19
16.00	11.30	-140.00	-145.80	-146.81	24.40	-168.47	146	46.06
16.50	11.80	-140.50	-146.30	-147.31	25.31	-168.57	133	45.96
17.00	12.30	-141.00	-146.80	-147.81	26.23	-168.65	121	45.87

Table 3-86. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Uncoded

33.00 = EARTH STATION G/T (DB/K)
29.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.50 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-134.00	-134.40	-137.21	15.20	-155.92	74	55.01
10.50	6.15	-134.50	-134.85	-137.69	15.84	-161.40	234	49.51
11.00	6.60	-135.00	-135.30	-138.16	16.50	-163.55	345	47.32
11.50	7.05	-135.50	-135.75	-138.64	17.19	-164.85	418	45.99
12.00	7.50	-136.00	-136.20	-139.11	17.90	-165.73	459	45.08
12.50	7.93	-136.50	-136.63	-139.58	18.60	-166.36	476	44.42
13.00	8.37	-137.00	-137.07	-140.05	19.34	-166.85	478	43.91
13.50	8.83	-137.50	-137.53	-140.53	20.10	-167.24	468	43.50
14.00	9.30	-138.00	-138.00	-141.01	20.90	-167.55	450	43.17
14.50	9.80	-138.50	-138.50	-141.51	21.76	-167.81	426	42.91
15.00	10.30	-139.00	-139.00	-142.01	22.63	-168.01	398	42.70
15.50	10.80	-139.50	-139.50	-142.51	23.51	-168.17	368	42.54
16.00	11.30	-140.00	-140.00	-143.01	24.40	-168.30	338	42.41
16.50	11.80	-140.50	-140.50	-143.51	25.31	-168.41	308	42.31
17.00	12.30	-141.00	-141.00	-144.01	26.23	-168.49	280	42.23

Table 3.87. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Coded

9.00 = EARTH STATION G/T (DB/K)
42.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.20 = DOWNLINK RAIN MARGIN (DB)
6.50 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
-.50	1.74	-123.50	-154.14	-154.14	7.11	-168.24	25	70.22
.00	1.82	-124.00	-154.22	-154.22	7.70	-170.99	47	66.98
.50	1.74	-124.50	-154.14	-154.14	8.09	-172.05	61	65.35
1.00	1.67	-125.00	-154.07	-154.08	8.50	-172.88	75	63.95
1.50	1.62	-125.50	-154.02	-154.03	9.01	-173.65	91	62.61
2.00	1.60	-126.00	-154.00	-154.01	9.40	-174.11	102	61.61
2.50	1.62	-126.50	-154.02	-154.03	9.59	-174.30	106	60.95
3.00	1.67	-127.00	-154.07	-154.08	9.80	-174.50	110	60.29
3.50	1.74	-127.50	-154.14	-154.15	10.05	-174.71	113	59.67
4.00	1.82	-128.00	-154.22	-154.23	10.30	-174.90	116	59.06
4.50	2.00	-128.50	-154.40	-154.41	10.52	-175.06	116	58.56
5.00	2.20	-129.00	-154.60	-154.61	10.80	-175.23	115	58.09
5.50	2.40	-129.50	-154.80	-154.81	11.15	-175.43	115	57.59
6.00	2.65	-130.00	-155.05	-155.06	11.50	-175.60	113	57.17
6.50	2.95	-130.50	-155.35	-155.36	11.84	-175.75	109	56.83
7.00	3.25	-131.00	-155.65	-155.66	12.20	-175.89	105	56.49
7.50	3.60	-131.50	-156.00	-156.02	12.56	-176.02	100	56.20
8.00	3.95	-132.00	-156.35	-156.37	13.00	-176.16	95	55.92
8.50	4.26	-132.50	-156.66	-156.67	13.55	-176.31	91	55.61
9.00	4.65	-133.00	-157.05	-157.07	14.10	-176.43	86	55.36
9.50	5.19	-133.50	-157.59	-157.61	14.63	-176.54	78	55.28
10.00	5.70	-134.00	-158.10	-158.12	15.20	-176.63	71	55.19
10.50	6.15	-134.50	-158.55	-158.57	15.84	-176.73	65	55.07
11.00	6.60	-135.00	-159.00	-159.02	16.50	-176.81	60	54.92
11.50	7.05	-135.50	-159.45	-159.47	17.19	-176.88	55	54.80
12.00	7.50	-136.00	-159.90	-159.92	17.90	-176.94	50	54.71

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Table 3-88. Link Capacity Calulcation - Multiple 50 kbps FDMA Channels Through Westar - Coded (Cont'd)

12.50	7.93	-136.50	-160.33	-160.35	18.60	-176.99	46	54.57
13.00	8.37	-137.00	-160.77	-160.79	19.34	-177.03	42	54.47
13.50	8.83	-137.50	-161.23	-161.25	20.10	-177.07	38	54.40
14.00	9.30	-138.00	-161.70	-161.72	20.90	-177.11	34	54.39
14.50	9.80	-138.50	-162.20	-162.22	21.76	-177.14	31	54.29
15.00	10.30	-139.00	-162.70	-162.72	22.63	-177.16	27	54.39
15.50	10.80	-139.50	-163.20	-163.22	23.51	-177.18	24	54.40
16.00	11.30	-140.00	-163.70	-163.72	24.40	-177.20	22	54.28
16.50	11.80	-140.50	-164.20	-164.22	25.31	-177.21	19	54.41
17.00	12.30	-141.00	-164.70	-164.72	26.23	-177.22	17	54.40

Table 3-89. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Coded

15.00 = EARTH STATION G/T (DB/K)
31.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.20 = DOWNLINK RAIN MARGIN (DB)
6.50 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
-.50	1.74	-123.50	-148.14	-148.15	7.11	-168.12	99	64.24
.00	1.82	-124.00	-148.22	-148.24	7.70	-170.93	186	61.00
.50	1.74	-124.50	-148.14	-148.16	8.09	-172.01	242	59.36
1.00	1.67	-125.00	-148.07	-148.09	8.50	-172.84	298	57.96
1.50	1.62	-125.50	-148.02	-148.04	9.01	-173.62	361	56.62
2.00	1.60	-126.00	-148.00	-148.03	9.40	-174.08	403	55.65
2.50	1.62	-126.50	-148.02	-148.05	9.59	-174.27	419	54.98
3.00	1.67	-127.00	-148.07	-148.10	9.80	-174.47	433	54.34
3.50	1.74	-127.50	-148.14	-148.18	10.05	-174.69	447	53.70
4.00	1.82	-128.00	-148.22	-148.26	10.30	-174.88	458	53.09
4.50	2.00	-128.50	-148.40	-148.44	10.52	-175.03	456	52.61
5.00	2.20	-129.00	-148.60	-148.65	10.80	-175.21	453	52.14
5.50	2.40	-129.50	-148.80	-148.85	11.15	-175.41	452	51.65
6.00	2.65	-130.00	-149.05	-149.10	11.50	-175.58	444	51.23
6.50	2.95	-130.50	-149.35	-149.41	11.84	-175.73	429	50.88
7.00	3.25	-131.00	-149.65	-149.71	12.20	-175.87	413	50.54
7.50	3.60	-131.50	-150.00	-150.06	12.56	-176.00	392	50.27
8.00	3.95	-132.00	-150.35	-150.41	13.00	-176.14	373	49.98
8.50	4.26	-132.50	-150.66	-150.72	13.55	-176.29	360	49.64
9.00	4.65	-133.00	-151.05	-151.12	14.10	-176.41	338	49.41
9.50	5.19	-133.50	-151.59	-151.66	14.63	-176.52	306	49.34
10.00	5.70	-134.00	-152.10	-152.17	15.20	-176.62	278	49.26
10.50	6.15	-134.50	-152.55	-152.62	15.84	-176.71	256	49.12
11.00	6.60	-135.00	-153.00	-153.07	16.50	-176.79	235	48.99
11.50	7.05	-135.50	-153.45	-153.52	17.19	-176.86	215	48.88
12.00	7.50	-136.00	-153.90	-153.97	17.90	-176.92	197	48.76

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Table 3-89. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Coded (Cont'd)

12.50	7.93	-136.50	-154.33	-154.40	18.60	-176.97	180	48.65
13.00	8.37	-137.00	-154.77	-154.85	19.34	-177.02	164	48.55
13.50	8.83	-137.50	-155.23	-155.30	20.10	-177.06	149	48.47
14.00	9.30	-138.00	-155.70	-155.77	20.90	-177.09	135	48.40
14.50	9.80	-138.50	-156.20	-156.27	21.76	-177.12	121	48.37
15.00	10.30	-139.00	-156.70	-156.77	22.63	-177.15	108	48.37
15.50	10.80	-139.50	-157.20	-157.27	23.51	-177.17	97	48.33
16.00	11.30	-140.00	-157.70	-157.77	24.40	-177.18	87	48.30
16.50	11.80	-140.50	-158.20	-158.27	25.31	-177.20	78	48.28
17.00	12.30	-141.00	-158.70	-158.77	26.23	-177.21	69	48.31

Table 3-90. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Coded

17.50 = EARTH STATION G/T (DB/K)
26.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.20 = DOWNLINK RAIN MARGIN (DB)
6.50 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
-.50	1.74	-123.50	-145.64	-145.67	7.11	-167.84	164	62.05
.00	1.82	-124.00	-145.72	-145.75	7.70	-170.79	318	58.68
.50	1.74	-124.50	-145.64	-145.67	8.09	-171.89	418	56.99
1.00	1.67	-125.00	-145.57	-145.61	8.50	-172.75	517	55.57
1.50	1.62	-125.50	-145.52	-145.56	9.01	-173.54	627	54.23
2.00	1.60	-126.00	-145.50	-145.55	9.40	-174.01	701	53.24
2.50	1.62	-126.50	-145.52	-145.57	9.59	-174.21	729	52.57
3.00	1.67	-127.00	-145.57	-145.63	9.80	-174.41	754	51.93
3.50	1.74	-127.50	-145.64	-145.71	10.05	-174.62	779	51.28
4.00	1.82	-128.00	-145.72	-145.79	10.30	-174.82	799	50.67
4.50	2.00	-128.50	-145.90	-145.98	10.52	-174.98	794	50.20
5.00	2.20	-129.00	-146.10	-146.18	10.80	-175.15	788	49.73
5.50	2.40	-129.50	-146.30	-146.39	11.15	-175.35	787	49.24
6.00	2.65	-130.00	-146.55	-146.65	11.50	-175.53	773	48.82
6.50	2.95	-130.50	-146.85	-146.95	11.84	-175.68	747	48.47
7.00	3.25	-131.00	-147.15	-147.25	12.20	-175.83	720	48.13
7.50	3.60	-131.50	-147.50	-147.61	12.56	-175.96	683	47.86
8.00	3.95	-132.00	-147.85	-147.96	13.00	-176.10	650	47.57
8.50	4.26	-132.50	-148.16	-148.27	13.55	-176.25	627	47.23
9.00	4.65	-133.00	-148.55	-148.67	14.10	-176.37	589	47.00
9.50	5.19	-133.50	-149.09	-149.21	14.63	-176.48	532	46.94
10.00	5.70	-134.00	-149.60	-149.72	15.20	-176.58	485	46.84
10.50	6.15	-134.50	-150.05	-150.17	15.84	-176.67	446	46.71
11.00	6.60	-135.00	-150.50	-150.62	16.50	-176.75	410	46.57
11.50	7.05	-135.50	-150.95	-151.07	17.19	-176.83	376	46.45
12.00	7.50	-136.00	-151.40	-151.52	17.90	-176.89	343	46.35

Continued Next Page

Table 3-90. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through Westar - Coded (Cont'd)

12.50	7.93	-136.50	-151.83	-151.96	18.60	-176.94	314	46.23
13.00	8.37	-137.00	-152.27	-152.40	19.34	-176.98	287	46.12
13.50	8.83	-137.50	-152.73	-152.86	20.10	-177.02	260	46.05
14.00	9.30	-138.00	-153.20	-153.33	20.90	-177.06	235	45.99
14.50	9.80	-138.50	-153.70	-153.83	21.76	-177.09	211	45.96
15.00	10.30	-139.00	-154.20	-154.33	22.63	-177.11	189	45.94
15.50	10.80	-139.50	-154.70	-154.83	23.51	-177.13	169	45.92
16.00	11.30	-140.00	-155.20	-155.33	24.40	-177.15	151	45.91
16.50	11.80	-140.50	-155.70	-155.83	25.31	-177.16	135	45.90
17.00	12.30	-141.00	-156.20	-156.33	26.23	-177.17	121	45.87

Table 3-91. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through ATS-6 - Uncoded

9.00 = EARTH STATION G/T (DB/K)
40.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.20 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-125.50	-143.10	-143.17	15.20	-158.26	32	50.95
10.50	6.15	-126.00	-143.55	-143.63	15.84	-162.20	71	46.99
11.00	6.60	-126.50	-144.00	-144.08	16.50	-164.05	99	45.04
11.50	7.05	-127.00	-144.45	-144.53	17.19	-165.23	117	43.82
12.00	7.50	-127.50	-144.90	-144.98	17.90	-166.05	127	42.96
12.50	7.93	-128.00	-145.33	-145.41	18.60	-166.63	132	42.29
13.00	8.37	-128.50	-145.77	-145.86	19.34	-167.09	132	41.79
13.50	8.83	-129.00	-146.23	-146.31	20.10	-167.46	130	41.36
14.00	9.30	-129.50	-146.70	-146.78	20.90	-167.76	125	41.03
14.50	9.80	-130.00	-147.20	-147.28	21.76	-168.00	118	40.78
15.00	10.30	-130.50	-147.70	-147.78	22.63	-168.20	110	40.59
15.50	10.80	-131.00	-148.20	-148.28	23.51	-168.35	101	40.46
16.00	11.30	-131.50	-148.70	-148.78	24.40	-168.48	93	40.32
16.50	11.80	-132.00	-149.20	-149.28	25.31	-168.58	85	40.21
17.00	12.30	-132.50	-149.70	-149.78	26.23	-168.66	77	40.14

Table 3-92. Link Capacity Calculation - Multiple 50 kbps FDMA Channels Through ATS-6 - Uncoded

12.00 = EARTH STATION G/T (DB/K)
32.00 = CARRIER TO ADJACENT CHANNEL INTERFERENCE (DB)
.20 = DOWNLINK RAIN MARGIN (DB)
14.60 = THRESHOLD C/N (DB)

INPUT BO (DB)	OUTPUT BO (DB)	UPLINK C/T (DBW/K)	DNLINK C/T (DBW/K)	TOTAL LINK C/T (DBW/K)	PER CHAN C/IM (DB)	PER CHAN REQ'D C/T (DBW/K)	NO. CHAN	UPLINK PER CHAN EIRP (DBW)
10.00	5.70	-125.50	-140.10	-140.25	15.20	-157.34	51	48.92
10.50	6.15	-126.00	-140.55	-140.70	15.84	-161.85	130	44.36
11.00	6.60	-126.50	-141.00	-141.15	16.50	-163.83	185	42.33
11.50	7.05	-127.00	-141.45	-141.60	17.19	-165.06	221	41.06
12.00	7.50	-127.50	-141.90	-142.05	17.90	-165.91	242	40.16
12.50	7.93	-128.00	-142.33	-142.49	18.60	-166.51	252	39.49
13.00	8.37	-128.50	-142.77	-142.93	19.34	-166.98	254	38.95
13.50	8.83	-129.00	-143.23	-143.39	20.10	-167.36	249	38.54
14.00	9.30	-129.50	-143.70	-143.86	20.90	-167.66	239	38.22
14.50	9.80	-130.00	-144.20	-144.36	21.76	-167.91	226	37.96
15.00	10.30	-130.50	-144.70	-144.86	22.63	-168.11	211	37.76
15.50	10.80	-131.00	-145.20	-145.36	23.51	-168.27	195	37.60
16.00	11.30	-131.50	-145.70	-145.86	24.40	-168.40	179	37.47
16.50	11.80	-132.00	-146.20	-146.36	25.31	-168.50	163	37.38
17.00	12.30	-132.50	-146.70	-146.86	26.23	-168.58	148	37.30

Table 3-93. Satellite Parameters Assumed for 50 kbps FDMA Capacity Calculation, Using Future 12/14 GHz Domsat Case

```
SATELLITE PARAMETERS:
   -80.50 = SATURATION FLUX DENSITY (DBW/M/M)
   -44.40 = ISOTROPIC ANTENNA AREA (DB-M-M)
    -1.00 = SATELLITE G/T (DB/K)
    43.90 = SATELLITE EIRP (DBW)
    44.80 = CHANNEL NOISE BANDWIDTH (DB-HZ)
   207.00 = UPLINK FREE SPACE LOSS (DB)
   205.60 = DOWNLINK FREE SPACE LOSS (DB)
      .00 = UPLINK ATMOSPHERIC ABSORPTION LOSS (DB)
      .00 = DOWNLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     2.90 = UPLINK RAIN MARGIN (DB)
     1.50 = UPLINK EARTH STATION POINTING LOSS (DB)
     1.00 = DOWNLINK EARTH STATION POINTING LOSS (DB)
      .50 = UPLINK SATELLITE POINTING LOSS (DB)
      .50 = DOWNLINK SATELLITE POINTING LOSS (DB)
      .00 = UPLINK POLARIZATION MISMATCH LOSS (DB)
      .00 = DOWNLINK POLARIZATION MISMATCH LOSS (DB)
    28.00 = EARTH STATION HPA C/IM (DB)
```


Table 3-94. Satellite Parameters Assumed for 50 kbps FDMA Capacity Calculation, Using CTS Case

```
SATELLITE PARAMETERS:
   -92.10 = SATURATION FLUX DENSITY (DBW/M/M)
   -44.40 = ISOTROPIC ANTENNA AREA (DB-M-M)
     5.30 = SATELLITE G/T (DB/K)
    59.00 = SATELLITE EIRP (DBW)
    44.80 = CHANNEL NOISE BANDWIDTH (DB-HZ)
   207.00 = UPLINK FREE SPACE LOSS (DB)
   205.60 = DOWNLINK FREE SPACE LOSS (DB)
      .00 = UPLINK ATMOSPHERIC ABSORPTION LOSS (DB)
      .00 = DOWNLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     2.90 = UPLINK RAIN MARGIN (DB)
     1.50 = UPLINK EARTH STATION POINTING LOSS (DB)
     1.00 = DOWNLINK EARTH STATION POINTING LOSS (DB)
      .70 = UPLINK SATELLITE POINTING LOSS (DB)
      .50 = DOWNLINK SATELLITE POINTING LOSS (DB)
      .00 = UPLINK POLARIZATION MISMATCH LOSS (DB)
      .00 = DOWNLINK POLARIZATION MISMATCH LOSS (DB)
    28.00 = EARTH STATION HPA C/IM (DB)
```

Table 3-95. Satellite Parameters Assumed for 50 kbps FDMA Capacity Calculation, Using Westar Case

```
SATELLITE PARAMETERS:
  -80.80 = SATURATION FLUX DENSITY (DBW/M/M)
  -37.00 = ISOTROPIC ANTENNA AREA (DB-M-M)
   -6.20 = SATELLITE G/T (DB/K)
   36.40 = SATELLITE EIRP (DBW)
   44.80 = CHANNEL NOISE BANDWIDTH (DB-HZ)
  199.60 = UPLINK FREE SPACE LOSS (DB)
  196.10 = DOWNLINK FREE SPACE LOSS (DB)
     .00 = UPLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     .00 = DOWNLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     .40 = UPLINK RAIN MARGIN (DB)
    1.00 = UPLINK EARTH STATION POINTING LOSS (DB)
    1.00 = DOWNLINK EARTH STATION POINTING LOSS (DB)
     .50 = UPLINK SATELLITE POINTING LOSS (DB)
     .50 = DOWNLINK SATELLITE POINTING LOSS (DB)
     .00 = UPLINK POLARIZATION MISMATCH LOSS (DB)
     .00 = DOWNLINK POLARIZATION MISMATCH LOSS (DB)
   28.00 = EARTH STATION HPA C/IM (DB)
```


Table 3-96 Satellite Parameters Assumed for 50 kbps FDMA Capacity Calculation, Using ATS-6 Case

```
SATELLITE PARAMETERS:
  -89.00 = SATURATION FLUX DENSITY (DBW/M/M)
  -37.00 = ISOTROPIC ANTENNA AREA (DB-M-M)
   10.50 = SATELLITE G/T (DB/K)
   51.40 = SATELLITE EIRP (DBW)
   44.80 = CHANNEL NOISE BANDWIDTH (DB-HZ)
  199.60 = UPLINK FREE SPACE LOSS (DB)
  196.10 = DOWNLINK FREE SPACE LOSS (DB)
     .00 = UPLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     .00 = DOWNLINK ATMOSPHERIC ABSORPTION LOSS (DB)
     .40 = UPLINK RAIN MARGIN (DB)
    1.00 = UPLINK EARTH STATION POINTING LOSS (DB)
    1.00 = DOWNLINK EARTH STATION POINTING LOSS (DB)
    1.00 = UPLINK SATELLITE POINTING LOSS (DB)
     .50 = DOWNLINK SATELLITE POINTING LOSS (DB)
     .00 = UPLINK POLARIZATION MISMATCH LOSS (DB)
     .00 = DOWNLINK POLARIZATION MISMATCH LOSS (DB)
   28.00 = EARTH STATION HPA C/IM (DB)
```

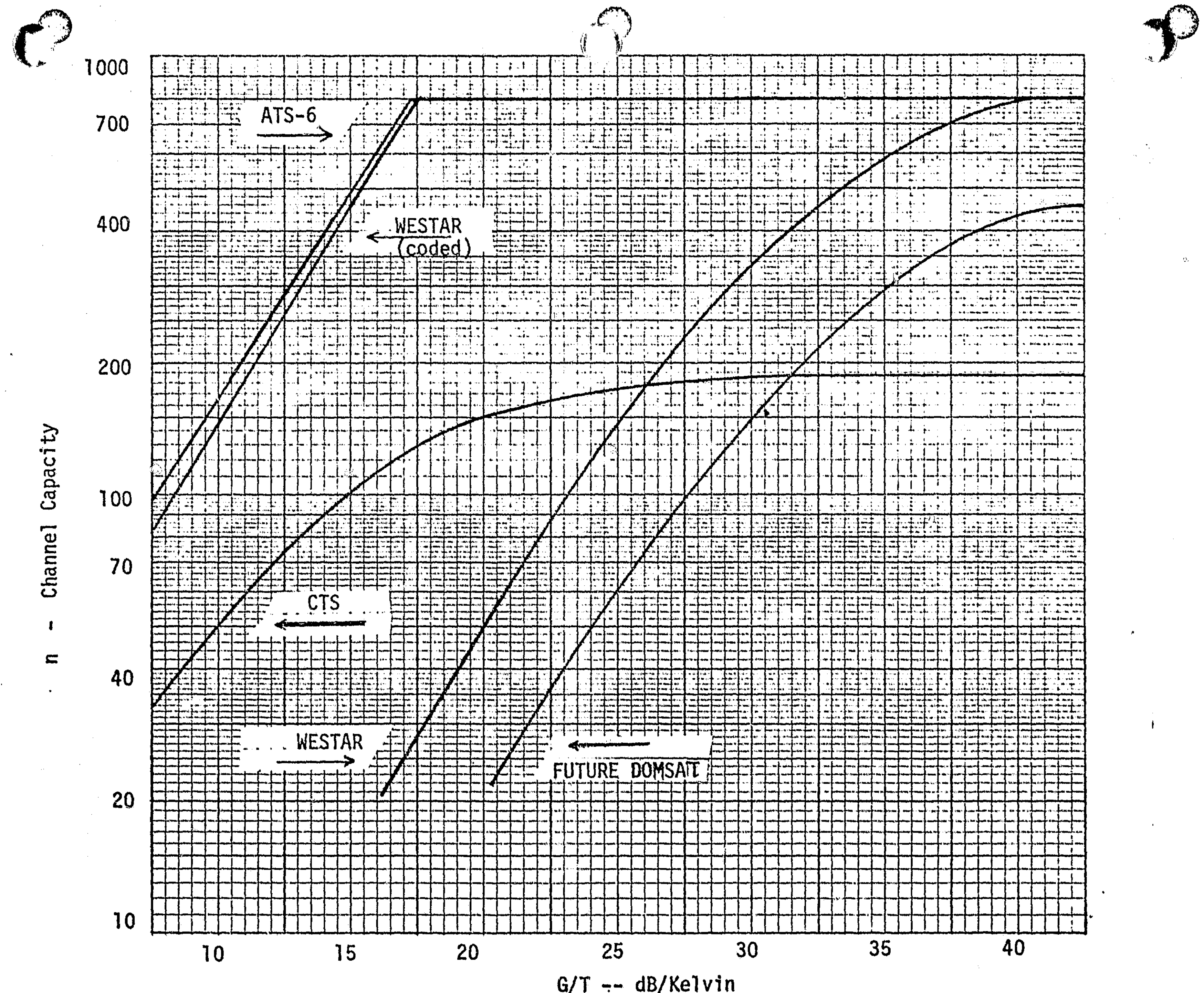

Figure 3-10. Transponder Channel Capacity as a Function of Earth Station G/T for 50 Kbps FDMA Cases

The two remaining cases in figure 3-10 DOMSAT (12/14) and CTS (12/14), exhibit an uplink limited characteristic, wherein the uplink C/T dominates the overall link C/T. As the G/T of the earth station is increased, the uplink C/T dominates more and more strongly, until a limiting value of channel capacity is reached, for example, 400-channels in the CTS (12/14) case. This is due to selecting the maximum possible gain of CTS for the transponder model. Since the gain of CTS can be varied, this uplink limiting condition can be avoided. Decreasing the transponder gain requires a higher uplink power level to achieve the same satellite output EIRP. Assuming that the lower gain does not significantly lower the satellite G/T, the net effect of the lower transponder gain is a higher uplink C/T at the expense of requiring a higher earth station EIRP. While the satellite baselines in this study have assumed a constant transponder gain, satellite systems requiring this added degree of flexibility can have transponder gain settings controlled from the ground, as for example is done in INTELSAT IV and CTS satellites.

Notice that for multiple earth station configurations the G/T_e required for another location is simply the difference between the path loss, path margins and downlink $EIRP_s$ contours. That is,

$$(G/T_e)_{\text{new location}} = (G/T_e)_{\text{Chicago}} + \Delta L_d + \Delta R_m + \Delta EIRP_s$$

where

$$\Delta L_d = (L_d)_{\text{new location}} - (L_d)_{\text{Chicago}} \quad \text{(dB)}$$

$$\Delta R_m = (R_m)_{\text{new location}} - (R_m)_{\text{Chicago}} \quad \text{(dB)}$$

$$\Delta EIRP_s = (EIRP_s)_{\text{Chicago}} - (EIRP_s)_{\text{new location}} \quad \text{(dB).}$$

Similarly the earth station $EIRP_e$ for another location is given approximately by,

$$(EIRP_e)_{\text{new location}} = (EIRP_e)_{\text{Chicago}} + \Delta L_u + \Delta R_m + \Delta\Psi + 10 \log n - 10 \log N$$

where $\Delta L_u = (L_u)_{\text{new location}} - (L_u)_{\text{Chicago}}$ (dB)

$$\Delta R_m = (R_m)_{\text{new location}} - (R_m)_{\text{Chicago}} \quad \text{(dB)}$$

$$\Delta\Psi = (\Psi_{sat})_{\text{new location}} - (\Psi_{sat})_{\text{Chicago}}$$

N = total number of equal sized channels in the transponder

n = number of channels being transmitted from the transmit earth station.

Note that the effective value of G/T_s can change in a multiple earth station configuration from that used in the optimization study. With multiple transmit earth stations the effective G/T_s is given by the expression:

$$(G/T_s)_{eff}' = \frac{1}{N} \sum_{i=1}^{N} M_i \, (G/T_s)_i$$

where $\sum_{i=1}^{N} M_i = N$.

M_i = number of channels transmitted from the i th earth station

$(G/T_s)_i$ is the satellite receive G/T for the i th earth station.

If this value differs signicantly from the G/T_s used in the capacity analysis then the G/T_e values may need to be adjusted accordingly. Note that the downlink rain margins assumed for the G/T_e values are for receive only stations and not for T/R stations. In some cases the allowable system noise temperature will be higher for an optimized T/R station, which permits lower downlink rain margins or conversely greater link margins. In the 50 Kbps QPSK/FDMA calculations presented in this report, a C/N_{IM} of 28 dB was assumed for the uplink transmitters.

If the HPA input backoffs are operated differently, this change needs to be made also. For example if all transmitting stations are transmitting only one channel then the uplink $(C/N)_{IM}$ becomes very large. On the other hand the probability that all channels will be equal level in the transponder is highly unlikely because of antenna pointing errors HPA level drifts, etc. Those channels which are lower than the average assuming the satellite input backoff has not changed will have a lower $(C/N)_{IM}$ due to the satellite intermodulation. Thus, for a first order approximation to the satellite capacity it is suggested that the capacity which corresponds to ± 1 dB change on BO_i from the optimum be taken as the more realistic value.

Tables 3-97 and 3-98 summarize some of the cases of the previous tables in a more condensed form. Tables 3-99 and 3-100 show possible earth stationccinfig-urations for the case where the system is designed for a total capacity of 100 50 Kbps data channels in the uncoded case and 25 Kbps data channels in the 1/2 rate FEC coded case. As expected, the coded case, shown for WESTAR, results in a significant reduction in the size of a receive only earth station. On the other hand the transmit/receive earth station size increases significantly because the optimum BO_i has moved from 13 dB in the uncoded case to 4 dB in the coded case. Since the 100 channel case is still below the knee of the CTS capacity versus G/T curve the CTS earth stations are the smallest except for Miami as was the case for the other transmission studies. Again ATS-6 with its advantage of high gain antennas and lower rain losses accommodates small earth stations as well.

Table 3-97. Summary of Capacity Versus G/T For 50 Kbps QPSK FDMA Through Different Satellites - Uncoded

Case	Max N	BO_i For Max N (dB)	N For $BO_i \pm 1$ dB	G/T_e (dB/K)	Channel EIRP For Max N (dBW)	Channel EIRP For $BO_i \mp 1$ dB (dBW)
ATS-6 (4/6)	132	13.0	125 to 127	9	41.8	41.0 to 43.0
	254	13.0	239 to 242	12	39.0	38.2 to 40.2
CTS (12/14)	42	13.0	39 to 41	9	47.0	45.7 to 47.0
	101	13.0	94 to 98	15	42.6	41.9 to 43.7
	156	12.5	151 to 141	21	41.2	40.3 to 42.6
Future Domsat (12/14)	89	13.0	84 to 86	27	55.7	53.8 to 55.7
	325	13.0	308 to 306	36	48.9	48.1 to 50.1
	458	13.0	433 to 434	42	47.4	46.6 to 48.6

Table 3-98. Summary of Capacity Versus G/T For 50 Kbps QPSK FDMA Cases Through WESTAR

Case	Max N	BO_i For Max N (dB)	N For BO_i ± 1 dB	G/T_e (dB/K)	Channel EIRP For Max N (dBW)	Channel EIRP For BO_i ± 1 dB (dBW)
Uncoded	62	13.0	58 to 60	21.0	52.8	52.1 to 53.9
	209	13.0	196 to 202	27.0	47.5	46.8 to 48.7
	478	13.0	450 to 459	33.0	43.9	43.2 to 45.1
Coded	116	4.5	115 to 113	9.0	58.6	57.6 to 59.7
	458	4.0	453 to 433	15.0	53.1	52.1 to 54.3
	799	4.0	788 to 754	17.5	50.7	49.7 to 51.9

Notes
1. (C/N) operational = 14.6 dB uncoded; 6.5 dB coded
2. Qu = 85.4 dBW
3. Qd = 83.7 dB

Table 3-99. 4 and 6 GHz Earth Station Configurations for 100 50 Kbps QPSK Carrier Transmission And Reception

Case	Required G/T (dB/K)	R.O Antenna Size (feet)	R.O Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
WESTAR Uncoded							
Los Angeles	24.0	20	115	70.2	20	3	115
Chicago	23.1	18	115	70.7	18	3	125
Miami	23.6	20	115	70.9	20	3	200
WESTAR Coded							
Los Angeles	9.3	8	520	78.7	45	3	2600
Chicago	8.4	8	870	79.2	45	3	2600
Miami	8.9	8	750	79.4	55	3	2600
ATS-6							
Los Angeles	7.5	8	870	63.7	12	1.5	870
Chicago	7.6	8	870	64.0	12	1.5	870
Miami	7.6	8	870	63.2	12	1.5	870

Table 3-100 12 and 14 GHz Earth Station Configurations for 100 50 Kbps QPSK Carrier Transmission and Reception

Case	Required G/T (dB/K)	R.O. Antenna Size (feet)	R.O. Preamp Noise Temp (°K)	Peak EIRP (dBW)	T/R Antenna Size (feet)	HPA Size (KW)	T/R Preamp Noise Temp (°K)
CTS Uncoded							
Los Angeles	17.3	8	755	61.3	8	450	755
Chicago	15.0	5	630	63.8	8	450	1700
Miami:							
Non-Diversity	31.6	35	630	77.3	35	1000	630
Diversity	21.5	12	755	64.0	12	450	755
Future DOMSAT Uncoded							
Los Angeles	31.9	35	630	73.1	35	200	630
Chicago	27.6	20	630	74.4	20	450	630
Miami:							
Non-Diversity	44.0	90	160	87.0	90	1000	160
Diversity	31.9	35	630	75.7	35	450	630

Link and Station Security Investigations

4.1 INTRODUCTION

In this section, a number of security aspects are investigated with emphasis on the communication satellite earth station and link security. Brief consideration is also given to the message security within the complete end-to-end communication link. In addition, the earth station link availabilities are investigated under normal operating conditions (i.e., no jamming or other overt actions). A brief comparison is made of the satellite link availabilities and leased terrestrial data lines. In this section, practical factors and a summary of FCC regulations on earth station locations are also given.

Both overt and covert actions by unauthorized and undesired individuals or groups were considered in the security investigations. Overt activity includes the following:

a. direct physical attack to vandalize, destroy or take over earth station
b. direct physical attack on earth station support and interconnect facilities
c. direct physical attack on critical ground support elements for the satellite
d. destroying or reduction of link's capability to perform adequately by means of interference (jamming) signals.

The only types of covert activities considered were the unauthorized monitoring of the communication satellite link and the injection of false messages. The probability of the above activities was not considered in this study. The security investigations briefly assessed the complexity and cost to accomplish and to circumvent the above activities which were unique to satellite link communications. These investigations are presented in the following subsections.

4.2 EARTH STATION LOCATION CONSIDERATIONS

4.2.1 General

There are a number forconsiderations for locating an earth station which need to be considered in detail of each specific earth station location. This effort is not an insignificant part of procuring an earth station. There are many intangible and subjective factors which ultimately can only be evaluated by the local users. Some general considerations will be briefly discussed in this section. Some of the topics addressed are:

a) possible advantages to the users for locating in the city
b) city versus county noise and interference
c) considerations for , as well as interconnection communication link to, a remote site.

There are clearly some strong advantages of locating the earth station as close to the local communications center as possible. In many cases,as close as possible would mean a roof-top location on a downtown city building. In some cases, such as for State Patrol facilities, this may mean a country location near a VHF or UHF base station facility. Some of the advantages are:

a) greater physical security
b) shared facilities to reduce the cost of real estate, leases, etc.
c) shared personnel to reduce operational and maintenance costs
d) elimination of costs associated with an interconnection communication link to a remote facility.
e) power, water, etc. are generally readily available.

There may be situations where a remote location is considered more advantageous. For examples the earth station antenna must have a clear field-of-view (first Fresnel zone clearance etc.) of the satellites with which it is to operate. Skylines of downtown sections are constantly changing as taller structures replace older buildings. Thus the possibility of having to change the earth station location at a later date because of blockage by newer structures should be considered. The wind forces are considerably higher on top of tall buildings than near the ground level. For extremely tall buildings, wind induced pointing errors may be significant. This may increase the costs of the antenna and any shelter type structures associated with such a station. The high power amplifiers (HPAs) must be located very close to the antenna. If the floor directly below the roof-top is not available for location of the HPAs, then it may be necessary to build a roof-top shelter. In general a roof-top location in the city will receive higher levels of interference and requires more artificial shielding of the antenna than any other location. Use of separate locations does enhance the partial surveilability of the communications network since the possibility that a common disaster, fire, earthquake, tornado, power blackout, water supply failure, etc. will wipe out both the earth station and the central switch board facility is low. If there is a significant expectation that the earth station would be subject to direct, violent, physical attack with the intent to destroy, it might be considered wiser and less costly to the community as a whole to place the earth station in a remote location.

4.2.2 Metropolitan Vs. Country Radio Noise

There are several factors to consider and trade off with respect to location of a communication satellite earth station. Many of these are not clear cut and can only remain as general intangibles until evaluated for a specific local situation. In this section, certain factors will be discussed briefly. The brevity of the study time period has not permitted a complete consideration of all factors.

The first factor to be considered is the general one of radio noise levels in metropolitan areas compared to those in the country. The man-made radio interference environment of a metropolitan area is the composite of emissions from three classes of man-made radio sources. In decreasing order of strength, the sources are (1) coherent transmitters used in commercial broadcast, mobile radio and telephone services, television, navigation, direction finding, and target tracking, (2) restricted radiation devices providing wireless actuated functions, and (3) incidental radio noise sources.

Interference arising from out-of-band emissions or intermodulation products produced by coherent transmitters have presented electromagnetic compatibility problems for many years to metropolitan users of sensitive radio receiving equipment. A large body of radio-frequency interference technology has been developed to treat coherent-source electromagnetic-compatibility problems. Metropolitan areas have much higher levels of interference because of the greater concentration of facilities in class (1) above. The most serious interference with earth stations is caused by terrestrial microwave radio relay links which share the same frequency band as the earth stations.

This problem is further compounded by the fact that typical terrestrial microwave links operate in a very narrowband on the order of 20 to 30 MHz, and thus many links may be located in a metropolitan area, whereas many earth stations operate over 500 MHz bandwidths and thus are susceptible to all of the nearby links within this band. Further, microwave links use vertical and horizontal polarization to provide additional discrimination between microwave links. Earth stations often employ circular polarization or a linear polarization which may not be oriented either vertically or horizontally. Because of their larger antenna and low noise rf front-ends, earth stations are much more sensitive than terrestrial microwave radio relay stations. A major factor in reduction of interference in earth stations from terrestrial radio links is the use of large antennas which have narrow beamwidths and which are pointed well above the local horizon. For earth stations in CONUS the elevation angle required to operate with a domestic satellite is between 30 and 55 degrees above a smooth earth horizon.

As the difference between the frequency band of the coherent transmitters in the metropolitan area and the earth station frequency band increase, the potential for interference decreases because of out-of-band rejection of the earth station rf filters. However, even this rule does not necessarily always apply because interference can enter the earth station through its low frequency circuits and even the power supplies if it is strong enough. A case to illustrate these points is the WESTAR ground station at Cedar Hill, Texas. It also shows that care should be taken when considering an earth station location near a high-power UHF facility such as a UHF TV transmitter, base station for a large regional UHF communication facility, etc. The harmonics of the UHF system can fall into the microwave receive band. However, an even more serious problem for locations near very powerful UHF stations can be induced rf currents in earth station radio equipment chassis, power supplies, etc. This in turn can induce interference signals into the radio's intermediate frequency and low frequency circuits. A case in point is the WESTAR earth station at Cedar Hill between Dallas and Fort Worth, Texas. This location was initially selected on the basis of two factors: (1) centrally located for the Dallas-Fort Worth metroplex and (2) the location of a box-canyon type of depression to provide earth shielding from the area microwave links. However, Cedar Hill is also the site of all of the public TV transmissions for the Dallas-Fort Worth metroplex including both the standard VHF and

UHF broadcast channels. The WESTAR earth station is located 1000 feet from the TV transmission antennas. The radiated power level of the top UHF channel is 250 kW, and the sixth harmonic falls into the 3.7 to 4.2 GHz receive band. However, as pointed out above, the more serious problem was the induced rf currents in the lower frequency portions of the radio circuits.

The problem was considered serious enough that a radio screen room was installed at the earth station to house the radio equipments. The use of a screen room is probably an over-kill solution. However, these installations are expected to operate for many years and this solution ensures protection in the event that even more powerful UHF interfering equipment is located at Cedar Hill. It should be pointed out that the signal-to-noise levels required of the WESTAR earth stations are about 10 dB better than those specified for this NALECOM study. Further, the Cedar Hill case represents an extreme case. Probably in most cases, standard rfi-filtering and shielding inherent in radio equipments and double-shielded cables would be adequate. Nevertheless, it is recommended that in such situations some precautions be taken.

In general, man-made radio noise caused by heavy industry and transportation are often highly localized and also decrease rapidly with higher radio frequencies such as 2 GHz and above. Since the type of activity which produces this type of noise is typically concentrated in cities, it is naturally expected to be higher in the cities than in the country. However, selection of a radio frequency such as 4 GHz or 12 GHz does not automatically eliminate the concern over man-made radio noise. As already pointed out, strong intense sources in the frequency band below 1200 MHz can enter the receiver through the lower frequency circuitry portions. Neither does selection of a country site versus a city site automatically eliminate this concern. Farmers commonly employ heavy machinery and welding equipments. Heavy transportation routes and other communication facilities are also found in the country.

Restricted radiation equipment improperly installed or poorly maintained is capable of generating strong radiation fields sufficient to interrupt essential communications services. A VHF band automatic garage door opener with excessive out-of-band emissions provides an often encountered example. More difficult to control or suppress are sources in the third class, incidental radio-noise emitters. Within this class most individual sources produce a low level of radiated interference that is confined to the neighborhood of the source. Because of their large numbers, the class of incidental noise sources has been elevated to a position of major importance as a metropolitan radio-noise pollutant.

That large numbers of potential incidental man-made noise sources occur in any metropolitan area may be seen from a listing of the principal known members of the class.[1]

- Automotive ignition and electrical systems
- Metal, wood and plastic processing and fabricating equipment
- Power distribution and transmission lines
- Electrical switches and silicon control rectifiers
- Electric motors and generators
- Electric railways
- Consumer appliances
- Medical and scientific equipment
- Gaseous discharge devices.

This grouping presents the incidental noise sources in an order of descending emission level. All listed sources produce significant interference in or below the HF band. The first three entries are the dominant contributors to urban incidental noise in the VHF band and lower UHF band. Only the first two categories are presently known to generate the metropolitan incidental noise background observed in the microwave frequency range (above 225 MHz and in the lower SHF band) both on and above the surface. Sources of both continuous and line spectra radiate in the

1 E. N. Skomal, "Man-Made Noise In the M/W Frequency Range," Microwave Journal, Vol 18, No 1, pp 44-47, January 1975.

microwave range. Automobile ignition systems and resistance welders generate continuous spectra; line spectra are observed to be generated by plastic fabrication equipment.

Figure 4-1 presents several sets of the most recently measured data for continuous spectra sources.[1-4] Electric field strength in decibels relative to one microvolt per meter per kilohertz of receiver bandwidth is plotted versus frequency from 225 MHz to above 4 GHz.

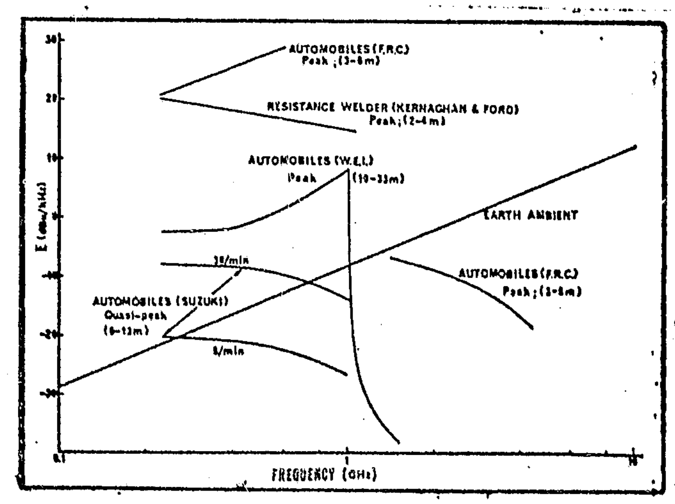

Figure 4-1. Continuous-spectra Incidental Radio-noise Sources.

1 E. N. Skomal, op. cit.

2 Fredrick Research Corp., "Factors for Predicting Radio Frequency Interference from Vehicle Ignition Systems," RAP-42 Report, Jan 1964.

3 White Electromagnetics Inc., "Ambient Electromagnetic Survey in Detroit, Michigan," Engineering Report 69-15, Oct 13, 1969.

4 Suzuki, H., "Characteristics of City Noise in the UHF Band," Jour Inst of Elect Commun Engrs (Japan), Vol 46, No 2, pp 186-194, Feb 1963.

The rise in field strength of automotive ignition noise in the lower UHF band is a manifestation of the third and highest frequency resonance occurring in the automotive emission spectrum. The rapid decline in automotive emission strength above 1 GHz is ascribable to the characteristics of ignition-noise waveform. When observed with very wideband receivers the ignition radiation pulse produced by each cylinder firing appears as an irregular, damped oscillation with fine structure pulses of widths between 1 and 5 nanoseconds. Suzuki's and FRC's data were obtained from roadside measurements at comparable observer-to-traffic separation distances of 10 to 13 meters and 3 to 7 meters respectively. The WEI automotive noise data were observed for groups of stationary vehicles running at maximum engine speed of 1500 rpm. The observer-to-vehicle separations varied between 11 and 33 meters.

Resistance-welding equipment used in metal fabrication produces spot welds with 150 kVA pulses applied between opposing electrodes.[1] At distances between 2 and 4 meters the peak radiated interference emitted by production units via the electrodes, power leads, and chassis is seen in figure 4-1 to be of comparable intensity to automotive ignition noise observed at similar distances. Also plotted in figure 4-1 for reference is the rms electric field strength of the earth's natural thermal ambient at 290°K for a 1 kHz detection bandwidth and a constant-gain antenna.

Two types of rf excited devices used in fabrication of plastic products produce line-spectrum interference and can produce large levels of microwave radiation at appreciable observation distances. One is rf excited preheaters driven by multikilowatt power amplifiers. Harmonics of the fundamental radiated by the power leads and chassis have been found at frequencies about 900 MHz.[2] The trend of measured harmonic levels with increasing frequency suggests that for the preheater significant harmonics occur above 1 GHz. The second type consists of the somewhat lower

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1 Kernaghan, W. A., and R. R. Ford, "Man-made RFI Noise Taipei, Taiwan," PCA-EMC-70-47A, 1843rd Electronics Eng Sqdn HQ Pac Comm Area (AFCS), May 28, 1971.

2 E. N. Skomal, ibid.

powered rf excited plastic welders used in plastic seam formation. These also have been examined and found to radiate high-intensity electric fields. The trend with increasing frequency also indicates that additional, intense harmonics may exist above 1 GHz the limiting frequency of the test equipment used by Pearce.[1] As with the higher powered preheaters, the plastic-welder radiation is coupled into space by the power leads and the chassis components. Surface and airborne surveys to determine the variation of man-made incidental radio noise according to location have been conducted in various metropolitan areas by many organizations. Currently one of the more interesting surveys is being conducted of the ATS-6 satellite taking advantage of the high sensitivity and narrow beam to observe man-made radio noise.

The location of a surface observer is known to affect the level of incidental noise power. Proximity to heavily traveled roads, shopping centers, and heavy industrial plants produces higher than average values of incidental noise power. These locations of high noise power may be treated as superimposed upon a mean noise power level which decreases with urban center separation distance at a rate which varies with observation frequency. Figure 4-2 taken from Skomel[2] shows that the average noise power decreases with increasing frequency occurring with a decrement of approximately -13 dB per decade frequency change. This frequency decrement is lower in the frequency range plotted than in the band above 1 GHz.[3] The lower-power slope in this interval is attributable to the existence of a resonance peak in the automotive ignition noise spectrum occurring in the UHF band between 300 and 700 MHz.

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1 Pearce, S. F., and J. H. Bull, "Interference from Industrial, Scientific and Medical Radio-Frequency Equipment," Report 5033, Electrical Research Association, Leatherhead, Surrey, England, Oct 1964.

2 E. N. Skomal, op. cit.

3 Skomal, E. N., "Analysis of Metropolitan Incidental Radio Noise Data," IEEE Trans on EMC, Vol EMC-15, No 2, May 1973, pp 45-57.

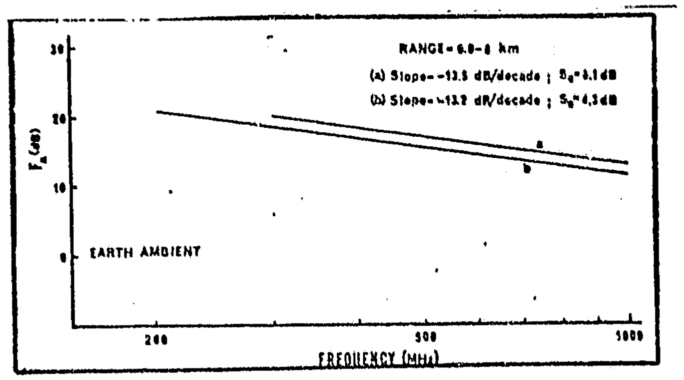

Figure 4-2. Metropolitan Area Composite Surface Incidental Radio Noise for Center Separation Distances of 0.8 to 8 km.

The quantity F_a shown is the ratio of the average incidental noise power to kT_oB expressed in decibels. Here k is Boltzman's constant, T_o is taken as 290°K and B is the receiver bandwidth. The two composite plots of figure 4-2 differ by less than 1.5 dB; the upper marked "a" was assembled from surface noise measurements conducted in New York, Melbourne, Australia, and Tel Aviv, Israel. The lower curve "b" presents data from Cleveland and Phoenix. The standard errors of estimate S_e for the least-squares fitted line to the data are also given.

4.2.3 Impact of FCC Regulations and Local Coherent Interference on Earth Station Site Selection

The Federal Communications Commission (FCC) requires that applicants for a new satellite communication earth station perform a radio frequency interference analysis for submission with their application for the earth station license. Part 25 of the FCC Rules and Regulations, Paragraph 25.203, details the analysis required. Briefly, an applicant must compute "great circle coordination distance contours" and "rain scatter coordination distance contours" for his selected site. After doing so, he must then coordinate with all current users and users with prior applications whose stations are within the computed contours and which share a frequency band in common with the proposed station. Coordination involves the calculation of the maximum interference power levels received at the proposed earth station or received at existing or prior application stations for a certain percentage at the time. These calculations involve considerations of local terrain profiles and rain statistics. FCC Paragraph 25 provides detailed calculation procedures, but other procedures can be used if the applicant can show that they are more applicable to the analysis in question. The act of coordination also requires the applicant to provide necessary information to those users with whom he is coordinating, and to reach mutually satisfactory agreement (including FCC agreement) that no harmful interference will result from the proposed earth station operation. Typically coordination activity costs for an earth station range between $10,000 to $25,000.

In general, the required coordination activities become more difficult when the earth station is located within a large city, since the city is likely to be a hub of established communication networks such as telephone company long distance microwave relay. Consequently it may be difficult or impossible to find a suitable earth station site within a large city. Even at distances of 10 to 20 miles from large metropolitan areas, it has sometimes been necessary to provide shielding of earth stations by means of digging pits or using existing shielding such as abandoned quarries. It is possible that future systems operating at 12/14 GHz will not be as severly hampered with respect to current 4/6 GHz systems. Microwave relay at the higher frequencies is not dense as it is at the lower frequencies. Also, the smaller antenna sites at 12/14 GHz will make shielding less difficult. A final observation on FCC regulatory impact is the possibility that a minimum diameter antenna (i.e., maximum beam width) may be specified at the future date. The motivation for this regulation would be the efficient use of available geosynchronous satellite orbital arc. Small diameter transmitting earth station antennas will, in general, require wider, and hence more wasteful orbital spacing than larger diameter antennas.

There is a significant difference between locating a receive only (R.O.) earth station in the city or locating a transmit/receive (T/R) earth station in the city. The transmission studies indicated that in general a cost-effective R.O. station would employ a smaller antenna than a T/R station. Further if forward error correction FEC codes are used the antenna sizes for R.O. stations were very much smaller than a T/R station. Size of the antenna is an important aspect of city location since the smaller the antenna size the easier it is to locate, install and maintain on top of a downtown building near other centralized communication facilities. It is also easier to relocate if necessary.

It is necessary to ensure that the antenna has a clear field-of-view of the satellites it is to operate. For objects within the near field of the antenna (i.e., distance less than $\pi D^2/\lambda$ where D/λ is the antenna diameter in wavelengths) the line of sight should clear obstacles by 1.5 D where D is the antenna diameter. For greater distances the line of sight should clear by the first Fresnel zone, i.e., by $(\lambda d)^{1/2}$ where d is the distance to the obstacle. There are several ways to combat local interference and/or jamming. One way is to use a natural or artifical barrier. Earth makes an effective barrier. So does dense foliage. A popular approach for a number of domestic earth stations located near major metroplexes is to put the earth stations inside an abandoned gravel pit. If the interference is entering the receive system through the antenna patterns then an artifical barrier or shield such as screen wire fences could be built around the antenna. If the interference is entering the radio system in a more direct way, then shielding of the radio equipments and/or the rooms containing the radio equipments may be required. Low level interference received through the antenna side lobes might be circumvented by selecting an antenna configuration with inherently low side lobe levels. Table 4-1 shows the ratio of the back lobes relative to the peak gain for different types of small reflector antennas.

Table 4-1 Relative RF and Cost Characteristics of Various Small Antenna Types

ANTENNA TYPE	OVERALL EFFICIENCY (%)	BACKLOBE ANTENNA NOISE TEMPERATURE (°K)	FRONT-TO-BACK RATIO (dB)	RELATIVE COST
Shaped Inverted Horn-Reflector[3,4]	68 to 78	1.5	68	2.5
Conventional Horn-Reflector[4]	68 to 76	1.0	70	3.0
Conventional Inverted Horn-Reflector[3,4]	60 to 70	2.0	67	2.0
Shaped Cassegrainian	60 to 68	6.0	60	1.8
Dielguide Cassegrainian	60 to 68	10.0	66	2.2
Paraboloid-Flat-Reflector With Scalar Feed[3]	57 to 65	8.0	68	1.4
Offset Cassegrainian[3]	57 to 65	15	55	1.7
Paraboloid-Flat-Reflector With Prime-Focus Feed[3]	54 to 60	10	66	1.2
Conventional Paraboloid With Shield/Tunnel	48 to 56	30	56	1.1
Conventional Paraboloid	48 to 56	26	36	1.0

Notes:

1. Estimated cost relative to a conventional paraboloid with prime-focus feed with same sized aperture.
2. For space communication application the higher efficiencies correspond to the receive frequency band whereas the lower efficiencies correspond to the transmitter frequency band.
3. These antenna types may be advantageously mounted on a 45° tilted Az-El type of mount.
4. Conical version.

If the interference is frequency selective such as coherent transmissions from other microwave type of stations, it might be possible to change the frequency of the satellite link to eliminate the problem. Another possibility for a small R.O. station in a high interference area would be to employ a self-adaptive phased array antenna. Normally phased array antennas are not selected for earth stations because of their high antenna noise temperature and relatively higher costs. However, for a very small R.O. station antenna noise temperature is a small contributor to the overall system noise temperature. For example, if the preamplifier/receiver noise temperature were 2600° K, then an increase of antenna noise temperature of 260°K (which is about the maximum over a reflector antenna an array could cause) would only decrease the G/T_e by 0.4 dB which can be accommodated by an increase in antenna area by 9.8 percent. Further if the receive C/N is dominated by interference rather than thermal noise, then it makes even less difference. A self-adaptive array antenna has the nice feature of automatically maximizing the desired signal-to-noise as long as it can identify the desired signal.[1)] To do this, the array, with the help of a small minicomputer or perhaps even a microprocesser, places a null right on the interference and keeps it there even though the interference moves or the satellite position moves.

4.2.4 Interconnection Links

Two types of interconnection links need to be considered. Remotely located earth stations may require a trunking link to transmit channels in bulk form from the remote earth station to the central distribution office location, for example, in the center of a large city. The second type of link is the local distribution, or subscriber loop type.

The remote earth station to central city distribution office link is typically a microwave link, but for smaller capacity earth stations, cable or even telephone line links could be used. In the case of a microwave link, the problems of frequency coordination must be considered. Coordination problems may exist between the microwave link and the earth station as well as with other existing or planned nearby systems.

1) R. L. Riegler and R. T. Compton, Jr., "An Adaptive Array for Interference Rejection, "Proc. IEEE Vol. 61, No. 6, p. 748, June 1973.

Within the city, local distribution subscriber loops are typically handled by cable or telephone lines. However, at higher data rates, short (less than a mile) LOS radio circuits are becomming practical at higher frequencies (18-30 GHz). At these higher frequencies, small antennas can have sufficiently high gain and narrow beamwidths for practical operation. Rain attentuation can be a problem, but for the short hops envisioned, substantial margin can be built into the link.

4.3 GROUND STATION SECURITY

For those ground stations remotely located from a criminal justice facility, security will be a problem. This section addresses this remote security problem.

Probably the most direct solution to the security problem would be to include the ground station in a criminal justice facility such as suburban highway patrol station, county sheriff's office, etc. that have officers on duty 24-hours a day. When this arrangement is not possible, a remotely monitored closed circuit TV system could provide facility observation and alarms.

The closed circuit TV observation would be transmitted to the criminal justice facility over the terrestrial microwave interconnect link of the ground station. The cost of an industrial type black and white TV camera with zoom capabilities is about $1,200. Assume three cameras are used with observation switched from camera-to-camera so that a single microwave channel can service the TV transmission. The cameras will be under control of the remotely located criminal justice facility where camera selection and zoom capabilities are remote controlled. Seismic intrusion sensors, electric eyes, and trip-wire alarms can be included to complement the closed-circuit TV coverage. When an intrusion is detected and identified as hostile, bell alarms and lights (at night) would provide the first deterrent. A public address system from the criminal justice facility over the microwave link could supply additional deterrent by issuing warning messages. The nearest suburban police or patrol facility also could be alerted.

The major cost item would be the microwave terrestrial link for on-sight TV monitoring. We assume that a terrestrial microwave interconnect link is available for the ground station transmission and receptions and at least two channels are clear for usage. The cost of the microwave equipment per channel hop (about 20 miles) is $12,000. The remainder of the microwave link such as antenna, waveguide, and shelter, would be included as ground station interconnection equipment. An estimate for the cost of this TV monitoring is listed in table 4-2.

Table 4-2. Cost Estimate of Remote Monitoring.

Equipment	Cost
Three TV cameras	$ 3,600
Sensors and Alarms	500
Installation	750
Microwave Equipment	12,000
Total	$16,170

This remotely controlled monitor and alarm system probably would provide adequate protection against vandalism, but a well-informed unfriendly agent most likely could bypass the monitoring and alarm system and gain unobserved access to the grounds of the facility.

A 24-hour security guard system could provide additional deterrent. The cost of this service is estimated at $19,000 per year; more if law enforcement officers are used.

4.4 UNAUTHORIZED MONITORING

4.4.1 General

This section discusses briefly the complexity and some cost factors associated with unauthorized monitoring of the transmission signals at various points along the link. Three specific cases were considered: a) monitoring the satellite transponder downlink transmissions via an unauthorized receiving station, b) monitoring the uplink transmission of an authorized earth station via an unauthorized receiving station, c) monitoring the terrestrial transmission link between the authorized earth stations and the source or designation terminal sets.

In order to obtain high signal quality in monitoring the satellite downlink transmission the unauthorized station would need comparable G/T values to those shown for the receive only stations in the downlink tables of section 3.0. The greater the G/T, the greater the complexity and cost associated with the unauthorized monitor station. However, a great deal of intelligence can be gained from signals of lesser quality than described for the authorized earth stations. Thus in general, the monitoring earth station costs and complexity will be less than that for an authorized receive only earth station.

Monitoring the satellite downlink is not very difficult as long as the monitoring station is reasonably well within the downlink satellite beam coverage. For satellites with fixed CONUS coverage type of beams such as WESTAR or CTS, there are many places where unauthorized monitoring could be conducted including off-shore (land or sea) locations. In general, these stations could be small, could be easily transportable or could even be airborne. On the other hand, satellites with very narrow steerable spot beams such as typified by ATS-6 requires that the unauthorized station be within several hundred miles of the authorized stations. At the same time, the greater downlink EIRP possible for an ATS-6 type of satellite permits even smaller monitor stations within the downlink beam.

The ease and complexity of monitoring the uplink transmission of an authorized earth station is a function of the line-of-sight distance to the earth station

and its EIRP. In general, it will not be very practical to receive energy through the main beam of the earth station because of the high elevation of the pointing angles. The average off-axis side lobe levels relative to isotropic are fairly independent of antenna size. Thus, the type of computations to compute interference between terrestrial microwave radio relay stations and earth stations, can be employed to compute the required G/T of an unauthorized monitoring station. In general, the monitoring station will have to be relatively close to the authorized earth station, preferably within line-of-sight. Although some energy is receivable beyond the horizon, the link becomes highly subject to fading and the size of the monitoring station grows rapidly with distance in order to maintain even a minimum signal quality a reasonable percentage of the time.

The ease and complexity of monitoring the terrestrial transmission link between the authorized station and the originating or designated receiver terminals is highly dependent upon the type and characteristic of the transmission link. Thus, this issue becomes highly dependent upon the exact local situation for each earth station. If the terrestrial transmission link is a microwave relay link, the monitoring problem becomes very similar to that for monitoring the uplink transmissions of the earth stations. One difference is the possibility of putting the monitor in line within the main beam of the transmitter station. Another difference is the potential of a wider range of radio frequencies to be considered. If the transmission link is a cable type of transmission system then access to the signal becomes a physical security problem. Conceptually, a physical tap could be placed anywhere along the transmission link including within the earth station itself. Physical security aspects were not dealt with in any detail because of the limited scope and time of this study.

Inherent within the concept of an unauthorized monitoring facility is that the facility contains or has access to the necessary signal processing equipment required to break the signal down into intelligence. Basically, this requires essentially the same signal processing equipments employed in the authorized network. However, as is pointed out, there are cases where an unauthorized monitoring facility could employ less expensive equipments which will retain the basic intelligence while sacrificing the quality.

Ultimately, the only positive technique for denying the intelligence to an unauthorized monitor of the transmissions within the network is to employ key operated scramblers and cryptographic equipments for securing the message itself. Because of the limited scope and time of this study, this subject was not treated in any detail.

4.4.2 Monitoring of Satellite Television Downlink Transmissions

Analog modulated television is relatively easy to monitor. Further, with separate carriers for video and audio, the listener has the option to listen to the audio only for the intelligence contained therein, which in many cases could be considerable. There are three basic reasons why analog television is so easy to monitor. One is that the authorized network signal quality is very high. The second is that television signals contain a lot of redundant information, and thirdly, standard TV broadcast receiving sets are readily available. It is very difficult to accurately assess the ease and cost of conducting such monitoring activities. The ingenuity of modern-day technicians/inventors should not be under-estimated.

Since the satellite links are designed to operate at input C/N ratios just above the threshold of conventional FM demodulators, a significant reduction in the G/T of the monitoring station will result in a significant reduction in output S/N ratios. But, because of the first two factors above, the unauthorized monitor station can gain a great deal of information with a signal-to-noise ratio on the order of 30 dB less than expected to be obtained for the authorized stations. Refer to table 4-3.

Further, the unauthorized monitoring station can counteract the reduction of input C/N without significant loss of information by using a smaller rf bandwidth than the authorized stations, particularly if the audio and video are on separate carriers. When the audio is submultiplexed with the video reduction of the rf bandwidth will reduce the sound quality considerably. In some cases, however, the monitoring station may elect to sacrifice the sound altogether for better picture information. As the rf bandwidth is reduced to maintain the input C/N ratio, the color information will be affected first. In general, SECAM III will hold its color fidelity for greater bandwidth reductions than NTSC.

Table 4-3. 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. Fredenhall 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.

Reduction of the baseband width as the rf bandwidth is reduced is required in proportion to the information retained in order to optimize the output S/N. For example, the baseband width of NTSC 525/60 color video is 4.2 MHz but a viewable picture in terms of intelligence can be obtained with a baseband width as small as 0.5 MHz. Re-optimizing the weighting and de-emphasis networks as the baseband width is reduced will also improve the output S/N.

With a separate FM sound carrier, the reduction of the predetection and post-detection bandwidths can be used to also retain the basic intelligence under low C/N conditions. Typical network TV sound channels have a test-tone-to-noise ratio of at least 50 dB with bandwidths of 8 to 15 kHz. However, most of the intelligence is in the voice range of 300 to 1800 Hz. Further, 80 percent word intelligibility of voice can be obtained with only a S/N of 14 dB.

Tables 4-4 and 4-5 illustrate various antenna and preamplifier combinations which could be used to monitor analog modulated downlink transmissions.

4.4.3 Direct Line of Sight (LOS) Propagation Mode

This section considers those modes of propagation from transmitting earth stations to nearby terrestrial receiving stations. Specifically, line-of-sight (LOS), diffraction and scatter propagation are considered. Some basic propagation models/assumptions used in Section 4.0 are presented.

In order to establish the performance requirements of a terrestrial monitoring station, or the potential for causing interference to a terrestrial receiving station it is first necessary to know the power density which will be received from the earth station to be monitored. For purposes of this analysis, it is assumed that the gain of the transmitting earth station, as a function of angle θ between the antenna boresite direction and the direction toward the monitoring station is given by

$$G = 32 - 25 \log(\theta) \text{ (dBi)} \quad 1^\circ \leq \theta \leq 48^\circ$$
$$-10 \text{ (dBi)} \quad 48^\circ < \theta \leq 180^\circ$$

This definition corresponds to the maximum allowable off-boresite antenna gain as given in the Rules and Regulations of the FCC, Part 25-Satellite Communications, September 1970, Paragraph 25.209 (a). According to the cited paragraph, "the peak gain of an individual sidelobe may be reduced by averaging its peak level with the peaks of the nearest sidelobes on either side or with the peaks of two nearest sidelobes on either side, provided that the level of no individual sidelobe exceeds the gain envelope given above by more than 6 dB." Since the exact sidelobe pattern is extremely complex and is a statistical function of the antenna's environment, flexures due to wind or snow loading, gravitational variation, mechanical stresses due to tracking, etc., the averaged gain envelope, rather than the potentially 6 dB higher, but unpredictable, value of an individual sidelobe, will be used in calculations.

A second consideration is the higher propagation loss due to rain and atmospheric absorption which will be encountered in the lower atmospheric propagation mechanisms considered here. For calculation purposes, the following absorption characteristics are assumed:

= 0.03218 dB/mile at f = 6 GHz

= 0.08045 dB/mile at f = 14 GHz

Table 4- 4 Antenna and Preamplifier Combinations For Full Bandwidth Monitoring WESTAR 4 GHz Downlink NSTC TV Transmissions In Los Angeles

Antenna Size (Ft)	Preamp Type	Preamp Noise Temp. (°K)	G/T (dB/K)	C/N_D (dB)	C/N_t (dB)	S/N (dB)	Cost ($1000)
15	Paramp	150	21.9	13.5	12.8	50.8	53.4
15	Paramp	200	20.9	12.5	12.0	50.0	51.9
15	Paramp	300	19.4	11.0	10.6	48.6	49.4
15	TDA	520	17.2	8.8	8.6	37.6	42.4
15	Transistor	800	15.4	7.0	6.8	28.8	40.6
15	Transistor	1200	13.8	5.4	5.3	22.0	40.4
12	Paramp	115	20.9	12.5	12.0	50.0	53.4
12	Paramp	150	20.0	11.6	11.1	49.1	50.4
12	Paramp	200	19.0	10.6	10.2	48.2	48.9
12	Paramp	300	17.5	9.1	8.8	39.0	46.4
12	TDA	520	15.3	6.9	6.7	28.2	39.4
12	Transistor	800	13.5	5.1	5.0	20.6	37.6
10	Paramp	75	20.6	12.2	11.7	49.7	55.4
10	Paramp	95	19.9	11.5	11.1	49.1	52.4
10	Paramp	115	19.3	10.9	10.5	48.5	51.4
10	Paramp	150	18.4	10.0	9.6	45.0	48.4
10	Paramp	200	17.4	9.0	8.7	38.4	46.9
10	Paramp	300	15.9	7.5	7.3	31.0	44.4
10	TDA	520	13.7	5.3	5.2	22.2	37.4
8	Paramp	65	19.1	10.7	10.3	48.3	55.4
8	Paramp	75	18.7	10.3	10.0	48.0	53.4
8	Paramp	95	18.0	9.6	9.3	42.8	50.4
8	Paramp	115	17.4	9.0	8.8	39.0	49.4
8	Paramp	150	16.5	8.1	7.9	33.7	46.4
8	Paramp	200	15.5	7.1	6.9	29.2	44.9
8	Paramp	300	14.0	5.6	5.5	23.0	42.4
6	Paramp	55	17.0	8.6	8.4	36.3	54.4
6	Paramp	65	16.6	8.2	8.0	34.0	53.4
6	Paramp	75	16.2	7.8	7.6	32.3	51.4
6	Paramp	95	15.5	7.1	6.9	29.2	48.4
6	Paramp	115	14.9	6.5	6.4	26.9	47.4
6	Paramp	150	14.0	5.6	5.5	23.0	44.4
5	Paramp	55	15.4	7.0	6.8	29.8	54.4
5	Paramp	65	15.0	6.6	6.5	27.4	52.4
5	Paramp	75	14.6	6.2	6.1	25.8	50.4
5	Paramp	95	13.9	5.5	5.4	22.5	49.4
5	Paramp	115	13.3	4.9	4.8	20.0	46.4
4	Paramp	55	13.5	5.1	5.0	20.6	53.4
4	Paramp	65	13.1	4.7	4.6	18.6	51.4
4	Paramp	75	12.7	4.3	4.2	16.8	49.4

Table 4-5. Antenna and PreAmplifier Combinations For Narrow Bandwidth Monitoring WESTAR 4 GHz Downlink NSTC TV Transmissions in Los Angeles

Antenna Size (Ft)	Preamp Type	Preamp Noise Temp. (°K)	G/T (dB/K)	C/N_D (dB)	C/N_t (dB)	S/N (dB)	Cost ($1000)
15	Paramp	150	21.9	13.5	12.8	50.8	53.4
15	Paramp	200	20.9	12.5	12.0	50.0	51.9
15	Paramp	300	19.4	11.0	10.6	48.6	49.4
15	TDA	520	17.2	10.1	9.9	43.9	42.4
15	Transistor	800	15.4	8.8	8.6	37.6	40.6
15	Transistor	1200	13.8	7.7	7.6	31.0	40.4
15	Transistor	1750	12.2	5.4	5.3	22.1	39.9
12	Paramp	115	20.9	12.5	12.0	50.0	53.4
12	Paramp	150	20.0	11.6	11.1	49.1	50.4
12	Paramp	200	19.0	10.6	10.2	48.2	48.9
12	Paramp	300	17.5	9.7	9.4	43.7	46.4
12	TDA	520	15.3	8.7	8.5	37.0	39.4
12	Transistor	800	13.5	7.1	7.0	28.7	37.6
12	Transistor	1200	11.6	4.7	4.6	18.4	37.4
10	Paramp	75	20.6	12.2	11.7	49.7	55.4
10	Paramp	95	19.9	11.5	11.1	49.1	52.4
10	Paramp	115	19.3	10.9	10.5	48.5	51.4
10	Paramp	150	18.4	10.0	9.6	45.0	48.4
10	Paramp	200	17.4	9.7	9.5	44.0	46.9
10	Paramp	300	15.9	8.8	8.6	37.5	44.4
10	TDA	520	13.7	7.2	7.1	30.4	37.4
10	Transistor	800	11.9	5.3	5.2	21.5	35.6

Table 4-5. Antenna and Preamplifier Combinations for Narrow Bandwidth Monitoring WESTAR 4 GHz Downlink NSTC TV Transmissions in Los Angeles - Continued.

Antenna Size (Ft)	Preamp Type	Preamp Noise Temp. (°K)	G/T (dB/K)	C/N_D (dB)	C/N_t (dB)	S/N (dB)	Cost ($1000)
8	Paramp	65	19.1	10.7	10.3	48.3	55.4
8	Paramp	75	18.7	10.3	10.0	48.0	53.4
8	Paramp	95	18.0	10.1	9.8	46.4	51.4
8	Paramp	115	17.4	9.7	9.4	43.7	49.4
8	Paramp	150	16.5	9.3	9.1	41.4	46.4
8	Paramp	200	15.5	8.8	8.6	38.0	44.9
8	Paramp	300	14.0	7.7	7.6	32.3	42.4
8	TDA	520	12.1	5.3	5.2	21.5	35.4
6	Paramp	55	17.0	9.5	9.3	43.0	55.4
6	Paramp	65	16.6	9.4	9.2	41.7	53.4
6	Paramp	75	16.2	9.2	9.0	40.4	51.4
6	Paramp	95	15.5	8.8	8.6	38.0	48.4
6	Paramp	115	14.9	8.6	8.4	36.4	47.4
6	Paramp	150	14.0	7.7	7.6	32.2	44.4
6	Paramp	200	13.0	6.5	6.4	26.6	42.9
6	Paramp	300	11.5	4.6	4.5	18.4	40.4
5	Paramp	55	15.4	9.2	9.0	40.4	54.4
5	Paramp	65	15.0	8.5	8.4	36.7	52.4
5	Paramp	75	14.6	8.3	8.2	35.4	50.4
5	Paramp	95	13.9	7.6	7.5	31.6	49.4
5	Paramp	115	13.3	6.7	6.6	28.2	46.4
5	Paramp	150	12.4	5.7	5.6	23.2	43.4
5	Paramp	200	11.4	4.5	4.4	17.7	41.9
4	Paramp	55	13.5	7.1	7.0	29.6	53.4
4	Paramp	65	13.1	6.6	6.5	27.0	51.4
4	Paramp	75	12.7	6.1	6.0	25.0	49.4
3.5	Paramp	55	12.3	5.7	5.6	22.7	52.9

These absorption characteristics were computed for standard sea level temperature and pressure, and represent the combined effects of oxygen and water vapor absorption. Correction factors for other altitudes are available.

As an example calculation, consider an earth station at Chicago which transmits an 8-T1 TDM carrier via the Westar satellite. The required performance of a monitoring station is calculated as follows:

1. Available C/T at the monitoring station is computed, assuming LOS propagation with no fading or obstacles.

   Thus,

$$\left(\frac{C}{T}\right)_{Avail} = EIRP\ (\theta) - L_{fs} - \alpha d + (G/T)_{mon}$$

   Where,

$$EIRP\ (\theta) = \begin{cases} P_t + 32 - 25 \log\theta & (dbW)\ 1° \le \theta \le 48° \\ P_t - 10 & (dbW)\ 48° < \theta \le 180° \end{cases}$$

   P_t = radiated power from earth station (dbW)

   L_{fs} = 96.573 + 20 log d + 20 log f = free space loss (dB)

   d = LOS distance from earth station to monitoring station (miles)

   f = transmit frequency (GHz)

   α = atmospheric attenuation (dB/mile)

   G/T = monitoring station G/T (dB/Kelvin)

2. Required C/T is calculated as in Section 2.2:

$$(C/T)\ \text{required} = (C/N)\ \text{threshold} + K+B \qquad (dB)$$

1) "Radar/Radio Tropospheric Absorption and Noise Temperature," L.V. Blake, Naval Research Laboratory Report 7461, October 1972, p. 13, Figure 5.

3. Equating the expressions in (1) and (2) and rearranging terms,

$$(G/T)_{mon} = 20 \log d + \alpha d - P_t + 20 \log f + (C/T)\ req$$

$$+ 96.573 - \begin{cases} (32 - 25 \log \theta) & , \text{ for } 1° \le \theta \le 48° \\ (-10) & , \text{ for } 48° < \theta \le 180° \end{cases}$$

Substituting the appropriate values from Table 3-47 , and using a 1dB loss factor between the earth station HPA output and the antenna,

α = 0.03218 dB/mile at 6 GHz

f = 6 GHz

P_t = (2399 watts/(ℓ_t) = 33.8dBw - 1dB = 32.8 dBw

$$(C/T)_{Req} = (C/N)_{Req} + K + B$$
$$= 14.6 - 228.6 + 68.7 = -145.3 \text{ dBw/Kelvin}$$

and,

$$(G/T)_{mon} = 20 \log d + 0.03218d + \begin{cases} (25 \log \theta - 97.97), & 1° \le \theta \le 48° \\ (-55.97) & , 48° < \theta \le 180° \end{cases}$$

This equation has been parametrically plotted in Figure 4-3. The monitoring station G/T required for threshold performance depends upon both distance from the earth station and the relative angle between the LOS directions from the earth station to the satellite and to the monitoring station. For the simple case considered, it is clear that the monitoring station "front end" is relatively simple and inexpensive. For example, a one-foot diameter antenna with 23dB gain and a 200,000 Kelvin system temperature will provide a G/T of -30dB/K. On the other hand, the baseband processing and modulation equipment required are similar to that required in the receive side of the earth station. Thus, for the example above, where a fairly high rate QPSK modem and a multiplex of the order of the T-2 hierarchy are required, the antenna and preamplifier may not be the determining cost factor. For the T1 FDMA cases, and even more-so for the 50 Kbps FDMA cases, the required baseband and modulation equipment costs become less of a burden. In any case, the above example shows

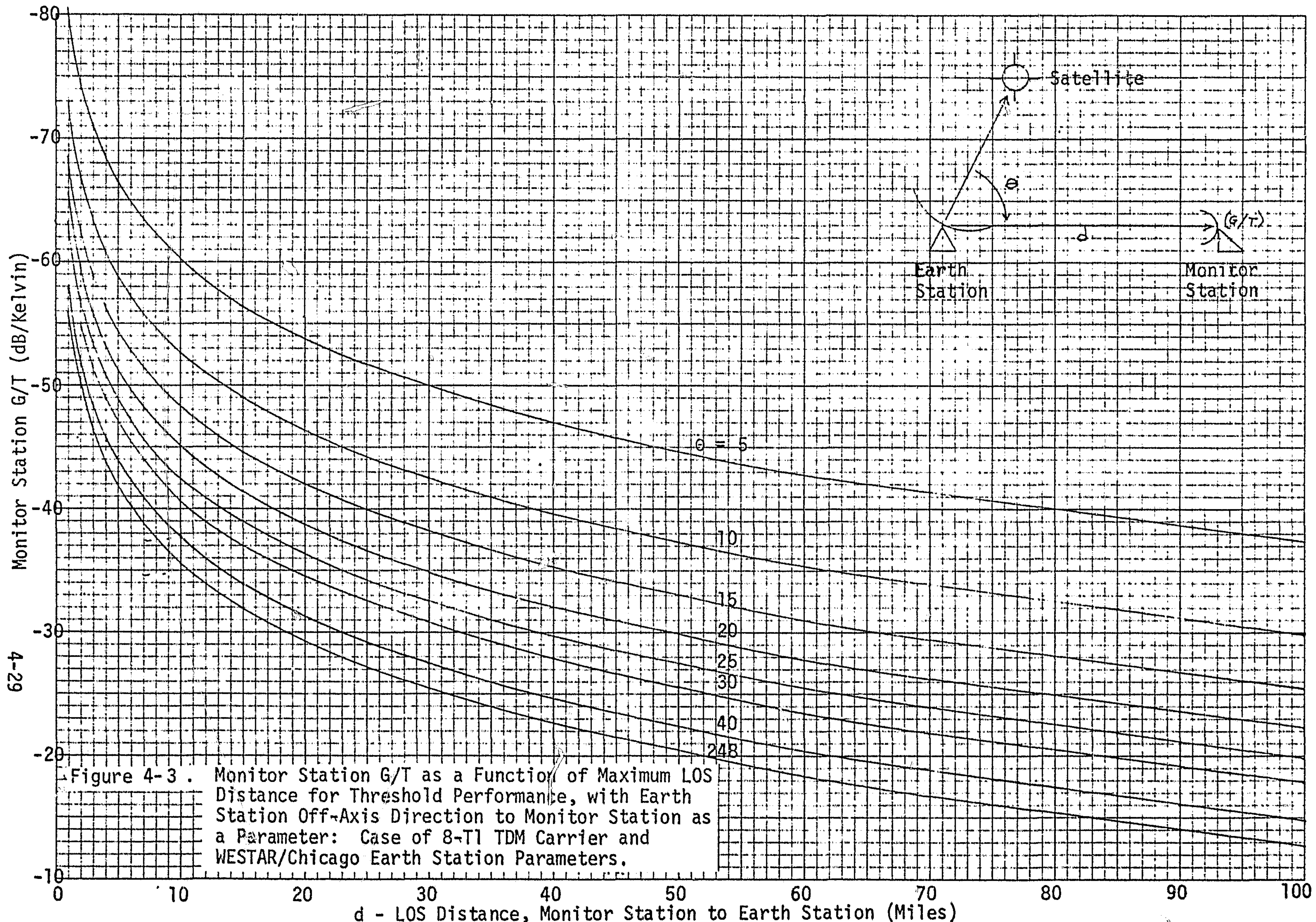

Figure 4-3. Monitor Station G/T as a Function of Maximum LOS Distance for Threshold Performance, with Earth Station Off-Axis Direction to Monitor Station as a Parameter: Case of 8-T1 TDM Carrier and WESTAR/Chicago Earth Station Parameters.

that it is quite feasible to monitor an earth station's transmissions with equipment which is smaller in size and lower in cost than that required to monitor the satellite. The best way to prevent unauthorized monitoring is probably to use encryption devices on those digital channels requiring security. Encryption devices for T-1 rates and lower are available for on the order of $500.00. Encryption keys could be changed periodically as required for the desired degree of security.

The above analysis has considered only the simplest LOS case. Many other potential modes of propagation between an earth station and a monitoring station exist, such as rain-scatter, knife-edge diffraction, tropo-scatter, etc. A procedure sometimes followed in lcoating an earth station is to place the station in a pit in order to provide r.f.i. shielding. Besides preventing undesired interference, such a procedure also makes LOS monitoring, such as discussed above, more difficult. Monitoring earth station transmissions by means of diffraction or scatter propagation mechanisms is a difficult analysis problem which must be dealt with on a case-by-case basis, using knowledge of the particular site in question. Thus, further examination of these areas has not been attempted in this study.

4.4.4 Earth Station Digital Data Monitoring Costs

The analyses of Section 3 show that for the T1 and 50 Kbps FDMA cases, the per-carrier power level transmitted from the earth station decreases as the number of carriers increases. Hence, a monitoring station requires a higher G/T when larger numbers of carriers access the satellite. Similarly, the T1 TDM carrier level remains constant as more T1 channels are added to the multiplex. Since the bandwidth of the carrier depends upon the number of multiplexed T1 data streams, the monitor station carrier to noise will degrade as more T1 streams are added, unless the monitor station G/T is increased. Therefore, in general, the monitor station G/T must be better when a larger total bit rate accesses the transponder than when smaller rates are used.

Baseband and Processing and Modulation Costs - 50 Kbps FDMA

The approximate cost of the baseband processing and modulation portion of a 50 Kbps FDMA station is $100K, assuming about twenty channels are monitored, or about $5K per channel. The cost per channel is higher if fewer channels are monitored, due to a "common equipment" cost of approximately $20K. As a rule of thumb, the cost of n channels may be estimated as $(20 + 4 n)K. For the coded cases, an added cost of $5K per channel is added for the Viterbi decoder.

Baseband Processing and Modulation Costs - T1 FDMA

A rate T1 modem designed to operate with a Viterbi decoder currently costs on the order of $15K. For a hard decision modem operating at higher (non-coded) Eb/No values, the price would be somewhat less, on the order of $10K. Viterbi decoders operating at T1 rates cost approximately $12K.

Baseband Processing and Modulation Costs - T1 TDM

The cost of T1 multiplex equipment can be based upon commercial T-hierarchy multiplexes. A T-2 multiplex combines 4 T-1 rates and costs from $4,800 - $5,400. A T-3 MUX combines 28 T-1 rates at a cost of about $25K. Viterbi decoders operating at 10 Mbps (about 6 T-1's) cost $16.6K. For higher rates, parallel operation can be assumed. Modems for this case range from the non-coded interface T1 rate modem to the Viterbi interface 60 Mbps modem. A known T1/Viterbi interface modem sells for about $15K. At the other extreme, a 60 Mbps modem is assumed to cost $50K.

A summary of baseband processing and modulation costs, for the cases discussed above, is given in Table 4-6

In comparing calculations of required monitor station antenna gain and receiver noise figure, it is noted that, if a 14dB noise figure is assumed, then a horn antenna will provide sufficient gain to achieve the required carrier to thermal noise ratio. Costs computed below are based upon horn antennas and 14dB NF pre-amplifiers; however, it should be realized that the noise environment of the monitor station may require an antenna with more directnity than a horn in order to reject sources of undesired interfering signals. Table 4-7 below summarizes monitor station total cost for the three digital carrier types considered. Cost is based upon major component cost plus 30% overhead for miscellaneous equipment and integration. It is clear from the table that the major cost factor for the monitoring station is the baseband processing and modulation equipment.

Table 4-6 Baseband Processing and Modulation Costs - Digital Carrier Monitoring Cases

50 Kbps FDMA	
Common Equipment (1 per 20 channels)	$20K
50 Kbps Demodulator	4K
50 Kbps Viterbi decoder	5K
T1 FDMA	
T1 Demodulator (low Eb/No, soft decision)	15K
T1 Demodulator (high Eb/No, hard decision)	10K
T1 Rate Viterbi Decoder	12K
T1 TDM	
4 T1 Multiplexer	5K
28 T1 Multiplexer	25K
T1 Demodulator (low Eb/No, soft decision)	15K
T1 Demodulator (high Eb/No, hard decision)	10K
38-T1 Demodulator (60 Mbps)	50K
6-T1 Viterbi Decoder	16.6K

Table 4-7 Summary of Total Monitoring Station Costs

Case	Number of Channels Monitored	Cost ($K)
T1-TDM (Uncoded)	1	32
"	8	45
"	28	121
T1-TDM (Coded)	1	55
"	8	74
T1-FDMA (Uncoded)	1	32
"	8	124
"	32	436
T1-FDMA (Coded)	1	55
"	8	300
50 Kbps-FDMA (Uncoded)	1	51
"	20	150
"	250	1632
50 Kbps-FDMA (Coded)	1	57
"	20	150
"	250	3257

4.5 FALSE TRANSMISSION/MESSAGE INJECTION

4.5.1 Introduction

This section deals with the possibilities of unauthorized injection of false transmissions/messages into the satellite communication link. In general, where the transmission system maintains separate message channels, it is relatively easy to insert a transmission with message into the system. Where the message channels are multiplexed into larger groupings for transmission in general, it is quite difficult to inject an unauthorized transmission/ message into the system without physically controlling the transmission facility portion of the earth station.

In section 3.0 of thi., study, both types of transmission concepts were considered. Cases which maintained separate message channels over the satellite link were:

a. separate analog video and sound rf carriers,
b. separate rf carriers for T1 carriers, i.e., T1-FDMA case,
c. separate rf carriers for 50 Kbps or 25 Kbps data channels, i.e., 50 Kbps-FDMA case.

Cases which multiplexed the channels into larger groupings were:

a. digital television,
b. time division multiplexed T1 carriers, i.e., T1-TDM.

In this discussion, we assume that the first three transmission modes, analog video, T1-FDMA, and 50 Kbps-FDMA are the only viable candidates for false message injection.

4.5.2 False Message Injection Via Satellite

To create a false video message via satellite, the unfriendly agent would require a ground transmission station with a greater uplink EIRP for TV transmission than that employed by the friendly terminals for TV transmission.

The unfriendly agent's tactic would be to increase his false message signal power at least 6 dB above the regular received signal in order to capture the limiter of the demodulator. This 6 dB increase would saturate the satellite transponder and instead of false message injection his efforts would be that of jamming. Consequently, false injection of a video signal would result in satellite jamming.

The TV sound which is frequency modulated on an an rf carrier could have a false message injected. At the satellite, this audio carrier is down 13 dB below satellite transponder saturation. Therefore, the unfriendly agent could increase is false audio signal 6 dB above the desired audio and capture the demodulator limiter. The false message would be distorted noticeable, but a false audio message could be injected in the TV reception. To be effective with his false TV audio injection, the unfriendly agent would need to monitor the downlink TV reception. This would require ground station equipment similar to that discussed in Section 4.4.2. on unauthorized monitoring. Since his uplink transmission could concentrate on the TV audio channel the transmission equipment cost would be reduced over that of a regular earth station. However, it is questionable whether or not injecting a false audio signal in the TV reception could be effective. He could utilized his resources in a more effective manner by concentrating on the digital transmission modes.

The 32 carrier case in the T1-FDMA transmission mode would be rather vulnerable to false message injection. For example, each of these carriers is down 28 dB below saturation and a false digital T1 message with 10 dB greater EIRP uplink power could essentially capture this channel of the receiver without saturating the satellite transponder. The detection of the false message would be degraded, but a false message bit error probability of 10^{-3} probably could be obtained.

When the T1-FDMA is only a two-carrier case than each is down only about 13 dB from satellite transponder saturation and the false digital message injection would not be very effective. A similar situation exists for the 50 Kbps data mode: A false message can be injected into a channel by the unfriendly agent increasing his uplink EIRP above that channels regular transmissions by about 10 dB. The false message injection is more effective when many 50 Kbps channels are operating through the satellite and each 50 Kbps carrier must be of a low level to prevent satellite transponder saturation. In this situation, the unfriendly agent can increase his EIRP enough to capture a particular channel, yet stay below satellite saturation. The received false message will be degraded, but is still can be accepted by the ground terminal as a true message.

The only reliable way to prevent a false (injected) message from being accepted as a true message is to employ encryption techniques. Commercial crypto generators are available at a modest cost from such suppliers as Crypto Industries, San Diego. Their model 213 crypto generator provides an economical means of data encryption. It is compatible with all digital transmission from zero to two million bits per second, and will provide both encryption for transmission and decryption for reception. The price for in quantities of 1 to 19 units is $525 per unit.

Encrypting the T1-FDMA and the 50 Kbps channels would not only provide protection against false message acceptance, but would prevent unauthorized monitoring from gaining information from the digital message. A code of the day, the key, could be supplied to each earth station on a periodic basis. The probability of a false preamble detection is less than one in 10^{20} while successful preamble detection is accomplished in up to 6.6% bit error rate environment.

In summary, false message injection via satellite is possible on the non-multiplex data transmission modes of T1-FDMA and the 50 Kbps. Injection of false TV video signal appears unlikely (by message injection through the satellite transponder) but false TV audio signal injection is a possibility. Transmissions that employ a large number of data channels would be the most vulnerable to false message injection whereas those transmissions with few would have the most protection. Using commercially available encryption equipment can eliminate false message acceptance.

4.5.3 False Message Injection via Ground or Terrestrial Link

A false message injection directly at the ground station in the analog TV signal is a possibility. The unfriendly agent only would have to have his signal power into the ground station antenna about 6 dB above the desired signal to capture the FM demodulator limiter. The received false signal would be received with noticeable degradation, but could be accepted as a true message. To estimate the equipment cost to the unfriendly agent to achieve this false message injection we will review some basic calculation:

Let X be the difference between the EIRP of the unfriendly agent's transmitter and the space loss between his transmitter and the earth station. It is easy to show that to achieve a Y dB advantage over the desired signal at the earth station that

$$X = -161 + Y + G_b \quad \text{(in dB)}$$

where G_b is the front-to-sidelobe ratio of the earth station antenna. Suppose Y = 6 dB, and consider G_b = 60 dB, then X = -95 dB. Further, suppose that the unfriendly agent can obtain a covert location with a line-of-sight distance of ten miles. Operating in the 6 GHz band his space loss is 128.6 dB, and his EIRP required to achieve this 6 dB advantage is 33.6 dB.

A typical covert microwave installation with a 10-foot dish and a one watt power can provide about 43 dBW; about 10 dB more than required to inject a false message in the TV video. The cost of his microwave 6 GHz transmitter, antenna, and shelter is about 14 to 16 thousand dollars. By locating his station nearer to the earth station, he can achieve an additional 6 dB for each one-half distance closer. Consequently, injection of false video message during true message reception is a likely situation. However, to be effective, the unfriendly agent would need to monitor the downlink signal from the satellite. This would require a minimum receive-only earth station.

As was discussed in the previous section, the non-multiplexed mode of data transmissions would be vulnerable to false message injection as would be the separate rf carrier TV audio. The unfriendly agent would be most effective operating the digital data since interference is less noticeable which would assist him in his covert operation. A 6 GHz one-watt transmitter costs about $8,000, a 10-foot antenna costs $5,000, waveguide $1,000, and the baseband equipment about $2,000. Including another $2,000 for a shelter, would bring his investment to $18,000. The earth station could overcome his $18,000 investment with a $1,050 cost of two crypto units for the digital data.

Similar equipment costs would be obtained when the microwave terrestrial link is the object of false message injection.

4.6 SUSCEPTIBILITY TO JAMMING

4.6.1 Introduction

As long as the jamming source is located within the main beam of the satellite receive antenna, jamming the satellite uplink is relatively easy. Moreover, the added advantage of being able to locate the jammer anywhere within the main beam would make jamming the satellite uplink attractive to persons or organizations with that intent. Satellites using CONUS coverage receive antenna beams may be jammed by a source located anywhere within the continental U.S. including offshore areas, or, at somewhat greater cost, by sources located in areas bordering the U.S. such as Cuba, Mexico or Canada. As the remainder of this section shows, the costs of completely jamming a satellite transponder using a relatively simple pulse jammer capable of being carried with antenna in a small van and operated from batteries, is comparatively small. In addition, such a jammer would be very difficult to locate. Not only would it be highly mobile, but also it need not be localized to any specific part of the satellite main beam which is a large area considering that the main beam may include an area greater than CONUS.

4.6.2 Susceptibility of Satellite to Jamming

The peak EIRP required by the jamming station is directly proportional to the satellite saturation flux density and given by the equation

$$(EIRP)_{sat} = \Psi + 10 \log (4\pi D^2)$$

where

EIRP = effective isotropic radiated power required to saturate a satellite transponder (dBW)

Ψ = satellite uplink saturation flux density (dB/m^2)

D = distance from earth station (jammer) to satellite.

Table 4-7 gives the uplink EIRP required to saturate each of the satellite models.

As section 2.2.5 indicated, desired signals being amplified in a non-linear satellite TWTA may be partially or completely suppressed by the presence of a jamming signal that drives the TWTA several dB past saturation. The exact amount of overdrive required depends upon the carrier-to-noise or bit energy to noise spectral density margins existing

Table 4-7. Required EIRP to Jam Satellite Transponder.

	WESTAR 4/6	FUTURE 12/14	ATS-6 4/6	CTS 12/14	ATS-6 2.6/6
Ψ (dBW/m^2)	-79.6[1]	-79[1]	-91[2]	-91.5[2]	-91[2]
$(EIRP)_{sat}$(dBW)	82.5	83.1	71.1	70.6	71.1
$(EIRP)_{JAM}$ (dBW)	85.5	86.1	74.1	73.6	74.1

Notes:

1 - for CONUS

2 - on beam axis

in the analog or digital links respectively. Figure 4-4 shows the signal suppression as a function of jamming signal strength.

Usually satellite links are designed with very small link margins (1 to 2 dB) due to the high cost of link margin in a satellite link. Such links would be very susceptible to suppression by a jamming signal. Some protection can be provided by increasing the link margins at a substantial increase in ground station cost. Even then the link can be jammed although at greater cost to the jammer. Table 4-8 also gives the required uplink EIRP to jam a satellite assuming link margins typical of a design in which jamming is not a consideration. The required uplink EIRP to jam the satellite is defined as that jammer power needed to reduce desired signals by at least 10 dB. With the operating margins existing in each of the transmission modes. a 10 dB loss in desired signal power will completely suppress desired signal transmission.

The required jamming signal may be generated in a variety of ways, some expensive and some relatively cheap. Although present generation TWT's or klystrons are capable of continuously generating up to about 10 kW at 6 GHz, the cost of such a jammer would be quite high. Moreover, its size and dc power requirements would force it to be located at a fixed location with the attendant risk of discovery. The size of the antenna itself would attract attention compromising its location.

A much more attractive jammer may be obtained using a 5 to 60 kW pulsed magnetron transmitter. Such transmitters are commercially available (although not at frequencies in a satellite uplink band), relatively inexpensive, light-weight and,since they are pulsed at low duty cycles, require very little dc power. They could be carried complete with an antenna and battery pack in a small van. Since they would be highly mobile, they would be very difficult to locate. Table 4-8 lists some of the pertinent parameters of such a jammer.

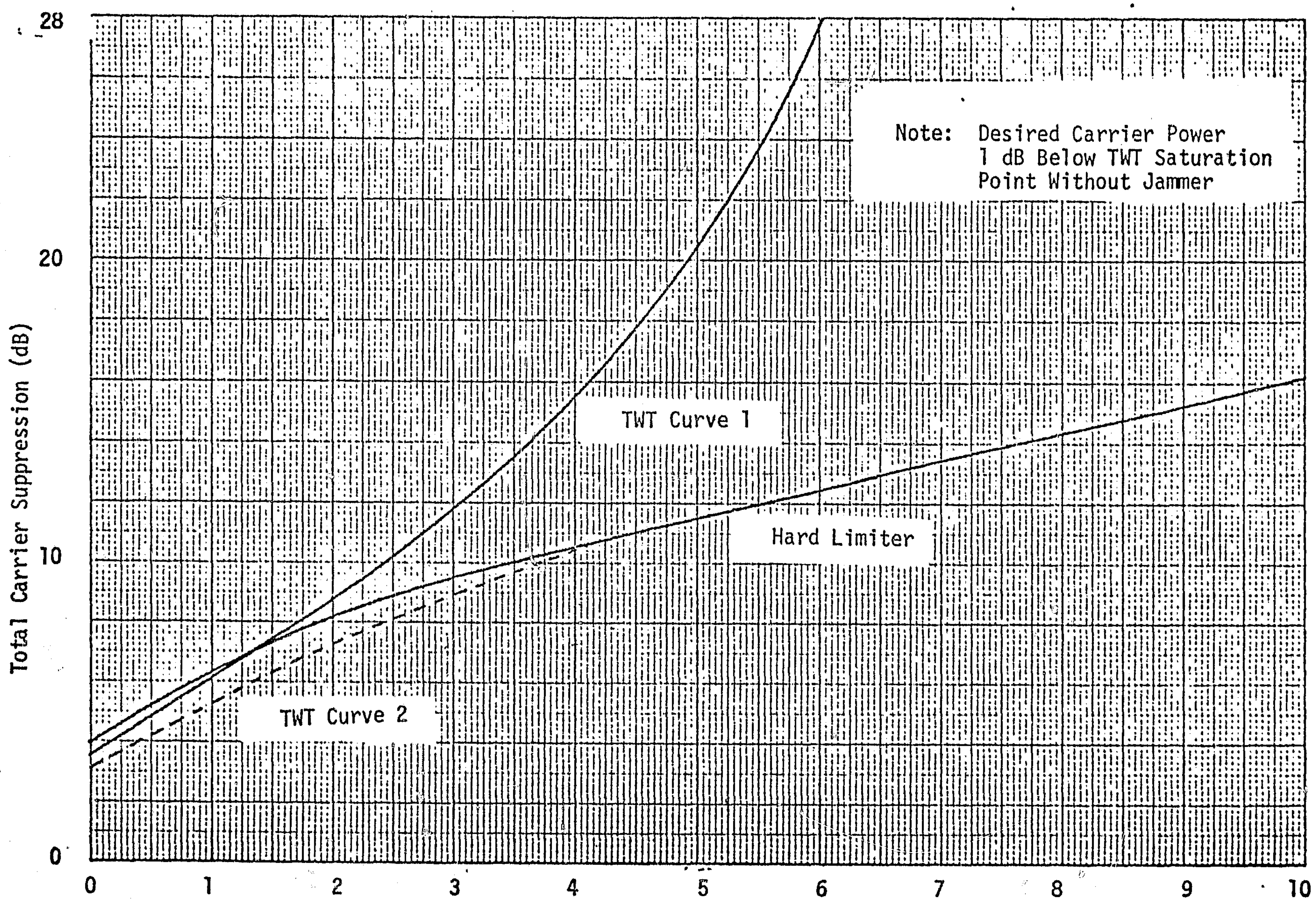

Figure 4-4. Total Desired Carrier Suppression Due to Jamming Signal (dB).

Table 4-8. Typical Pulse Magnetron Characteristics.

Frequency Range:	dependent on magnetron tube availability but could include both 6 and 14 GHz satellite uplink bands.
Output Power:	can easily obtain 5 to 65 kW peak.
Pulse Duration:	0.5 to 3 μsec, typical.
Pulse Repetition Rate:	0 to 1250 pps, typical.
Required DC Power:	150 to 2000 watts depending on output power.
Weight:	25 pounds, typical.
Size:	8 inches x 8 inches x 12 inches, typical.
Cost:	≈$15,000 depending principally upon tube availability.

Magnetron transmitters are presently widely used as radar transmitters in commercial and military applications. In these applications they have operated at frequencies other than those used in the satellite bands. Consequently, off-the-shelf magnetron pulse transmitters at these frequencies are not available. However, tubes at these frequencies would be a simple adaptation of existing designs. It is altogether conceivable that a knowledgeable person could fabricate a magnetron transmitter capable of operating in the satellite uplink bands from government surplus equipments.

Megnetron pulse transmitter costs are relatively low - on the average about $15,000 for a complete transmitter including power supply. Transmitter costs are more sensitive to availability of a magnetron tube at the right frequency than they are to transmitter power output.

With such high peak power outputs, such jammers may employ relatively small antennas that are very portable or even mobile. Table 4-9 shows the trade between transmitter power and antenna size to produce the EIRP needed to jam a satellite for each of the satellite models. It is readily apparent that such jammers may operate with very small antennas.

Several methods exist to counteract to some extent the effect of a jammer:

a. reduce the uplink sensitivity by changing the gain of the satellite.
b. employ spread spectrum modulation techniques.
c. encode messages into small packets with provision for packet retransmission as required.
d. use a satellite with a hard limiter and a combination of the above methods.

Military communication programs have developed a large amount of technology on each of the above techniques. However, the briefness of this study does not permit a detailed consideration of any of them.

	WESTAR 4/6	FUTURE 12/14	ATS-6 4/6	CTS 12/14	ATS 2.6/6
Required Jammer EIRP (dBw)	85.5	86.1	74.1	73.6	74.1
Jammer EIRP' (8 Kw)	39.0	39.0	39.0	39.0	39.0
Antenna Gain (dBi)	46.5	47.1	35.1	34.6	35.1
Antenna Diameter	15'	7.5'	4'	2.1'	4'
Approximate Jammer Cost[2] $	30K	22.5K	19K	17.1K	19K
Jammer EIRP' (30 Kw)	44.8	44.8	44.8	44.8	44.8
Antenna Gain (dBi)	40.7	41.3	29.3	28.8	29.3
Antenna Diameter	7.5'	3.4'	2'	<1'	2'
Approximate Jammer Cost[2] $	22.5K	18.4K	17K	15K	17K

1 - Pulsed magnetion jammer

2 - Includes transmitter, antenna and power supply

Table 4-9 Satellite Uplink Jammer Costs

It is of interest to consider the required power relative to the desired signal in the 50 Kbps QPSK FDMA uncoded case to cause a specific degradation. For this discussion consider the Westar transponder with 80 total channels and a nominal BO_i of 13 dB. Refer to Table 4-10. First assume that the jamming power fills the transponder uniformly and that the 50 Kbps channels are uniformly spaced across the transponder bandwidth. In order to move the BO_i of the transponder to 12 dB, the total jammer power in the transponder band must be 5.87 dB below the total power of the 80 50 Kbps channels. Changing the backoff point decreases the average received C/N to 14.69 versus a C/N operational of 14.6 and a received C/N of 15.15 dB at a BO_i of 13 dB. In addition a certain percentage of the jammer energy falls into the channels. Specifically the carrier-to-jammer noise in a channel is 17.6 dB which causes a net received C/N of 11.57 dB which is 3 dB below $(C/N)_{operational}$. Depending upon how much of the links margin (ie downlink pointing, rain etc.) have been used it is possible that under clear weather conditions, particularly at 12 GHz where the rain margins are high, that the average received BER is not significantly off of 10^{-5}. However a 3 dB degradation can be achieved with a rather modest level of jamming power. It follows that additional jamming power will degrade the performance more. For example, approximately 3.5 dB increase in jammer power would place the BO_i point at approximately 11.0 dB which results in a net degradation of **3.6 dB.**

There are a number of courses of action to reduce the jammer's effectiveness. If the antenna gain on the satellite is adjustable, the gain of the satellite could be reduced and the power of the authorized stations increased to where the new operating point on the satellite is essentially equivalent to the previous 13 dB BO_i point prior to jamming. If the satellite employs a narrow spot beam, shifting the beam to reduce the jammer uplink advantage can be tried. It is conceivable that several small jammers scattered throughout could be used simultaneously to achieve the same effect as one single larger jammer. Another alternative is to reduce the number of channels and balance the power of the remaining ones to the optimum BO_i point. Switching to a FEC code would result in some advantage to the authorized transmissions. Switching to a TDMA mode with the transponder being driven to saturation would require a significant increase in uplink power to effect transmission. Alternatively a CDMA mode could be used with modulations having high time bandwidth products to reject interference and jamming.

Table 4-11 Degradation of Broadband Jammer of Satellite for 80 50 Kbps FDMA Channels Through WESTAR

BO_i (dB)	Jammer To Desired Uplink Power (dB)	C/N_J (dB)	C/N_{IM} (dB)	$(C/T)_{Avail}$ (dBW/K)	C/N_{Net} (dB)	Link Margin (dB)
10	-0.02	11.75	15.20	-146.45	9.4	-5.2
11	-2.33	14.06	16.50	-147.36	11.0	-3.6
12	-5.87	17.60	17.90	-148.27	11.6	-3.0
13	-∞	∞	19.34	-149.15	15.2	+0.6

Notes:

1. Assumes a G/T_e of 21 dB
2. Assumes link margin relative to C/N_{op} = 14.6 dB

4.6.3 Susceptibility of Local Station to Jamming

Local station jamming is defined as an active electronic encroachment upon the communications link of the local NALECOM station. This encroachment may be accidental or deliberate, unintentional or openly hostile. This section is oriented toward the deliberate, intelligent, actively hostile attack upon the communications link of the local stations by persons seeking to reduce or disable the communications capability of this link. While the orientation of the section is toward deliberate acts against the link, many of the results can be equally well applied to accidental jamming of the link by other emitters located nearby. Jamming or spoofing can be applied to the transmit or receive links of the station, however, receive jamming is a much more cost effective approach, from the jammer's point of view, in the systems under study here. Transmit jamming will then be viewed as a receive jamming effort against a distant receive site or against the network as a whole. As such, transmit jamming will be categorized with receive jamming and satellite jamming and will not be discussed separately in this section.

The jammer has a potentially very great geographical advantage when operating against a fixed location Satcom terminal. A part of this advantage comes from his flexibility of operation and mobility. The greatest part of this advantage, however, comes from the large distance difference, and therefore, large space loss difference, between the potential jammer locations and the location of a synchronous satellite, both relative to the receiving terminal. Figure 4-5 shows the geographic advantage of a jammer, as a function of his distance from the terminal, relative to a synchronous satellite directly overhead. Since the satellites considered in this study are in equatorial orbits, the terminal look angles to the satellites are below zenith and the distance to the satellite is greater than that assumed in the previous statement. This increase in distance to the satellite will increase the jammer's geographic advantage by as much as 1 - 1.5 dB for typical working look angles to the satellites. This added advantage will be neglected to simplify the analysis since it is small compared to the inherent geographic advantage. The flexibility of operation and mobility increase the jammer's advantage due to the element of surprise and the selection of time and target.

The jammer has a number of electronic attack techniques from which to choose. Several of these are listed below in the general categories of jamming types.

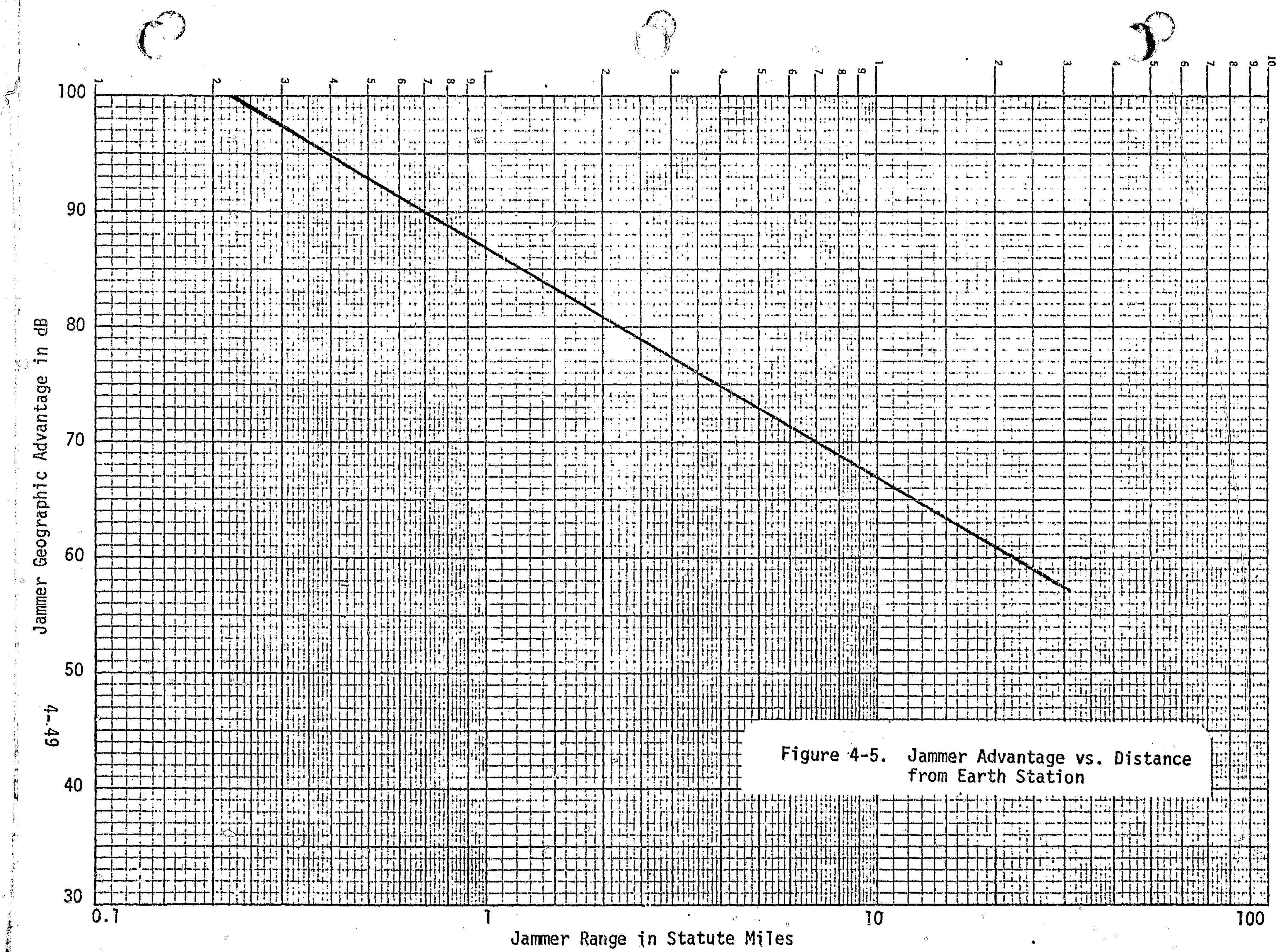

Figure 4-5. Jammer Advantage vs. Distance from Earth Station

a. Uncorrelated Jammers
   1. Random Noise
   2. Continuous Wave
   3. Amplitude Modulation
   4. Angle Modulation
   5. Pulse Modulation

b. Correlated or Uncorrelated Jammers
   1. Repeated or Replica Signals
   2. Psuedo Random Signals

c. Combinations of Jamming Types

The uncorrelated jammers are generally used to raise the receiver noise level and signal threshold or to cover the signal and capture the receiver or prevent the intended signal from capturing it. They are commonly called power jammers or brute force jammers. The correlated jammers are generally used to confuse the receiver with signals which are identical or very closely related to the signals intended to be received. They, however, have some false information placed on them in some manner to confuse the receiver. The correlated jammers and techniques can also be used as uncorrelated jammers. They are commonly called spoofer jammers.

The uncorrelated jammers are generally simpler, less sophisticated, less expensive to implement and require less knowledge of the receiving signals and systems than the correlated jammers. The uncorrelated jammer is the type selected for use in modeling because the above noted reasons make it much easier to mount an attack with one of these types of jammers. The analysis will be based on one of two types of jammers; either the random noise model used to raise the threshold above levels attainable from the satellite or the or the modulation model used to capture the receiver on a power basis on the assumption of the nonexistence of anticapture devices within the receiver. It is assumed that the receive system is operating with a total margin of 6 dB. It is also assumed that if the operating point can be overwhelmed by an additional 4 dB above that margin, or a total of 10 dB, then the received signal information will be totally distorted or masked to an extent that it is unusable.

Figure 4-6 shows the gain of various sizes of parabolic antennas for the 4 GHz and 12 GHz receive bands with the antenna efficiencies assumed to be 65%. For each group of antennas the bound for D/λ less than 100 has been shown. Figure 4-7 shows the CCIR and FCC standard for antenna pattern gain as a function of angle off the antenna boresight. The figure illustrates the function

$$G(dB) = 32 - 25 \log \emptyset$$

where: G is the antenna pattern gain in dB
$\emptyset$ is the angle off antenna boresight
$1° \leq \emptyset \leq 48°$

which is in dB above isotropic $\emptyset$ and is the envelope containing the peak side lobes of the antenna pattern. This function is generally accurate for high gain, high efficiency antennas with D/λ >100 in the frequency range from 1 GHz -10 GHz. Recently much work has been done to show its validity into the 20 GHz range and this validity is herein assumed. Figure 4-8 again shows the information of figures 4-6 and 4-7 but with a common gain axis to illustrate the difference in attainable boresight gain versus off-boresight gain. Again the D/λ <100 bounds and the performance of the smaller sized antennas are shown. While the pattern gains do not strictly hold for these smaller sizes, they can serve as relatively accurante guidelines.

For a given antenna size and frequency, the difference between the antenna boresight gain and the off-boresight pattern gain is the level down from the peak of the beam or the antenna pattern isolation. This antenna pattern isolation for a given off-boresight angle is the difference in levels that must be injected into the antenna pattern at the boresight and off-boresight angles to achieve equal power levels into the receiver. Figures 4-9 and 4-10 show the antenna pattern isolations for the 4 GHz and 12 GHz frequency bands respectively. The maximum and minimum pattern isolation bounds are for the 180° angle off-boresight (or far out sidelobes) and the 1° angle off-boresight (or near in sidelobes) respectively. It can be reasonably assumed for this system that no receiving antenna will have less than a 20° elevation angle to any probable synchronous satellite. This will raise the minimum antenna pattern isolation for both frequency bands by approximately 32.5 dB under the assumption that the jammer is ground based and restricted to an operation on or near an earth tangent

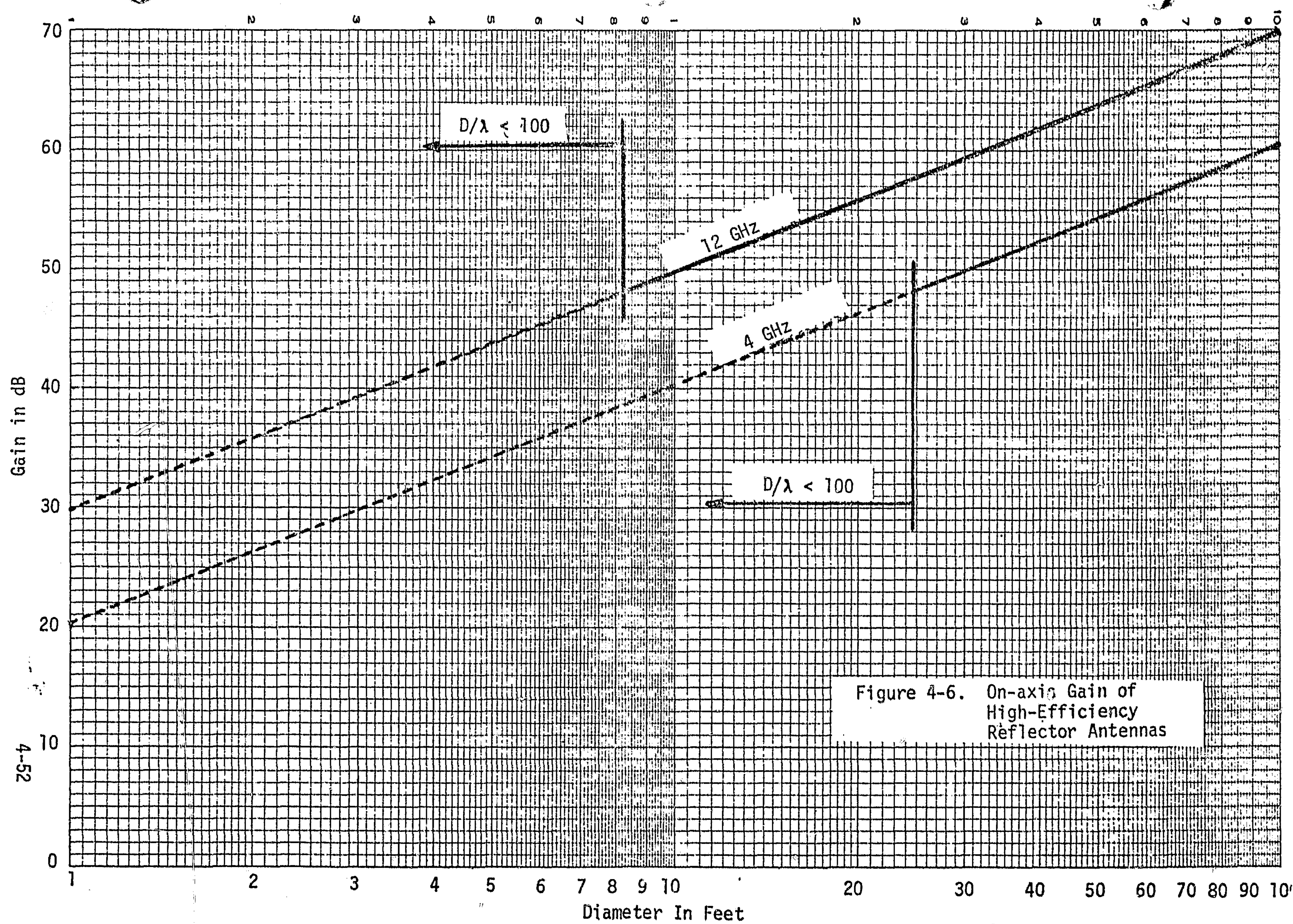

Figure 4-6. On-axis Gain of High-Efficiency Reflector Antennas

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4 OF 5

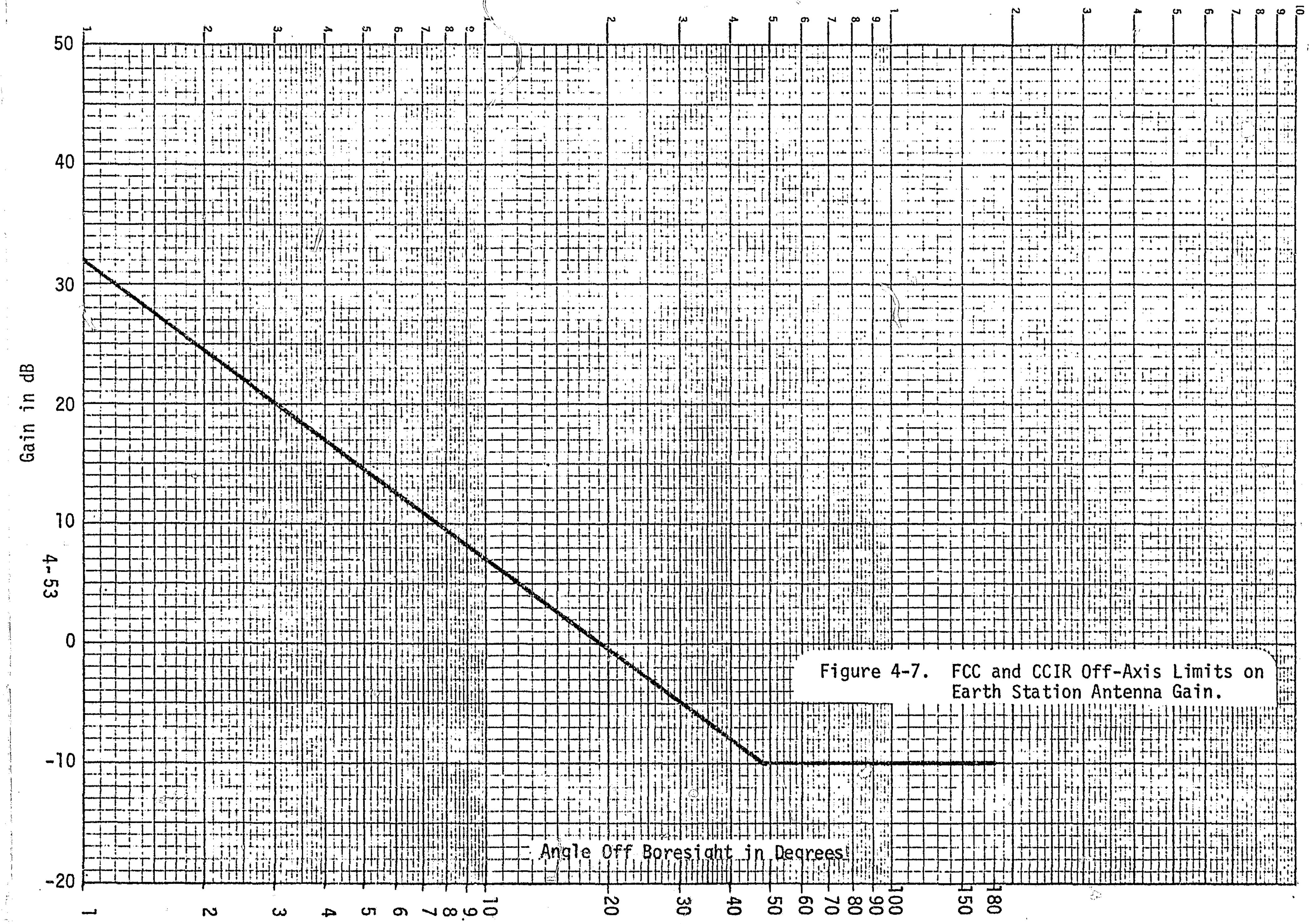


Figure 4-7. FCC and CCIR Off-Axis Limits on Earth Station Antenna Gain.

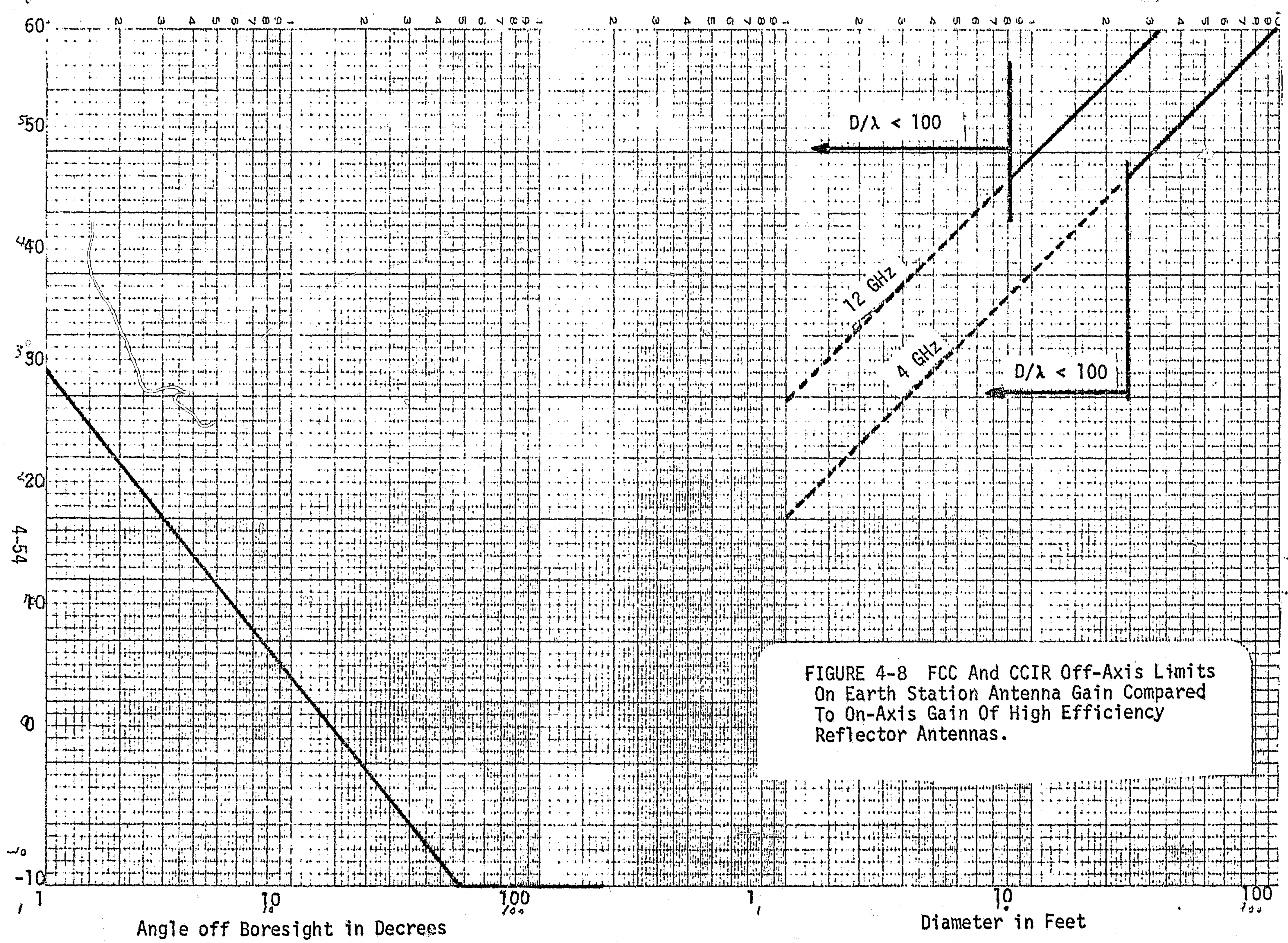


FIGURE 4-8 FCC And CCIR Off-Axis Limits On Earth Station Antenna Gain Compared To On-Axis Gain Of High Efficiency Reflector Antennas.

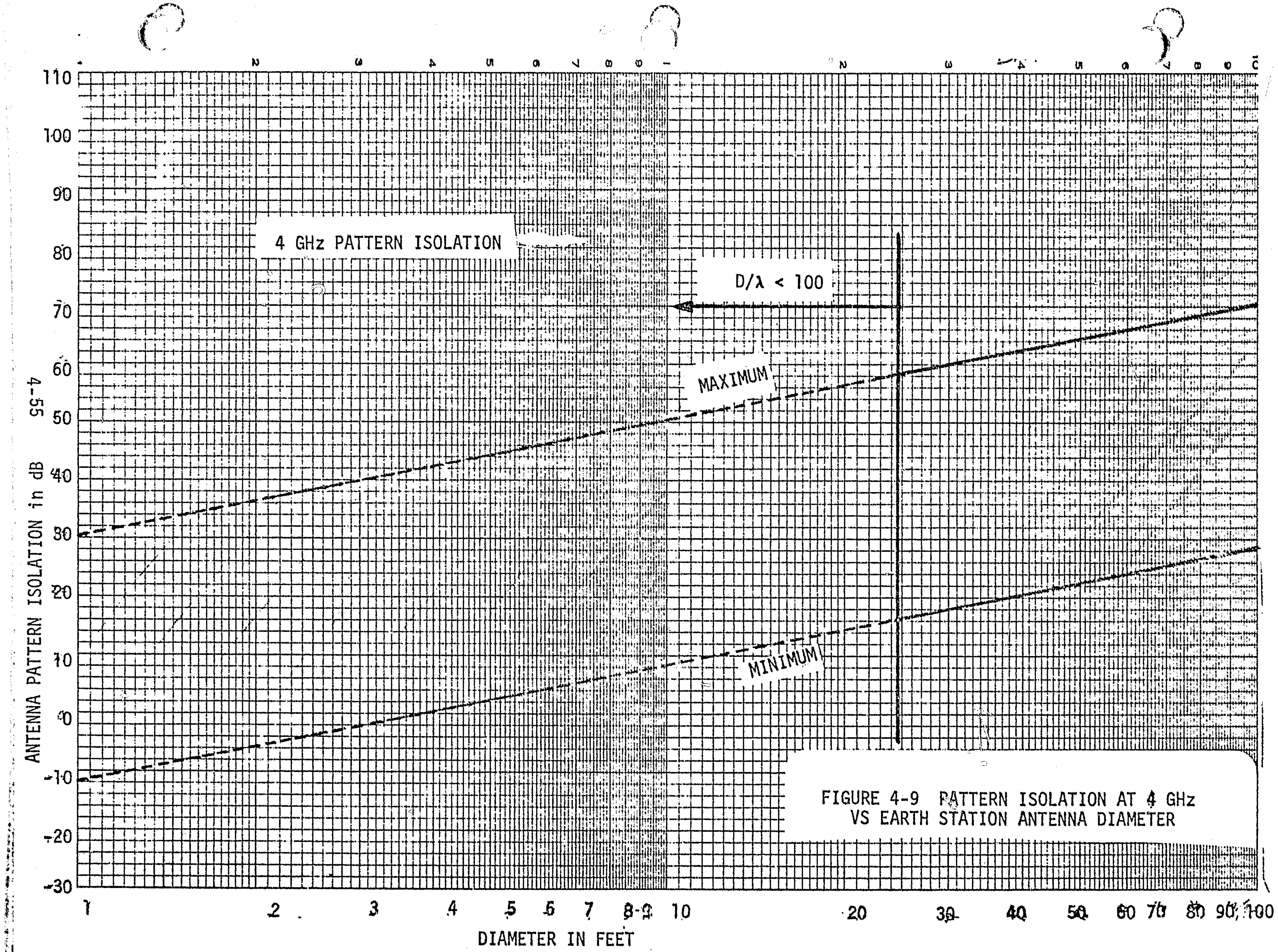


FIGURE 4-9 PATTERN ISOLATION AT 4 GHz
VS EARTH STATION ANTENNA DIAMETER

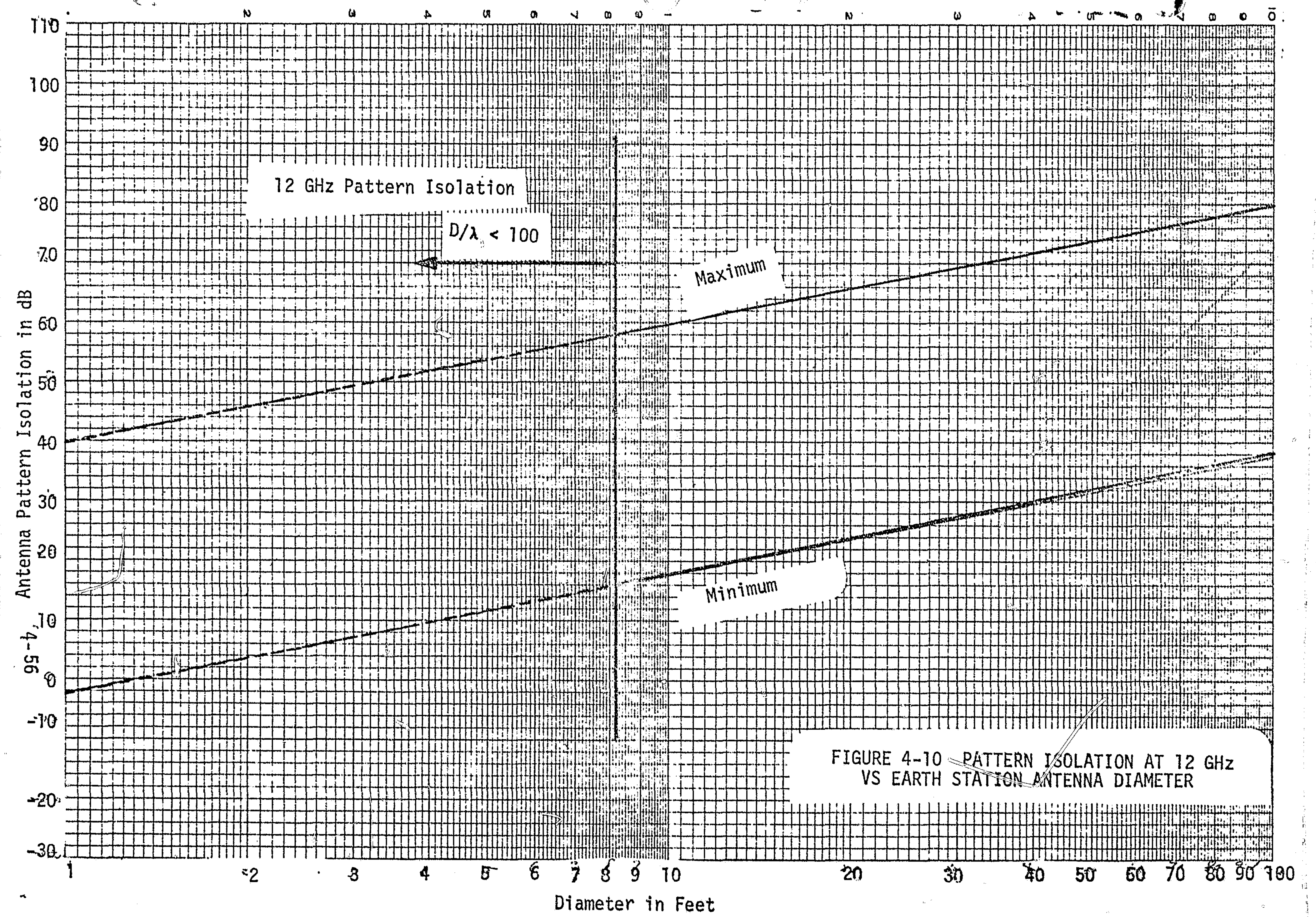


FIGURE 4-10 PATTERN ISOLATION AT 12 GHz VS EARTH STATION ANTENNA DIAMETER

plane within a radius of 30 miles of the receive terminal. These assumptions are based upon a line of sight type model. Jammers that are not ground based will be discussed later. Figure 4-11 shows the new minimums for both the 4 GHz and the 12 GHz frequency bands. Also shown is the jammer geographic advantage less the 10 dB margin and suppression factor for various listed distances from the receive terminal. These ranges, of course, are normalized to the satellite EIRP which the receive terminal ordinarily works with. Figure 4-11 shows that within a 2 mile radius even the largest (100') antenna at 4 GHz can be jammed from the side of the antenna inclined away from the satellite with an EIRP equal to the EIRP of the satellite allocated to that receive terminal. In the same configuration, a jammer within a radius of 1 mile can jam the largest (70') 12 GHz antenna. If the jammer is located on the side of the antenna inclined toward the satellite the ranges of jamming radius are 6 miles and 3 miles for the 4 GHz and 12 GHz antennas respectively. The following shows the approximate jamming radii for the various antenna size and direction bounds at the worst case of 20° elevation angles to the satellite.

		4 GHz	12 GHz
Largest Size	Back	2.2 mi.	1.0 mi.
	Front	6.5 mi.	3.1 mi.
Smallest Size	Back	8.6 mi.	9.0 mi.
	Front	25.8 mi.	26.9 mi.

These radii are normalized to the ordinary working satellite EIRP and this ordinary EIRP will vary with the satellite, the receive terminal and the information signaling types and rates. However, we can arrive at a good upper bound on the required jamming power by considering that the entire satellite downlink EIRP is devoted to the particular receive terminal. The following shows the required jamming power as a function of satellite and frequency. The power ranges denote EIRP in the direction of various terminals for earth coverage or region coverage beams.

	4 GHz	12 GHz
WESTAR	35-36 dBw	
ATS-6	51.5 dBw	
Future Domsat		38-44 dBw
CTS		57-59 dBw

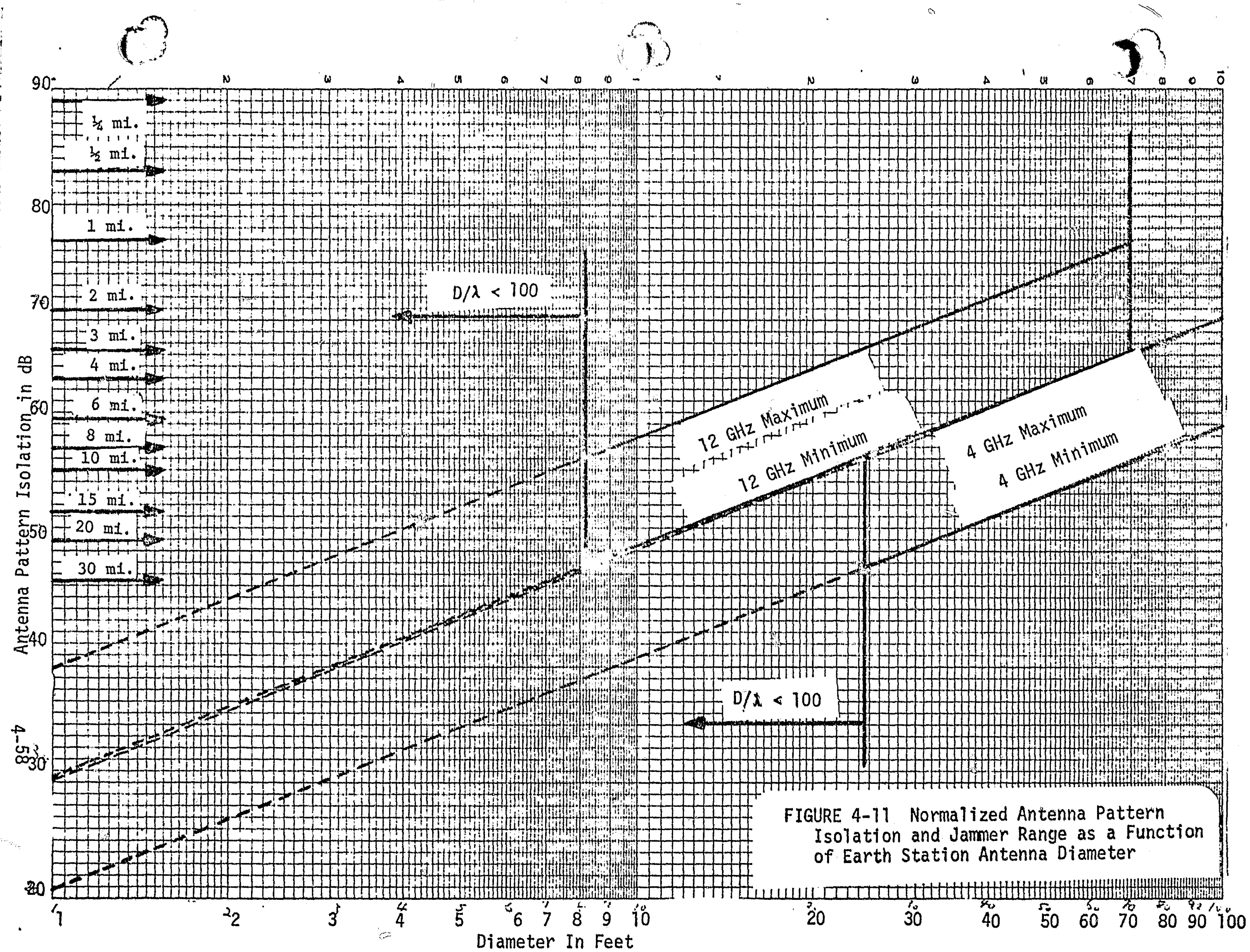


FIGURE 4-11 Normalized Antenna Pattern Isolation and Jammer Range as a Function of Earth Station Antenna Diameter

The satellites, of course, are small, light, mobile platforms with limited available power. It is therefore highly feasible to provide a similar function in a ground based mobile platform with equal or greater power level capabilities than the satellite and with possibly several jamming modes available. This ground based platform would not be under nearly so severe restrictions on weight, power consumption, stability or environment as is the satellite. This platform could be highly mobile and very inexpensive. The estimated hardware cost range of this type of functional machine is $2.5K to $60K. The lower cost is associated with much used and modified hardware. The upper cost is associated with a higher capability, more flexible operation, more mobility, better disguised, more new and specialized hardware.

As can be seen from the above discussion the closer to the terminal and its boresight a jammer can be positioned, the more effective it is with greatly reduced cost as a function of its closer position. A non-ground based jammer, i.e., airborne in some manner, must of necessity be relatively close to the antenna to inject signals into the antenna around the boresight angle. This is due to the rapid change in height above the ground as the antenna elevation angle moves upward. Thus, if a jammer could be so positioned it would gain a further advantage on the antenna isolation pattern and the range. This would mean very low power, light weight devices could be capable of jamming the receive terminal. They might be mounted on aircraft, balloons, kites, model airplanes or projectiles fired through the beam. As a class, however, these jammer threats would be more of a one-time, sudden disruption for a short period of time type of threat as contrasted to the more long term, as well as short term, jamming threat or degraded operation in the models presented previously.

4.7 EARTH STATION AVAILABILITY AND REDUNDANCY REQUIREMENTS

4.7.1 Introduction

This section presents the results of earth station availability analysis and redundancy required to meet the following availabilities:

	TV Transmissions	Digital Data Transmissions
Receive Only Stations	0.997735	0.998745
Transmit/Receive Stations	0.995475	0.997494

Equipment availability was calculated using the following expressions. The availability of a unit is defined by:

$$A = \frac{\text{Uptime}}{\text{Uptime} + \text{Downtime}} = \frac{MTBF_i}{MTBF_i + MTR_i} = \frac{1}{1 + \lambda_i MTR_i}$$

where: $MTBF_i$ = mean-time-between-failures

MTR_i = mean-time-to-restore

λ_i = failure rate $= \frac{1}{MTBF_i}$.

This equation assumes an alarm and renewal maintenance policy which implies that a failed unit is restored to an operable state within the MTR after receipt of an alarm.

$$MTR_i = MTTR_i + TT_i + (1 - PS_i)\ TR_i$$

where: $MTTR_i$ = mean-time-to-repair (replace) failed module

TT_i = travel time required for maintenance personal to reach the site of failure

PS_i = The probability of having a spare module of the failed type on site

TR_i = Time required to obtain a spare from an outside source when no spare is available.

Parameters used for the availability calculations are:

MTTR = 2 hours for non-tracking antenna
1 hour for preamp and HPA
.5 hour for all other equipment

TT + (1-Ps) TR = 4 hours for all equipment

λ = (shown on each flow diagram)

Module failure rates used in the analysis were obtained from the following sources:

Vendor supplied failure rates based on MIL-HDBK-217A
Failure rate source
Part count predictions based on MIL-HDBK-217A.

Field performance experience indicated that MIL-HDBK-217A failure rates are conservative when applied to Collins equipment. Data obtained through a formal data collection program with several customers having large quantities of Collins microwave equipment shows the coverage MTBF's for Collins equipment are commonly two times those predicted using MIL-HDBK-217A as a failure rate source.

The failure rates used for the digital equipment are considered very preliminary as adequate equipment definition was not available to perform part count predictions.

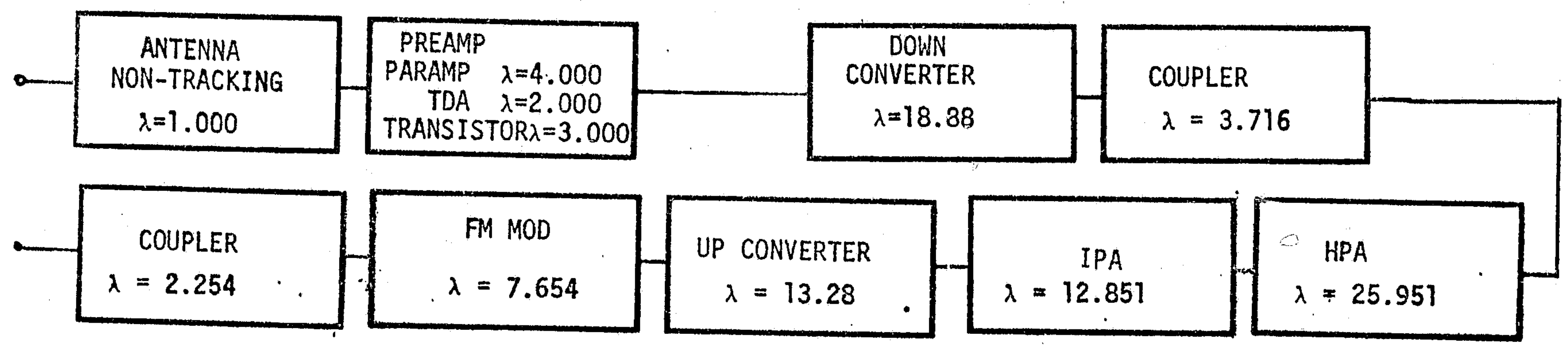
Two types of antenna systems were considered--non-tracking and auto-tracking. Three types of preamps were considered-- uncooled paramp, TDA and transistor. For digital quipment both coded and non-coded systems were considered. The configurations considered are shown on each availability flow diagram. In all cases air cooled klystron tube HPA's were assumed. The availability was determined for the equipment needed for receive only, transmit only and complete receive-transmit station. The receive-transmit availability is not the product of the receive availability and the transmit availability as some equipment, such as the antenna, is common to both functions.

4.7.2 Analysis Results

The availability analysis results are shown in Figures 4-12 through 4-16. Each figure shows the tabular results of each type of earth station configuration investigated.

The analog TV systems, for receive only, will meet the required availability of .997735 with no redundancy. For transmit only the HPA must be redundant in order to meet the required availability of .997735. The complete station will meet the required availability of .995475 with only the HPA redundant for all the configurations analyzed.

Figure 4-12. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz Earth Station For Analog TV With Audio Subcarrier

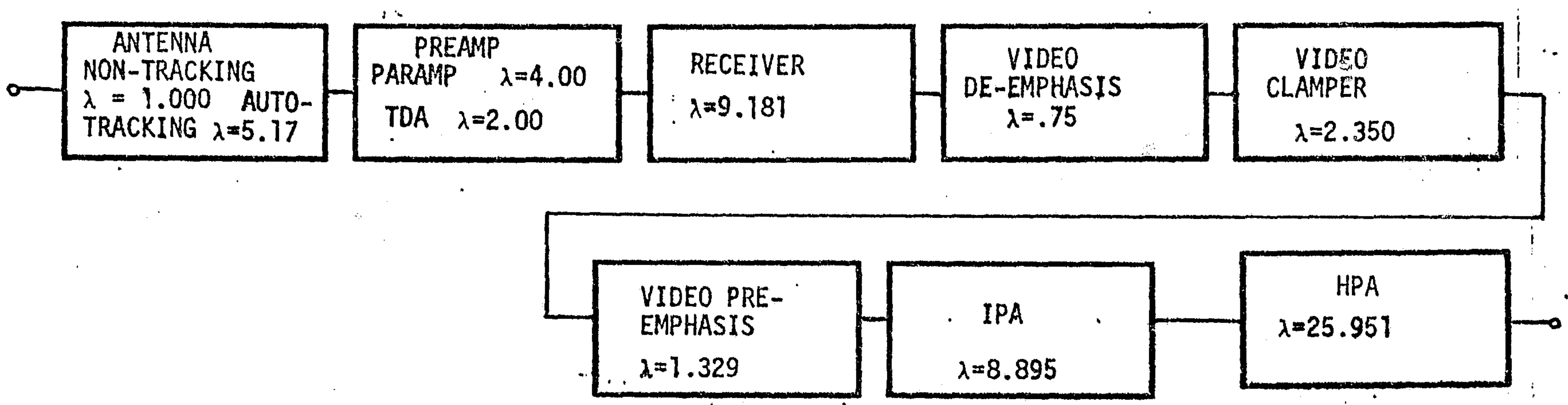


AVAILABILITY RESULTS

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	T/R AVAILABILITY	PARAMP TYPE
.998776	.997026	.995866	Transistor Amp
.998824	.997026	.995914	TDA
.998724	.997026	.995814	Paramp

With redundant HPA Transmit would be .998318 and Receive/Transmit would be .997104

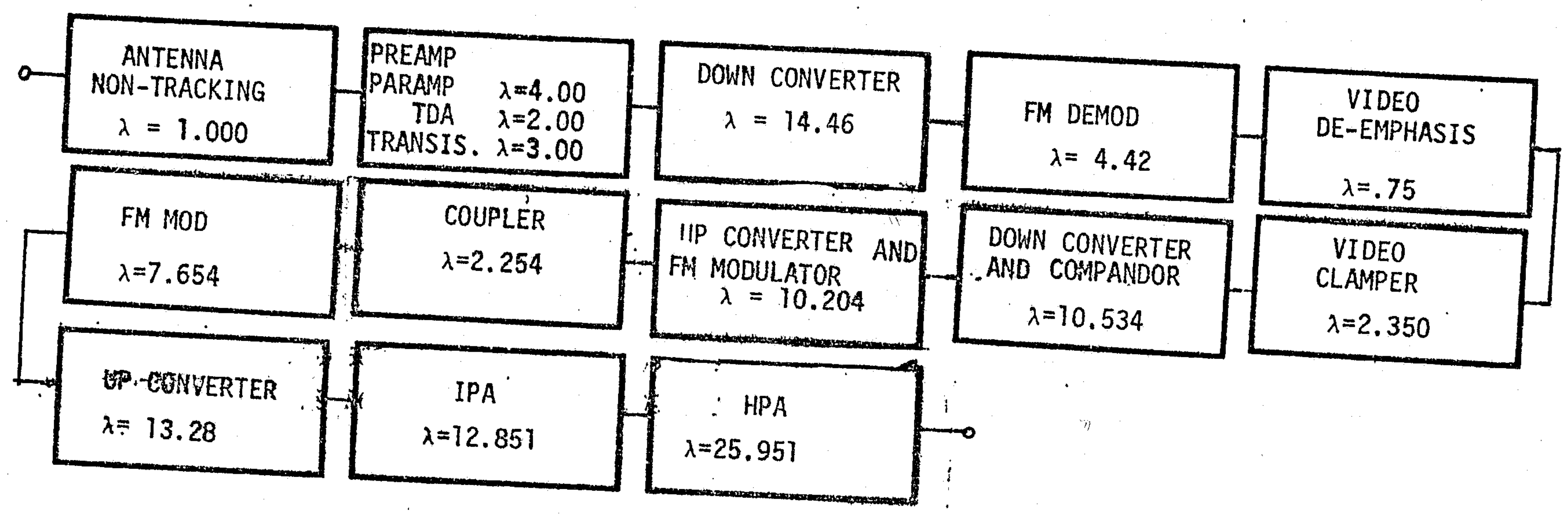
Figure 4-13. Availability Analysis Block Diagram of Non-Redundant 12/14 GHz Earth Station For Analog TV With Audio Subcarrier.



AVAILABILITY RESULTS

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	T/R AVAILABILITY	PREAMP TYPE	ANTENNA TYPE
.999198	.998324	.997574	Paramp	Non-Tracking
.999298	.998324	.997673	TDA	Non-Tracking
.999015	.998142	.997391	Paramp	Tracking
.999115	.998142	.997491	TDA	Tracking

Figure 4-14. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz Earth Station For TV With Separate Audio Carrier.

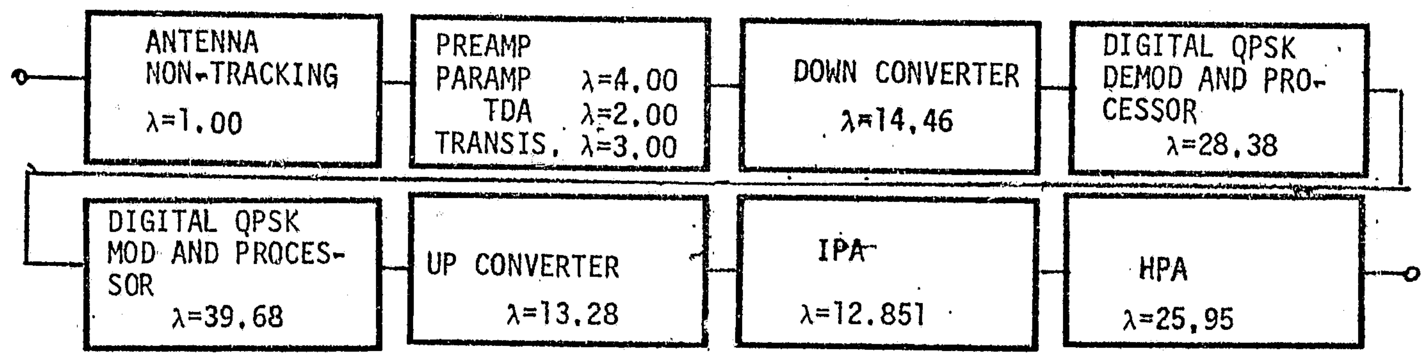


AVAILABILITY RESULTS

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	T/R AVAILABILITY	PARAMP TYPE
.998279	.996569	.994914	Paramp
.998379	.996569	.995013	TDA
.998329	.996569	.994963	Transistor

With redundant HPA Transmit would be .997860 and Receive/Transmit would be .996253

Figure 4-15. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz Earth Station for Digital TV.



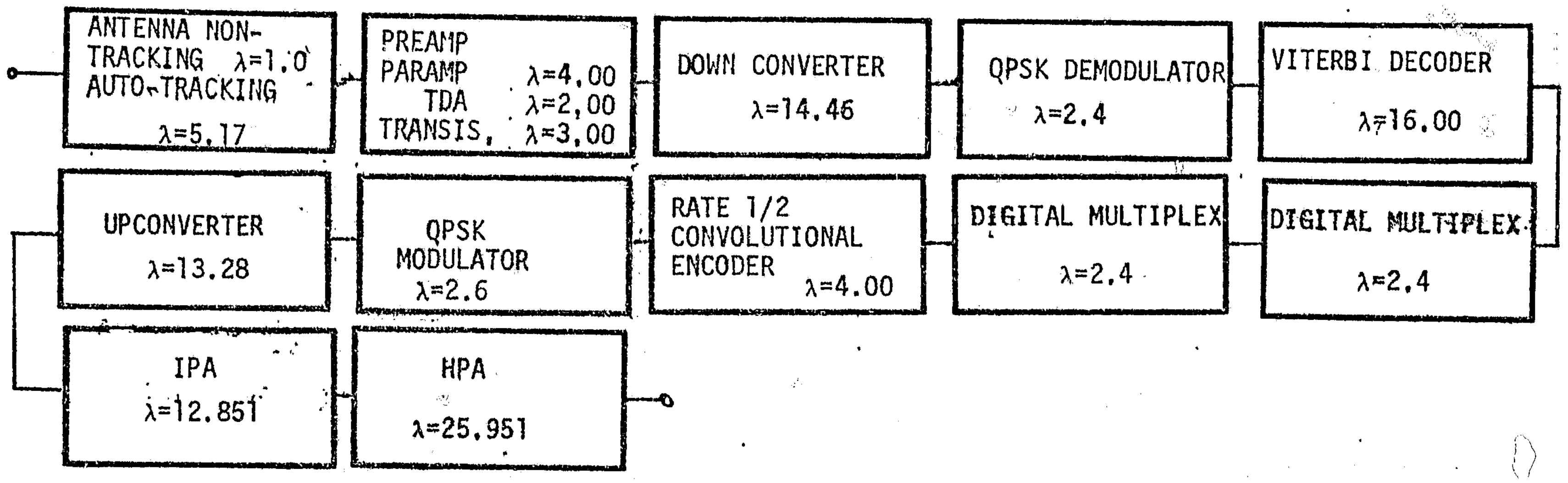
AVAILABILITY RESULTS

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE
.997816	.995693	.993578	Paramp
.997915	.995693	.993677	TDA
.997866	.995693	.993628	Transistor

With redundant digital both receive and transmit and redundant HPA

Rcv = .999088; Tx = .998760 and Rc/Tx = .997909

Figure 4-16. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz Earth Station T1/TDM Per Channel.



AVAILABILITY RESULTS WITH DECODER

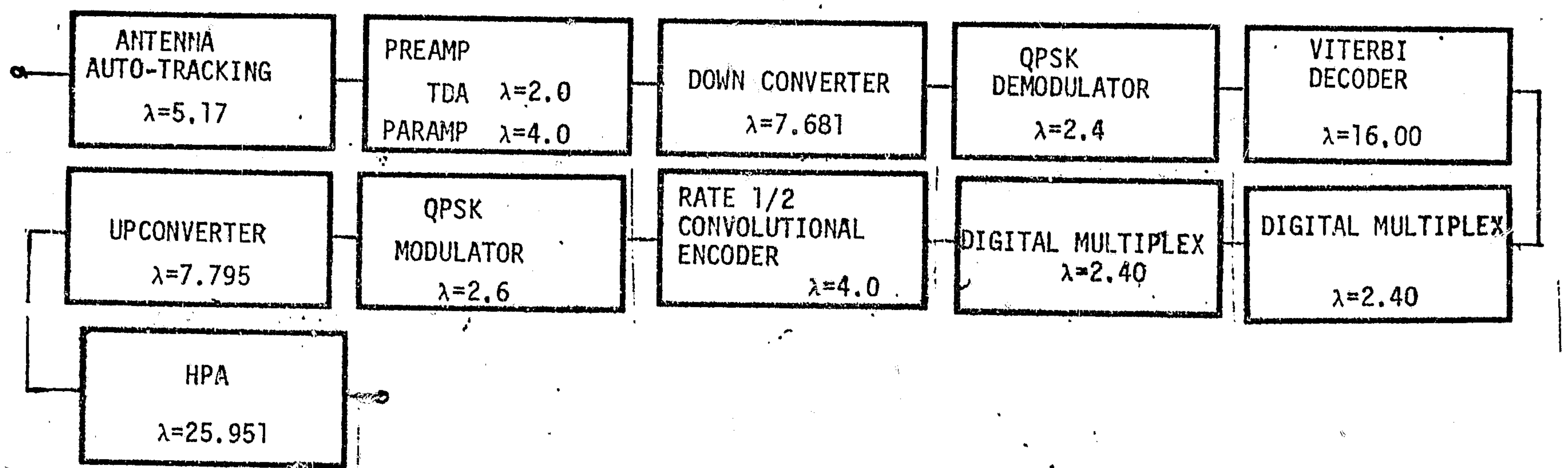
RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998156	.997067	.995288	Paramp	Non-Tracking
.998255	.997067	.995387	TDA	Non-Tracking
.998206	.997067	.995338	Transistor	Non-Tracking
.997983	.996895	.995116	Paramp	Auto-Tracking
.998083	.996895	.995215	TDA	Auto-Tracking
.998033	.995895	.995166	Transistor	Auto-Tracking

AVAILABILITY RESULTS WITHOUT DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998874	.997247	.996183	Paramp	Non-Tracking
.998974	.997247	.996283	TDA	Non-Tracking
.998924	.997247	.996233	Transistor	Non-Tracking
.998702	.997074	.996012	Paramp	Auto-Tracking
.998802	.997074	.996112	TDA	Auto-Tracking
.998752	.997074	.996062	Transistor	Auto-Tracking

Redundant Digital RCV A = .998917 Redundant HPA & Digital TX A = .998591 Rc/Tx A = .997742

Figure 4-17. Availability Analysis Block Diagram of Non-Redundant 12/14 GHz T1/TDM



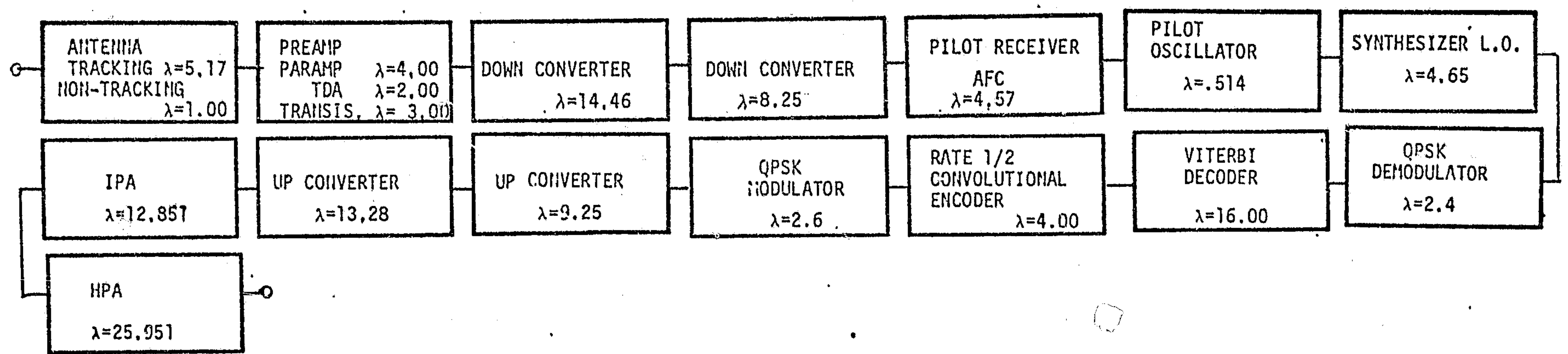
AVAILABILITY RESULTS

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	
.998388	.997717	.996341	TDA	With Decoder
.998288	.997717	.996241	Paramp	With Decoder
.999106	.997897	.997237	TDA	Without Decoder
.999006	.997897	.997132	Paramp	Without Decoder

WITH SPACE DIVERSITY

RCV A = .999997 TX A = .999995 RC/TX A = .999986

Figure 4-18. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz T1-FDMA Per Channel



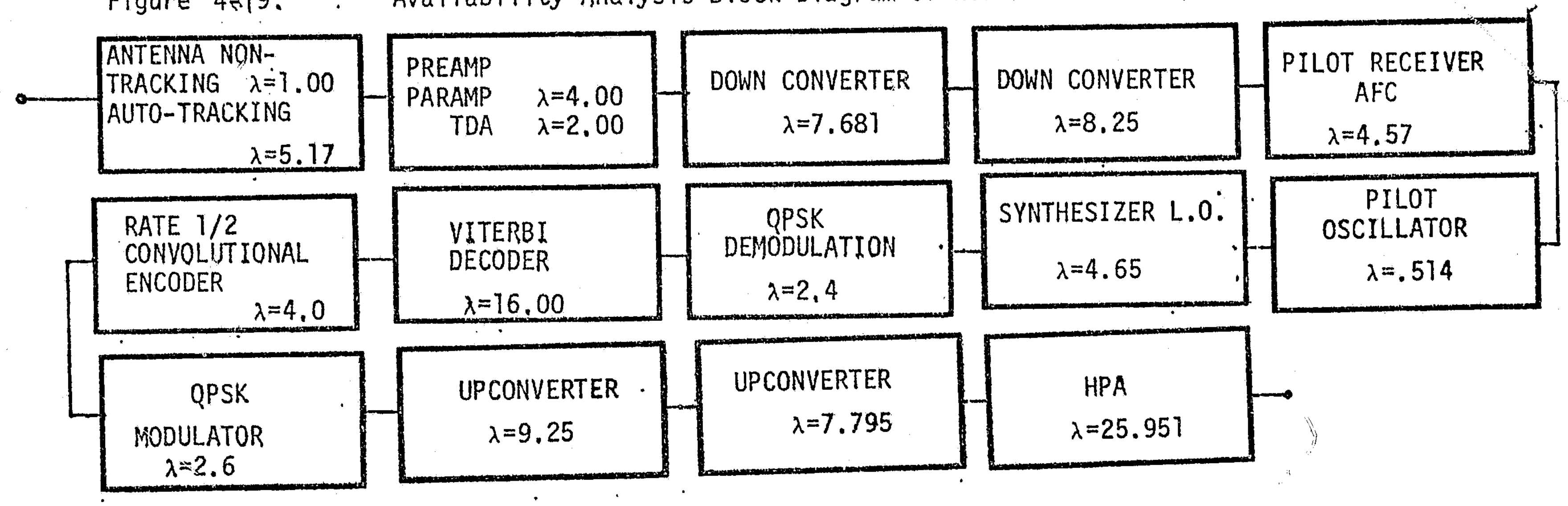
AVAILABILITY RESULTS WITH DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE	COMMENTS
.997813	.995828	.994111	Paramp	Tracking	
.997913	.995828	.994212	TDA	Tracking	
.997863	.995828	.994162	Transistor	Tracking	Redundant Digital
.997985	.996000	.994283	Paramp	Non-Tracking	Rcv A = .998685
.998085	.996000	.994383	TDA	Non-Tracking	
.998035	.996000	.994333	Transistor	Non-Tracking	Redundant HPA & Digital Tx

AVAILABILITY RESULTS WITHOUT DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE	COMMENTS
.997993	.996545	.995007	Paramp	Tracking	
.998093	.996545	.995107	TDA	Tracking	
.998043	.996545	.995057	Transistor	Tracking	Rcv/Tx A = .997095
.998165	.996717	.995179	Paramp	Non-Tracking	
.998274	.996717	.995287	TDA	Non-Tracking	
.998215	.996717	.995228	Transistor	Non-Tracking	

Figure 4-19. Availability Analysis Block Diagram of Non-Redundant 12/14 GHz T1/FDMA



AVAILABILITY RESULTS (WITH DECODER)

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998117	.996649	.995235	Paramp	Auto-Tracking
.998217	.996649	.995335	TDA	Auto-Tracking
.998290	.996821	.995408	Paramp	Non-Tracking
.998390	.996821	.995508	TDA	Non-Tracking

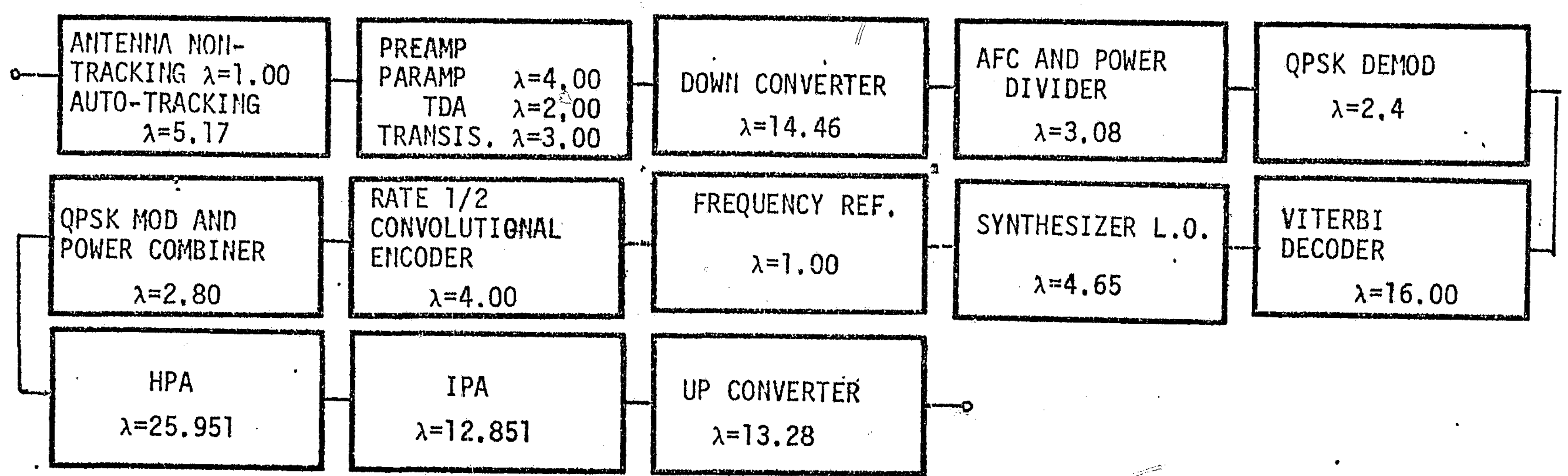
AVAILABILITY RESULTS WITHOUT DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998297	.997367	.996131	Paramp	Auto-Tracking
.998397	.997367	.996231	TDA	Auto-Tracking
.998469	.997539	.996303	Paramp	Non-Tracking
.998569	.997539	.996403	TDA	Non-Tracking

WITH SPACE DIVERSITY

RCV A = .999996 TX A = .999989 RC/TX A = .999977

Figure 4-20. Availability Analysis Block Diagram of Non-Redundant 4/6 GHz Earth Station for 50 Kbps - Single Channel Per Carrier.



AVAILABILITY RESULTS WITH DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.997866	.996907	.995098	Paramp	Non-Tracking
.997966	.996907	.995197	TDA	Non-Tracking
.997916	.996907	.995147	Transistor	Non-Tracking
.997694	.996735	.994926	Paramp	Auto-Tracking
.997794	.996735	.995026	TDA	Auto-Tracking
.997744	.996735	.994976	Transistor	Auto-Tracking

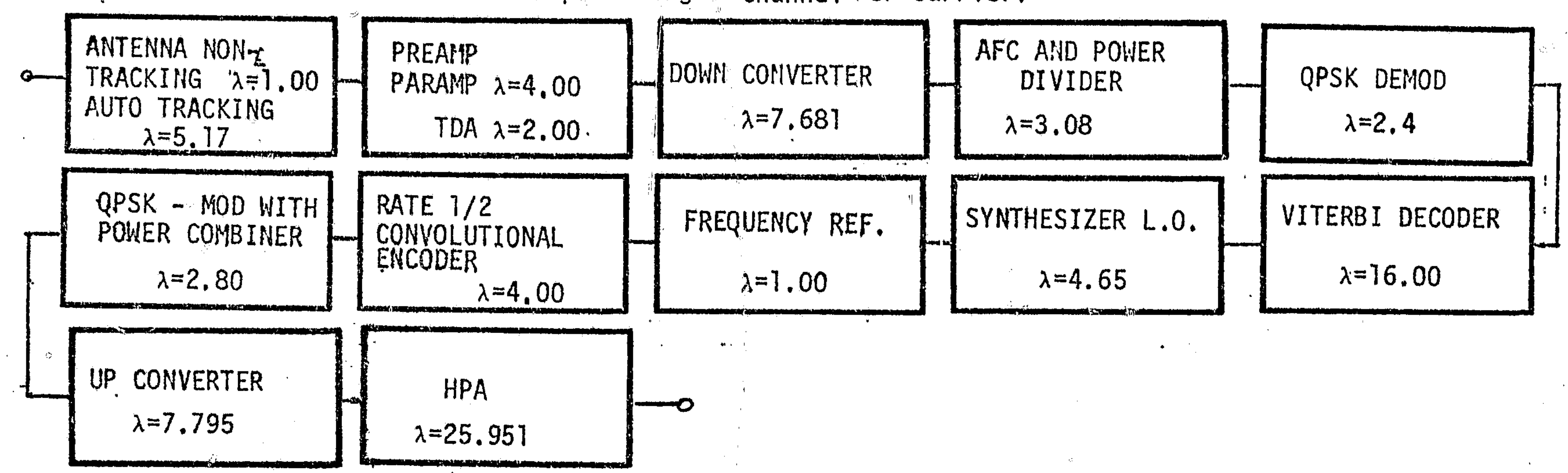
AVAILABILITY RESULTS WITHOUT DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998585	.997087	.995994	Paramp	Non-Tracking
.998685	.997087	.996094	TDA	Non-Tracking
.998633	.997087	.996042	Transistor	Non-Tracking
.998412	.996915	.995821	Paramp	Auto-Tracking
.998512	.996915	.995921	TDA	Auto-Tracking
.998462	.996915	.995871	Transistor	Auto-Tracking

Redundant digital Receive A = .998872 - - Redundant HPA and digital transmit A = .998546 - -

R/T A = .997697

Figure 4-21. Availability Analysis Block Diagram of Non-Redundant 12/14 GHz Earth Station for 50 Kbps - Single Channel Per Carrier.



AVAILABILITY RESULTS WITH DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998176	.997735	.976228	Paramp	Non-Tracking
.998276	.997735	.976328	TDA	Non-Tracking
.998003	.997563	.996055	Paramp	Auto-Tracking
.998103	.997563	.996155	TDA	Auto-Tracking

AVAILABILITY RESULTS WITHOUT DECODER

RECEIVE AVAILABILITY	TRANSMIT AVAILABILITY	R/T AVAILABILITY	PARAMP TYPE	ANTENNA TYPE
.998894	.997915	.997124	Paramp	Non-Tracking
.998994	.997915	.997224	TDA	Non-Tracking
.998722	.997742	.996952	Paramp	Auto-Tracking
.998822	.997742	.997052	TDA	Auto-Tracking

Redundant digital
RCV A = .999177

Redundant HPA & Digital
TXM A. = .999371

RC/TX A. = .998826

Only the worst case condition was considered for redundant units. For the digital TV configuration the digital equipment, both receive and transmit, along with the HPA must be redundant in order for the system to meets its required availability.

None of the digital system configuration can meet their availability requirement without redundancy. Redundant digital equipment in the receive station will allow the receive section to meet its required availability. Both the HPA and the digital equipment in the transmit section must be redundant in order for the transmit section to meet its requirement.

Additional analyses are needed to determine the optimum use of redundancy to meet the required system availability.

5.1 Conclusions

From the transmission studies it was concluded that:

a) SECAM III 625/50 color television provides the highest link performance, resolution and color fidelity.

b) Digital TV offers the greatest potential for maximizing the use of satellite resources.

c) Time-division-multiplexing of 1.544 mbps data rate channels (T1-TDM cases) into nx 1.544 mbps data rates for a single transmitting earth station in a broadcast mode results in an efficient use of the satellite resources and the smallest G/T values.

d) Single 1.544 mbps channels per carrier in a FDMA mode (T1-FDMA cases) reduces the earth station baseband equipment complexity and increases the flexibility over c) but it requires much larger G/T values.

e) In both T1-TDM and T1-FDMA cases the use of 1/2 rate coding can be used to achieve significant reduction of the required G/T values but reduces the data throughput by one-half.

f) For all of the T1-TDM and T1-FDMA modes the required HPA size does not significantly change.

g) The 50 Kbps-FDMA cases are somewhat less efficient for transmitting a total amount of data through the satellite, but provide flexible useage of the satellite.

h) In the FDMA cases optimizing the gain of the satellites (e.g., CTS) would increase the capacity for a fixed earth station G/T values.

i) The earth station requirements are highly dependent upon the satellite locations, the location of the earth station and the radio frequency required path availabilities.

j) The spotbeam transponder models, CTS and ATS-6 allowed the smallest G/T values provided the earth station was located favorable in the beam.

k) 12-GHz and 14 GHz are subject to severe rain attenuation along the Gulf of Mexico and Eastern parts of the United States requiring either large earth stations in most cases or two small earth stations spaced several miles apart.

From the earth station availability studies it was concluded that:

a) For analog color TV with subcarrier audio redundancy does not appear to be required.

b) For analog color TV with separate FM carrier for audio it appeared that redundancy of the HPA at the transmit end would be required if an auto-tracking antenna was used.

c) For all digital tranmission cases it appears that redundancy for the receive and transmit portions would be required.

From the earth station location investigations, no specific conclusions were reached because this can only be evaluated after detailed investigation of a specific local situation. General conclusions were:

a) City rf broadband noise and line spectra noise is significantly greater in the city then in the country, but it decreases rapidly with distance.

b) Frequency interference and location coordination requirements of the FCC will make it difficult to locate a transmit/receive earth station in a large metroplex without benefit of natural or artificial shielding.

c) A number of receive only earth station configurations which satisfied the transmission requirements in Section 3.0 were very small and the only barrier to their location in a downtown section of a major city is obtaining a field of view and the high interference level.

d) Interference levels for small antennas can be reduced effectively by various means such as shielding and use of adaptive phased arrays.

Conclusions from the brief investigations of the security related aspects of jamming, unauthorized monitoring and false message injection, where:

a) The monitoring of the analog television signals are not extremely difficult because of the high signal-to-noise level and inherent redunancy in analog video and sound.

b) Jamming of the satellite and the earth station are very easy using pulsed transmitters.

c) Monitoring of the earth stations is also very easy if the monitor station can establish a line-of-sight path.

d) Monitoring of the digital transmission requires that the monitoring station use or have access to digital communication equipments essentially identical to the authorized receiving stations.

e) In view of d) above, digital TV and T1-TDM equipments would be the most difficult to obtain.

f) For the FDMA modes the required receive G/T and/or gain of the monitoring station must be larger as the total number of channels is larger.

g) It is difficult to inject false messages into transmission modes which multiplex the channels together.

h) The lower the individual channel carrier power for non-multiplexed transmission modes, the easier it is to inject false messages, e.g., separate audio channel for TV, or a 50 Kbps channel when the total number of channels is large.

i) Optimum gain set of the satellite, use of codes, reduction of data through put are some of ways to minimize low level jammer threats.

j) The only positive transmission security techniques are message source encryption and antijam spread spectrum techniques.

5.2 Recommendations for Future Efforts

Examination of the preceding sections of this report reveals that, although the information presented satisfies the requirements of the statement of work, the scope of the study is too large to be adequately trated in a two-man month effort. Few of the issues could be treated in the depth needed to adequately evaluate use of satellite communications for low enforcement usage.

It recommended that NALECOM fund a follow-on satellite usage study to examine their problems in greater depth. Much more effort is needed to develop solutions to some of the link security problems identified in section 4. Application of anti-jam measures used on military applications, for example, is so costly that they generally cannot be used in systems intended for use by organizations with limited budgets. The follow-on study needs to explore which of the military anti-jam techniques are cost-effective in a low-cost system and develop recommendations for anti-jam measures. The problems of link security identified here also require examination of military techniques to select those most cost effective. Although sample earth station designs meeting link availability requirements were presented in section 3, time limitation did not permit the link availability to be optimized for the lowest cost system. These and other problem areas need to be explored in greater depth to obtain satisfactory answers before an actual satellite communication system satisying NALECOM needs can be implemented in a cost-effective manner.

It also recommended that NALECOM use the follow-on satellite usage study to develop a set of preliminary system specifications. These specifications could be used to procure two or three low-cost earth stations that would permit NALECOM to evaluate for itself the uses to which satellite communications might be advantageous. For example, one earth station could be placed in Washington, D. C. and the others installed in a mobile van that could traverse the country permitting local law enforcement groups to evaluate for themselves the potential benefit a satellite communication system might provide the law enforcement community. These tests would provide NALECOM with valuable information to assist them in determining the future need for satellite communications in the law enforment community.

The bulk of the message exchange currently used by the law-enforcement agencies is very short and/or low data rate messages. These types of message transmissions were not addressed in this study and should be given consideration in a follow-on study. These types of messages lend themselves to packet transmission and network techniques which is currently proving to be very cost-effective and flexible for terrestrial networks as well as for satellite links. Digital packet messages techniques can be made very secure and can be extended to very small mobile and possibly even hand held sets. Although not studied here, the authors of this report feel that the packet message and radio techniques offers the best possible solution for the bulk of the law enforcement messages. There does also appear to be a need for video and image transmission also. Digital encoding and transmission appears to be the best implemented approach for such transmissions. This area also needs further study.

END