FINAL REPORT

INTRA-SYSTEM AND INTER-SYSTEM INTERFERENCE IN SATELLITE COMMUNICATION SYSTEMS USING FREQUENCY BANDS FROM 800 MHz to 21.5 GHz

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SED SYSTEMS LTD.

SED SYSTEMS LTD.
SYSTEMS DIVISION

SASKATOON CANADA

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TABLE OF CONTENTS

6.0 FIXED-SATELLITE BANDS AT 4.4 - 4.7 GHz

7.0 AUXILIARY-SATELLITE BANDS NEAR 5 GHz

8.0 FIXED-SATELLITE AND AUXILIARY-SATELLITE BANDS NEAR 6 GHz

9.0 FIXED-SATELLITE BANDS AT 10.7 - 11.7 GHz

10.0 FIXED-SATELLITE AND BROADCASTING-SATELLITE BANDS NEAR 12 GHz

11.0 FEASIBILITY OF USING 4.4 - 4.7 (UPLINK) AND 12.2 - 12.5 GHz (DOWNLINK) BANDS BY THE BROADCASTING-SATELLITE SERVICE

12.0 AUXILIARY-SATELLITE BANDS AT 15 GHz

13.0 FIXED-SATELLITE BANDS BETWEEN 17.0 and 21.5 GHz

GLOSSARY OF SYMBOLS

A_{ap} = antenna aperture area

A_{IN} = attenuation of receiver input filter in the transmitter frequency band, in dB

B = RF carrier bandwidth

BW = usable uplink or downlink bandwidth

C/N = carrier-to-thermal noise ratio, in dB. If explicitly stated, it may refer to the overall carrier to noise and distortion ratio.

D = diameter of a parabolic reflector antenna, in m.

EIRP = on-axis e.i.r.p. in dBW of a satellite or earth station transmitter.

f_{SEP} = separation frequency between an uplink and a downlink band

f_{LO} = local oscillator frequency

f_{RF} = carrier frequency at mixer input

F = power flux density at the earth's surface, in dBW/m^2 in a specified bandwidth.

G_{LNA} = gain of a low noise amplifier (LNA) in dB

G = gain of an antenna in dB, in a particular direction. If it is subscripted with "R" it is a receiving antenna gain; with "T" it is a transmitting antenna gain; with "o" it is an on-axis gain; with "E" it is an earth station antenna gain; with "SAT" it is a satellite antenna gain; with "MOB" it is a mobile station antenna gain.

G/T = receiving station figure of merit, in dB/K

I_{CP} = RX/TX antenna cross-polarization isolation, in dB

I_D = energy dispersal improvement factor, in dB, relating the power in a specified band to that of the unmodulated carrier.

k = Boltzmann's constant (1.38×10^{-23} watts/Hz/K)

L_b = transmission loss between two physically separated isotropic antennas, in dB. Specified for a given fraction of the time. If subscripted with "MIN" it is the minimum permissible basic transmission loss.

L_T = transmission loss in dB between two physically separated antennas, i.e., the ratio of received-to-transmitted power

$L_{FREE\ SPACE}$ = free space loss in dB between two sites

L_{LINK} = total link margin in dB

L_{MISC} = portion of link margin in dB for antenna feeder, duplexer, and beam pointing losses.

L_{FADE} = portion of link margin in dB for multipath or ionospheric fading losses.

n = number of poles in a Chebyshev filter

P_c = interfering carrier power in dBW at the output of an LNA (used in receiver output filter calculations). If subscripted with "MAX" it is the maximum allowable power at the output of the LNA to ensure that intermodulation distortion products generated in the LNA are below the maximum permitted value.

P_{IM} = level of third order intermodulation distortion power in dBW in a specified band at the output of an LNA.

P_{IP} = third order intermodulation distortion power intercept point (referenced to the output of the LNA) in dBW.

$P_{IM,MAX}$ = maximum permissible intermodulation distortion power in dBW in a specified band, at the LNA input.

P_T = out-of-band transmitter power in dBW in a specified bandwidth at the HPA output. If subscripted with "MAX" it is the maximum permissible value.

P_I = interference power in dBW in a specified bandwidth at the input of a receiver. If it is subscripted with "MAX" it is the maximum permissible value.

P_{TX} = carrier power in dBW at the output of an HPA.

$P_{M,CLEAR}$ = carrier power in dBW at mobile station LNA input during non-fading conditions.

$P_{R,MIN}$ = minimum required carrier power in dBW at the LNA input.

$P_{S,CLEAR}$ = carrier power in dBW at satellite LNA during non-fading conditions.

P_d = carrier power in dBW at the output of a satellite HPA.

P_{up} = carrier power in dBW at the output of an earth station HPA.

P_{TV} = output power in dBW of a TV broadcasting-satellite HPA.

r = separation distance between two stations. For earth-space paths, a value of 38,000 km is used.

R_A = inter-satellite separation distance for satellites in antipodal positions (83,000 km).

R_G = nominal radius of geosynchronous orbit arc (42,000 km).

T_{eff} = effective antenna noise temperature (K).

T_d = downlink earth station receiving system noise temperature (K).

T_{up} = satellite receiving system noise temperature (K).

δ = manmade noise power flux density in dBm/m^2 per unit bandwidth.

Δf_D = peak-to-peak frequency deviation of TV dispersal waveform.

ΔG_T, ΔG_R = transmitting and receiving antenna discriminations in dB in a specified direction, i.e., the ratio of the antenna gain-to-the on-axis antenna gain.

η = antenna aperture efficiency (approximately 0.54).

ϕ = angle between an antenna boresight and a specified direction (i.e., the off-axis angle).

ϕ_o = the 3db beamwidth of an antenna.

λ = wavelength

Θ_s = satellite separation angle

Ω = ratio of frequency difference from a filter center frequency-to-one-half of the 3 dB bandwidth of the filter.

1.0 INTRODUCTION

This report documents a technical study carried out by SED Systems Ltd., under Supply and Services Contract OSU77-00404 with the Department of Communications. The purpose of the study was to investigate the seriousness of intra-system and inter-system interference pertaining to satellite communication systems operating in a number of frequency bands between 800 MHz and 20 GHz, and to determine the constraints on the use of these bands by several proposed services. The frequency plans investigated reflect the allocations described in Canada's Second Draft Proposal for the 1979 ITU World Administrative Radio Conference, 11 February, 1978.

For purposes of this study, intra-system interference refers to the interference which exists in a satellite or earth station due to the uplink and downlink bands being closely spaced. Inter-system interference refers to the interference which exists in a satellite communication system due to its uplink (or downlink) frequency band being shared by or spaced close to those of other satellite communication systems.

For each of the frequency bands considered in this report, baseline technical characteristics of the communication systems involved are described, together with the analysis techniques used to determine the levels of interference which can be expected, and the major tradeoffs and constraints which affect the use of the various bands. Wherever possible, the technical parameters of the baseline communications systems for each of the bands have been chosen from C.C.I.R. literature. In cases where this was not possible, characteristics of the systems were chosen on basis that they reflect current or expected technological trends.

2.0 SUMMARY

The main investigations and results of this study are presented in summary form in this chapter.

- 806 - 890 MHz Band

The feasibility of using this band for a mobile-satellite service is investigated in Chapter 3. It was found that for a Canadian-coverage system, uplink and downlink bandwidths of approximately 30 MHz can be obtained if cross-polarized uplink and downlink antennas are employed and sharp cut-off filters used at the input to the satellite LNA and at the output of the HPA.

- Mobile-Satellite Bands Near 1.5 GHz

Intra-system interference in land, maritime, and aeronautical mobile-satellite bands near 1.5 GHz is investigated in Chapter 4. It was found that although the uplink and downlink bands for each service are closely spaced, the required RX/TX isolation can be achieved in the spacecraft transponder.

- 2.5 GHz Bands

The sharing of frequency bands near 2.5 GHz by the auxiliary-satellite service and the broadcasting-satellite service is investigated in Chapter 5. It was found that intra-system interference in the auxiliary-satellite should not impact the use of the bands by that service. Inter-system interference between the two services occurs on both the uplink and the downlink and will constrain the sharing of the bands.

- 4.4 - 4.7 GHz Band

Inter-system interference between fixed-satellite systems using this band as both an uplink and a downlink is studied in Chapter 6. It was found that inter-satellite interference between closely spaced satellites and between satellites located in anti-podal positions can occur but will be a less severe problem than the interference which can occur between earth stations. This interference will place severe constraints on using the band for both up and downlinks.

- Bands Near 5 GHz

Intra-system interference in an auxiliary-satellite system using the 5.0 - 5.27 GHz band for both the uplink and downlink is studied in Chapter 7. It was found that uplink and downlink bandwidths of approximately 100 MHz can be obtained, depending primarily on the characteristics of the spacecraft transponder.

- Bands Near 6 GHz

Inter-system interference between fixed-satellite and auxiliary-satellite services using uplink bands between 5.825 - 6.925 GHz is studied in Chapter 8. It was found that the satellite spacing can be used to control the levels of both co-channel and out-of-band interference into the spacecraft receivers and that the auxiliary-service is the one which is the more susceptible to interference.

- 10.7 - 11.7 GHz Bands

Inter-system interference between uplink and downlink fixed-satellite services sharing this band is investigated in Chapter 9. The problem is very similar to that studied in Chapter 6 for comparable systems using the 4.4 - 4.7 GHz bands. It was found that interference between satellites and between earth stations will impose constraints on band sharing.

- Bands Near 12 GHz

Intra-system interference in a broadcasting-satellite system utilizing uplink and downlink bands in the region 10.7 - 13.25 GHz is investigated in Chapter 10. Inter-system interference between fixed-satellite uplinks and spurious emissions from broadcasting-satellites using the 11.7 - 12.5 GHz band is also investigated. It was found that intra-system interference will place contraints on the pairing of the uplink and downlink bands for use by a broadcasting-satellite. It was also found that spurious emissions from the broadcasting-satellite will not cause interference into the 12.5 - 13.25 GHz uplink if a 9 MHz guardband is used at the 12.5 GHz edge of the downlink band.

- 4.4 - 4.7 GHz/ 12.2 - 12.5 GHz Bands

The use of the 4.4 - 4.7 GHz band as a feeder link to a broadcasting-satellite using the 12.2 - 12.5 GHz downlink band is investigated in Chapter 11. It was found that use of this pair of bands is feasible and should not constrain the design of a broadcasting-satellite.

- 15 GHz Bands

Intra-system interference in an auxiliary-satellite system using the 15.45 - 15.75 GHz band is investigated in Chapter 12. It was found that usable uplink and downlink bandwidths of approximately 100 MHz can be obtained, depending on system design parameters such as satellite EIRP and output filter complexity.

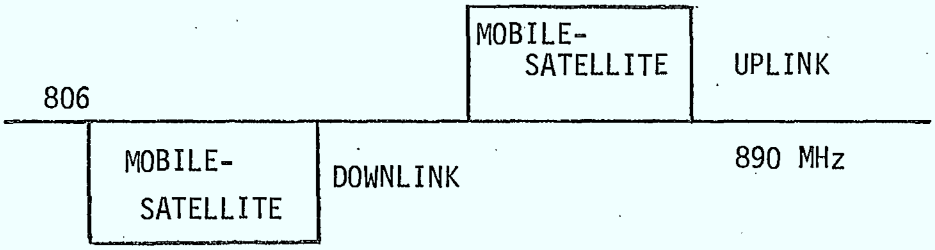
. 17 - 21.5 GHz Bands

Inter-system interference caused by spurious emissions from fixed-satellite systems using the 17.0 - 17.5 GHz uplink and 17.7 - 21.5 GHz downlink bands is investigated in Chapter 13. It was found that the uplink band can be brought to within 24 MHz of the downlink band before interference becomes a problem.

3.0 806-890 MHz MOBILE-SATELLITE BAND

3.1 Introduction

The 806-890 MHz frequency band is investigated in this chapter. The proposed use of this band by the Mobile-Satellite Service is shown below.



A potential intra-system interference problem exists in the spacecraft of a mobile-satellite communications system utilizing such closely spaced uplink and downlink bands due to spurious emissions from the satellite transmitter falling in the uplink band.

The anticipated traffic in such a system on which the subsequent analysis is based is single channel per carrier narrowband voice or data, with the satellite transponders operating in an FDMA mode (possibly with demand assignment of channels). As a result, intermodulation distortion generated by the multi-carrier operation of nonlinear HPA's and by passive nonlinearities in the transponder components (e.g. antenna duplexer) may restrict the efficient use of the band by this class of service.

Because of the close spacing of the uplink and downlink bands, filter complexity (narrowband filters with sharp cutoffs) may pose a problem in obtaining sufficient usable bandwidth. Other technical characteristics of the system will also influence the choice of uplink/downlink bandwidths but in a less direct fashion than the factors just mentioned.

3.2 Baseline System Characteristics

Before investigating the interrelationships between usable uplink/downlink bandwidth and system characteristics, the technical parameters which characterize a baseline mobile-satellite communication system will be presented. These characteristics are presented in Table 3.2/1 and are consistent with those given in References 3.2/1 and 3.2/2 for mobile-satellite systems in the 900 MHz and 1.5 GHz regions of the frequency spectrum. From the system parameters given in Table 3.2/1 it is possible to calculate other system parameters that will influence the utilization of the band.

The uplink will be investigated first. To maintain in a given channel a specified uplink C/N during non-fading conditions, the received carrier power at the input of the satellite receiver must exceed $P_{S,\ CLEAR}$ given by:

$$P_{S,CLEAR} = \left(\frac{C}{N}\right)_{up} + 10 \log \left(k T_{up} B\right) + L_{FADE}\ ,\ dB \qquad (3.2.1)$$

where

$\left(\frac{C}{N}\right)_{up}$ = uplink carrier-to-thermal noise that must be exceeded at least 99% of the time.

T_{up} = satellite receiving system noise temperature, including both antenna and LNA contributions (K).

B = RF noise bandwidth of the channel, assumed to equal the bit rate

L_{fade} = fading margin on link, exceeded no more than 1% of the time (dB).

TABLE 3.2/1 TECHNICAL CHARACTERISTICS OF A LAND MOBILE-SATELLITE SYSTEM

- Carriers:
    - 16 kbps FFSK or QPSK (bandwidth = 16 kHz)
    - 32 kbps FFSK or QPSK (bandwidth = 32 kHz)

- Satellite Characteristics:
    - Canada Coverage beam:
        - on-axis gain = 30 dB
        - edge gain = 27 dB
        - polarization = circular
        - 3-dB beamwidth = $4^{o} \times 7^{o}$
        - diameter = 17 ft.
    - LNA and antenna noise temp = 450 K (average)
        - may increase to 800 K during periods of high solar activity
        - HPA carrier-to-IM distortion ratio = 15 dB.

- Mobile Station Characteristics:
    - Transmitter power less than 10 watts
    - Single carrier operation assumed
    - Antenna gain less than 20 dB (deployable dish or helix)

- C/N and Path Loss:
    - Uplink C/N = 15 dB, exceeded at least 99% of the time.
    - Downlink C/N = 13 dB, exceeded at least 99% of the time.
    - Free space loss = 182.4 dB
    - Total link margin = 10 dB, exceeded no more than 1% of the time.
      Made up of: 2 dB feeder, duplexer losses and
      8 dB fading margin (from Reference 3.2/1)

Note: C/N refers to thermal noise only.

The EIRP of the mobile station required to provide this non-faded signal level is given by

$$(EIRP)_{MOB} = P_{S,CLEAR} - G_{R,SAT} + L_{MISC} + L_{\substack{FREE\\SPACE}}, \ dBW \tag{3.2.2}$$

where

$G_{R,SAT}$ = spacecraft antenna gain in the direction of the mobile station. In the worst case, the station is at the edge of the satellite coverage area and G_R is assumed to be 3 dB down from the spacecraft on-axis gain.

L_{MISC} = duplexer, feeder loss, 2 dB

$L_{\substack{FREE\\SPACE}}$ = free space loss $= -20 \log \left(\frac{\lambda}{4\pi r} \right)$, dB

r = 38000 km

λ = wavelength.

From equations 3.2.1 and 3.2.2, the following relationship is obtained:

$$(EIRP)_{MOB} = \left(\frac{C}{N}\right)_{up} + L_{LINK} + L_{\substack{FREE\\SPACE}} + 10 \log (k T_{up} B) - G_{R,SAT} \ , dBW \tag{3.2.3}$$

where L_{LINK} = total link margin.

This equation has been used to determine the required uplink EIRP for a variety of spacecraft antenna gains, as shown in Figure 3.2/1.

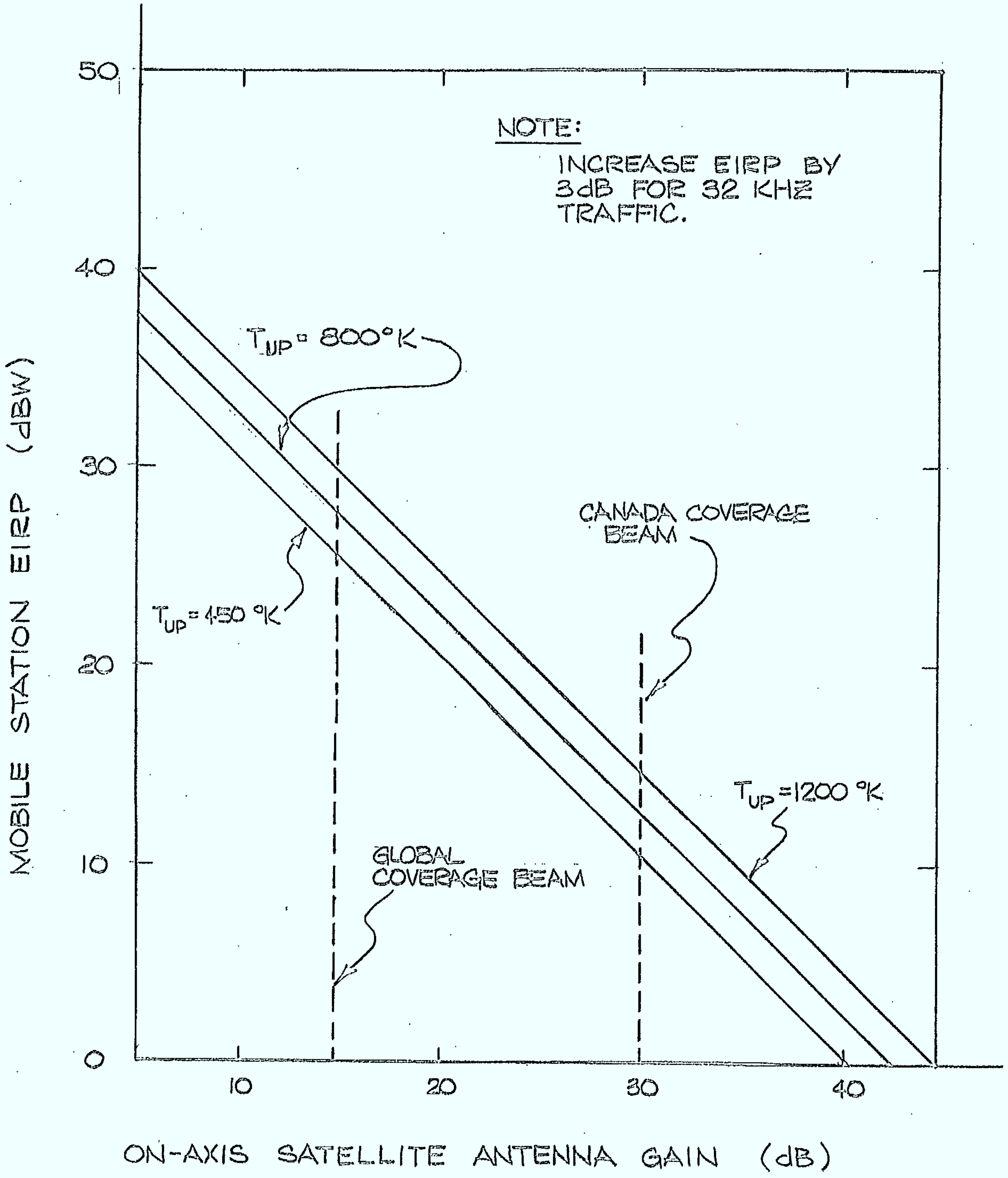


FIG. 3.2/1 UPLINK EIRP FOR 806-890 MHZ MOBILE SATELLITE SYSTEM (16 KHZ CARRIERS)

The downlink characteristics of the system will now be discussed. Equations similar to 3.2.1, 3.2.2, and 3.2.3 can be derived for the downlink, to determine the satellite EIRP per carrier required to maintain an overall C/N due to uplink and downlink thermal noise and intermodulation distortion of 10 dB.

The communication system considered here utilizes satellite transponders in which the mobile-satellite uplink and downlink bands are paired with downlink and uplink bands respectively in the proposed auxiliary-satellite service. As a result, mobile-to-mobile station links will involve a double-hop link through the satellite. The auxiliary links (i.e., the feeder links to and from a central earth station) are higher quality links than those in the mobile-satellite band, as larger antennas, higher power transmitters and more sensitive receivers can be used.

An overall carrier-to-noise and distortion ratio of 19 dB is assumed for the auxiliary-satellite downlink (ie: made up of a carrier-to-thermal noise ratio of 25 dB and a carrier-to-intermodulation distortion ratio of 20 dB). The auxiliary-satellite uplink carrier-to-thermal noise ratio is assumed to be 25 dB also. The carrier-to-IM noise ratio for the mobile-satellite downlink is assumed to be relatively low, ie., 15 dB, as the spacecraft HPA will be operating near saturation for this type of service. The overall carrier-to-noise and distortion ratio for the three types of links are given in Table 3.2/2.

The downlink thermal noise level in the 800 MHz band is very dependent on solar activity and on manmade noise caused by industrial machinery, automobile ignitions, etc. The levels of solar and manmade noise, from References 3.2/3 and 3.2/4 are shown in Figures 3.2/2 and 3.2/3 respectively. The power flux density per unit bandwidth, in dBm/m^2/kHz, can be converted to an effective temperature if the frequency and receiving antenna effective area are known. For an isotropic (0 dB) antenna, the effective area is given by

TABLE 3.2/2: OVERALL CARRIER-TO-NOISE AND DISTORTION RATIOS FOR AN 800 MHz MOBILE-SATELLITE SYSTEM

Type of Link	Downlink Carrier-To-Thermal Noise Ratio (dB)		
	10	13	16
Mobile-To-Mobile (Double-hop)	7.5	8.9	9.8
Auxiliary Station-To-Mobile (Single-hop)	8.7	10.7	12.2
Mobile Station-To-Auxiliary Station (Single-hop)	13.5	13.5	13.5

NOTE: Assumes that no regeneration or error correction used in central station.

. Assumes: . mobile-satellite uplink carrier-to-thermal noise ratio = 15 dB
. mobile-satellite downlink carrier-to-IM noise ratio = 15 dB
. auxiliary-satellite downlink carrier-to-noise and distortion ratio = 19 dB

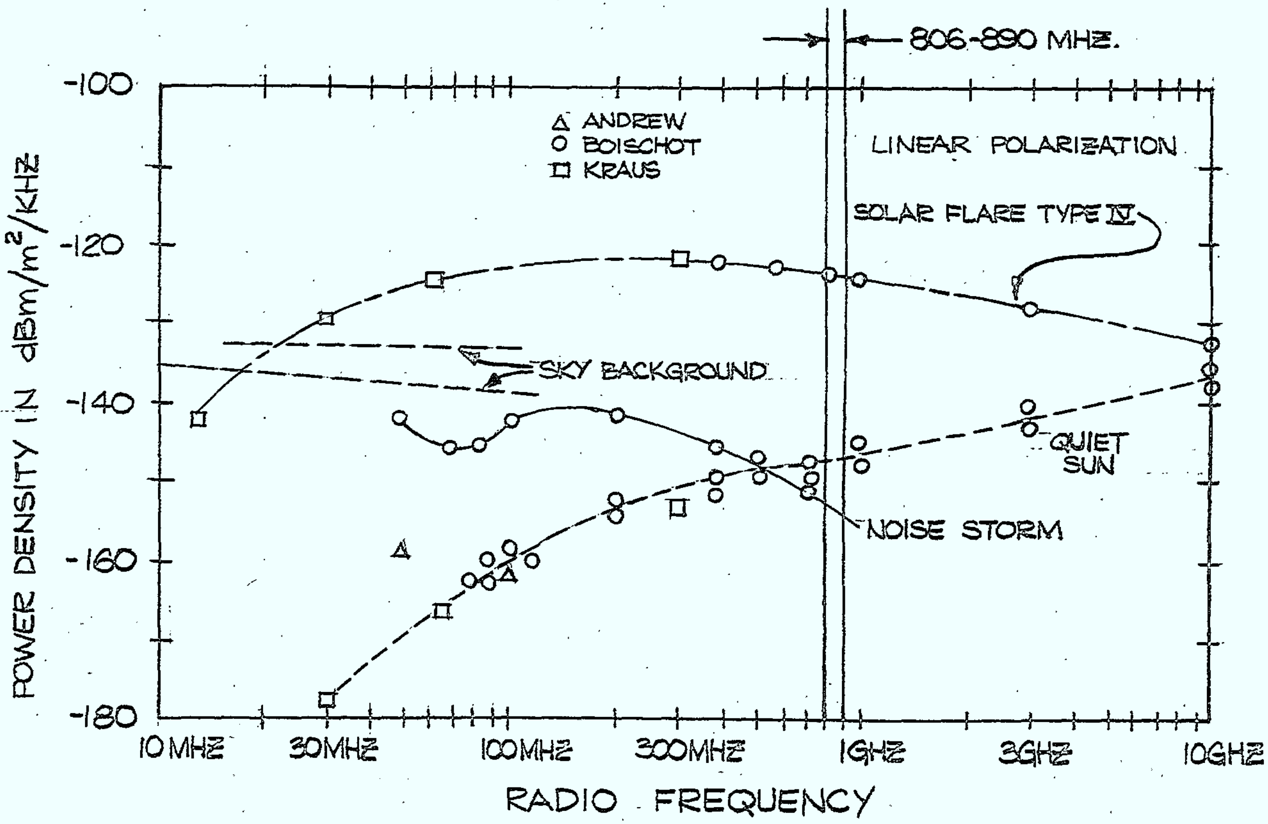


FIG. 3.2/2

SOLAR, PLANETARY AND STELLAR NOISE
(FROM REFERENCE 3.2/3)

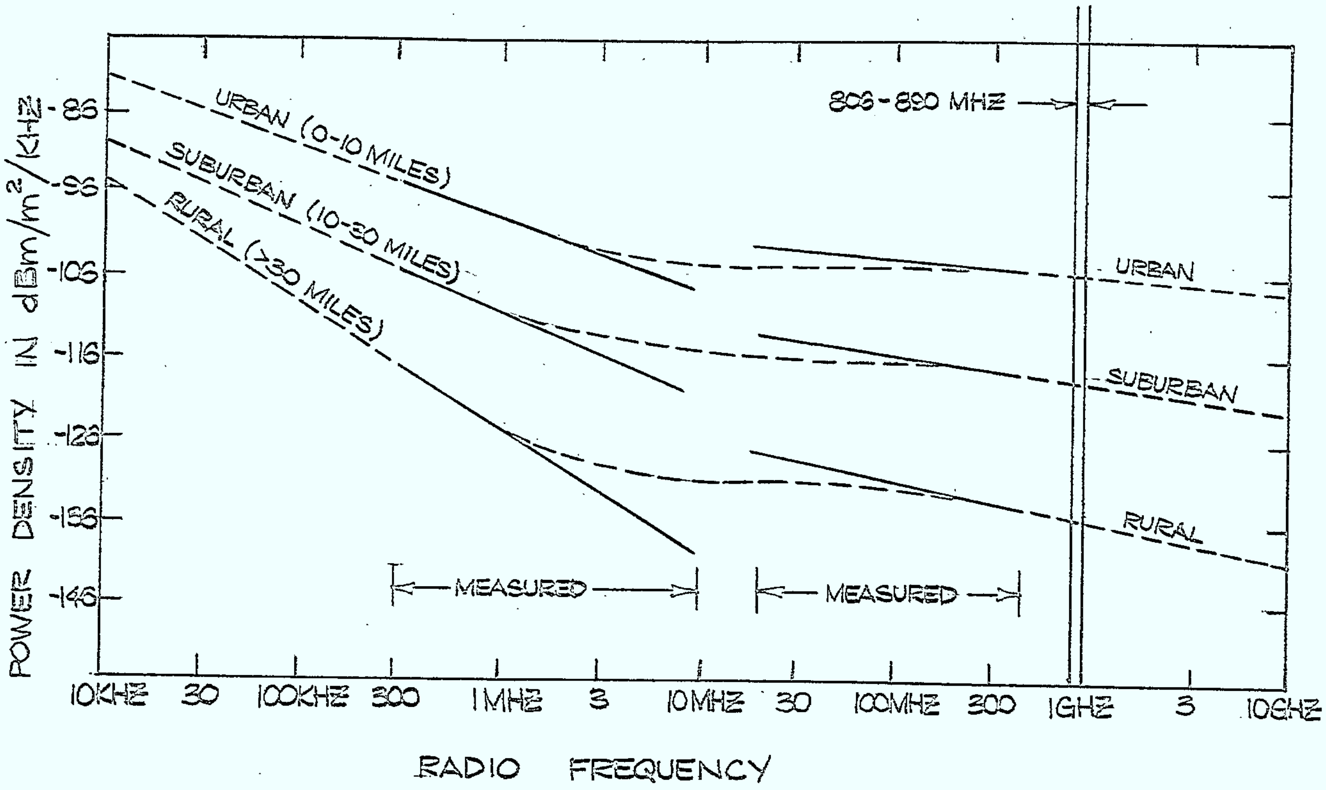


FIG. 3.2/3

MEDIAN INCIDENTAL MAN-MADE NOISE BASED ON LOSSLESS OMNI-DIRECTIONAL ANTENNA NEAR SURFACE (FROM REFERENCE 3.2/4)

$$A_{ap} = \frac{\lambda^2}{4\pi} \quad , \tag{3.2.4}$$

and so the effective antenna temperature is

$$T_{eff} = A_{ap} \; 10^{[0.1 \times S]} \quad , K \tag{3.2.5}$$

where S is the power flux density per unit bandwidth in dBm/m^2/kHz and k is Boltzmann's constant. At 850 MHz, a noise temperature of 200 K corresponds to a flux density of -125 dBm/m^2/kHz. For directional antennas the noise temperature will usually be lower than for an isotropic antenna if the sun is not in the mainbeam of the antenna.

The antenna temperature for quiet sun conditions in a rural (low manmade noise) area for various receiving antenna gains, and the earth terminal receiving system noise temperature for an LNA with a 2 dB noise figure and 1 dB loss are listed in Table 3.2/3.

Operation in urban areas can increase the antenna noise by 10 dB or more in the 800 MHz frequency band. Similarly, during periods of high solar activity, the antenna noise temperature can increase by 3 dB. Type IV solar flares, that occur occasionally during periods of high solar activity can last for periods of several days. The antenna noise temperature can be increased by more than 15 dB during this type of solar activity, and will probably impair the operation of the communication system unless excessive margin is allowed.

The equation for the downlink C/N is now presented. This equation allows the satellite EIRP to be determined as a function of the various other factors involved. The received

TABLE 3.2/3 MOBILE-STATION ANTENNA NOISE TEMPERATURES AT 850 MHz

GAIN, dB	6	10	15	20	25	30
Antenna Temp, (K)	185	200	250	270	300	320
System Noise Temp (K)	415	430	480	500	530	550
G/T (dB/K)	-20	-16.3	-11.8	-7.0	-2.2	2.59

Note: . LNA Noise Figure = 2 dB
Feeder loss = 1 dB

power at the mobile receiver must, for clear weather conditions, exceed:

$$P_{M,CLEAR} = \left(\frac{C}{N}\right)_D + 10\log(kT_d B) + L_{FADE}, \text{ dBW} \tag{3.2.6}$$

where

$\left(\frac{C}{N}\right)_D$ = downlink carrier-to-thermal noise ratio that must be exceeded at least 99% of the time.

T_d = mobile receiving system downlink noise temperature, including manmade and solar noise contributions

L_{FADE} = fade margin (exceeded no more than 1% of the time).

The satellite EIRP is given by:

$$(EIRP)_{SAT} = P_{M,CLEAR} - G_{R,MOB} + L_{MISC} + L_{FREE\ SPACE}, \text{ dBW} \tag{3.2.7}$$

where

$G_{R,MOB}$ = mobile station RX antenna gain in the direction of the satellite (dB)

L_{MISC} = miscellaneous duplexer, feeder loss, 2 dB

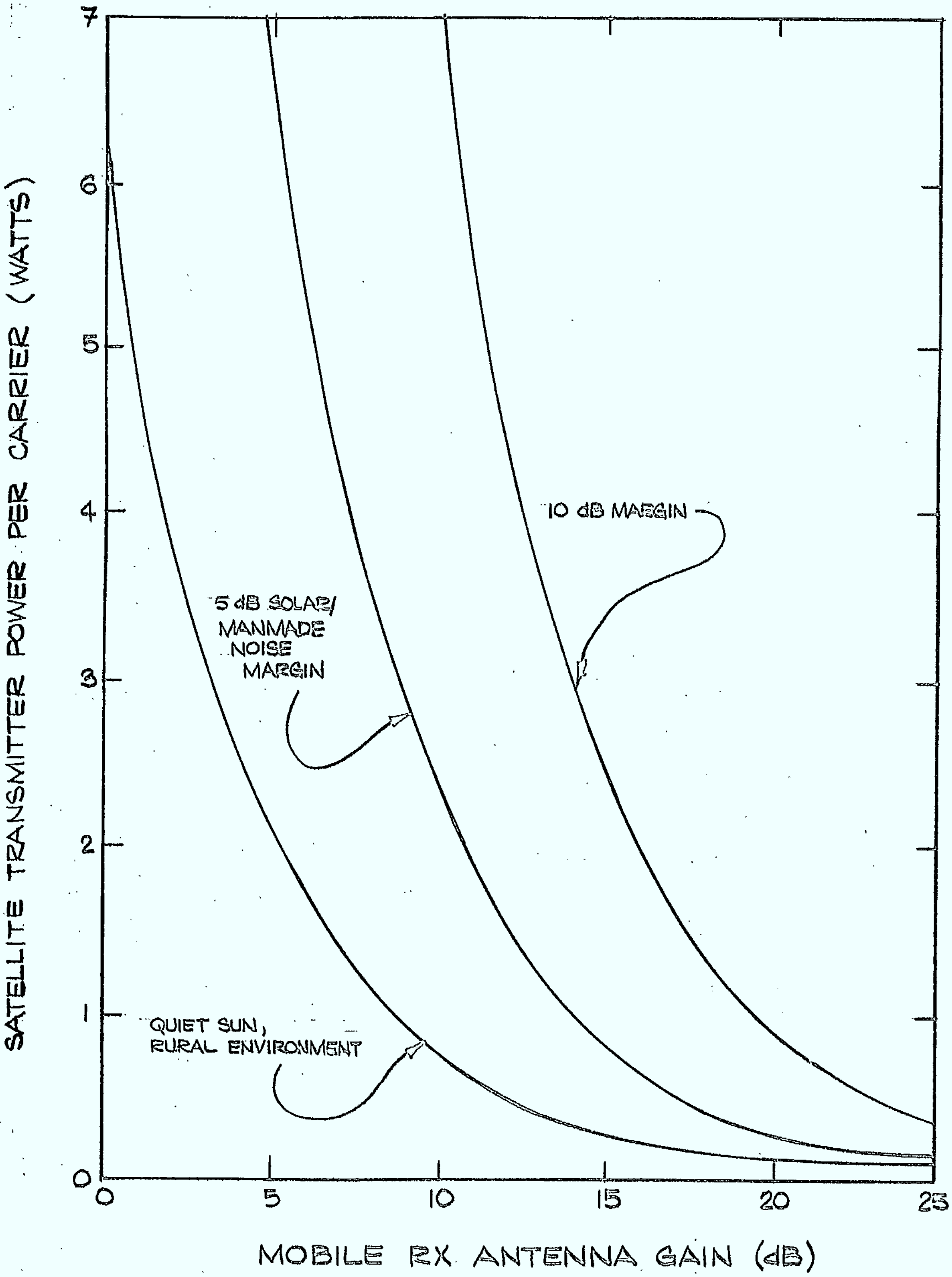
$L_{FREE\ SPACE}$ = free space loss, assumed to be the same as on the mobile uplink

Substituting from equation 3.2.6 yields:

$$(EIRP)_{SAT} = \left(\frac{C}{N}\right)_D + L_{LINK} + L_{FREE\ SPACE} + 10\log(kT_d B) - G_{R,MOB}, \text{ dBW}. \tag{3.2.8}$$

Using values from Tables 3.2/1 and 3.2/3 the satellite per carrier transmitter power for a 30 dB on-axis spacecraft gain (27 dB at edge of coverage area), is plotted in Figure 3.2/4.

From this figure it can be seen that the antenna gain for the mobile receiver will be an important factor in determining the satellite transmitter power. For multicarrier operation very little HPA backoff can be allowed and so intermodulation products will be a significant fraction of the noise budget for the downlink. For this reason, a relatively low carrier-to-intermodulation distortion noise ratio of 15 dB is assumed.



NOTE 1:
ASSUMES CANADIAN COVERAGE ANTENNA (G_0 = 30 dB)

NOTE 2:
FOR 32 KHZ CARRIERS INCREASE TX POWER BY A FACTOR OF 2.

FIG. 3.2/4 SATELLITE TRANSMITTER POWER FOR 800 MHZ MOBILE-SATELLITE SYSTEM

3.3 Satellite IM Distortion and Filtering

The effects of IM distortion and filtering in the satellite will now be considered to determine the usable uplink and downlink bandwidths that can be obtained for this communication system.

Conceptually, the spacecraft communication electronics for the 806-890 MHz band is illustrated in Figure 3.3/1. As will be shown, two intra-system interference modes must be considered in determining the uplink and downlink bandwidths.

The first is caused by intermodulation distortion products at the HPA output falling in the uplink receiving band. This interference is controlled by the filter at the output of the HPA. The second is caused by the generation of IM products in the wideband LNA due to the presence of the downlink transmitted signal. The input filter must attenuate signals in the downlink band to a level at which the intermodulation products generated in the LNA are significantly below the noise level. The choice of these filters will directly determine the usable uplink and downlink bandwidths and their minimum separation.

The isolation that must be provided by the HPA output filter will now be determined. IM products at the LNA input falling in the satellite receive band must be attenuated to values which are typically 10 dB below the uplink thermal noise level. Using 450 K as the uplink noise temperature, the maximum allowable IM power in a 16 kHz band is -170 dBW.

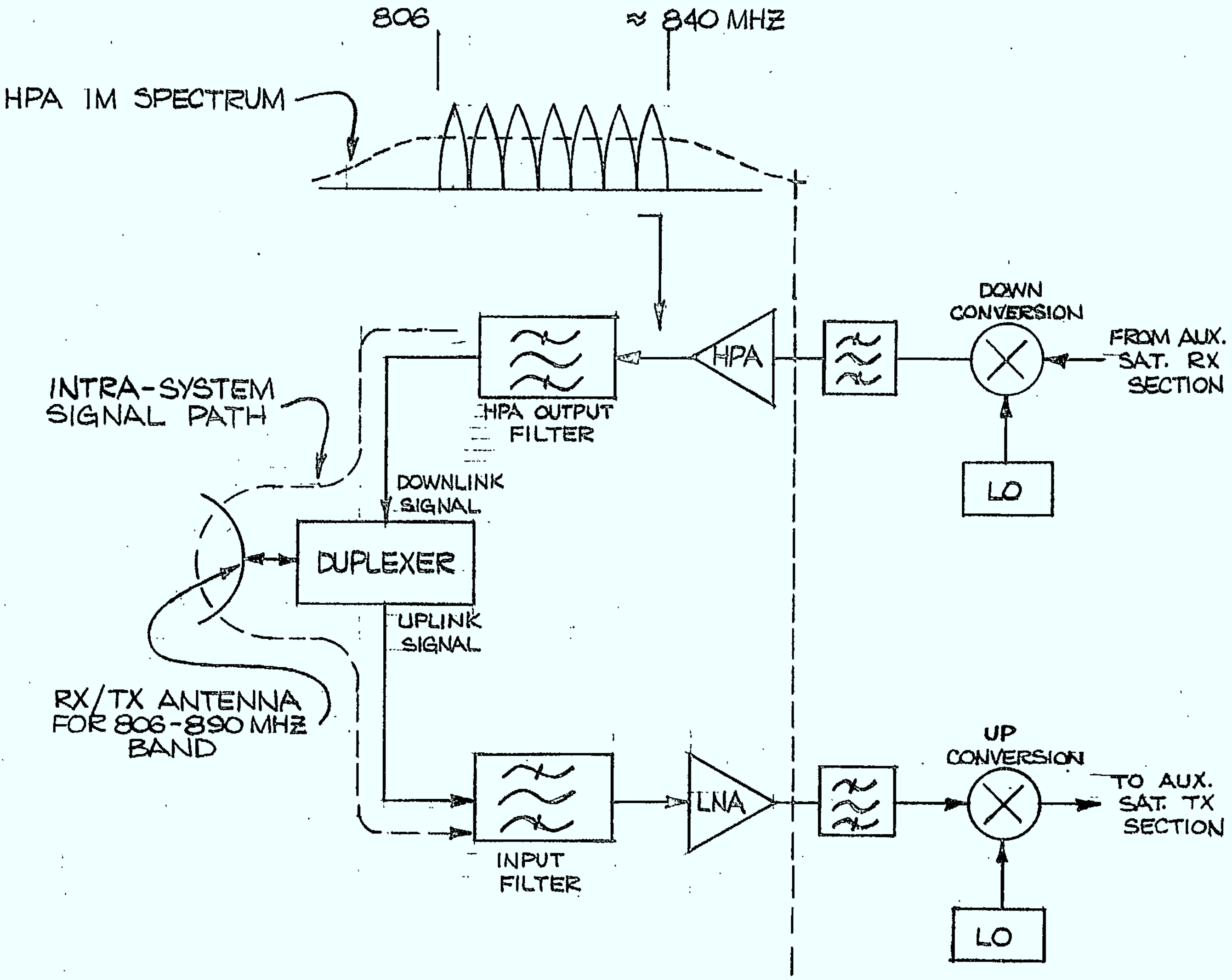


FIG. 3.3/1 CONCEPTUAL BLOCK DIAGRAM OF THE 806-890 MHz SPACECRAFT RX AND TX SECTIONS

The IM product output spectrum from the HPA depends on the device transfer characteristics, the number of carriers, the amplifier backoff, the spacing of the carriers, and their relative power levels. For many equal power carriers, the IM spectrum is approximately Gaussian (Reference 3.3/1). For a solid-state type HPA operating near saturation, the carrier-to-IM ratio can be as low as 15 dB in the bandwidth containing the carriers, and decreases rather slowly outside of this bandwidth. As only estimates of the spectrum can be made without measurements it will be assumed that the spectrum decreases by 7-10 dB per unit of transponder output bandwidth.

The isolation that must be provided by the output filter is determined as follows:

Output Power at HPA = 0 dBW/Carrier

IM level in RX band = -30 dBW in a 16 kHz band

Max. allowable IM level = -170 dBW in a 16 kHz band

Required Isolation = 140 dB

Cross Polarization Isolation = 30 dB

ISOLATION BY FILTERING = 110 dB

It is possible to achieve this level of isolation but care must be taken to ensure that passive intermodulation distortion does not approach this value. Preliminary studies by RCA on MUSAT and by TRW on FLTSATCOM indicate that levels 135 dB below the carrier can be achieved. As a result, this source of intra-system interference will not be a contributing factor in determining the uplink and downlink bandwidths. Passive intermodulation in antenna and duplexer components can be alleviated to a large extent by utilizing separate antennas for transmit and receive.

The cross polarization isolation represents the isolation that is achievable by using orthogonally polarized uplink and downlink signals. If separate receive and transmit antennas are used, this value can be increased significantly and hence results in simpler filters. It is expected however that a single antenna will be the preferred approach and so the bandwidths and separation frequency will be determined on this basis.

The isolation that must be provided by the input filter at the LNA will now be determined. The level of 3rd order intermodulation distortion generated by the LNA in the uplink band from two carriers in the downlink band will be used as an estimate of the IM power caused by this mode of intra-system interference. This IM distortion level is much lower than that of the HPA since the LNA must operate in a much more linear region. Typically, the behaviour of the 3rd order IM is characterized by the "intercept point" of the amplifier as follows. If two carriers at the LNA output have a power P_c, then the 3rd order intermodulation products caused by these carriers have a power of

$$P_{IM} = P_c - 2 \times (P_{IP} - P_c) \quad , \quad dBW \tag{3.3.1}$$

where P_{IP} is the third order intercept point of the device. Now the maximum allowable IM power in any 16 kHz band at the LNA input is -170 dBW. Typical LNA gains are in the 40 to 50 dB range, resulting in a maximum allowable IM level at the LNA output of -130 dBW. The maximum allowable carrier power at the LNA output is then given by

$$P_{c,MAX} = \frac{1}{3}\left[2 P_{IP} - 130\right] \quad , \quad dBW . \tag{3.3.2}$$

The value of P_c is determined by the carrier power at the HPA output P_{TX}, the cross polarization isolation I_{CP}, the input filter attenuation in the downlink band A_{IN}, and the LNA gain G_{LNA}, i.e.

$$P_c = P_{TX} - I_{CP} - A_{IN} + G_{LNA} \text{, dBW.} \qquad (3.3.3)$$

The isolation that must be provided by the input filter is given by

$$A_{IN} = P_{TX} - I_{CP} + G_{LNA} - \frac{1}{3}\left[2P_I - 130\right] \text{, dB.} \qquad (3.3.4)$$

Typical values of the intercept point range from 0 to -10 dBW for amplifiers in this band. Using P_{IP} = -10 dBW and G_{LNA} = 40 dB yields A_{IN} = 60 dB for a transmitter power of 0 dBW/carrier. As this calculation can only give a rough estimate of the intermodulation power in the LNA, a margin of 10 dB will be added to A_{IN} to give a receive filter isolation of at least 70 dB across the downlink band.

The downlink transmitted carrier power at the LNA input is approximately -70 dBW. For an LNA with a gain of 40 dB, this corresponds to a power at the LNA output of -30 dBW. Typically, LNA's saturate with output powers of -10 to -20 dBW, (1 dB compression point) resulting in a margin of at least 10 dB below compression. As a result, the LNA will operate at least 10 dB below saturation and the level of the resulting intermodulation products will be the determining factor in selecting the input filter.

Filters for both the output and input stages can be conveniently characterized by multi-pole Chebyshev or elliptic function filters, as either is representative of achievable RF filters used at 800 MHz. In the following analysis, Chebyshev filters will be assumed. The attenuation characteristics for the filters up to 10th order, are shown in Figure 3.3/2 (from Reference 3.3/2). In the region Ω = 2 to 6, a simple curve-fitting technique has been used to obtain the attenuation in this frequency range:

$$A = (8.6n - 2)\ln|\Omega| + 4.2n - 12 \text{, dB} \qquad (3.3.5)$$

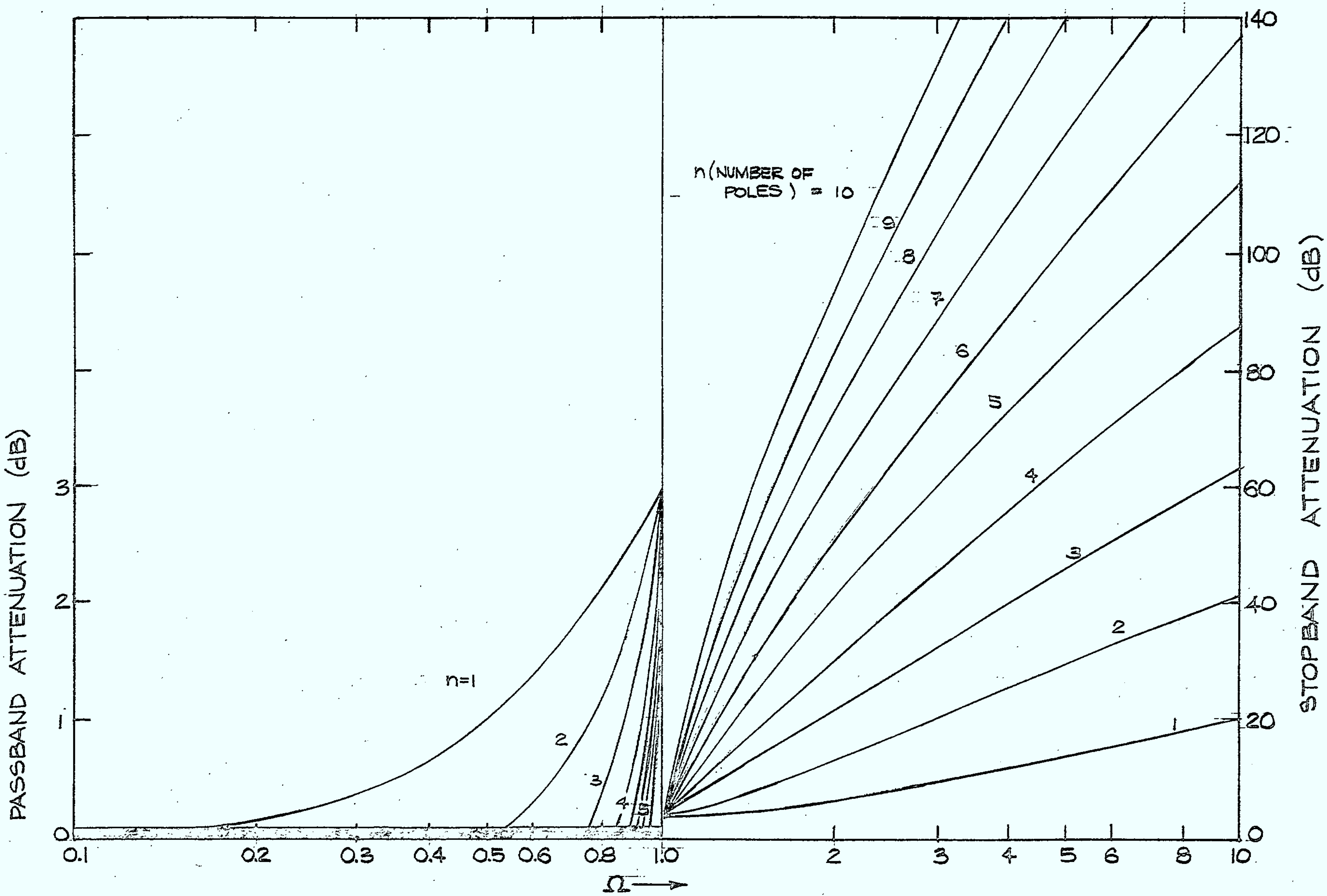


FIG. 3.3/2 ATTENUATION CHARACTERISTICS FOR CHEBYSHEV FILTER WITH 0.1 dB RIPPLE (FROM REFERENCE 3.3/2) $\Omega = \left(\frac{f}{f_c}\right)$

where n is the order of the filter, i.e., the number of poles, and Ω is the ratio of the frequency difference from the filter center frequency to one-half of the 3-dB bandwidth of the filter.

In determining the maximum usable uplink and downlink bandwidths in the 806-890 MHz band, several assumptions will be made.

First, the uplink bandwidth is assumed to equal the downlink bandwidth. Second, the uplink band is assumed to be adjacent to the 890 MHz band limit. As a result, the satellite transmitter filter will determine the usable bandwidth, based on the requirement that 110 dB attenuation be provided at the lower edge of the uplink band, as illustrated in Figure 3.3/3. For a given complexity of output filter (i.e., n) the usable bandwidth, BW, is determined from the conditions:

(i) $$890 - 806 = 84 \text{ MHz} = f_{SEP} + 2\,BW \qquad (3.3.6)$$

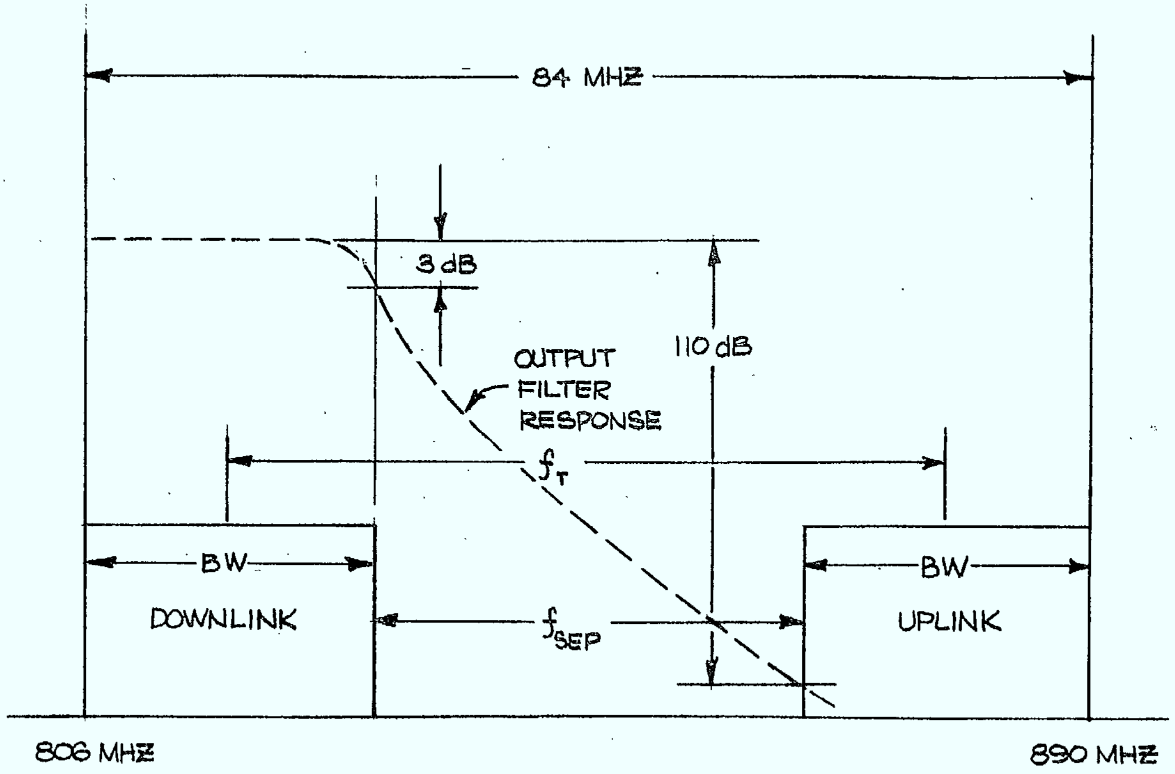
where f_{SEP} is the separation frequency between the bands, and

(ii) the attenuation given by equation 3.3.5 equals 110 dB at

$$\Omega = \left(\frac{\frac{BW}{2} + f_{SEP}}{\frac{BW}{2}} \right) . \qquad (3.3.7)$$

These conditions yield the bandwidths given in Table 3.3/1. The sensitivity of the bandwidth to filter isolation is illustrated in Figure 3.3/4, in which the bandwidths corresponding to attenuations ± 10 dB from 110 dB are shown.

From Table 3.3/1 and Figure 3.3/4, it is evident that the use of the 806 - 890 MHz band will depend primarily on the complexity of the satellite output filter. The tradeoff between filter complexity and bandwidth illustrated in Figure 3.3/4 indicates



BW = USABLE UPLINK OR DOWNLINK BANDWIDTH
f_T = TRANSLATION FREQUENCY
f_{SEP} = BAND SEPARATION

FIG. 3.3/3 ILLUSTRATION OF SATELLITE HPA OUTPUT FILTER RESPONSE AND USABLE BANDWIDTHS

TABLE 3.3/1 UPLINK / DOWNLINK BANDWIDTHS
IN 806 - 890 MHz BAND

NUMBER OF POLES	BANDWIDTH (MHz)	TRANSLATION FREQUENCY (MHz)	BAND SEPARATION (MHz)	% of 806-890 MHz band utilized
7	23.5	60.5	37	56
8	26.8	57.2	30.4	64
9	29.4	54.6	25.2	70
10	31.4	52.6	21.2	75
11	33.1	50.9	17.8	79
12	34.4	49.6	15.2	82

NOTE: BASED ON SATELLITE HPA OUTPUT FILTER ATTENUATION OF 110 dB IN UPLINK BAND.

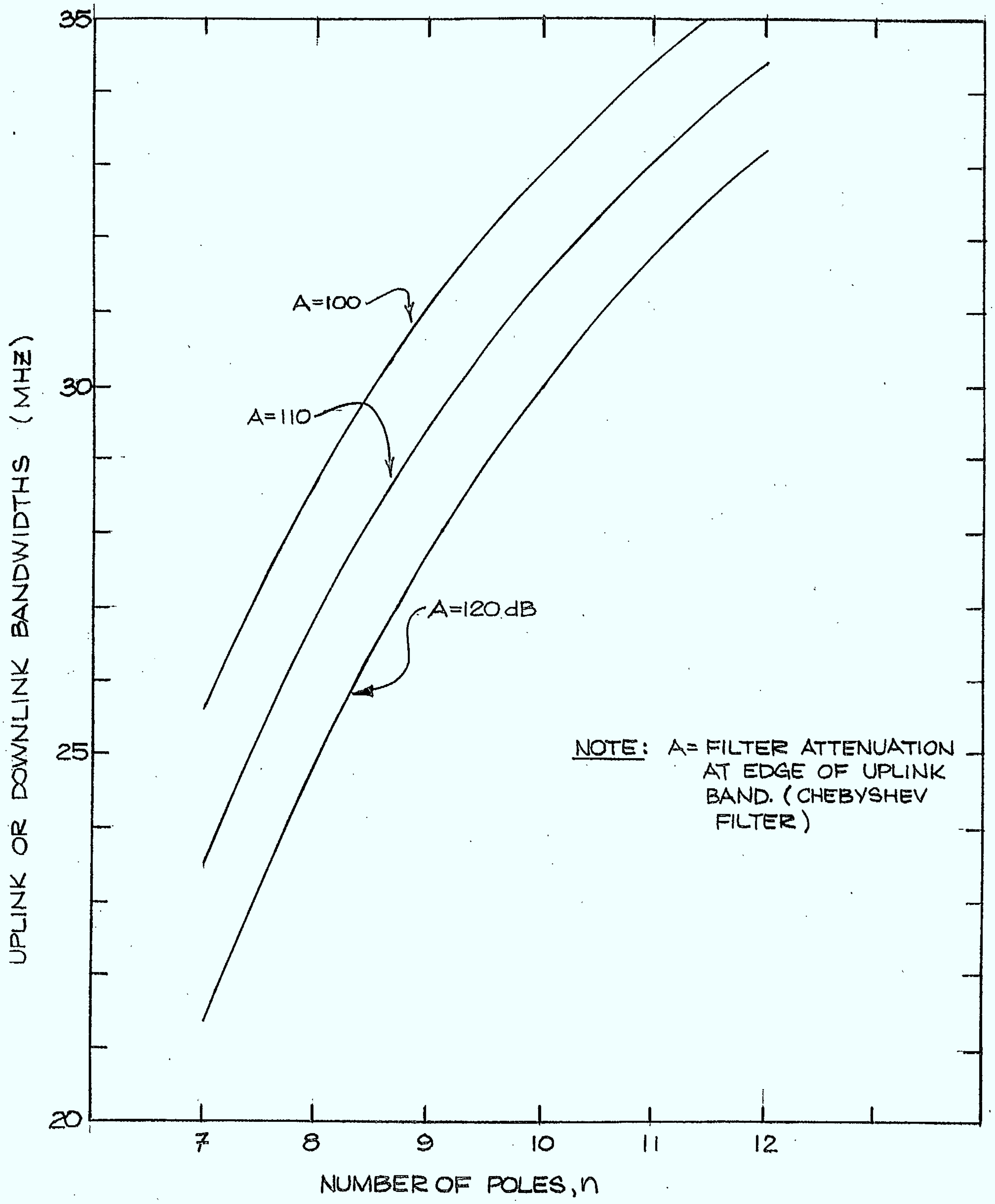


FIG. 3.3/4 UPLINK OR DOWNLINK BANDWIDTHS FOR VARIOUS SPACECRAFT OUTPUT FILTERS

that usable uplink and downlink bandwidths from 25 to 33 MHz are possible.

The out-of-band emissions from the spacecraft transmitter at frequencies less than 806 MHz will consist primarily of intermodulation distortion products. These products will be rapidly attenuated by the output filter. At 806 MHz, the IM levels should be down at least 18 dB relative to the inband carrier power (distributed over the RF bandwidth of the carrier), assuming the output filter 3 dB point occurs at 806 MHz. For 0 dBW 16 kHz carriers, the effective spurious emission power density is approximately -18 dBW in a 16 kHz band, resulting in a peak power flux density per unit bandwidth at the center of the coverage area of -132 dBW/m^2/kHz (assumes 30 dB spacecraft on-axis gain). This corresponds to a power flux density comparable to manmade noise in rural areas. The interference to any broadcast receivers operating below 806 MHz, which must tolerate levels of spurious noise as high as -106 dBW/m^2/kHz in urban areas (see Figure 3.2/3), should therefore be negligible.

The ground segment of the mobile-satellite system will not be a significant factor in determining the maximum usable bandwidths in the 806 - 890 MHz band as the IM distortion problem is much less severe within the mobile station than in the satellite, particularly if a push-to-talk mode of operation is used.

3.4 Summary

The feasibility of using the 806 - 890 MHz band to carry both uplink and downlink traffic in the mobile-satellite service has been demonstrated for a system employing a Canada-coverage spacecraft antenna.

The primary constraint on the uplink and downlink bandwidth in this type of system is the RX/TX isolation required in the satellite. It has been shown that because of the high level of intermodulation distortion products generated in the satellite HPA, an output filter which reduces the emissions by at least 110 dB in the satellite receive band is required. For the purposes of this study, a Chebyshev output filter has been assumed to facilitate the tradeoff study between filter complexity and bandwidth. Figure 3.3/4 illustrates this tradeoff. Values of n near 9 or 10 result in usable uplink and downlink bandwidths of 30 MHz and usage of 71.4% of the possible 84 MHz band.

REFERENCES

3.2/1 "Technical Considerations for a Land Mobile-Satellite Service Operating in Band 9", Draft New Report, Working Group 8-F, Doc 8/840-E, 19 January 1978.

3.2/2 "Technical Characteristics of Systems Providing Communications and/or Radiodetermination Using Satellite Techniques for Aircraft and/or ships", CCIR Report 601, 1974.

3.2/3 "Electromagnetic Interference and Compatibility", Volume 5, EMC handbook, by W.G. Duff and D.R. White, Don White Consultants, Maryland, 1972.

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3.3/1 "Calculation of Intermodulation Due to Amplitude Limiting of Multiple Carriers", C.R. Cahn, IEEE Trans. Comm. Tech., Dec. 1968.

3.3/2 "Handbook of Filter Synthesis", A.E. Zverev, 1957, Publ. John Wiley and Sons.

4.0 MARITIME, AERONAUTICAL, AND LAND MOBILE-SATELLITE BANDS NEAR 1.5 GHz

4.1 Introduction

Intra-system interference in a number of mobile-satellite bands near 1.5 GHz is investigated in this chapter to determine the maximum usable bandwidths and possible guardbands required for various frequency plans. Two frequency plans are investigated for each of the land mobile, aeronautical mobile, and maritime mobile-satellite services. These frequency plans are shown in Figure 4.1/1. The first plan is consistent with Canada's Second Draft Proposal, while the second plan is a more recent proposed band allocation.

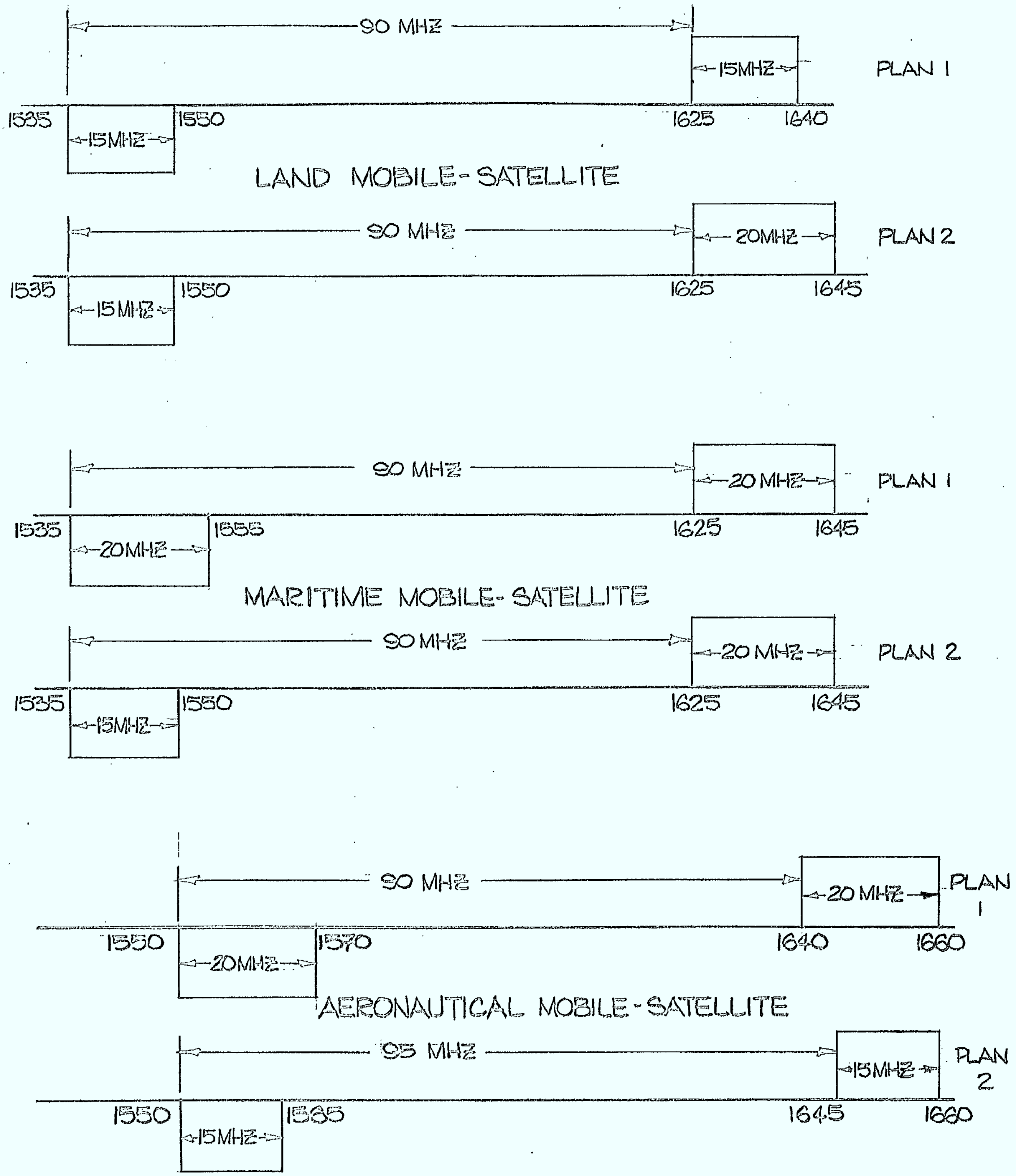


FIG. 4.1/1 FREQUENCY PLANS FOR L-BAND MOBILE-SATELLITE SERVICES

4.2 Land Mobile-Satellite Service

The anticipated traffic in the land mobile-satellite service is narrowband voice and data carriers. The characteristics of the uplink and downlink of a representative satellite system for this service are summarized in Tables 4.2/1 and 4.2/2. The values contained in the tables are consistent with those given in Reference 4.2/1 for a general land mobile-satellite service.

Using Table 4.2/1, the uplink earth station transmitter power will be a function of the spacecraft and earth station antenna gains, and is given by:

$$P_{up} = 54.5 - G_{0,SAT} - G_{0,E} \quad , \quad dBW \tag{4.2.1}$$

where $G_{0,SAT}$ is the satellite receiving antenna gain and $G_{0,E}$ is the earth station transmitting antenna gain. This equation gives the transmitter power for a station at the edge of the satellite's coverage zone (i.e., satellite gain is assumed to be 3 dB below the on-axis gain $G_{0,SAT}$. In terms of the earth station antenna diameter, the power is given by:

$$P_{up} = 32.8 - G_{0,SAT} - 20 \log D \quad , \quad dBW \tag{4.2.2}$$

where D is the diameter in metres. This equation is plotted in Figure 4.2/1 for a range of spacecraft antenna gains and earth station diameters. For an easily transported earth station, the antenna must be as small as possible. In this frequency range, antennas on the order of 1 to 2 metres will provide uplink transmit gains of 20 to 27 dB. When used with a 30 dB spacecraft antenna, uplink transmitter powers on the order of 0.5 to 2 watts will be required. For lower gain spacecraft antennas, the uplink transmitter power requirement may make the portability of the earth station more difficult as transmitter powers on the order of 10 to 100 watts could be required.

TABLE 4.2/1 Land Mobile-Satellite Uplink at 1.6 GHz

- Carrier: Narrowband Voice or Digital Data
- RF Bandwidth = 16 kHz
- Required Uplink C/N = 15 dB, exceeded at least 99% of the time
- Free Space Loss = 188 dB
- Ionospheric Fade Margin = 0.5 dB, exceeded no more than 1% of the time
- Miscellaneous Feeder, Duplexer Losses = 2 dB
- Multipath, Antenna Pointing Losses = 2 dB
- Total Link Losses = 4.5 dB
- Satellite System Noise Temperature = 1000 K
- kTB = -156.6 dBW
- Minimum Required Carrier Power at LNA input = -141 dBW

Note: C/N includes thermal noise only.

TABLE 4.2/2 Land Mobile-Satellite Downlink at 1.5 GHz

- Carrier: Narrowband Voice or Data
- RF Bandwidth = 16 kHz
- Required Downlink C/N = 13 dB, exceeded at least 99% of the time
- Free Space Loss = 188 dB
- Link Margin = 4.5 dB
- LNA Noise Figure = 4 dB
- LNA Noise Temperature = 440 K
- Antenna Noise Temperature = 120 K
- Feeder Loss = 0.5 dB
- Receiving System Noise Temperature = 578 K
- kTB = -159 dBW
- Minimum Required Carrier Power at LNA Input = -146 dBW

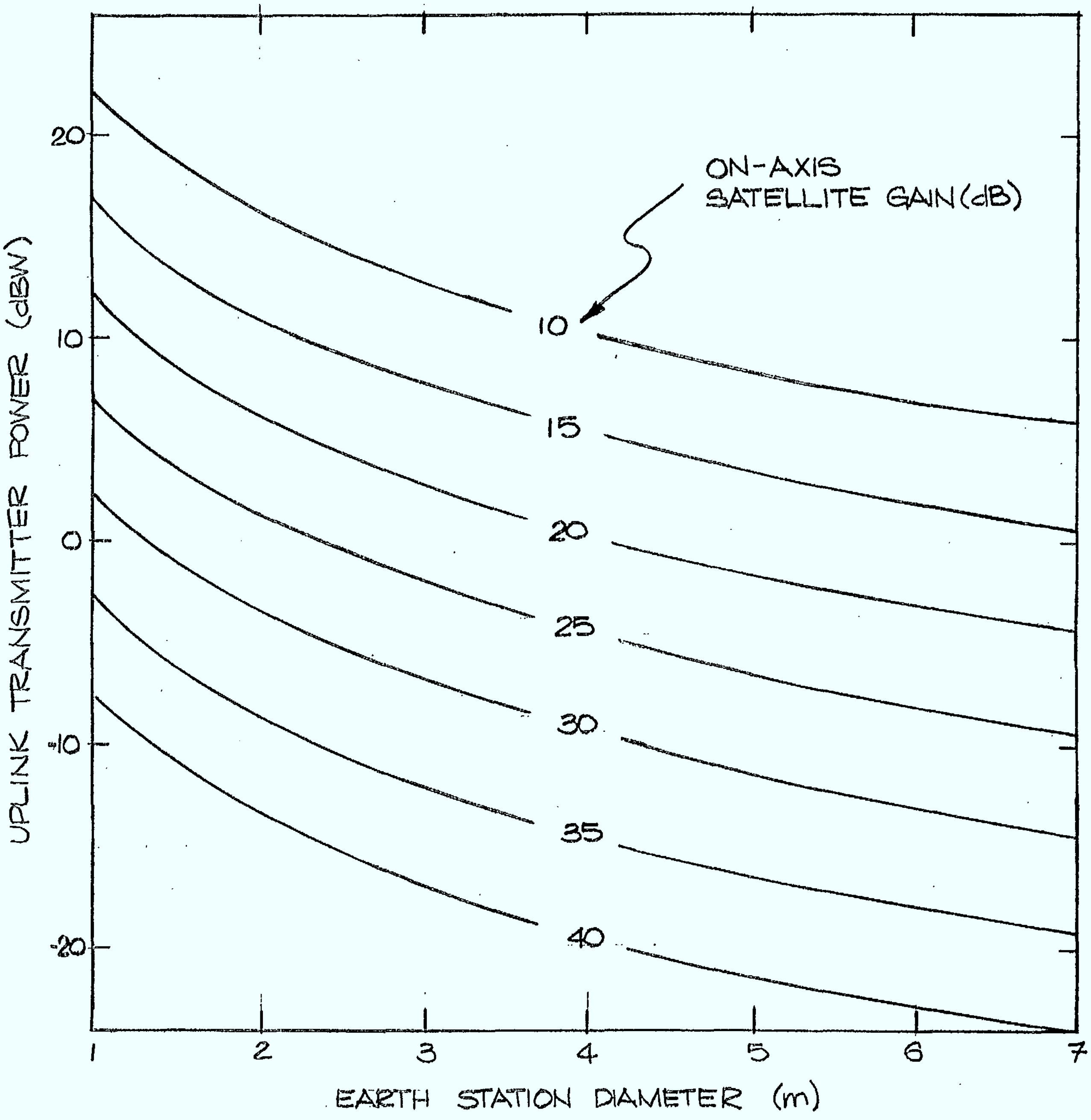


FIG. 4.2/1 UPLINK TRANSMITTER POWER FOR L-BAND LAND MOBILE-SATELLITE SYSTEM

The downlink satellite on-axis EIRP required to provide service to a transportable earth station is given by:

$$(EIRP)_{SAT} = 49.5 - G_{o,E} \quad , \ dBW \tag{4.2.3}$$

where $G_{o,E}$ is the on-axis earth station gain. In terms of the earth station diameter, the downlink transmitter power is given by:

$$P_d = 28.3 - G_{o,SAT} - 20 \log D \quad , \ dBW . \tag{4.2.4}$$

Comparison with equation 4.2.2 indicates that the satellite transmitter power output will be 4.5 dB lower than the corresponding ground station transmitter power output for the same spacecraft TX/RX antenna gains.

The spurious emissions from the spacecraft transmitter will consist mainly of IM distortion products generated as a result of multicarrier transponder operation. As very little output backoff can be used, the inband carrier-to-IM noise ratio will be on the order of 16 dB for an output backoff of 3 dB (Reference 4.2/1). For a Canadian coverage system, the satellite boresight transmit antenna gain must be on the order of 30 dB. Assuming that 1 metre antennas are used for the ground stations, the satellite transmitter power per carrier must be approximately 1 watt. Assuming that a wideband transponder is used and that 300 watts of transmitter power is available, then at 3 dB backoff, 150 active carriers can be supported. For a circuit voice activity factor of 0.4, 375 FDMA voice channels spaced 25 kHz apart and occupying a total of 9.375 MHz could be supported by the system.

With such a large number of closely-spaced and nominally equal power carriers the out-of-band IM spectrum at the HPA output will be approximately Guassian. In the uplink band, 75 MHz from the upper edge of the downlink band (in either Plan 1 or Plan 2), the intermodulation distortion spectrum will be down at least 40 dB from its in-band value (assuming a rather conservative rolloff of 3 dB per unit transmitter bandwidth). The isolation that must be provided by an output filter, following the method of section 3.3, is given by:

Output Power at HPA = 0 dBW/carrier
IM Level in Receive Band = -56 dBW in a 16 kHz band
Max. Allowable IM Level = -151 dBW in a 16 kHz band

Required Isolation = 95 dB

Cross Polarization Isolation = 30 dB

Isolation Required by Output Fitler = 65 dB

Adding a further 5 dB margin to be conservative brings the required isolation to 70 dB.

Assuming that a single wideband Chebyshev filter is used, with 3 dB points at 1535 and 1550 MHz (plan 1 or plan 2), then the isolation required at the edge of the uplink band will be exceeded for filters with n = 4. As a result, this mode of intra-system interference can be controlled easily. It should be noted that if orthogonally polarized up and downlink antennas are not used, then 95 - 100 dB of isolation must be provided by the output filter. This isolation can be achieved for both frequency plans by using a 5th order Chebyshev filter.

The other mode of intra-system interference that is considered is that of IM products, generated in the LNA, falling in the satellite receive band. Following the method used in obtaining equation 3.3.4, the attenuation which the satellite receive input filter must exhibit at frequencies within the satellite transmit band is given by:

$$A_{IN} = P_d - I_{CP} + G_{LNA} - \frac{1}{3}\left[2P_{IP} + P_{IM,MAX} + G_{LNA}\right], \text{ dB} \qquad (4.2.5)$$

where P_d is the downlink carrier power (0 dBW), I_{CP} is any antenna cross polarization isolation (either 0 or 30 dB), G_{LNA} is the LNA gain (40 dB), P_{IP} is the third order intercept point of the LNA (-10 dBW), and $P_{IM,MAX}$ is the maximum permissible IM power level at the LNA input, (-151 dBW in a 16 kHz band). Substituting the appropriate values gives:

$$A_{IN} = \begin{cases} 84 \text{ dB, assuming co-polarized TX/RX satellite antennas} \\ 54 \text{ dB, assuming cross-polarized TX/RX satellite antennas} \end{cases}$$

These values indicate that implementation of the input filter will not be a problem, as the isolation it must provide is approximately 5 to 15 dB less than that required of the output filter. This level of input filtering also ensures that a 25 dB margin against LNA saturation is met.

Spurious emissions from the mobile earth station at frequencies below 1625 MHz and above 1645 MHz will now be considered. For single carrier operation typical of these stations, spurious intermodulation distortion power outside of the uplink band will be more than 60 dB below the carrier power in a 16 kHz band. Assuming that a 10 watt transmitter is used, the out-of-band power in a 16 kHz band will be less than -50 dBW at the antenna terminals. For isotropic antennas separated by 1 km, the received power (assuming free space propagation) is less than -146 dBW per 16 kHz band. As this value is comparable to the downlink system noise of a mobile receiver, it may be necessary to use an output filter to suppress these spurious emissions. Since the level of filtering is not large, this potential mode of interference should not place difficult to meet constraints on the operation of a mobile-satellite system in either of the proposed bands.

4.3 Maritime Mobile-Satellite Bands

The characteristics of a mobile-satellite system operating in the 1.5 GHz region of the spectrum will be very similar to those of the land mobile-satellite service. In the case of the maritime service, however, a margin for multipath interference must be added to the link. For a satellite system at 1.5 GHz, a multipath margin of 2 to 3 dB is required although the actual amount will depend largely on system and environmental parameters and the desired system availability (Reference 4.3/1). The required uplink ground station transmitter power and the satellite downlink transmitter power will be slightly higher than those of the land mobile-satellite system just discussed to maintain the same quality of service.

The frequency plans for the maritime mobile-satellite service are similar to those of the land mobile-satellite service, except for slight differences in bandwidth. Thus the results of the previous section can be equally applied to the maritime service as well.

4.4 Aeronautical Mobile-Satellite Bands

The aeronautical mobile-satellite service at 1.5 GHz will have characteristics similar to those of a land mobile-satellite system. In this case however, multipath fading and antenna polarization mismatch will affect the transmitter power levels at both the aircraft and the spacecraft. At 1.5 GHz, circularly polarized spacecraft antennas will probably be used as Faraday rotation and polarizer alignment can produce polarization orientation losses in linearly polarized systems.

Faraday rotation angles of 10 degrees (Reference 4.4/1) can occur at these frequencies depending, among other things, on the location of the aircraft and the satellite. The alignment of transmitting and receiving antenna polarizers is a more severe problem for a system using linear polarization. Typical aircraft antennas radiate linearly polarized signals. To avoid the alignment problem, the satellite would utilize a circularly polarized antenna. The mismatch factor in this case is 3 dB, and must be compensated for by the use of more powerful transmitters and higher gain antennas.

The antenna gains available for aircraft are generally of lower gain than those used in the land mobile-satellite service. Values on the order of 7 to 15 dB are currently used at 1.5 GHz (Reference 4.4/2).

To compensate for the lower antenna gains and higher link margins that characterize an aeronautical system, lower C/N values must be accepted. Assuming values 3 dB lower than those chosen for the land mobile system, the uplink carrier power is given by:

$$P_{up} = P_{R,MIN} - G_{\theta,E} - (G_{\theta,SAT} - 3\,dB) + (L_{\substack{FREE\\SPACE}} + L_{\substack{ANTENNA\\MISMATCH}} + L_{MULTIPATH} + L_{MISC}) \qquad (4.4.1)$$

$$= 60 - G_{\theta,E} - G_{\theta,SAT}\ ,\ dBW\ .$$

For an aircraft antenna gain of 15 dB and a spacecraft antenna gain of 30 dB, an uplink power of 15 dBW (32 watts) is required. The satellite transmitter power is given by:

$$\begin{aligned} P_d &= -149 - G_{0,E} - [G_{0,SAT} - 3] + [188 + 3 + 4 + 2] \\ &= 51 - G_{0,E} - G_{0,SAT} \quad , \text{dBW} . \end{aligned} \tag{4.4.2}$$

For the same RX/TX antenna gains, a satellite transmitter power of 5 dBW would be required.

The additional downlink power requirement means that less traffic can be handled by an aeronautical mobile-satellite system than by a land mobile-satellite system. The higher EIRP's on the downlink imply that the satellite HPA must operate near saturation, and so spurious emissions will be higher than in the land mobile-satellite case. This will require slightly more RX/TX isolation in the spacecraft but should not place any serious constraints on the use of these bands. The spurious emissions from aircraft transmitters at frequencies above 1660 MHz will have to be controlled, as the 1660 - 1670 MHz band is allocated for research in radio astronomy. This may require a guardband on the order of 3 to 4 MHz at the 1660 MHz edge of the aeronautical mobile-satellite uplink band to reduce spurious emissions from their value at the edge of the band.

4.5 Summary

In this chapter, intra-system interference in three mobile-satellite services was investigated. Generally, there will be much similarity in system parameters for the three systems, with the major differences occurring as a result of the link margins and antenna gains which characterize systems in the land, maritime, and aeronautical-mobile services.

It was found that RX/TX isolation is not a serious problem in this band for any of the proposed frequency plans due to the large uplink/downlink band separation frequency (90 MHz) relative to the downlink bandwidth (15 to 20 MHz).

Spurious emissions from aircraft may present a problem to services using frequencies above and below the uplink band. The upper edge of the band may require a guardband, however, to protect a radio astronomy band at 1660 - 1670 MHz. This guardband will be on the order of 3 to 4 MHz.

REFERENCES

4.2/1 "Technical Considerations for a Land Mobile-Satellite Service Operating in Band 9". Draft New Report, Working Group 8-F, DOC 8/480-E, 19 January 1978.

4.2/2 "UHF - SHF Satellite Communications Link Calculations", Bell Northern Research, Study Contract No. PL 36100-4-0995, Final Report for DOC, Canada, July, 1975.

4.3/1 "Technical Characteristics of Systems Providing Communication And/Or Radiodetermination Using Satellite Techniques for Aircraft and/or Ships - Consideration of Possible Technical Characteristics for a Maritime Satellite System for Public Correspondence", CCIR Report 601, 1974.

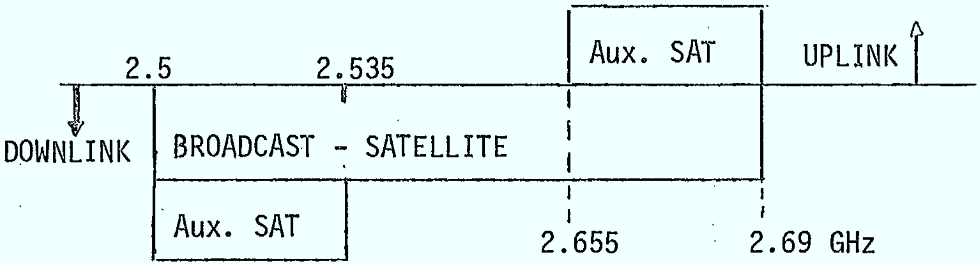
4.4/1 "Analysis of Ionospheric Propagation and General Antenna Models in OFUS", SED Doc. No. 0802-50-TR-101, February 28, 1977.

4.4/2 "Aeronautical L-Band Technology Tests With the ATS-6 Satellite", J.M. Gutwein and R.G. Bland, U.S. Dept. of Transportation, Transportation Systems Center, 1976.

5.0 AUXILIARY AND BROADCASTING-SATELLITE BANDS NEAR 2.5 GHz

5.1 Introduction

Intra-system interference in a pair of auxiliary-satellite bands near 2.5 GHz, and the inter-system interference between a broadcast-satellite and the auxiliary-satellite service sharing these bands is investigated in this chapter. The frequency plan studied is shown below, and is consistent with Canada's Second Draft Proposal.



5.2 System Characteristics

The uplink and downlink characteristics and performance requirements of the auxiliary-satellite system are shown in Tables 5.2/1 and 5.2/2. These values are similar to those used in Chapters 7 and 12, with the exceptions of propagation margins and noise temperatures.

The earth station uplink and satellite downlink transmitter powers are given by:

$$\begin{aligned} P_{up} &= 68.2 - G_{o,SAT} - G_{o,E}\ ,\ dBW \\ &= 42.6 - G_{o,SAT} - 20\log D\ ,\ dBW \end{aligned} \qquad (5.2.1)$$

$$\begin{aligned} P_{d} &= 60 - G_{o,SAT} - G_{o,E}\ ,\ dBW \\ &= 34.4 - G_{o,SAT} - 20\log D\ ,\ dBW \end{aligned} \qquad (5.2.2)$$

where $G_{o,SAT}$ is the on-axis gain of the satellite, $G_{o,E}$ is the gain of the earth station, and D is the earth station diameter in metres. The transmitter powers are plotted in Figures 5.2/1 and 5.2/2 for a range of $G_{o,SAT}$ and D.

The characteristics of the broadcasting-satellite downlink are shown in Table 5.2/3. These characteristics are applicable to a community reception system and are based on values given in References 5.2/1 and 5.2/2. The downlink EIRP specified in Table 5.2/3 is the on-axis EIRP. It contains a 3 dB margin so that the required C/N can be obtained at the edge of a satellite's coverage zone. To achieve an EIRP this large will require the use of high gain spot beam spacecraft antennas. At 2.5 GHz, the on-axis gain of a parabolic reflector antenna is given by:

$$G_o = 25.6 + 20\log D\ ,\ dB \qquad (5.2.3)$$

TABLE 5.2/1: Characteristics of Auxiliary-Satellite Uplink at 2.6 GHz

. Carrier: Narrowband Voice or Digital Data Bandwidth	= 16 kHz
. Required Uplink C/N	= 25 dB, exceeded at least 99% of the time
. Free Space Loss	= 192 dB
. Total Uplink Margin	= 3 dB, exceeded no more than 1% of the time
. Satellite Receive System Noise Temperature	= 1500 K
kTB	= -154.8 dBW
. Minimum Required Carrier Power at LNA Input	= -129.8 dBW

TABLE 5.2/2: Characteristics of Auxiliary-Satellite Downlink at 2.5 GHz

. Bandwidth	= 16 kHz
. Required Downlink Carrier-to-Thermal Noise Ratio	= 25 dB, exceeded at least 99% of the time
. *Carrier-to-IM Ratio	= 20 dB
. Overall C/(N+D)	= 19 dB
. Free Space Loss	= 192 dB
. Total Downlink Margin	= 3 dB, exceeded no more than 1% of the time
. Ground Station Receiving System Noise Temperature	= 200 K
kTB	= -163.5 dBW
. Minimum Required Carrier Power at LNA Input	= -138 dBW

*NOTE: Assumes multicarrier satellite HPA operation so downlink performance is limited by IM distortion.

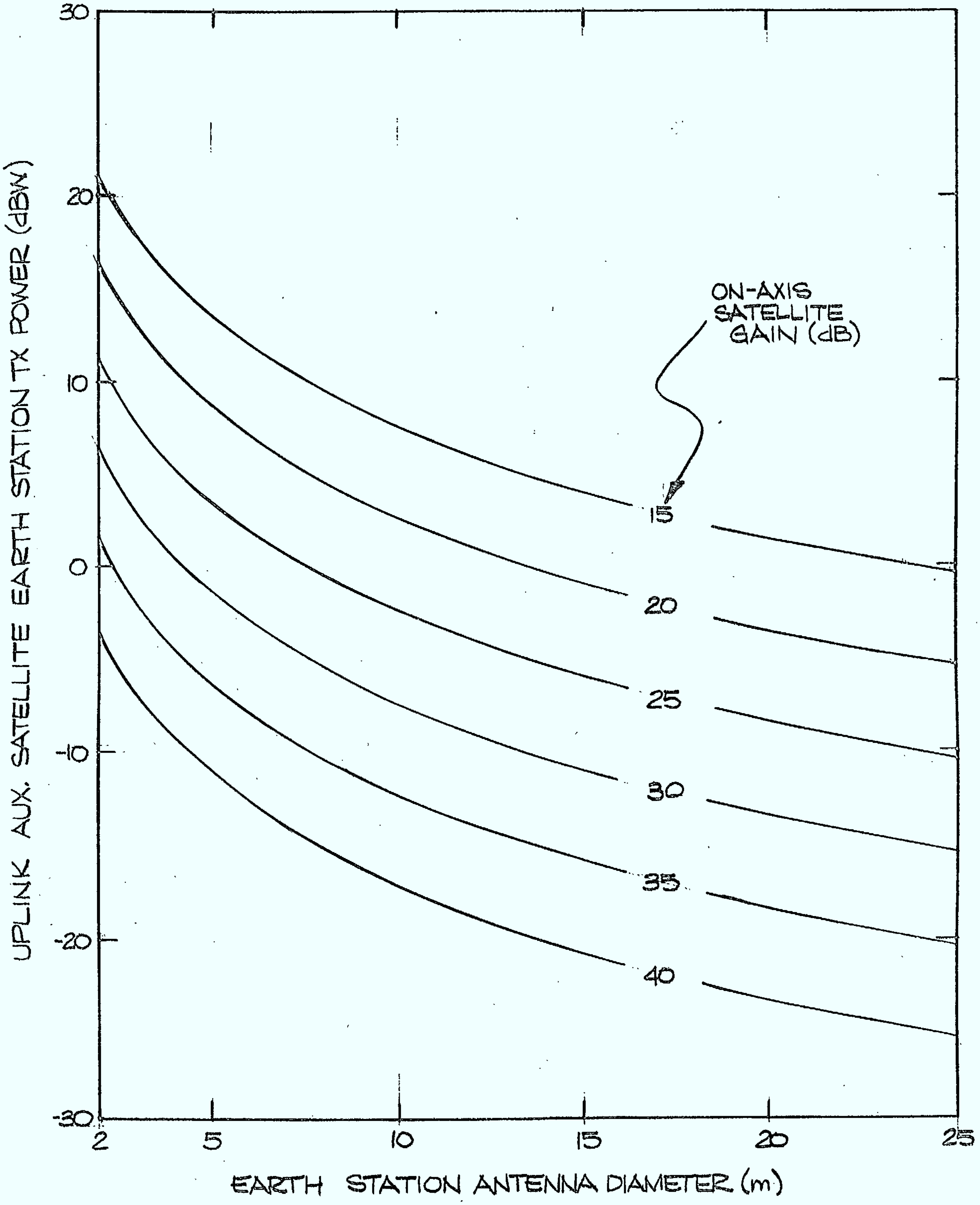


FIG. 5.2/1 UPLINK TRANSMITTER POWER FOR AUX. SATELLITE SERVICE AT 2.5 GHZ

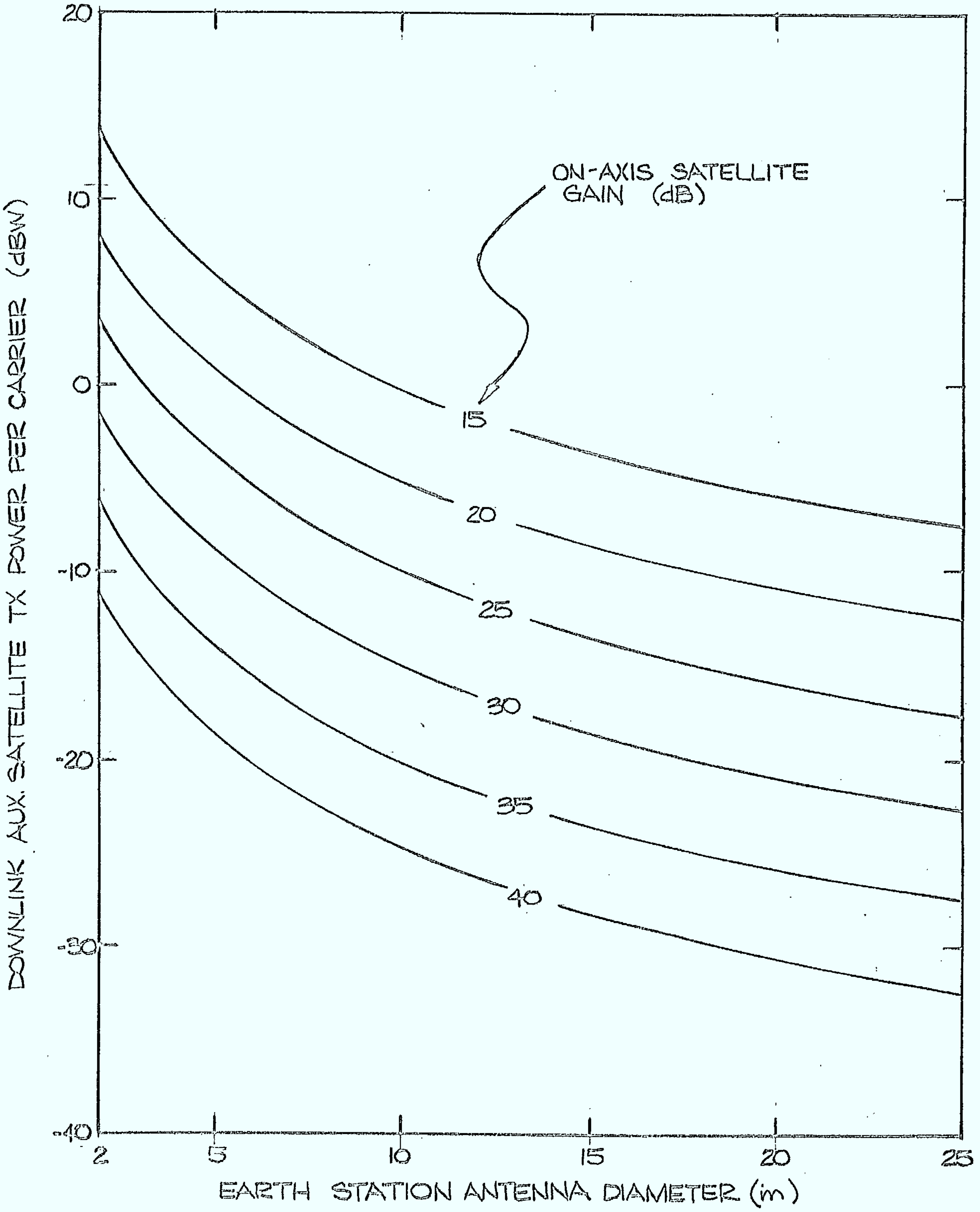


FIGURE 5.2/2 DOWNLINK TRANSMITTER POWER FOR AUX. SATELLITE SERVICE AT 2.5 GHZ.

TABLE 5.2/3: Characteristics of Broadcast-Satellite Downlink at 2.5 GHz

- Carrier: FM/TV
- Bandwidth = 23 MHz
- Required Downlink C/N = 17 dB, exceeded at least 99% of the worst month
- Free Space Loss = 192 dB
- LNA Noise Figure = 4 dB
- Ground Station Receiving Noise Temperature = 480 K
  kTB = -128 dBW
- Total Downlink Margin = 2 dB, exceeded no more than 1% of worst month made up of:
  0.2 dB propagation losses
  0.5 dB antenna pointing
  1.3 dB duplexer, feeder losses
- Minimum Required Carrier Power at LNA Input = -111 dBW
- Earth Station Receiving Antenna Gain (3m paraboloid) = 36 dB
- Downlink EIRP = 50 dBW

NOTE:
- Assumes community reception.
- EIRP is limited by flux density limitation in the downlink band.

where D is in metres. An antenna gain of 40 dB (corresponding to a 3 dB beamwidth of 1.7°) will require a 5.2 m (17.2 ft.) diameter antenna. This implies that some form of deployable antenna, possibly similar to that used on ATS-F,* may be required to implement a broadcasting-satellite service at 2.5 GHz.

It should be noted that the downlink EIRP of the satellite is determined by a flux density limitation in the 2.5 - 2.69 GHz band. To meet this limit will require the use of energy dispersal to reduce the power in a 4 KHz band to acceptable levels. The amount of energy dispersal (ie, ratio of the power in a 4 KHz band-to-the unmodulated carrier power), is given by:

$$I_D = 10 \log \left(\frac{\Delta f_D}{4 kHz} \right) , dB \tag{5.2.4}$$

where Δf_D is the peak-to-peak deviation of the dispersal waveform. For a 2 MHz deviation the dispersal improvement is 27 dB, resulting in flux density at the center of the coverage area of:

$$F = (EIRP)_{SAT} - I_D - 162.6 \ dBW/m^2 \text{ in a } 4 \ kHz \text{ band.} \tag{5.2.5}$$

For elevation angles of 21 degrees, the flux density limit is -140 dBW/m^2 in any 4 kHz band. For 27 dB of energy dispersal, the maximum downlink EIRP is 50 dBW.

5.3 Intra-System Interference in the Auxiliary-Satellite System

The effects of spurious emissions from the spacecraft transmitter into the uplink auxiliary-satellite band at 2.655 - 2.69 GHz can be a potential problem in this service for such closely-spaced bands. To protect the spacecraft receiver from such emissions, a filter at the output of the HPA must be used to ensure that spurious emissions in the uplink band are reduced to an acceptable level. The other form of intra-system interference that must be considered occurs if intermodulation products are generated in the spacecraft LNA and fall in the uplink band, or if the LNA is saturated by the presence of strong signals in the downlink band. This mode of interference can be controlled by a filter in front of the LNA.

The level of spurious emissions occurring in the satellite receive band due to intermodulation distortion arising from multicarrier operation of the satellite HPA will now be estimated. For a global coverage system, the spacecraft antenna gain will be approximately 15 dB. From Figure 5.2/2, it can be seen that a downlink carrier power of approximately -6 dBW will be required, if 20m earth terminals are used.

For a satellite channel to handle 100 active carriers, a total output power of 14 dBW is required. A 200 watt TWT, operating at 9 dB output backoff will supply this power.

The carrier-to-IM ratio would be on the order of 25 dB in this case and the spectrum of IM products out-of-band would be approximately Gaussian in shape (Reference 5.3/1). As the uplink band is 120 MHz from the downlink band, and since the 100 active carriers would occupy approximately 6.25 MHz (ie, an activity factor of 0.4 and a carrier spacing of 25 kHz is assumed), then the IM spectrum should be down at least 40 dB, in the uplink band.

This is a conservative estimate, based on information presented in References 5.3/2 and 5.3/3 which suggest that the IM spectrum should fall off even more rapidly. However, it should be recognized that the actual IM spectrum roll-off will to some extent be device dependent and therefore can only be determined with any significant degree of accuracy when the actual satellite TWT characteristic is known.

For co-polarized receiving and transmitting antennas, the isolation that must be provided by the HPA output filter will now be estimated. This estimate is based on the assumption that the spurious emissions in the uplink band must be at least 10 dB below the receiver thermal noise level:

- Carrier Output Power = P_d, dBW/carrier
- IM Level in Receive Band = $P_d - 65$, dBW in a 16 kHz band
- Maximum Allowable IM = -164.8 dBW in a 16 kHz band

Isolation Required = $P_d + 100$, dB

For a carrier power of -6 dBW, an isolation of about 94 dB is required. Assuming that the 3-dB points of the output filter occur at the edges of the downlink band, a 5-pole Chebyshev filter would be required to provide the necessary isolation (i.e., a 5-pole Chebyshev filter provides 100 dB isolation at the lower edge of the uplink band, while a 4-pole filter provides 80 dB isolation). As this filter is not difficult to implement, this mode of interference should not impact the uplink and downlink frequency allocations.

The second mode of intra-system interference to be considered occurs in the LNA. Following the method described in Section 3.3, the isolation that must be provided by the satellite input filter can be estimated. Assuming an LNA gain of 40 and a third order intercept point of -10 dBW, the required isolation is approximately 90 dB (including an 8 dB margin to allow for the approximations made). As this isolation can be met with a 5th order Chebyshev filter, this mode of interference should not impact the use of these bands. This level of filtering will also ensure that the LNA is not operated near saturation.

The isolation required at the earth station, assuming a 15 dB spacecraft antenna gain and a 20 m earth station antenna, is approximately 110 dB for the HPA output filter and 95 dB for the receiver input filter. These isolations can be obtained with 6th and 5th order Chebyshev filters respectively. This type of filter, although possible, is difficult to implement. The problem would be simplified significantly if oppositely polarized uplink and downlink carriers are utilized, as an additional 30 dB of isolation could be obtained, reducing the complexity of the filters.

5.4 Inter-System Interference Between the Broadcasting and Auxiliary-Satellite Services at 2.5 GHz

5.4.1 Introduction

In the proposed frequency plan, the broadcasting-satellite service band at 2.5 GHz is shared by the uplink and downlink bands used by the auxiliary-satellite service. Several modes of interference are possible between these two services, including:

- Interference from a broadcast-satellite into an auxiliary-service satellite. Two geometric configurations can contribute to the problem. The first is that of adjacent satellites while the second occurs for satellites located in antipodal positions. This mode of interference is studied in Section 5.4.2.
- Interference from an auxiliary-service earth station into a broadcast-service earth station. This mode of interference is also studied in Section 5.4.2.
- Interference from a broadcast-satellite into an auxiliary-satellite earth station. This mode of interference is studied in Section 5.4.3.
- Interference from an auxiliary-satellite into a broadcast-service earth station. This mode of interference is also studied in Section 5.4.3.

5.4.2 Inter-System Interference in the 2.655 - 2.69 GHz Band

Inter-satellite interference between closely spaced satellites will be investigated first. For closely spaced satellites, the level of interference received in a 16 kHz band by the auxiliary-service satellite receiver is given by:

$$P_I = P_{TV} + G_T + G_R + 20\log\left(\frac{\lambda}{4\pi R_G \theta_S}\right) , \qquad (5.4.1)$$

where P_{TV} is the transmitted power of the broadcast TV signal in a 16 kHz band in the 2.655 - 2.69 GHz band (in dBW), G_T is the gain of the broadcast-satellite antenna (in dB), G_R is the gain of the auxiliary-satellite receiving antenna, R_G the radius of the geosynchronous orbit arc and θ_S is the inter-satellite spacing. Assuming that the peak-to-peak frequency deviation of the dispersal waveform used on the TV signal is 2 MHz, then in a 16 kHz band, the power of the TV carrier is reduced by 21 dB. For a 20 dBW satellite transmitter, the power in the auxiliary-satellite receiving band (16 kHz) is -1 dBW. The interference power at the input of the auxiliary-satellite's LNA is:

$$P_I = -158.7 + G_T + G_R - 20\log\theta_{S,deg} , \ dB . \qquad (5.4.2)$$

From Table 5.2/1, the received power of the auxiliary-satellite carrier is -129.8 dBW. The resulting C/I ratio is given by:

$$\left(\frac{C}{I}\right) = 28.9 - G_T - G_R + 20\log\theta_{S,deg} , \ dB . \qquad (5.4.3)$$

This ratio is plotted in Figure 5.4/1 for various values of the spacecraft antenna gains. The Figure indicates that this mode of interference may be a problem if the far sidelobe levels of the spacecraft

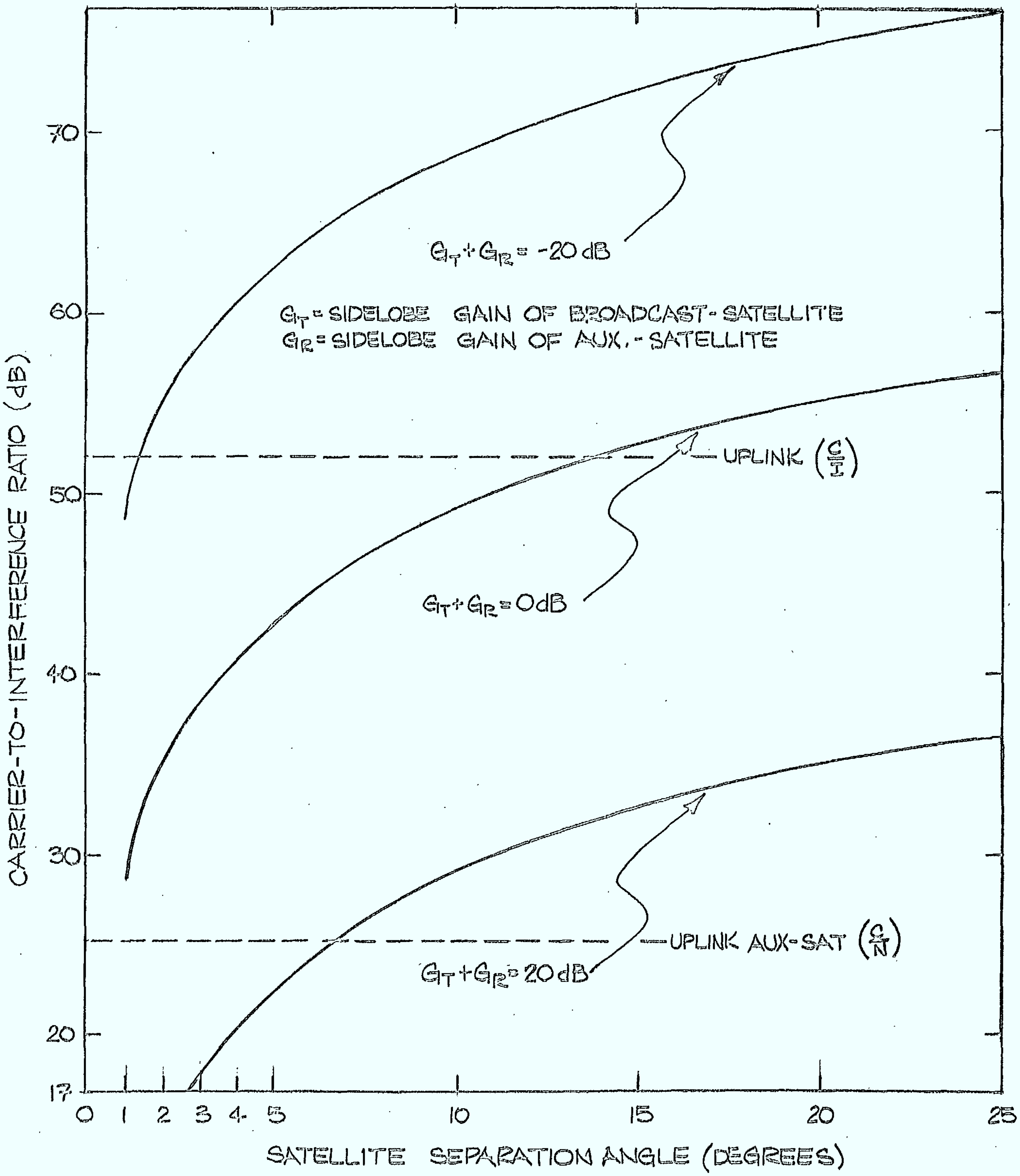


FIG. 5.4/1 C/I FOR AN AUXILIARY-SATELLITE UPLINK AT 2.5 GHZ (FM/TV INTERFERENCE FROM A BROADCASTING SATELLITE)

antenna are not carefully controlled. If values of -10 dB can be obtained, then the satellites could be spaced approximately 0.5 degrees apart, assuming an acceptable C/I on the order of 35 dB.

The second mode of inter-satellite interference occurs when the satellites are in antipodal positions. In this case, the interference power is given by:

$$P_I = P_{TV} + G_T + G_R + 20 \log \left(\frac{\lambda}{4\pi R_A} \right) , \tag{5.4.4}$$

where R_A is the nominal satellite separation (83000 km). The antenna gains can be much larger in this case than those experienced in the adjacent satellite situation. Assuming a downlink EIRP of 50 dBW for the broadcast-satellite, the C/I ratio is given by:

$$\left(\frac{C}{I} \right) = 31.8 + \Delta G_T + \Delta G_R - G_{o,R} \text{ , dB} \tag{5.4.5}$$

where ΔG_T is the discrimination of the broadcasting-satellite's antenna in the direction of the auxiliary-satellite, ΔG_R is the discrimination of the auxiliary-satellite antenna in the direction of the broadcasting-satellite, and $G_{o,R}$ is the on-axis gain of the auxiliary-satellite antenna.

In the worst case, ΔG_T and ΔG_R are 3 dB. For an auxiliary-satellite with an on-axis gain of 15 dB, the C/I ratio is 22.8 dB, indicating the severity of the problem in its worst case. To obtain a C/I ratio of 40 dB, the sum of the antenna discriminations would have to exceed 23.2 dB. This mode of interference could thus have a serious impact on the proposed sharing of the 2.655 - 2.69 GHz band.

The other mode of interference to be considered occurs when earth stations in the broadcasting-satellite service experience interference from the auxiliary-service earth station transmitters. This interference depends on the physical locations of the stations and on the uplink transmitter power. Assuming that the uplink carriers from an auxiliary-service earth station are spaced 25 kHz apart, and that at any time 40% are active, then in a 23 MHz band approximately 370 carriers may fall into the receiver bandwidth. The interference power received by the TV receiver is:

$$P_I = P_{up} + 10 \log(370) + G_T + G_R - L_b(1\% \text{ worst month}), \text{ dBW} \tag{5.4.6}$$

where L_b is the basic transmission loss between two isotropic antennas exceeded for 99% of the worst month (ie, approximately 99.75% of the time) and G_T and G_R are the gains of the antennas in the plane of the horizon. For a given C/I ratio, the basic transmission loss that must be exceeded is given by:

$$L_b = 136.7 + \left(\frac{C}{I}\right) + P_{up} + G_T + G_R \text{ , dB .} \tag{5.4.7}$$

For a 36 dB community reception antenna at a high-latitude location elevation angles as low as 5 degrees may be required. From equation 5.4.13, the maximum antenna gain in the plane of the horizon would be 12 dB. For an earth station in the auxiliary-satellite service, such low elevation angles would not be common and a value of 10 degrees minimum elevation is assumed giving a gain, G_T, of 7 dB in the plane of the horizon. For a 10 m station, uplink carrier powers of 7.6 dBW will be required (assuming a 15 dB spacecraft antenna gain). Substituting these values into equation 5.4.7 gives:

$$L_b = 162.4 + \left(\frac{C}{I}\right) \text{ , dB .} \tag{5.4.8}$$

From Reference 5.4/1 the basic transmission loss can be obtained as a function of site separation distance. For great circle paths, the transmission loss is plotted in Figure 5.4/2. To obtain a loss of 192 dB, which is required for a C/I ratio of 30 dB, the stations may have to be separated by more than 360 km. For separations less than this, coordination of the two services will be required.

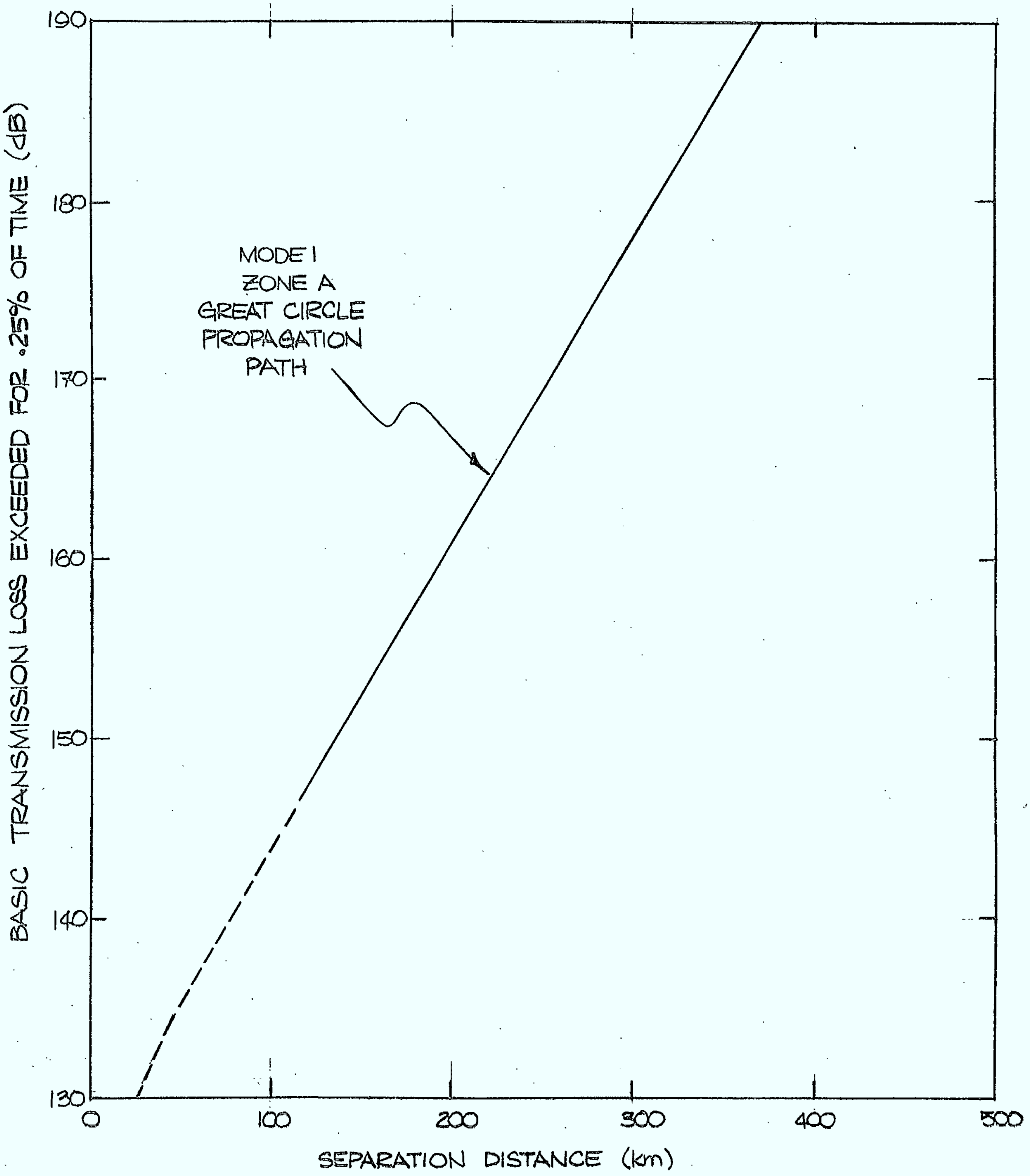


FIG. 5.4/2 BASIC TRANSMISSION LOSS EXCEEDED FOR ALL BUT .25% OF THE TIME AT 2.5 GHZ.

5.4.3 Inter-System Interference in the 2.5 - 2.535 GHz Band

Interference into the ground segment of the auxiliary-satellite service by a broadcasting-satellite will be considered first. The interference power received by an earth station in the auxiliary-satellite service located in the coverage zone of a broadcasting-satellite, assuming that both services use the same polarization, is given by:

$$\begin{aligned} P_I &= P_{TV} + G_{g,T} + (32 - 25 \log \varphi) - 193 \\ &= (50-21) + 32 - 25 \log \varphi - 193 \\ &= -132 - 25 \log \varphi \quad , \text{dBW} \end{aligned} \qquad (5.4.9)$$

where φ is the angle (in degrees) between the auxiliary-service earth station boresight and the broadcasting-satellite. Assuming that the received power of the auxiliary-service carrier is -138 dBW, the C/I ratio is given by:

$$\left(\frac{C}{I}\right) = -6 + 25 \log \varphi \quad , \text{dB} . \qquad (5.4.10)$$

It is evident that even for very large off-axis angles (ie, $\varphi \geqslant 48^{\circ}$, where the earth station gain is -10 dB), the C/I ratio is only 36 dB. As this ratio is 16 dB larger than that assumed for the downlink carrier-to-IM distortion noise ratio, this mode of interference should not affect the auxiliary-satellite service in this case. For smaller off-axis angles, corresponding to smaller satellite-separation angles, the C/I ratio decreases rapidly to values which would affect the operation of the auxiliary-satellite service. This ratio can be improved in a number of ways as follows:

- Coordinate the frequency plans of the two services so that co-channel operation does not occur.

- Coordinate the services so that the auxiliary-service earth stations do not operate in the same geographic area as broadcasting-satellite earth stations.

- Use orthogonal polarizations on the satellite downlinks of the two services (eg., RH circular on the broadcasting-satellite downlink and LH circular on the auxiliary-satellite downlink).

It is likely that combinations of the techniques listed, in addition to other sharing strategies, would have to be utilized to permit the sharing of the 2.5 - 2.535 GHz band by the two services.

Interference from the auxiliary-satellite into earth stations in the broadcast service is now considered. Assuming that carriers in the auxiliary-satellite downlink are spaced 25 kHz apart, and that at any time 40% are active, then in a 23 MHz band, there would be approximately 370 simultaneously active carriers. If each is transmitted at a power P_d, the total power received by a community TV receiver operating in the broadcasting-satellite service would be:

$$\begin{aligned} P_I &= P_d + 10 \log(370) + G_T + G_R - 193 \\ &= P_d + G_T + G_R - 167.3 \quad , \text{dBW} \end{aligned} \qquad (5.4.11)$$

where G_T is the downlink gain of the auxiliary-satellite antenna, and P_d is the transmitter power per carrier. Assuming that the minimum received power of the TV signal is -111 dBW, then the C/I ratio is given by:

$$\left(\frac{C}{I}\right) = 56.3 - P_d - G_T - G_R \quad , \text{dB} \; . \qquad (5.4.12)$$

The sidelobe gain of the community TV receive station, from Reference 5.4/2, is given by:

$$G_R = \max\left\{\begin{array}{l} G_{0,R} - 10.5 - 25 \log\left(\frac{\varphi}{\varphi_0}\right), \text{ dB} \\ 0 \text{ dB} \end{array}\right. \qquad (5.4.13)$$

where $G_{0,R}$ is the on-axis gain of the receiving station, φ is the off-axis angle, and φ_0 is the 3-dB beamwidth, given by:

$$\varphi_0 = 170 \left[10^{-0.05 G_{0,R}} \right], \text{ deg.} \qquad (5.4.14)$$

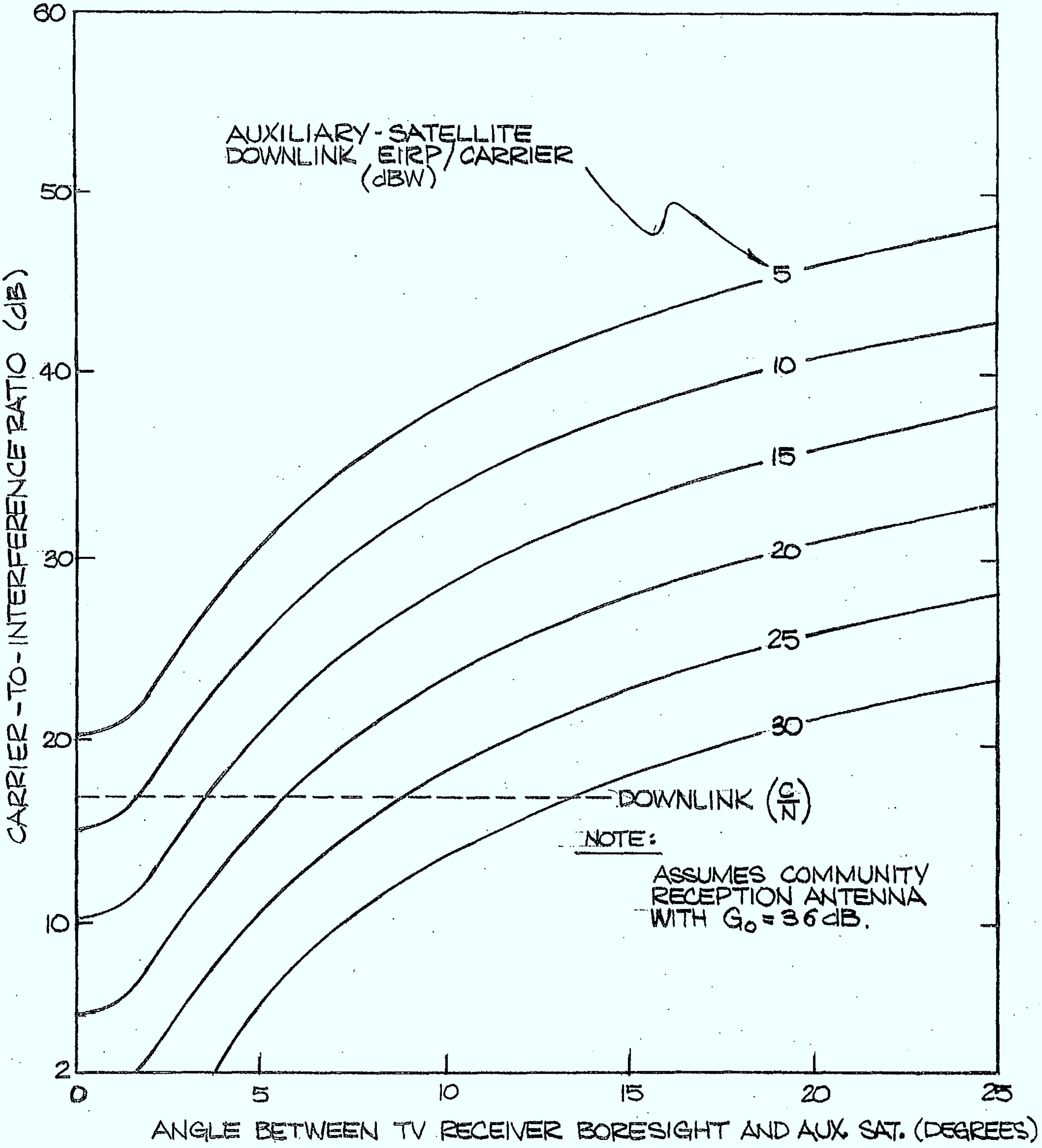
Substituting into equation 5.4.13 gives:

$$G_R = 47.3 - 0.25 G_{0,R} - 25 \log \varphi \text{ , dB} \qquad (5.4.15)$$

Replacing the term $P_d + G_T$ in equation 5.4.12 by the per carrier auxiliary-satellite EIRP and substituting equation 5.4.15 into 5.4.12 gives:

$$\left(\frac{C}{I}\right) = 11 - (EIRP)_{SAT} + 0.25 G_{0,R} + 25 \log \varphi \text{ , dB.} \qquad (5.4.16)$$

This equation is plotted in Figure 5.4/3 for a community broadcast receiving station with an on-axis gain of 36 dB. An auxiliary-satellite service downlink EIRP of 14.4 dBW would be required if 10m antennas are used in the auxiliary-service earth station. In this case, the satellites would have to be separated such that at least a 12 degree off-axis angle is obtained at the TV receiving station for a C/I ratio of 30 dB. If 20m antennas are used, the EIRP per carrier can be reduced to 8 dBW and the off-axis angle to 7 degrees for the same C/I performance.



NOTE:

ASSUMES COMMUNITY RECEPTION ANTENNA WITH $G_0 = 36$ dB.

FIG. 5.4/3 $\left(\frac{C}{I}\right)$ RATIOS FOR INTERFERENCE FROM AUX. SAT. DOWNLINK INTO COMMUNITY TV RECEIVER IN 2.5 GHZ. BAND

This mode of interference is much less severe however than the interference into an auxiliary-service earth station and it will be this mode which will put the most severe constraints on the sharing of the downlink bands.

5.5 Summary

In this chapter, the sharing of frequency bands near 2.5 GHz by the auxiliary-satellite and broadcasting-satellite services was investigated. It was found that intra-system interference in the auxiliary-satellite and earth stations can be controlled relatively easily and should not impact the proposed band allocations.

Inter-system interference between the broadcasting-satellite service and the auxiliary-satellite service can be quite extensive in these bands however. It was found that in the 2.5 - 2.535 GHz auxiliary-satellite downlink band, the following interference problems can exist:

- INTERFERENCE INTO AUXILIARY-SERVICE EARTH STATIONS
  Downlink emissions from a broadcasting-satellite can create intolerable levels of interference at an auxiliary-service earth station. Some form of sharing strategy, possibly involving frequency coordination and orthogonal polarizations for the two services, will be required to permit the sharing of this band.

- INTERFERENCE INTO BROADCAST RECEIVER
  Downlink emissions from an auxiliary-service satellite can cause unacceptable levels of interference at a community broadcast receiving station. The levels of interference can be reduced to acceptable levels by separating the satellites by 7 to 12 degrees.

In the proposed auxiliary-service uplink band from 2.655 - 2.69 GHz, it was found that two modes of interference can exist that may restrict the sharing of the band:

- INTERFERENCE INTO AUXILIARY-SERVICE SATELLITE
  Emissions from a nearby broadcasting-satellite can require satellite separations on the order of 0.5 to 5 degrees depending primarily on the far sidelobe patterns of the spacecraft antennas.

Satellites located in near antipodal positions can result in intolerable levels of interference at the auxiliary-service satellite depending on the spacecraft antenna gains in the direction of one another. This interference can be reduced to acceptable values by controlling the antenna discrimination of both satellites.

INTERFERENCE INTO BROADCAST RECEIVER

Emissions from earth stations in the auxiliary-satellite service may cause objectionable interference at a community broadcast receiver. In the worst case, station separations on the order of 360 km may be required to allow sharing of the band. For stations separated by less than this amount, coordination of the two services may be required.

REFERENCES

5.2/1 "Broadcasting-Satellite Service: Sound and Television-Frequency-Sharing Between the Broadcasting Satellite Service and Terrestrial Services", CCIR Draft Report 631 - 1, DOC, 10-11/1106-E, 16 March, 1978, Kyoto.

5.2/2 "Broadcasting-Satellite Service", CCIR XIVth Plenary Assembly, DOC. 010-11/1114-E, 16 March, 1978, Kyoto.

5.3/1 "Calculation of Intermodulation Due to Amplitude Limiting of Multiple Carriers', C.R. Cahn, IEEE Trans. Comm. Tech., December, 1968.

5.3/2 "SCPC Satellite Telephony With 4-D Coded Quadrature Amplitude Modulation", G.R. Welti, COMSAT Technical Review, Vol. 7, No. 1, Spring 1977.

5.3/3 "UHF-SHF Satellite Communications Link Calculations", Study Contract Co. PL 3600-4-00995 for DOC, Canada, by Bell Northern Research, July, 1975.

5.4/1 "Determination of Coordination Area", DOC 4-9/1112-E, 28 March, 1978, CCIR, Kyoto.

5.4/2 "Broadcasting-Satellite Service: Sound and Television-Frequency-Sharing Between the Broadcasting Satellite Service and Terrestrial Services", CCIR Draft Report 631-1, DOC 10-11/1106-E, 16 March, 1978, Kyoto.

6.0 FIXED-SATELLITE BANDS AT 4.4 - 4.7 GHz

6.1 Introduction

In Region 2, the 4.4 - 4.7 GHz band is allocated as an uplink band for domestic fixed-satellite systems. A requirement by the international fixed-satellite service for a downlink band in the same frequency range is investigated in this chapter. The feasibility of sharing this band will depend on the levels of inter-system interference. The following co-channel interference modes are investigated:

- Satellite-to-satellite in which interference from closely spaced and antipodal satellites may occur.

- Earth station-to-earth station, in which indirect (i.e., rain scatter) propagation modes exist, and hence interference may occur.

6.2 System Characteristics

The uplink carrier is assumed to be an FM/TV carrier feeding a broadcast-satellite. The characteristics of this link, summarized in Table 6.2/1, are based on the recommendations in Reference 6.2/1 and are consistent with those used in Reference 6.2/2.

The earth station EIRP required to provide a minimum received carrier power of -96 dBW at the input to the satellite LNA is given by:

$$(EIRP)_{up} = -95\text{ dBW} - \left[(G_{0,SAT} - 3\text{ dB}) - (L_{\text{FREE SPACE}} + L_{\text{LINK}}) \right] \qquad (6.2.1)$$

$$= -95\text{ dBW} - G_{0,SAT} + 202.9 \qquad (6.2.2)$$

$$= 107.9 - G_{0,SAT}\text{, dBW.}$$

The earth station on-axis gain G_0, is given by

$$G_0 = 10 \log \left[\eta \left(\frac{\pi D}{\lambda} \right)^2 \right], \quad \text{dB} \qquad (6.2.3)$$

where η is the aperture efficiency ($\simeq 0.54$), D is the antenna diameter, and λ is the wavelength. Substituting (6.2.3) into (6.2.2) and rearranging gives the minimum required uplink transmitter power for the FM/TV carrier:

$$P_{up} = 77.5 - G_{0,SAT} - 20 \log D\text{, dBW} \qquad (6.2.4)$$

where D is in metres. This equation is plotted in Figure 6.2/1 for a range of spacecraft antenna gains and earth station diameters.

TABLE 6.2/1: Characteristics of an FM/TV Uplink in 4.4 - 4.7 Band

- Carrier: FM/TV
- Bandwidth: 23 MHz
- Required Uplink C/N = 27 dB, exceeded at least 99.9% of time
- Free Space Loss = 197 dB
- Uplink Clear Weather Attenuation = 0.2 dB
- Rain Attenuation = 0.7 dB, exceeded no more than 0.1% of the time
- Feeder, Duplexer, Pointing Losses = 2 dB
- Total Link Margin = 2.9 dB
- Uplink Noise Temperature = 2000 K
- kTB = -122 dBW
- Minimum Required Carrier Power at LNA Input = -95 dBW
- Satellite Antenna Gain Range = 15 to 40 dB
- Earth Station EIRP Range = 92.3 to 67.3 dBW

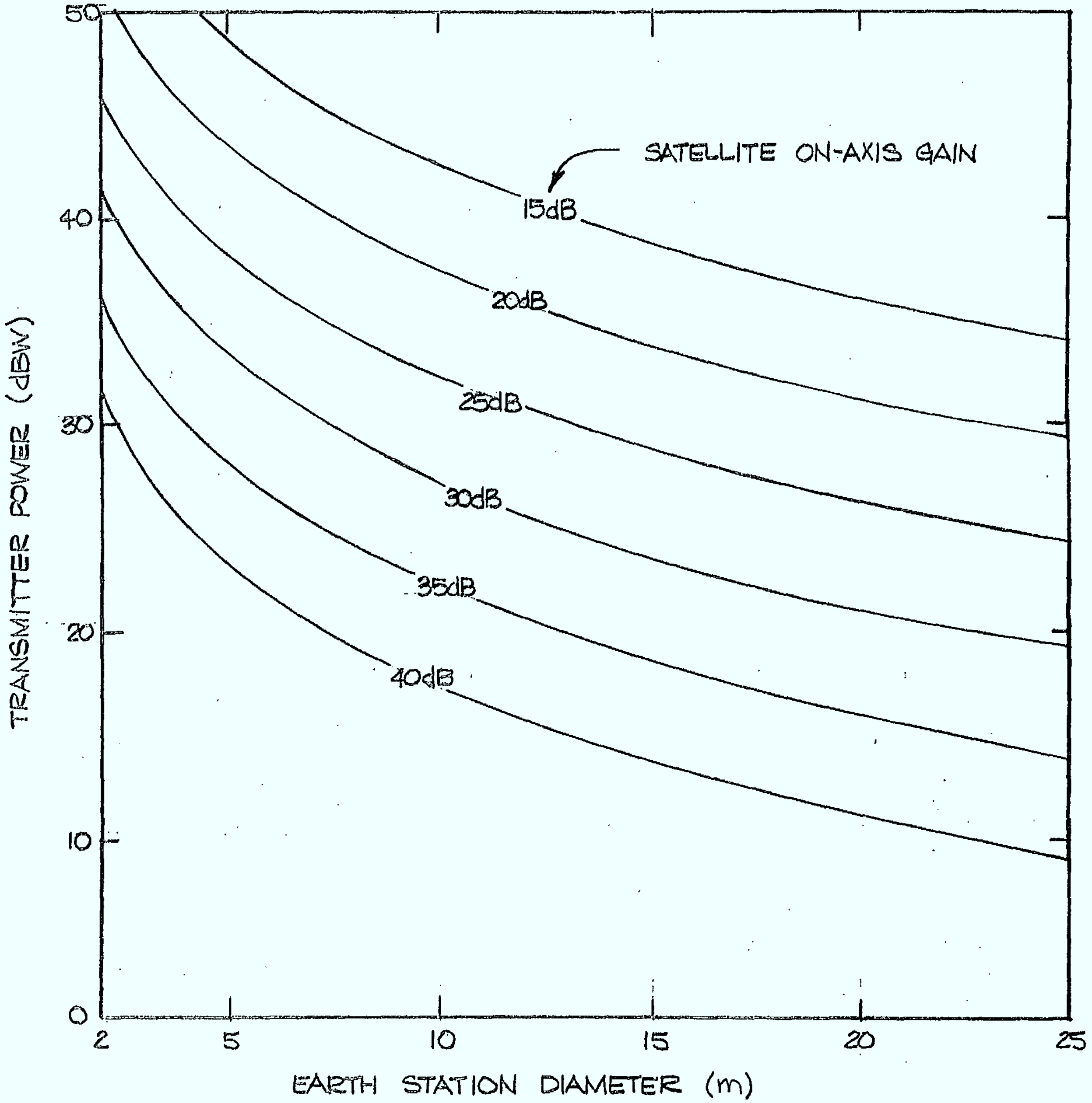


FIG. 6.2/1 MINIMUM UPLINK TRANSMITTER POWER FOR AN FM/TV CARRIER IN 4.4 - 4.7 GHZ BAND

The downlink traffic in the other fixed-satellite system can consist of a variety of carriers including high-capacity FDM/FM telephony, FM/TV, digital voice and data, etc.. Two carriers are considered in this study. The first is a high capacity 960 channel telephone carrier, while the second is a low capacity 24 channel telephone carrier. The characteristics of these downlinks are summarized in Table 6.2/2. The values used are typical of INTELSAT-type carriers and values used in Reference 6.2/2. The downlink satellite EIRP required to provide the minimum signal quality at the edge of the coverage zone is given by:

$$(EIRP)_{SAT} = P_{R,MIN} - G_{0,E} + 203.3 \text{ , dBW .} \qquad (6.2.5)$$

Using equation 6.2.3 for the earth station antenna gain and rearranging equation 6.2.5 gives the satellite transmitter power required for each downlink carrier:

$$P_d = 172.9 + P_{R,MIN} - 20 \log D - G_{0,SAT} \text{, dBW} \qquad (6.2.6)$$

For a global coverage system, the satellite on-axis gain could be as low as 16 dB, requiring a downlink transmitted carrier power of 10 dBW to a 6 m station for the 24 channel carrier, and 13 dBW to a 30 m station for the 960 channel carrier.

TABLE 6.2/2: Characteristics of Fixed-Sat. Downlink in 4.4 - 4.7 GHz Band

CARRIER: 24 Channel FDM/FM

Bandwidth = 2 MHz

Required Downlink C/N = 13 dB, exceeded at least 99.99% of the time

Link Margin = 3 dB, exceeded no more than 0.01% of the time

Earth Station LNA Noise Temp. = 70 K

Antenna Feeder Loss = 0.5 dB

Antenna Temperature = 50 K

System Noise Temperature = 152 K

kTB = -144 dBW

Minimum Required Carrier Power at LNA Input = -131 dBW

CARRIER: 960 Channel FDM/FM

Bandwidth = 36 MHz

Required Downlink C/N = 18.4 dB, exceeded at least 99.99% of the time

Link Margin = 3 dB, exceeded no more than 0.01% of the time

Earth Station LNA Noise Temp. = 30 K

Antenna Feeder Loss = 0.5 dB

Antenna Temperature = 50 K

System Noise Temp. = 110 K

kTB = -133 dBW

Minimum Required Carrier Power at LNA Input = -114.6 dBW

6.3 Interference Between Satellites

The first mode of inter-satellite interference to be studied involves closely spaced satellites, in which the downlink carriers interfere with the FM/TV uplink. The level of received interference power P_I, at the LNA input is given by:

$$P_I = P_d + G_T + G_R + 20 \log \left(\frac{\lambda}{4\pi R_G \theta_S} \right) , \ dBW \qquad (6.3.1)$$

where P_d is the downlink carrier power in a 23 MHz band, G_T and G_R are the spacecraft antenna gains in the direction of one another, R_G is the radius of the orbit arc, and θ_S is the inter-satellite spacing.

The antenna gain pattern recommended by the CCIR for spacecraft antennas (Reference 6.3/1) is shown in Figure 6.3/1. Typically for satellites with separations less than 10^0, the off-axis angle for adjacent satellite interference will be greater than 80 degrees and the antenna gains will be on the order of 0 dB or less. Figure 6.3/2 shows the received interference power as a function of satellite separation for 0 dB antenna gains.

The minimum uplink FM/TV carrier power at the satellite receiver is -95 dBW. If the permissible interference level is 10 dB below the uplink thermal noise level, i.e., -132 dBW, the resulting C/I ratio will be 37 dB. For downlink carrier powers less than 10 dBW, a satellite spacing of 0.15 degrees would suffice. However, in Reference 6.2/2, a value of C/I of 45 dB was used in a similar analysis. The satellite spacing in this case must exceed 0.3 degrees. If the spacecraft antenna gains exceed 0 dB in the direction of one another, then the satellite spacing must be increased. If a C/I ratio of 45 dB is used, and the sum of the antenna gains is increased by 10 dB, the minimum spacing increases to 1 degree (for a 10 dBW downlink carrier). As the uplink and downlink are intended for domestic and international systems, respectively, this mode of interference should not impact Canada's use of the 4.4 - 4.7 GHz band.

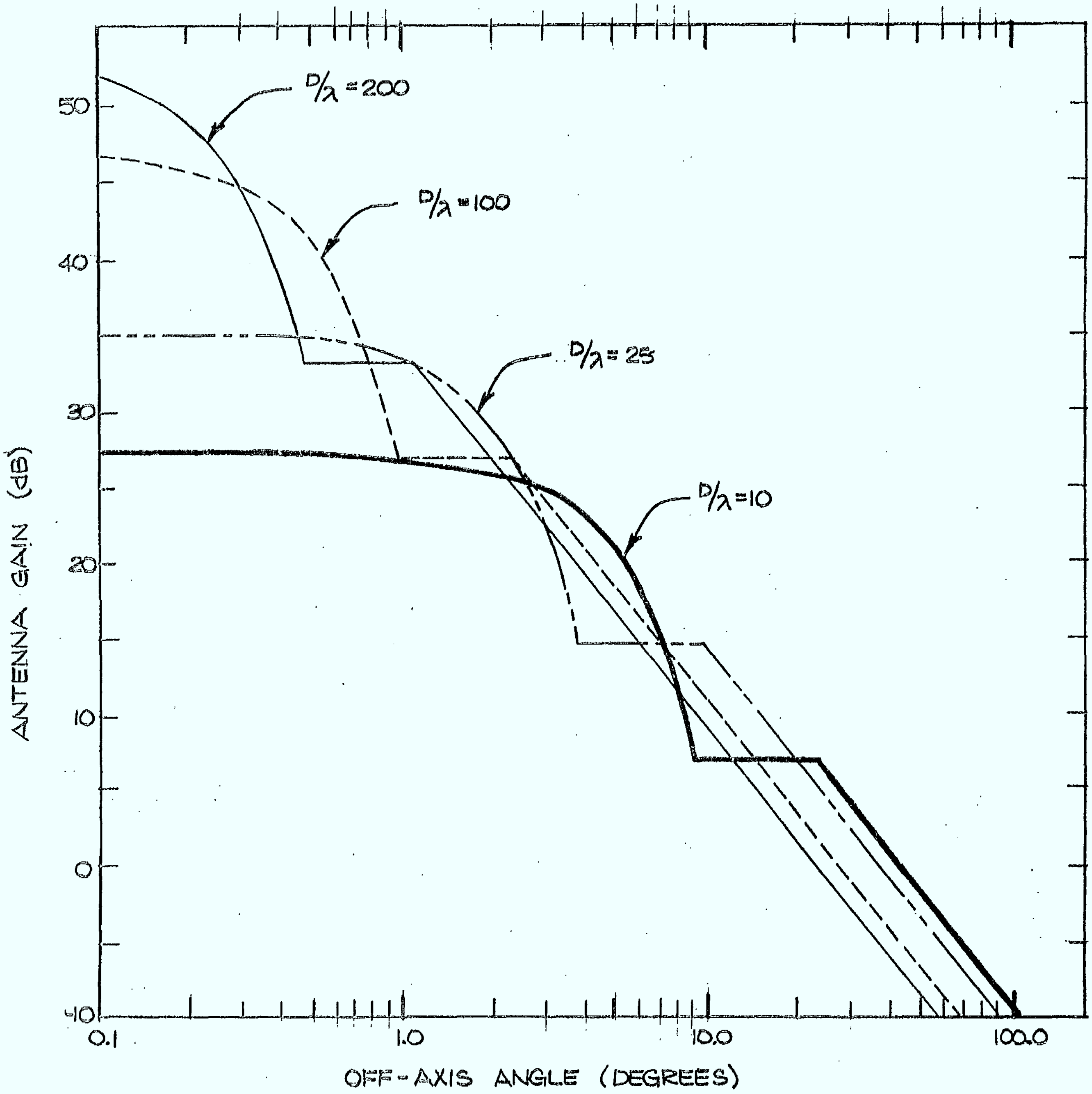


FIG. 6.3/1 CCIR SATELLITE ANTENNA PATTERN

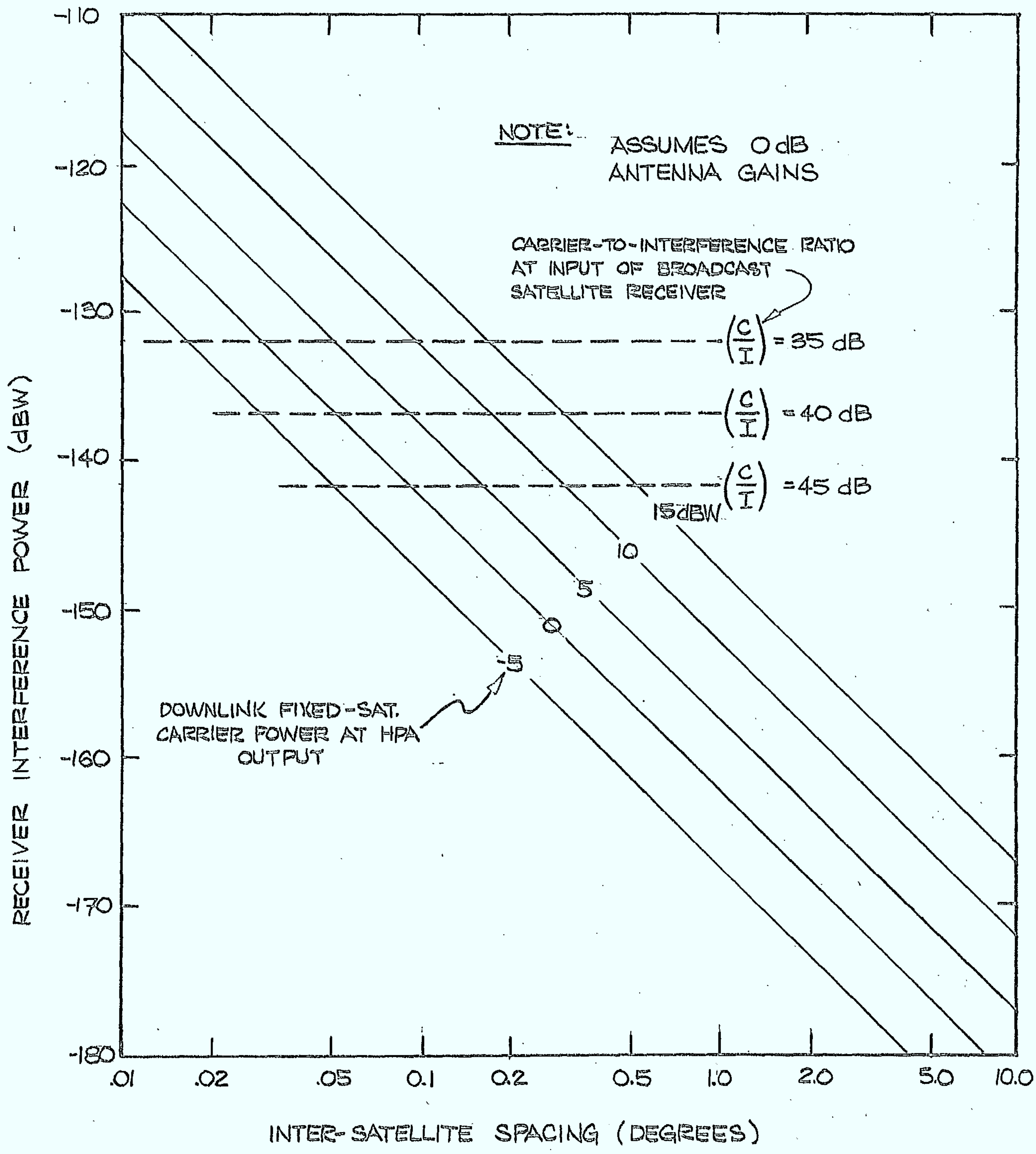


FIG. 6.3/2 INTERFERENCE POWER AT BROADCAST-SAT. RECEIVER FROM A COCHANNEL DOWNLINK CARRIER ON A CLOSELY SPACED SATELLITE IN 4.4-4.7 GHz BAND.

The other inter-satellite interference mode occurs when the two satellites are located in near-antipodal positions. The interference power at the uplink receiver is given by:

$$P_I = P_d + G_T + G_R + 20\log\left(\frac{\lambda}{4\pi R_A}\right) \quad , dBW \qquad (6.3.2)$$

where R_A is the satellite separation distance (83000 km).

In a worse case situation, it is assumed that G_T and G_R are only 3 dB down from their respective on-axis gains. Denoting ΔG_R and ΔG_T as the discriminations of the receiving and transmitting antennas respectively, then

$$P_I = (EIRP)_{SAT} - (\Delta G_T + \Delta G_R) + G_{0,R} - 203.5 \quad , dBW \qquad (6.3.3)$$

where $G_{o,R}$ is the on-axis gain of the broadcasting-satellite antenna.

This equation is plotted in Figure 6.3/3 for a 44.5 dB (1 degree beamwidth) spacecraft receiving antenna gain. This gain could be obtained with a 16 foot diameter antenna operating at 4.5 GHz, and probably represents an upper limit for commercial use in this band.

Assuming that the maximum permissible interference from an antipodal satellite results in an uplink C/I of 45 dB, then in the worst case, for downlink EIRP's in excess of 25 dBW, this limit may be exceeded. However, if the spacecraft antenna gains in the antipodal position are decreased by more than 3 dB from their on-axis values, higher EIRP's can be tolerated. Similarly, if the minimum C/I ratio is decreased from 45 dB to 35 dB, higher EIRP's could also be tolerated. It should also be noted that typical downlink EIRP's for INTELSAT-type carriers (960 voice channels) are on the order of 24 dBW. As a result, systems with characteristics similar to the existing fixed-satellite systems should not impair the operation of a broadcast-

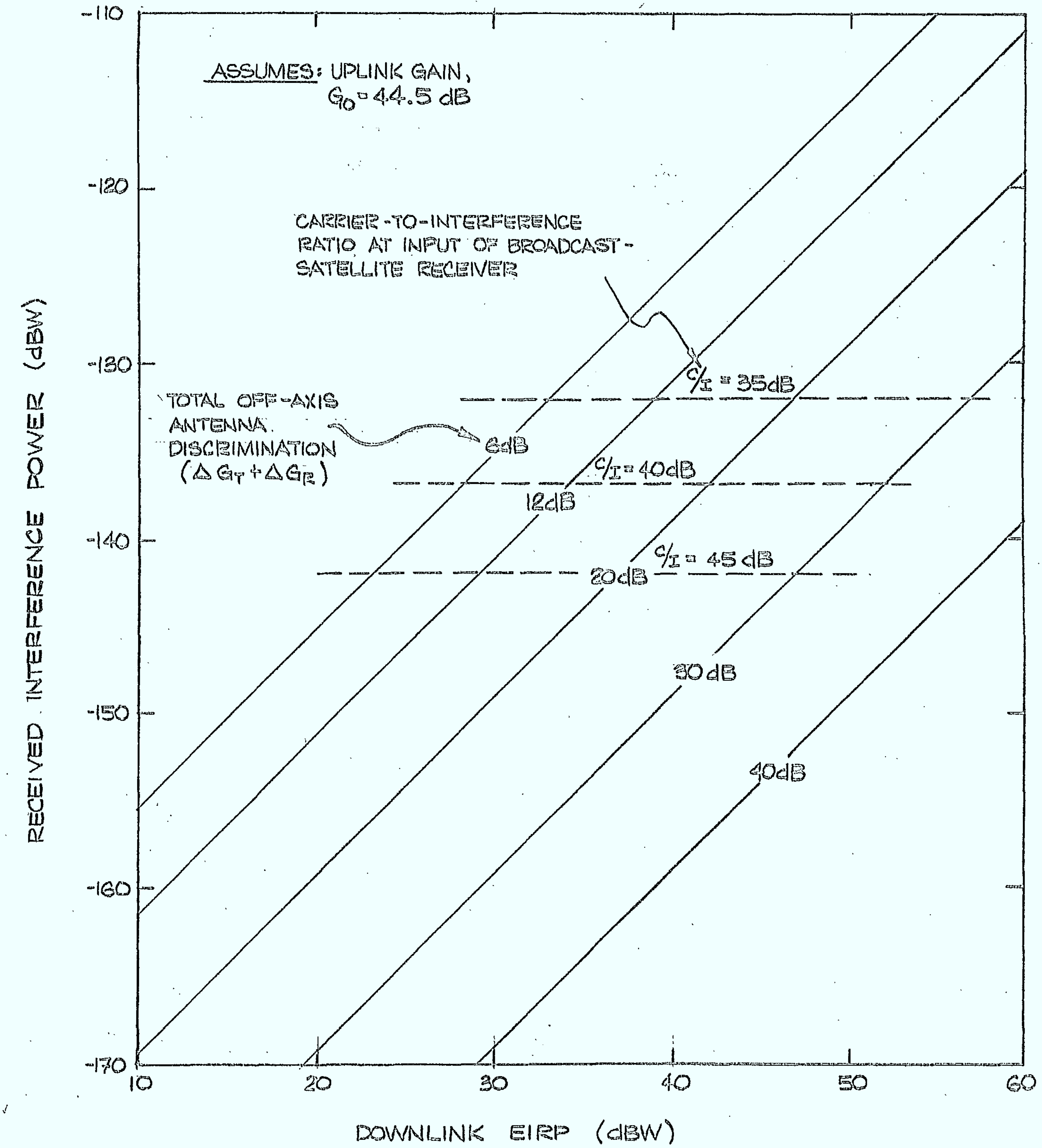


FIG. 6.3/3 ANTIPODAL SATELLITE (FIXED-SAT.) INTERFERENCE INTO BROADCASTING-SAT. IN 4.4 - 4.7 GHZ. BAND

satellite feeder link in the 4.4 - 4.7 GHz band. In general, however, coordination of the satellites could be required, particularly if high gain spot beam antennas are used.

6.4 Interference Between Earth Stations

In this case, emissions from an earth station transmitting an FM/TV carrier to a broadcast-satellite may cause interference at a downlink fixed-satellite earth station. The interference power P_I, into the earth station receiver, exceeded for less than 0.01% of the time is given by:

$$P_I = P_{up} + G_T + G_R - L_b(0.01\%) \quad , \text{dBW} \qquad (6.4.1)$$

where P_{up} is the uplink transmitter power, G_T and G_R are the maximum horizon gains of the two earth stations, and L_b (0.01%) is the basic transmission loss between two physically separated isotropic antennas which is not exceeded for 0.01% of the time. This loss is plotted in Figure 6.4/1 (from Reference 6.4/1) as a function of separation distance. The transmission loss, L_T, defined as the ratio of received to transmitted power, is given by:

$$L_T = L_b(0.01\%) + G_T + G_R \quad , \text{dB} . \qquad (6.4.2)$$

For the two downlink carriers considered (24 and 960 channel FDM/FM) a maximum permissible interference power level exists. Thus for a given FM/TV uplink power, a minimum permissible transmission loss can be defined. For the 24 channel FDM/FM downlink it is assumed that all of the power of the interfering FM/TV carrier can fall into the 2 MHz band and hence

$$L_{min} = P_{up} - \left[-131 - \left(\frac{C}{I}\right)\right] \quad , \text{dB} . \qquad (6.4.3)$$

If it is assumed that for 99.99% of the time the C/I ratio must exceed 23 dB (i.e., 10 dB higher than the carrier-to-thermal noise ratio), then

$$L_{min} = P_{up} + 154 \quad , \text{dB} . \qquad (6.4.4)$$

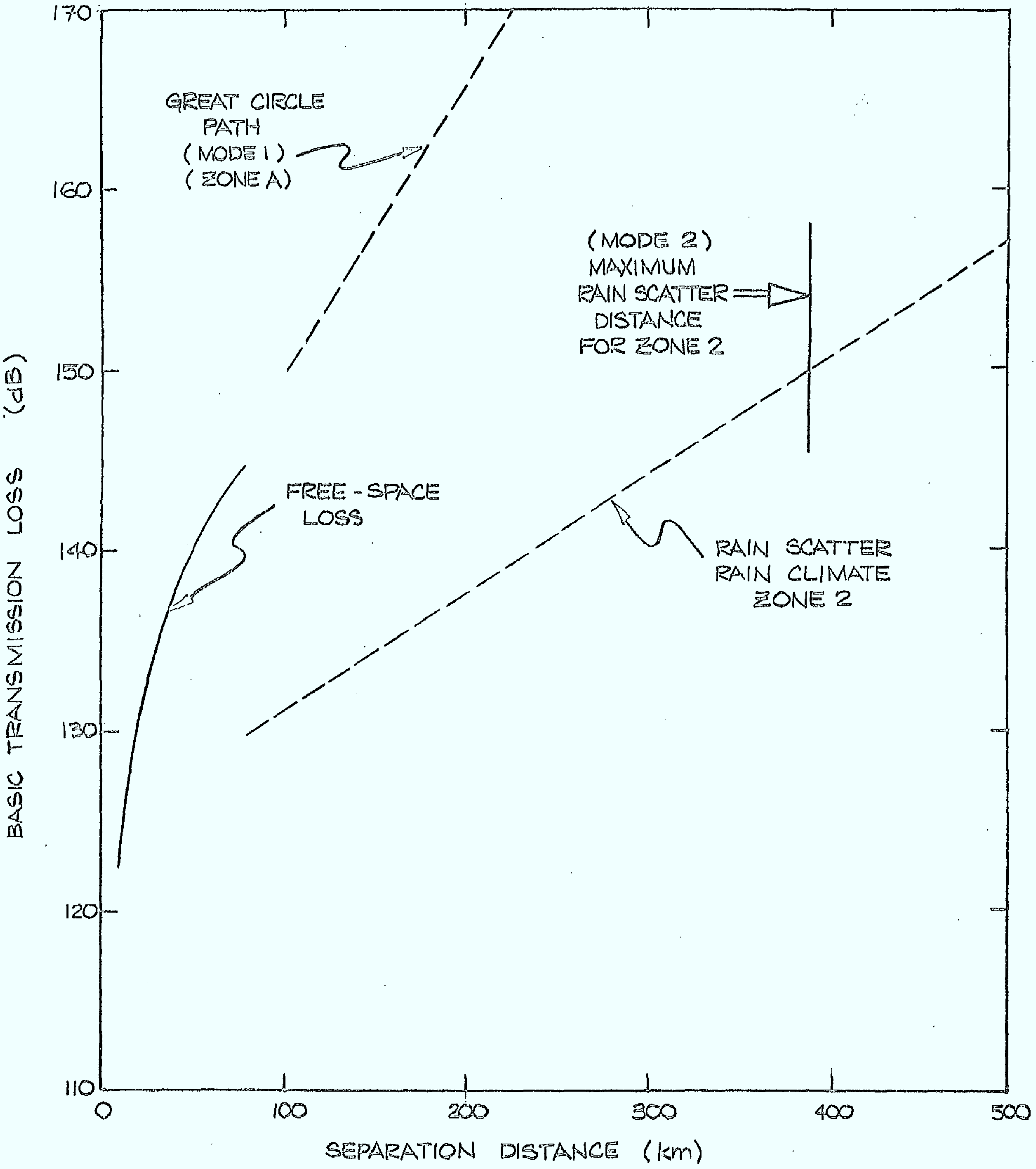


FIG. 6.4/1 TRANSMISSION LOSS BETWEEN ISOTROPIC ANTENNAS AT 4.5 GHz EXCEEDED FOR 0.01% OF TIME

The basic transmission loss must exceed

$$L_{b,min}(0.01\%) = P_{up} + 154 + G_T + G_R \text{ , dB .} \qquad (6.4.5)$$

As shown in Figure 6.2/1, the uplink transmitter power may range from 10 to 30 dBW. For various antenna gains G_T and G_R, the corresponding minimum basic transmission loss is given in Table 6.4/1 as a function of the uplink transmitter power. From Figure 6.4/1, it is evident that the minimum transmission losses given in Table 6.4/1 correspond to station separation distances ranging from 100 to 400 km. As a result, coordination between the uplink and downlink stations will be required if they are separated by less than the distance corresponding to the minimum basic transmission loss. In general, the Mode 1 (tropospheric great circle propagation) curve shown in Figure 6.4/1 will apply. The rain scatter curve (Mode 2) represents a pessimistic estimate of the expected transmission loss since it is based on the simultaneous intersection of the antenna mainbeams within a rain cell. Such a situation is highly unlikely for two largely separated earth stations.

The other downlink carrier to be considered is the 960 channel FDM/FM carrier. For a C/I ratio of 28.4 dB the minimum basic transmission loss which must be exceeded is:

$$L_{b,min}(0.01\%) = P_{up} + 143 + G_T + G_R \text{ , dB .} \qquad (6.4.6)$$

Values of $L_{b,\ Min}$ (0.01%) are given in Table 6.4/2. For the same uplink power and antenna gains, the transmission loss is 11 dB less in this case than for the 24 channel FDM/FM carrier, illustrating the fact that narrow-band carriers are more susceptible to interference and hence more difficult to coordinate.

TABLE 6.4/1: Minimum Basic Transmission Loss Required to Protect a 24 Channel FDM/FM Downlink
P = 0.01% percentage of time

Uplink TX Power (dBW)	Basic Transmission Loss (dB)		
	$G_T + G_R = -20$dB	$G_T + G_R = 0$dB	$G_T + G_R = 14$ dB*
5	139	159	173
10	144	164	178
15	149	169	183
20	154	174	188
25	159	179	193
30	164	184	198
35	169	189	203

* NOTE: For 10 degree elevation angle the maximum antenna gain in the horizon plane is:
$G = 32 - 25 \log (10) = 7$ dB, so $G_T + G_R = 14$ dB

TABLE 6.4/2: Minimum Basic Transmission Loss Required to Protect a 960 Channel FDM/FM Downlink

P = 0.01% = percentage of time

Uplink TX Power (dBW)	Basic Transmission Loss (dB)		
	$G_T + G_R$ = -20 dB	$G_T + G_R$ = 0 dB	$G_T + G_R$ = 14 dB
5	128	148	163
10	133	153	168
15	138	158	173
20	143	163	178
25	148	168	183
30	153	173	188
35	158	178	193

6.5 Summary

Inter-system interference between two fixed-satellite systems sharing uplink and downlink bands has been examined in this chapter. Two modes of inter-satellite interference were investigated. Both adjacent satellite and antipodal satellite geometries were considered. It was found that the minimum inter-satellite spacing is in the range 0.15 to 1 degree, depending on the downlink carrier power. In the case of antipodal satellites, it was found that the fixed-satellite may in some cases cause excessive interference into the broadcasting-satellite if the spacecraft antenna gains beyond the earth's limb are not controlled. In general however, the inter-satellite interference problem is not as severe as the earth station interference problem.

For typical uplink transmitter powers, it was found that coordination contours on the order of several hundred kilometers can be expected, requiring coordination of earth station locations, frequency plans, power levels, etc. , between the two systems.

REFERENCES

6.2/1 "Broadcast-Satellite Service", DOC. 10-11/1114-E, 16 March, 1978, CCIR XIVth Plenary Assembly, Kyoto.

6.2/2 "Study For the SPM On Frequency Band Sharing Between The Fixed And Broadcasting Satellite Services", DOC. SPM/4/42-1, CCIR Study Groups, SPM, Geneva, 1978.

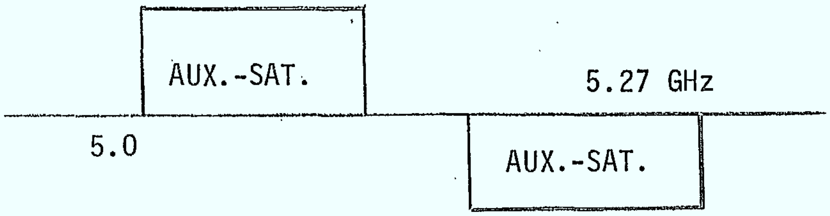
6.3/1 "Spacecraft Antenna Patterns In The Fixed-Satellite Service", CCIR Report AJ/4, Geneva 1972.

6.4/1 "Determination of Coordination Area", Doc. 4-9/1112-E, 28 March, 1978, CCIR, Kyoto.

7.0 AUXILIARY-SATELLITE BANDS NEAR 5 GHz

7.1 Introduction

In this chapter, the proposed use of the 5.0 - 5.27 GHz band by the auxiliary-satellite service to provide links between earth stations at fixed locations and satellites in the mobile-satellite service is investigated. The proposed frequency plan is shown below:



The maximum usable uplink and downlink bandwidths available in this band depend on the levels of intra-system interference in the spacecraft. As such, the interference problem is very similar to that investigated in Chapter 3. In this chapter, the maximum usable bandwidths and their separation is studied using many of the analysis techniques and equations given in Chapter 3.

7.2 System Characteristics

The uplink and downlink system characteristics and performance requirements used in the analysis are summarized in Tables 7.2/1 and 7.2/2. These values are similar to those used in Chapter 12, with the exceptions of propagation margins and noise temperatures to reflect the difference in frequency.

The downlink transmitted carrier power required to maintain a C/N of 25 dB (at least 99% of the time) at the edge of the earth coverage zone of the satellite is given by:

$$P = 66 - G_{0,SAT} - G_{0,E} \text{ , dBW} \tag{7.2.1}$$

where $G_{0,\ SAT}$ is the on-axis gain of the satellite transmitting antenna, and $G_{0,E}$ is the receiving earth station's on-axis gain. This gain can be expressed in terms of the earth station diameter using

$$G_0 = 10 \log \left(\eta \left(\frac{\pi D}{\lambda} \right)^2 \right) \text{ , dB} \tag{7.2.2}$$

where η is the aperture efficiency (≈ 0.54). The downlink carrier power, P_d is given by

$$P = 34.3 - G_{0,SAT} - 20 \log D \text{ , dBW} \tag{7.2.3}$$

where D is the earth station diameter (in metres). This equation is plotted in Figure 7.2/1 for a range of D and $G_{0,\ SAT}$. Comparison with equation 12.2.2 indicates that in the 5 - 5.27 GHz band, satellite transmitter powers 8 dB lower can be used than in the 15 GHz band for the same size satellite and earth station antenna.

TABLE 7.2/1 Characteristics of the Auxiliary-Satellite Uplink at 5 GHz

. Carrier: Narrowband Voice or Digital Data	
Bandwidth	= 16 kHz
. Required Uplink	= 25 dB, exceeded at least 99% of the time
. Free Space Loss	= 198 dB
. Clear Weather Tropospheric Absorption	= 0.2 dB
. Feeder, Duplexer, Pointing Loss	= 2.5 dB
. Rain Attenuation	= 0.3 dB, 1% of time
. Total Link Margin	= 3.0 dB
. Uplink Noise Temperature	= 1000 K
kTB	= -153.5 dBW
. Minimum Required Carrier Power at LNA Input	= -128 dBW

Note: C/N is the carrier-to-thermal noise ratio.

TABLE 7.2/2 Characteristics of the Auxiliary-Satellite Downlink at 5 GHz

- Bandwidth = 16 kHz
- Required Downlink C/N = 25 dB, exceeded at least 99% of the time
- Carrier-to-IM Ratio = 20 dB
- Free Space Loss = 198 dB
- Clear Weather Tropospheric Absorption = 0.2 dB
- Rain Attenuation = 0.3 dB, 1% of time
- Feeder, Duplexer, Pointing Losses = 2.5 dB
- Total Downlink Margin = 3 dB
- Antenna Noise Temperature = 100 K
- Antenna Insertion Loss = 0.5 dB
- Earth Station LNA Noise Temp. = 75 K
- Downlink Noise Temperature = 196 K

kTB = -163.6 dBW

- Minimum Required Carrier Power at LNA Input = -138 dBW

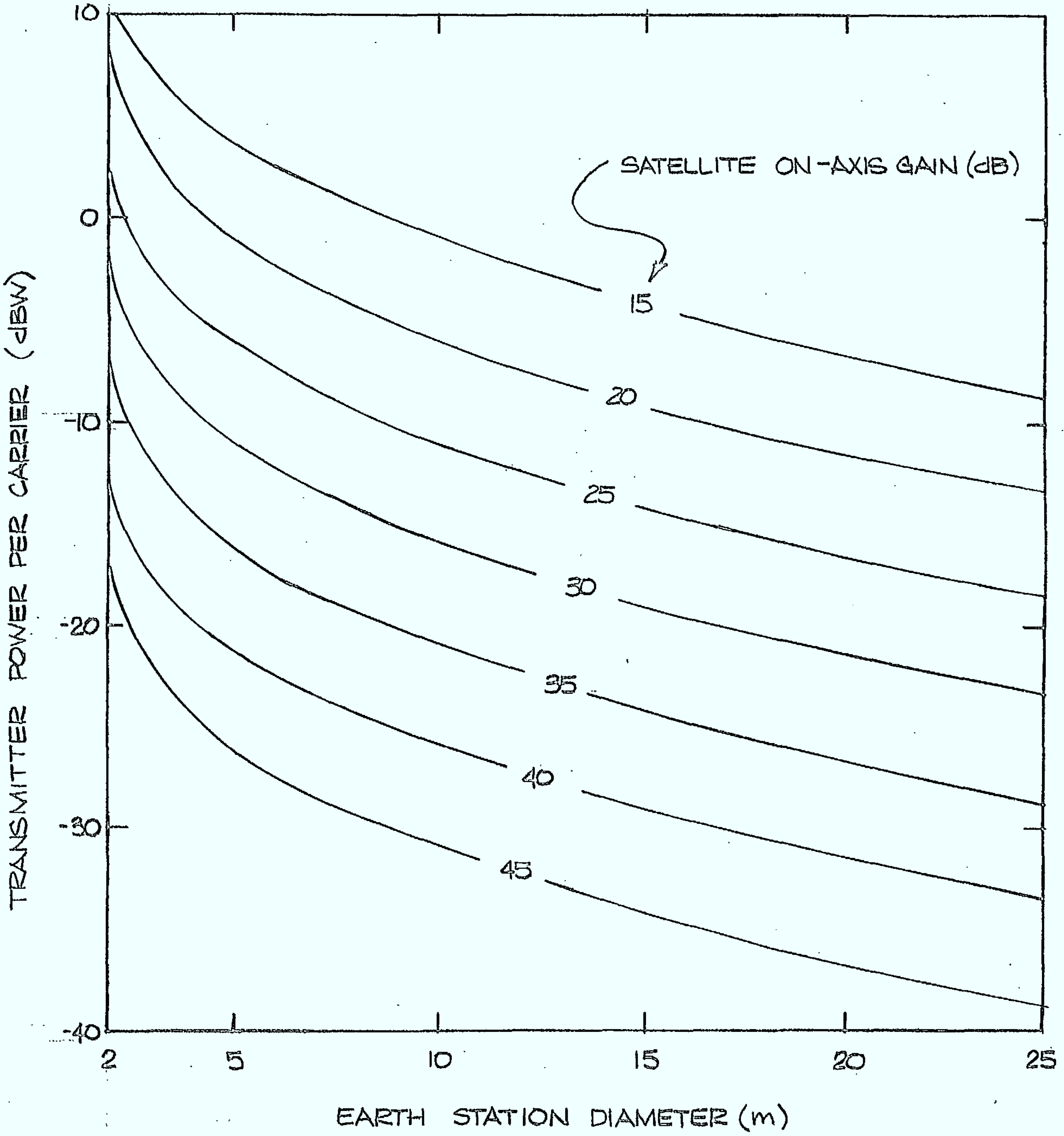


FIG. 7.2/1 SATELLITE TRANSMITTER POWER PER CARRIER VERSUS EARTH STATION DIAMETER FOR AUX-SAT. SERVICE AT 5 GHZ.

For a global-coverage beam ($G_{0, SAT}$ = 15 dB), downlink carrier powers of -4.2 dBW are required for a 15m earth station. Assuming that the carriers are spaced 25 kHz apart and that at any time 40% are active, will require a 6.25 MHz transponder for a system capable of handling 100 carriers. The HPA output power will be -4.2 + 10 log (100) = 15.8 dBW. For a 300 watt TWT, an output backoff of 8.9 dB is available. As a result, the intermodulation distortion products at the output of the HPA should result in a carrier-to-IM noise ratio of 25 dB (estimated from Reference 7.2/1). The IM distortion power spectrum for this many carriers is approximately Gaussian (Reference 7.2/2). Intermodulation products falling in the uplink band will degrade the operation of the satellite if they are not attenuated below the thermal noise level at the satellite receiver input. The IM spectrum used in the subsequent analysis is shown in Figure 7.2/2.

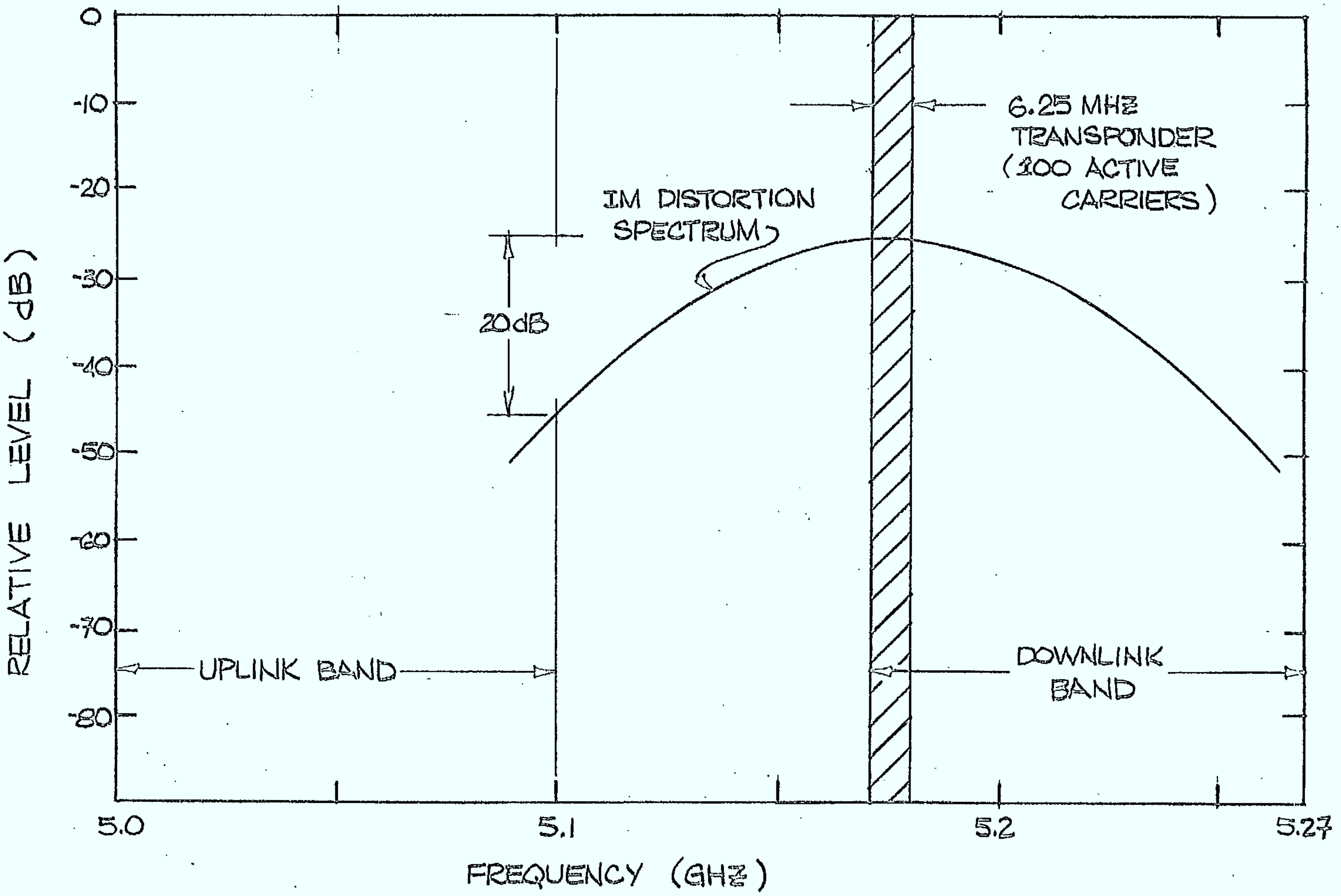


FIG. 7.2/2 INTERMODULATION DISTORTION SPECTRUM AT SATELLITE HPA OUTPUT (NO FILTERING)

7.3 Satellite Filtering and Usable Bandwidths

The effects of IM distortion and filtering in the satellite will now be considered. The first intra-system interference mode occurs when IM distortion products from the HPA fall in the uplink band, as illustrated in Figure 7.2/2. This interference is controlled by a filter at the output of the HPA. The second mode occurs when IM products are generated by the satellite LNA. As the LNA is a wideband device, it will amplify signals in the downlink as well as in the uplink bands. If an input filter is not used to suppress any signals in the downlink portion of the spectrum, the amplifier may be saturated or it may generate IM products in the uplink band that can impair the operation of the satellite. The choice of the LNA input filter and the HPA output filter will determine the usable uplink and downlink bandwidths that can be achieved in the 5.0 - 5.27 GHz band.

The HPA output filtering problem will be considered first. Assuming that IM products falling in the uplink band must be attenuated to levels atleast 10 dB below the uplink thermal noise, then the maximum allowable IM power in a 16 kHz band is -163.5 dBW. The attenuation of the output filter in the uplink band is determined as follows:

- Output carrier power at HPA output = P_d dBW
- IM level in uplink band at HPA output = P_d - 45, dBW in a 16 kHz band

Max. Allowable IM at LNA input = -163.5 dBW in a 16 kHz band

Required Isolation = P_d + 119, dB

Antenna Cross Polarization Isolation = 30 dB

Isolation required by Output Filter = P_d + 89 dB

A margin of 5 dB (to account for various approximations) is added to this to give the required filter attenuation of $P_d + 94$ dB, where P_d is in dBW.

The isolation that must be provided by the receiver input filter will now be determined. As in Chapter 3, the level of third order intermodulation generated in the uplink band from two carriers in the downlink band will be used to estimate the IM power generated in the LNA. Following the derivation used to obtain equation 3.3.4, the attenuation that must be provided by the input filter in the downlink band is given by:

$$A_{IN} = P_d - I_{CP} + G_{LNA} - \frac{1}{3}\left(2P_{IP} + P_{IM,MAX} + G_{LNA}\right) \; ; \; dB \qquad (7.3.1)$$

where P_d is the carrier power at the output of the HPA (in dBW), I_{CP} is the antenna cross polarization isolation (30 dB), G_{LNA} is the gain of the LNA (40 dB), P_{IP} is the 3rd order intercept point (-10 dBW) and $P_{IM,\ MAX}$ is the maximum allowable IM power in a 16 kHz band at the input of the LNA. Substituting the appropriate values into this equation gives:

$$\begin{aligned} A &= P_T - 30 + 40 - \frac{1}{3}\left(2(-10) - 163.5 + 40\right) \\ &= P_T + 58 \ , \ dB \end{aligned} \qquad (7.3.2)$$

A margin of 10 dB is added to this to give the receive filter isolation, due to the approximate nature of the calculation.

$$A = P_T + 68 \, dB \qquad (7.3.3)$$

This attenuation will also ensure that the LNA operates well below saturation.

As this attenuation is approximately 25 dB lower than that required of the HPA output filter, the output filter will determine the usable bandwidths. It is assumed that the output filter 3 dB points occur at the lower edge of the downlink band and at the 5.27 GHz edge of the band and that equal uplink and downlink bands are required. If a Chebyshev filter is used for the output filter then it is possible to determine the maximum usable bandwidths for a given downlink carrier power in terms of the filter order, n. The separation frequency between the high edge of the uplink band and the lower edge of the downlink band, denoted f_{SEP} is then given by:

$$f_{SEP} = 270 - 2\,BW\,,\quad MHz \tag{7.3.4}$$

where BW is the uplink or downlink bandwidth in MHz. Using equations 7.3.4 and 3.3.5, equating the filter attenuation to P_d + 95 dB, and rearranging yields:

$$BW = \frac{540}{3 + \exp\left\{\frac{(P_d + 95) + (12 - 4.2n)}{(9.6n - 2)}\right\}}\,,\quad MHz. \tag{7.3.5}$$

This equation is plotted in Figure 7.3/1. For n = 7 or 8, the range of usable uplink/downlink bandwidths for a Canadian-coverage system is 96 to 104 MHz for a system using 10m earth stations. For a global coverage system, the spacecraft antenna gain is approximately 15 dB, requiring a -4.2 dBW transmitter power per carrier for a 15 m earth station. The corresponding usable uplink and downlink bandwidth is in the range 88 to 95 MHz. For a system utilizing a spot beam satellite with an on-axis gain of 38 dB (2 degree beamdwidth), the usable bandwidth is in the range 102 to 108 MHz for a 10 m earth station antenna.

In the above analysis, the assumption was made that the usable bandwidth extends to the 5.27 GHz edge of the band. The spurious emissions from the spacecraft at frequencies above 5.27 GHz consist of IM distortion products. At the band edge, these emissions are 28 dB below the downlink carrier power in a 16 kHz band. If the minimum earth station diameter is 10 metres in this band, then the required downlink EIRP per carrier is 15 dBW. The power flux density at the earth's surface of spurious emissions above 5.27 GHz will be -175 dBW/m^2 in a 16 kHz band. If this flux density is received by an isotropic antenna the power at the antenna's terminals will be -210 dBW in a 16 kHz band. This would raise the earth terminal antenna temperature by less than 0.005 K and is therefore negligible. In most cases, however, larger earth stations would be used in the 5 - 5.27 GHz band to permit higher traffic levels, and the spurious emissions would be lower. As a result, spurious emissions from the spacecraft should not pose a problem to other services operating above 5.27 GHz.

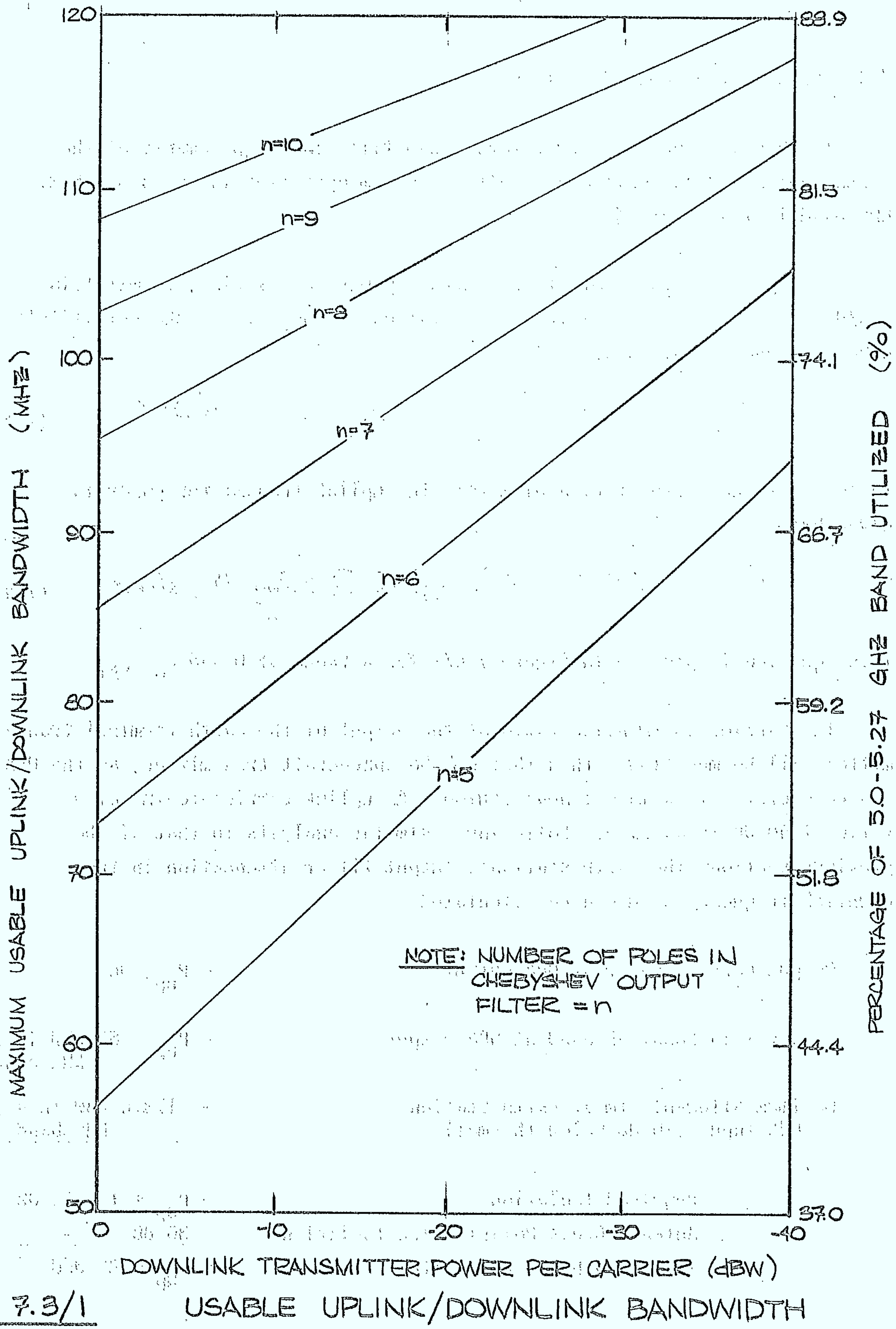


FIG. 7.3/1 USABLE UPLINK/DOWNLINK BANDWIDTH AS A FUNCTION OF SATELLITE TRANSMITTER POWER AND OUTPUT FILTER COMPLEXITY

7.4 Earth Station Considerations

In this section, the power levels and filtering requirements of the earth segment of an auxiliary-satellite system operating in the 5.0 - 5.27 GHz band is investigated.

The uplink earth terminal transmitter power per carrier, to maintain a C/N of 25 dB at the satellite for a station at the edge of the satellite's coverage zone, is given by:

$$P_{up} = 76 - G_{0,E} - G_{0,SAT}\ , \ dBW \tag{7.4.1}$$

In terms of the earth station diameter, the uplink transmitter power is given by:

$$P_{up} = 44.3 - G_{0,SAT} - 20 \log D\ , \ dBW \tag{7.4.2}$$

This equation is plotted in Figure 7.4/1 for a range of D and $G_{0,\ SAT}$.

The carrier-to-IM noise ratio at the output of the earth terminal transmitter will be much lower than that of the spacecraft transmitter, as the HPA can be operated in a more linear region. An uplink carrier-to-IM noise ratio of 40 dB is assumed. Following a similar analysis to that of the previous section, the earth station's output filter attenuation in the downlink frequency band can be calculated:

Output Carrier Power at HPA Output = P_{up}, dBW

IM Level in Downlink Band at HPA Output = P_{up} - 60 dBW in a 16 kHz band

Maximum Allowable IM at Earth Station LNA Input (10 dB below thermal) = -173.6 dBW in a 16 kHz band

Required Isolation = P_{up} + 113.6, dB

Antenna Cross Polarization Isolation = 30 dB

Isolation by output filter = P_{up} + 83 dBW

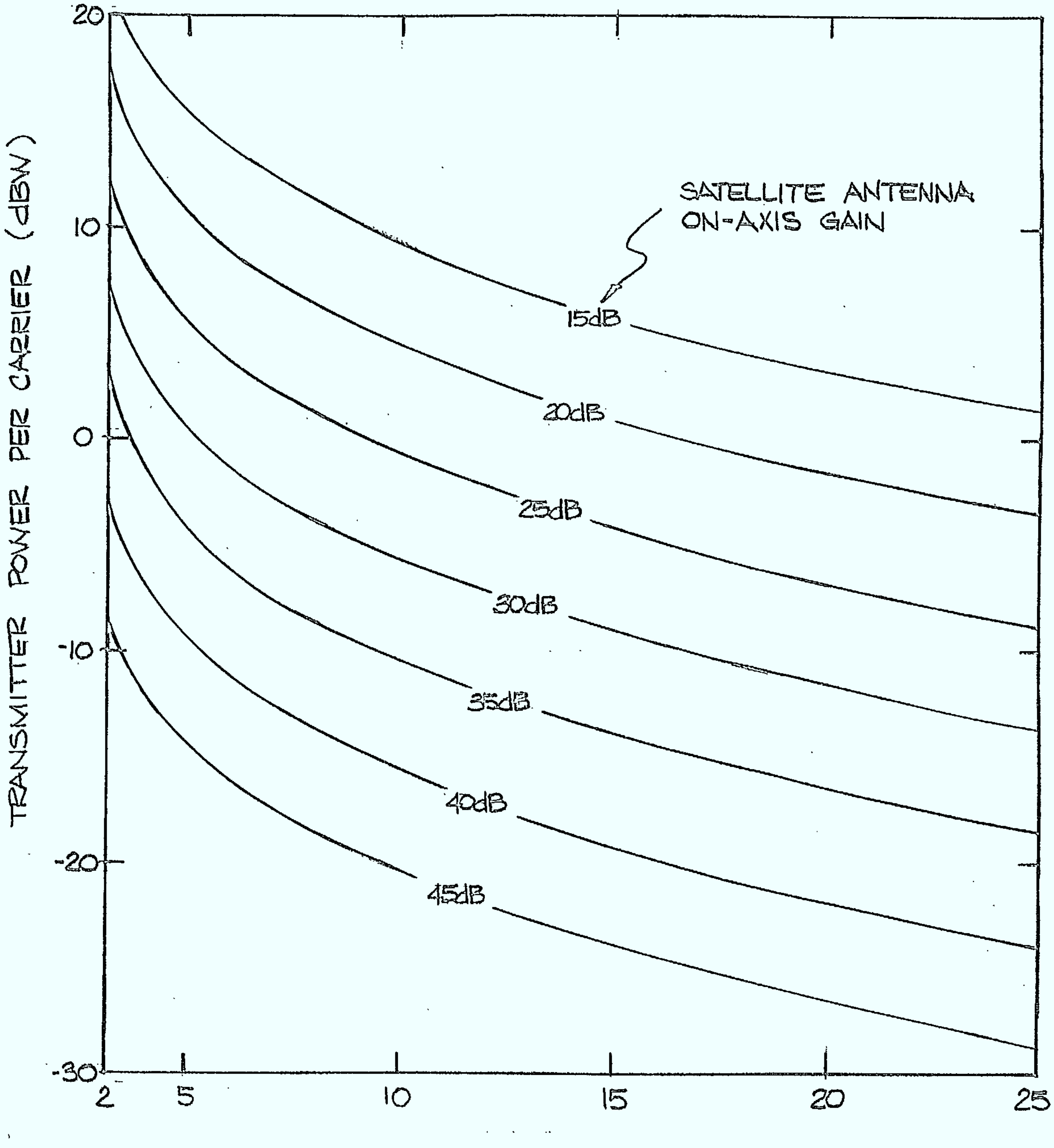


FIG. 7.4/1 EARTH STATION TRANSMITTER POWER PER CARRIER VERSUS EARTH STATION DIAMETER FOR AUX-SAT SERVICE AT 5 GHZ.

Allowing for the higher earth station transmitter power than that required on the downlink, the output filter attenuation at the earth station will be similar to that of the spacecraft. As filter size and weight is not a constraint in the earth station, the uplink and downlink bandwidths will be constrained by the spacecraft filters rather than those of the earth stations.

7.5 Summary

The potential use of the 5.0 - 5.27 GHz band by the auxiliary-satellite service was investigated in this chapter. It was found that the spacecraft output filter required to isolate the receiving section from spurious intermodulation distortion products places the major constraint on the usable uplink and downlink bandwidths. The filtering requirements are dependent primarily on the downlink carrier power at the output of the spacecraft HPA which is in turn is determined by the size of the earth station antenna.

It was found that a significant portion of the available 270 MHz band can be utilized for this type of service, with uplink/downlink bandwidths ranging from 85 to 110 MHz depending on the complexity (ie, number of poles) of the output filter and the required downlink transmitter power.

The earth station segment was briefly studied to determine whether it might impact the choice of bandwidths. It was found that although higher powered transmitters and more sensitive receivers must be employed in the earth station than in the spacecraft, the isolation required by filtering is comparable to that in the satellite. As a result, the space segment will be the determining factor in choosing bandwidths for this service.

REFERENCES

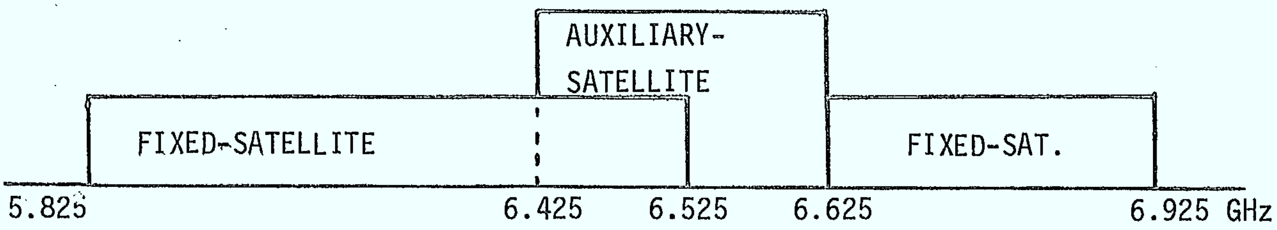
7.2/1 "SCPC Satellite Telephony With 4-D Coded Quadrature Amplitude Modulation", G.R. Welti, COMSAT Technical Review, Vol. 7, No. 1, Spring 1977.

7.2/2 "Calculation of Intermodulation Due to Amplitude Limiting of Multiple Carriers", C.R. Cahn, IEEE. Trans. Comm. Tech., Dec. 1968.

8.0 FIXED-SATELLITE AND AUXILIARY-SATELLITE BANDS NEAR 6 GHz

8.1 Introduction

In this chapter, inter-system interference between the fixed-satellite service and the auxiliary-satellite service in bands near 6 GHz is investigated. The proposed frequency plan is shown below:



The band from 5.825 to 6.425 GHz is currently used by Telesat, INTELSAT, and others, and contains high capacity FDM/FM telephony, FM/TV, and PSK traffic in addition to narrowband SCPC voice and data traffic. Traffic in the auxiliary-satellite service will consist of narrowband SCPC voice and data traffic also. It is assumed that traffic in the 6.625 - 6.925 GHz band will be similar to that in the band below 6.425 GHz.

The interference modes which can exist between the systems using this frequency plan include:

- Interference into the auxiliary-satellite receiver due to the presence of SCPC fixed-satellite uplink signals in the 6.425 to 6.525 GHz band.
- Interference into the auxiliary-satellite receiver due to the presence of spurious emissions from high capacity fixed-satellite uplink signals originating from carriers with assigned frequencies below 6.425 GHz and above 6.625 GHz.

- Interference into the fixed-satellite receiver due to the presence of co-channel auxiliary-service uplink carriers in the 6.425 - 6.525 GHz band. The interfered-with signals are SCPC carriers.
- Interference into the fixed-satellite receivers at frequencies below 6.425 GHz and at frequencies above 6.625 GHz due to the presence of spurious emissions from an auxiliary-service earth station.

These interference modes are investigated for a variety of fixed-satellite uplink carriers to determine some of the technical factors affecting the sharing of these bands.

8.2 System Characteristics

The characteristics of the auxiliary-satellite uplink are summarized in Table 8.2/1. The values used are very similar to those used in the analysis of the auxiliary-satellite service at 5 GHz (Chapter 7). In this case however, the uplink transmitter power per carrier is given by:

$$P_{up} = 78.5 - G_{o,E} - G_{o,SAT} \text{ , dBW} \tag{8.2.1}$$

where $G_{o,E}$ is the on-axis gain of the earth station antenna and $G_{o,SAT}$ is the gain of the satellite antenna. This is the required power for a station at the edge of the satellite coverage zone. In terms of the earth station diameter, the power is given by

$$P_{up} = 44.5 - 20 \log D - G_{o,SAT} \text{ , dBW .} \tag{8.2.2}$$

This equation is plotted in Figure 8.2/1 for a range of earth station diameters D, and spacecraft gains $G_{o,SAT}$. For 10 m earth stations operating with a 30 dB spacecraft antenna gain (ie, Canadian coverage antenna) an uplink power of -5.5 dBW per carrier is required.

If the auxiliary-satellite earth station operates in the same frequency range as a wideband receiver, then more than one carrier can act as an interferer. Assuming a carrier spacing of 25 kHz and an activity factor of 0.4 (ie, only 40 percent of the channels are active at any time), then in a bandwidth B, (where B is large compared to the channel spacing), N carriers can contribute to the interference, where

$$N = \left(\frac{B}{25\,kHz}\right) \times 0.4 \text{ .} \tag{8.2.3}$$

For a 40 kHz SCPC fixed-satellite uplink, it is assumed that 3 auxiliary-satellite carriers can enter the receiver passband. For a receiver with a 2 MHz bandwidth 32 carriers can enter, and for a

TABLE 8.2/1 Characteristics of Auxiliary-Satellite Uplink at 6 GHz

- Carrier: 16 kHz Narrowband Voice or Data
- Required Uplink C/N ≃ 25 dB, exceeded at least 99% of the time
- Free Space Loss ≃ 200.3 dB
- Clear Weather Tropospheric Absorption ≃ 0.3 dB
- Rain Attenuation ≃ 0.4 dB, exceeded no more than 1% of the time
- Feeder, Duplexer, Pointing Loss ≃ 2.5 dB
- Total Uplink Margin ≃ 3.2 dB
- Uplink Noise Temperature ≃ 2000 K
  kTB ≃ -153.5 dBW
- Minimum Required Carrier Power at LNA Input ≃ -128 dBW
- Earth Station Sidelobe Gain ≃ 32 - 25 log θ
- Minimum Boresight Elevation Angle ≃ 10 degrees

Note: Rain margin is for 10 degree elevation angle path.

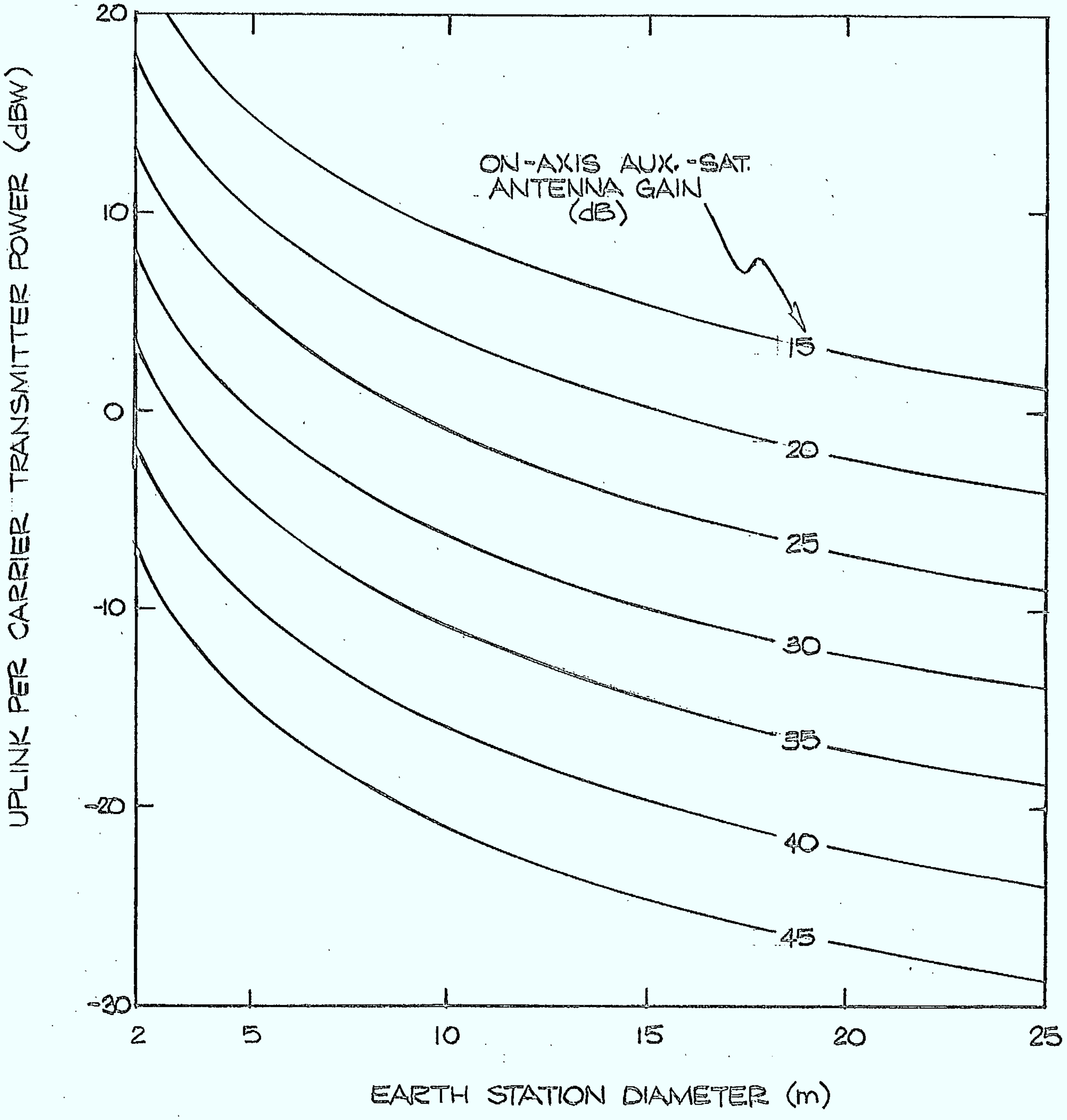


FIG. 8.2/1 6 GHZ. AUXILIARY-SATELLITE EARTH STATION TRANSMITTER POWER PER CARRIER

36 MHz bandwidth 576 carriers can enter the receiver.

The characteristics of the fixed-satellite uplink carriers are summarized in Table 8.2/2. Three carriers are considered. The first is a high capacity 960 voice channel FDM/FM carrier with characteristics similar to those used in the Telesat (Reference 8.2/1) and INTELSAT (Reference 8.2/2) systems while the second is a low capacity 24 channel FDM/FM carrier. The third carrier considered is typical of SCPC thin route or SPADE-type carriers (Reference 8.2/3). The required uplink transmitter powers for these three carriers, as a function of the earth station diameter D, and fixed-satellite on-axis gain $G_{o,R}$, for a station at the edge of the satellite's coverage zone are:

$$\left.\begin{aligned} P_{T,960} &= 91.1 - 20\log D - G_{o,R}\ , \text{dBW} \\ P_{T,24} &= 71.1 - 20\log D - G_{o,R}\ , \text{dBW} \\ P_{T,SCPC} &= 46.1 - 20\log D - G_{o,R}\ , \text{dBW} \end{aligned}\right\} \qquad (8.2.4)$$

These equations are plotted in Figures 8.2/2, 8.2/3, and 8.2/4 for a range of D and $G_{o,R}$.

If any of these carriers occupy the same band as an auxiliary-satellite receiver, then only a portion of the carrier power given by equation 8.2.4 will enter a 16 kHz band at the auxiliary-satellite receiver. For the 40 kHz SCPC carrier it is assumed that all of the transmitter power can enter a 16 kHz bandwidth. For the 36 MHz FDM/FM carrier, the "spreading factor" given in Reference 8.2/4 can be used to estimate the power in a 16 kHz band. A 33 dB reduction in power in a 4 kHz band from a carrier occupying a 40 MHz band was reported. Assuming that a similar value applies for the 36 MHz carrier, then in a 16 kHz band the full carrier power would be reduced by 27 dB. For the 2 MHz FDM/FM carrier, a value of 13 dB is assumed.

TABLE 8.2/2: Characteristics of Fixed-Satellite Uplink Carriers at 6 GHz

- Carrier:
  - 960 Channel FDM/FM Carrier
  - Bandwidth = 36 MHz
  - Required Uplink C/N = 35 dB, exceeded at least 99.99% of the time
  - Thermal Noise Level kTB = -118 dBW
  - Minimum Required Carrier Power at LNA Input = -83 dBW
- Carrier:
  - 24 Channel FDM/FM Carrier
  - Bandwidth = 2 MHz
  - Required Uplink C/N = 28 dB, exceeded at least 99. 99% of the time
  - Thermal Noise Level, kTB = -131 dBW
  - Minimum Required Carrier Power at LNA Input = -103 dBW
- Carrier:
  - SCPC Digital Voice
  - Bandwidth = 40 kHz
  - Required Uplink C/N = 20 dB, exceeded at least 99.99% of the time
  - Thermal Noise Level, kTB = -148 dBW
  - Minimum Received Carrier Power at LNA Input = -128 dBW
- Free Space Loss = 200.3 dB
- Tropospheric Absorption = 0.2 dB
- Rain Margin = 0.9 dB, exceeded no more than 0.01% of the time
- Feeder, Duplexer, Pointing Loss = 3 dB
- Total Uplink Margin = 4.1 dB
- Uplink Noise Temperature = 3000 K

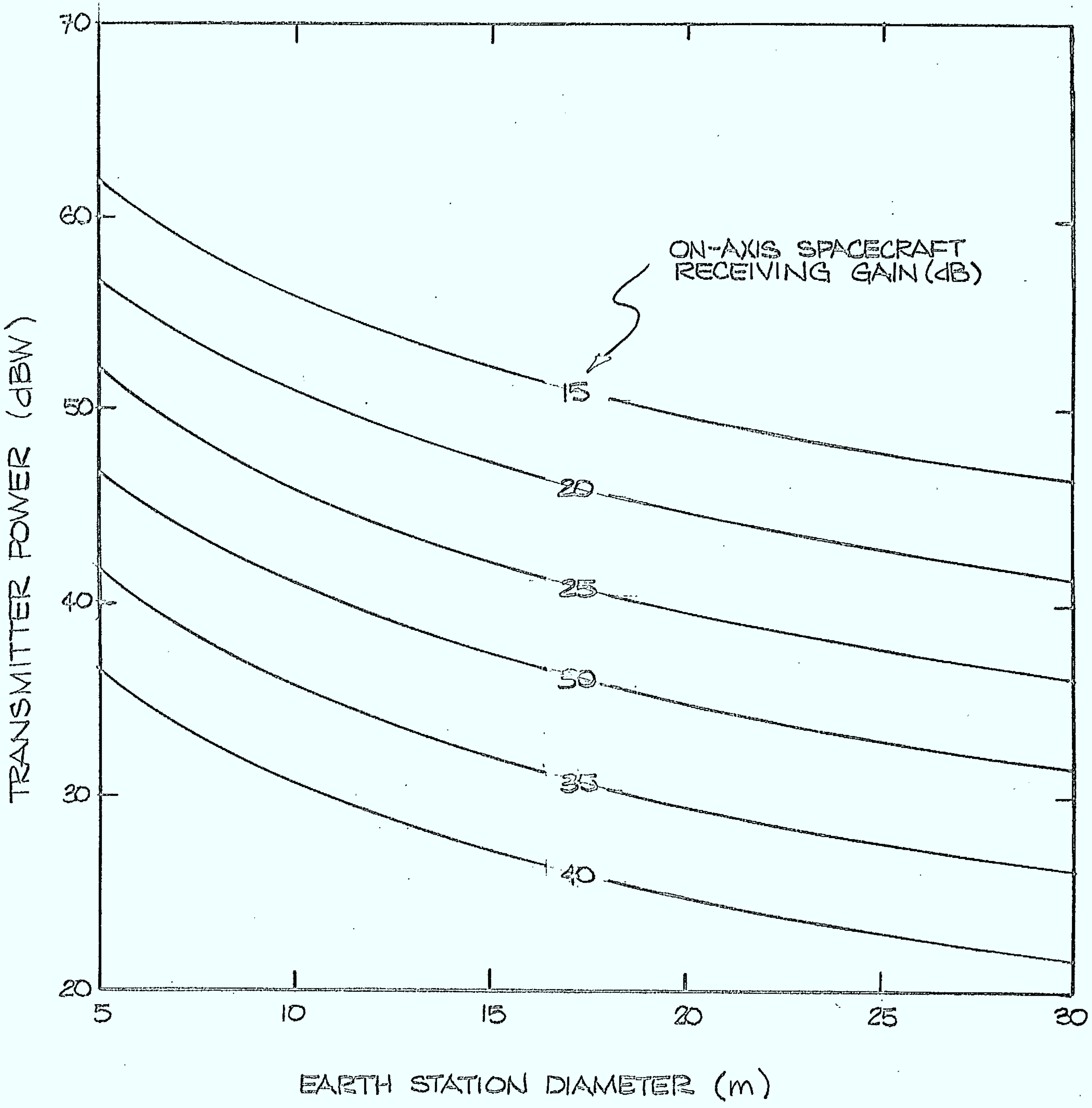


FIG. 8.2/2 UPLINK TRANSMITTER POWER FOR A 960 CHANNEL FDM/FM CARRIER AT 6.5 GHZ.

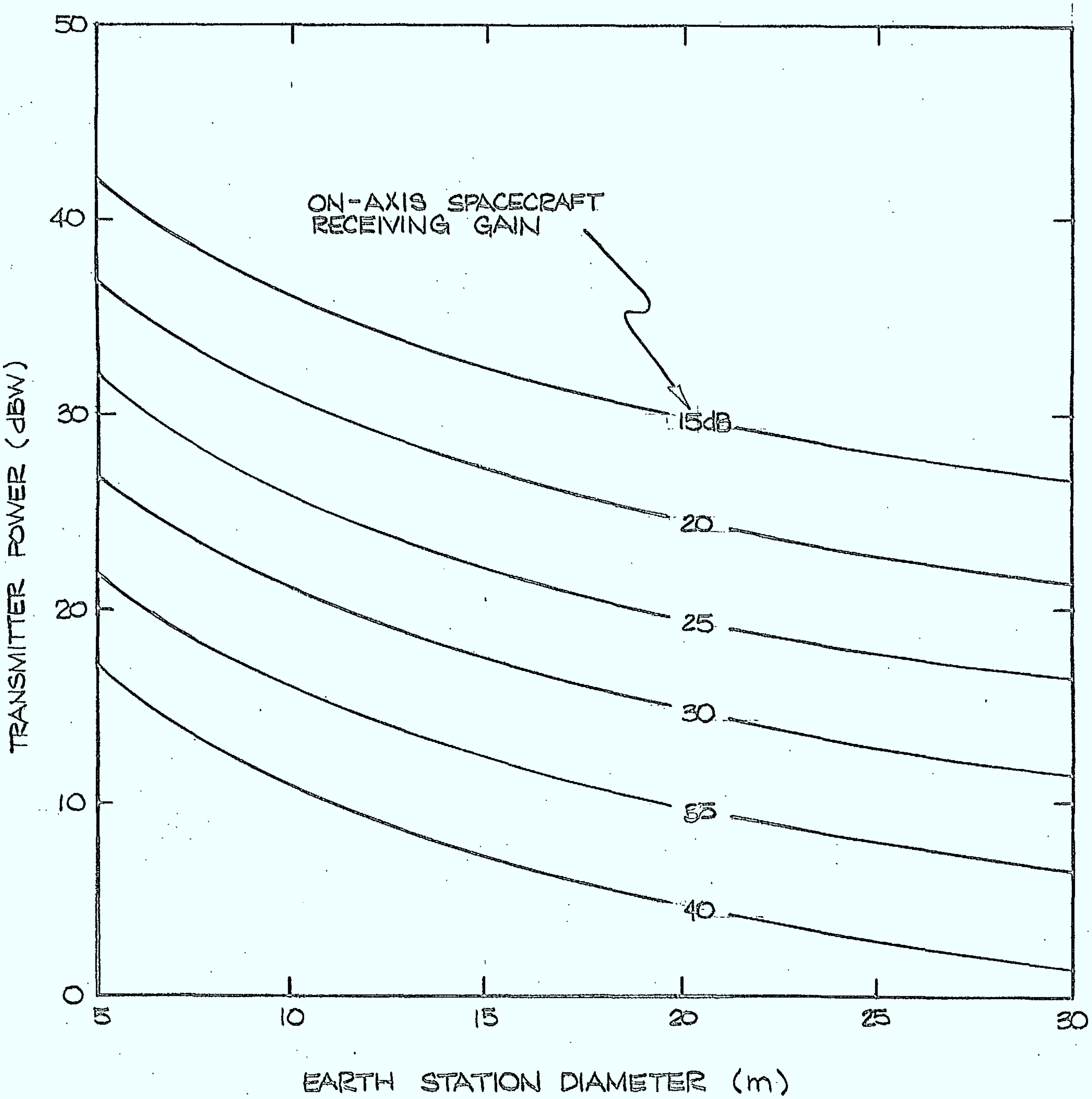


FIG. 8.2/3 UPLINK TRANSMITTER POWER FOR A 24 CHANNEL FDM/FM CARRIER AT 6.5 GHz.

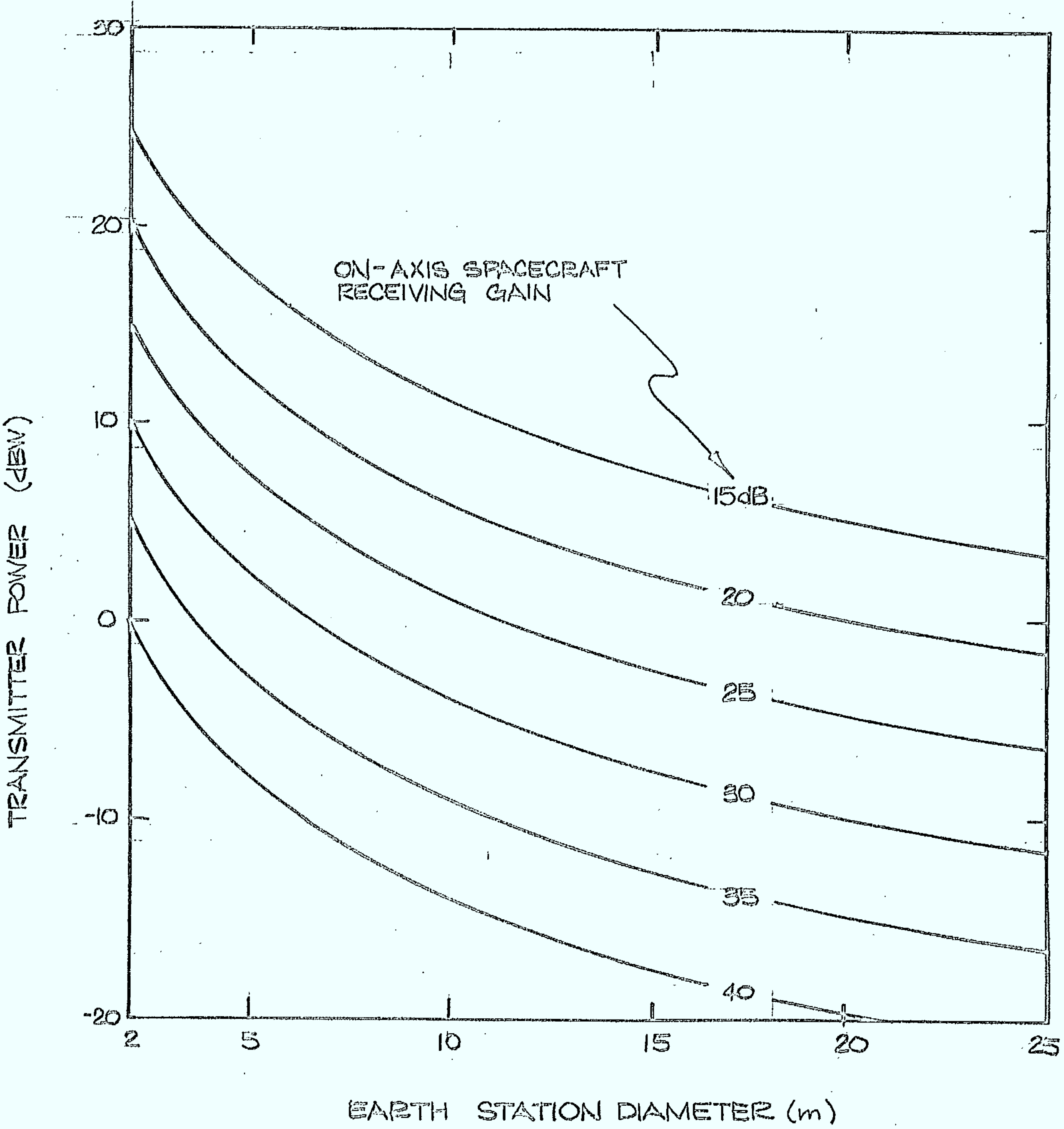


FIG. 8.2/4 UPLINK TRANSMITTER POWER FOR A SCPC CARRIER AT 6.5 GHZ.

8.3 Interference into Auxiliary-Satellite Uplink

Inter-system interference from earth stations in the fixed-satellite service into an auxiliary-satellite receiver is investigated in this section. The case of co-channel interference is considered first.

The interference power in a 16 kHz band at the input to the auxiliary-satellite receiver is given by

$$P_I = P_T + G_T + G_R - 201 \quad , \text{dBW} \tag{8.3.1}$$

where P_T is the fixed-satellite earth station transmitter power in a 16 kHz band, G_T is the earth station antenna gain, and G_R is the gain of the auxiliary-satellite antenna. This equation includes the assumption that no polarization discrimination is used. Using a received carrier power of -128 dBW for the auxiliary service carrier and assuming the fixed service earth station is in the coverage zone of the auxiliary-satellite, then the uplink C/I ratio is given by

$$\left(\frac{C}{I}\right) = 73 - P_T - G_T - G_{o,R} \quad , dB . \tag{8.3.2}$$

where $G_{o,R}$ is the on-axis gain of the auxiliary-satellite antenna. Using the CCIR sidelobe gain pattern for the fixed-satellite earth station ($G = 32 - 25 \log\varphi$), the carrier-to-interference ratio is given by

$$\left(\frac{C}{I}\right) = 41 - P_T - 25 \log \varphi - G_{oR} \quad , dB \tag{8.3.3}$$

where φ is the angle between the auxiliary-satellite and the boresight of the interfering earth station. For a C/I ratio of 35 dB, the off-axis angle must exceed

$$\log \varphi_{min} = \frac{1}{25}\left[P_T + G_{R,o} \right] - 0.24 \quad . \tag{8.3.4}$$

For the 40 kHz SCPC interferor P_T is equal to the uplink transmitted carrier power. The minimum off-axis angle is shown in Figure 8.3/1 for this interferor. From Figure 8.2/4 it can be seen that the uplink transmitter power will range from -10 dB transmission to a spot beam receiving antenna to 10 dB for a global coverage satellite antenna. To protect the auxiliary-satellite uplink, the fixed-satellite must be separated from the auxiliary-satellite such that the off-axis angle at the fixed-satellite earth station exceeds the value given in equation 8.3.4. This angle is approximately equal to the inter-satellite spacing.

For a 24 channel FDM/FM interferor, P_T is 13 dB less than the uplink transmitter power. The minimum off-axis angle in this case is given by

$$\log \varphi_{min} = \frac{1}{25}\left[P_T + G_{\theta,R} \right] - 0.76 \quad . \qquad (8.3.5)$$

This equation is plotted in Figure 8.3/2. From Figure 8.2/3, it can be seen that the transmitter power of the interfering carrier can range from 5 to 30 dBW, depending on the earth station diameter and the fixed-satellite antenna gain. In general, the off-axis angle will be larger in this case than for a SCPC interferor.

The other uplink interfering carrier considered is a 960 channel FDM/FM carrier. In this case, P_T is 27 dB less than the earth station transmitter power and

$$\log \varphi_{min} = \frac{1}{25}\left[P_T + G_{\theta R} \right] - 1.32 \quad . \qquad (8.3.6)$$

This equation is plotted in Figure 8.3/3. Typically, uplink transmitter powers on the order of 30 to 35 dBW are currently used for this type of carrier. As a result, off-axis angles in the range 3 to 30 degrees would be necessary to protect an auxiliary-service uplink, depending on the characteristics of each system.

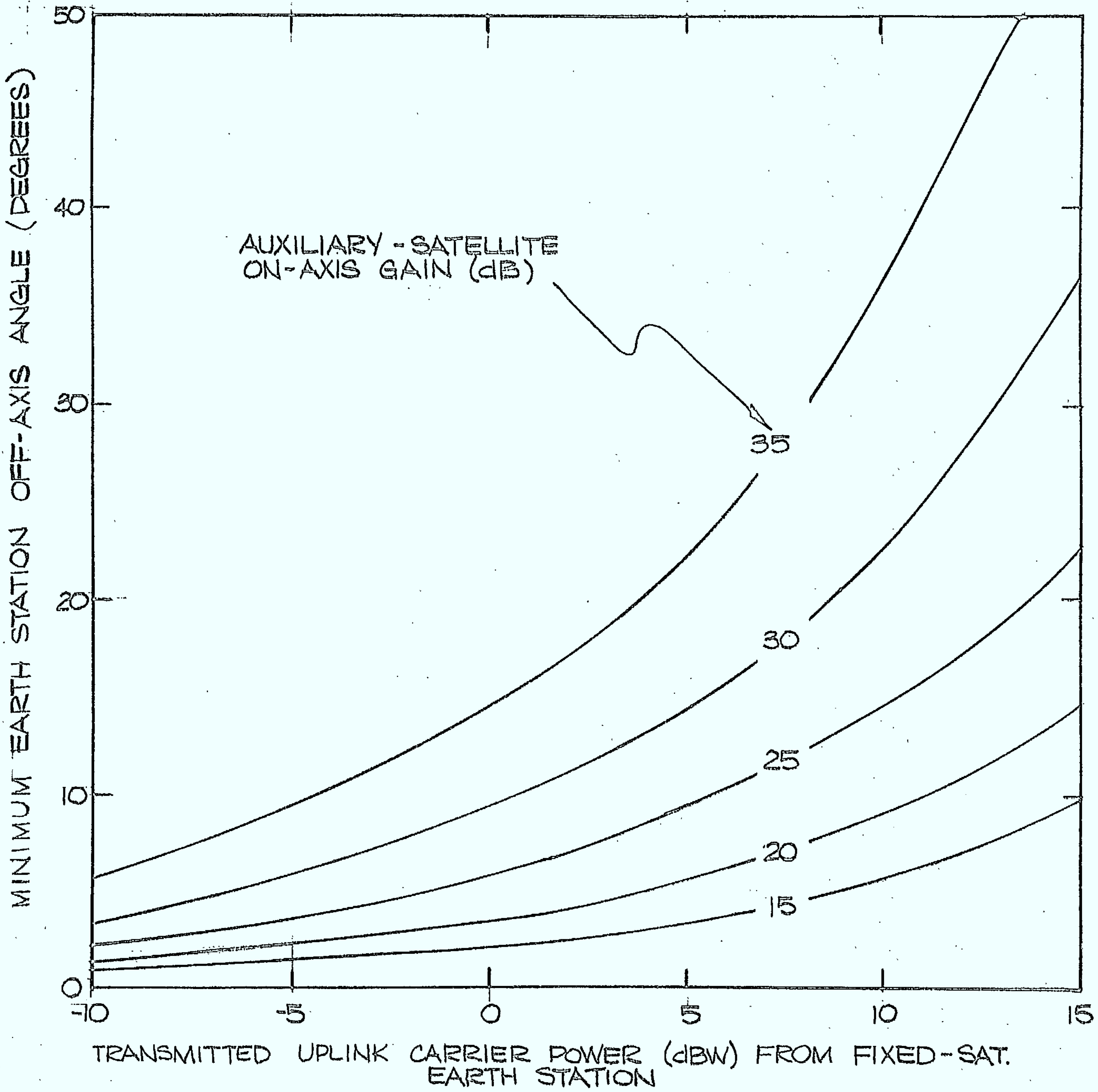


FIG. 8.3/1 MINIMUM FIXED-SAT EARTH STATION OFF-AXIS ANGLE REQUIRED TO PROTECT AN AUX.-SAT UPLINK FROM A FIXED-SAT SCPC CARRIER AT 6.5 GHZ.

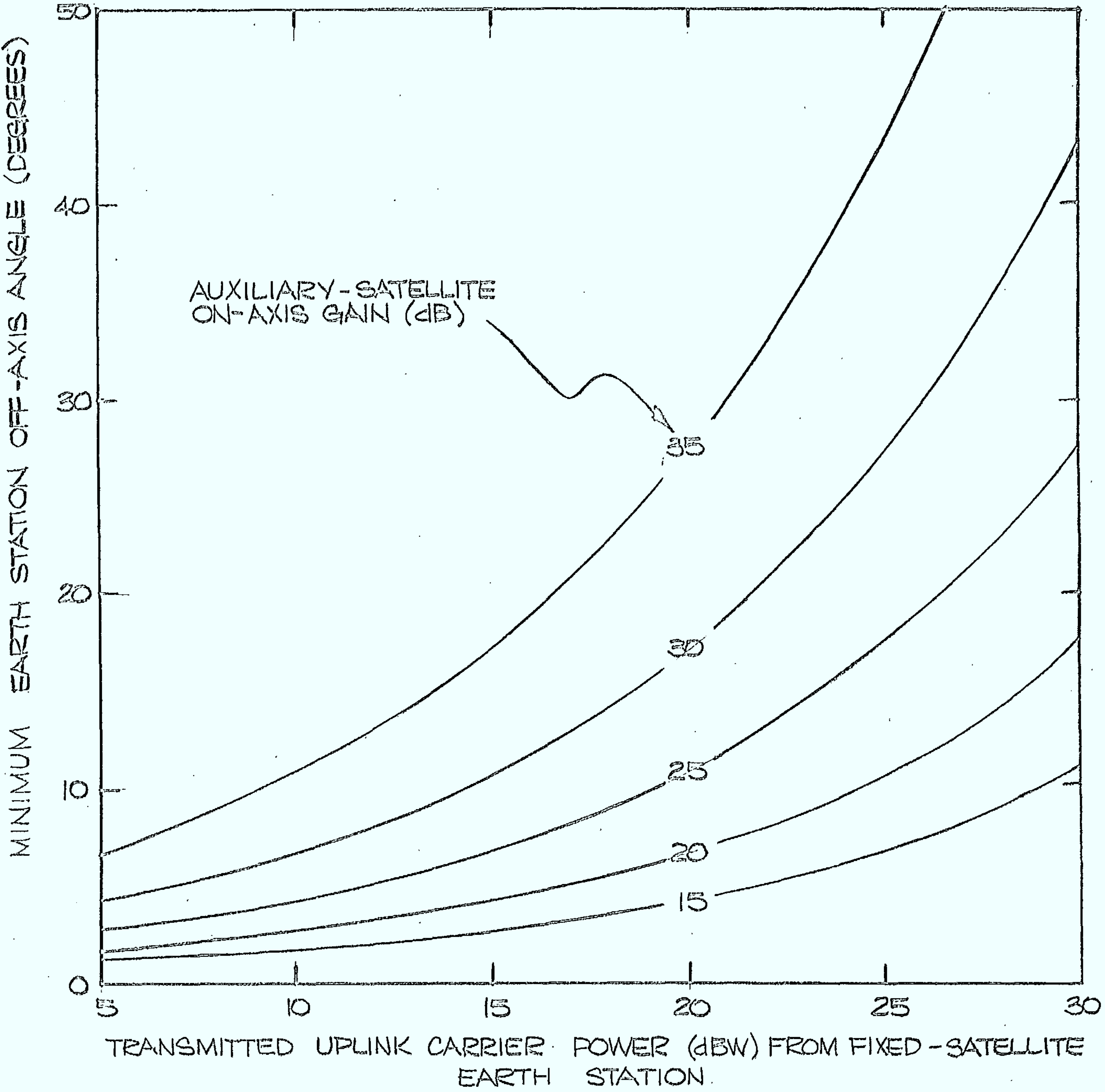


FIG. 8.3/2 MINIMUM FIXED-SAT. EARTH STATION OFF-AXIS ANGLE REQUIRED TO PROTECT AN AUX.-SAT. UPLINK FROM A FIXED-SAT. 24 CHANNEL FDM/FM UPLINK CARRIER AT 6.5 GHz.

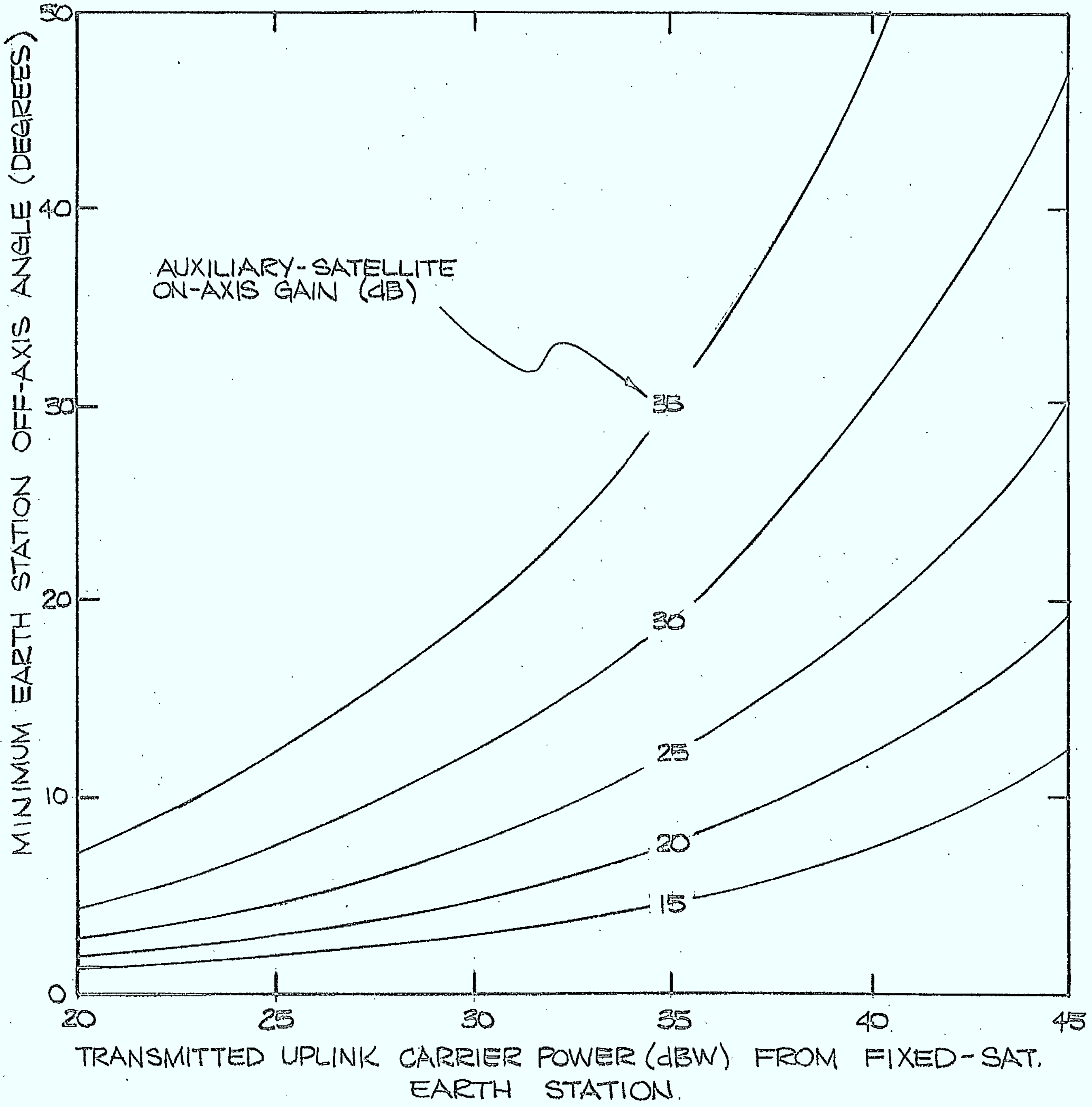


FIG. 8.3/3 MINIMUM FIXED-SAT. EARTH STATION OFF-AXIS ANGLE REQUIRED TO PROTECT AN AUX.-SAT. UPLINK FROM A FIXED-SAT. 960-CHANNEL FDM/FM CARRIER AT 6.5 GHZ.

To illustrate the relative severity of the interference from each type of carrier, an example is presented. For a fixed-satellite system using 30 m earth stations and a spacecraft antenna gain of 30 dB, the following earth station transmitter powers are required:

. SCPC : -11 dBW

. 24 channel FDM/FM : 13 dBW

. 960 channel FDM/FM : 33 dBW

If the auxiliary-satellite on-axis gain is also 30 dB, the fixed-satellite earth station off-axis angle for each carrier must be at least:

. SCPC : 3.3 degrees

. 24 channel FDM/FM : 9.1 degrees

. 960 channel FDM/FM : 15.8 degrees

This indicates that the SCPC fixed-satellite traffic will be the least severe of the fixed-satellite interferors.

From the analysis presented in this section, it is evident that an interference problem will exist in the 6.425 - 6.625 GHz band if the fixed-satellite and auxiliary-satellite services share the band. Methods for reducing the level of interference in the auxiliary-satellite receiver include the use of:

- high gain fixed-satellite spacecraft antennas
- large fixed-satellite earth station antennas
- energy dispersal techniques to reduce the uplink power in a 16 kHz band.

All of these techniques would tend to increase the cost of the fixed-satellite system and coordination of the two services would still be required in general. As satellite spacings on the order of 5 to 10 degrees would still be required the sharing of this band may be difficult to achieve, particularly for high capacity traffic.

The other source of interference into an auxiliary-satellite receiver operating in this band is spurious emissions from fixed-satellite earth stations operating in the 5.825 - 6.425 GHz and 6.625 - 6.925 GHz bands. The maximum permissible spurious EIRP in a 16 kHz band in the 6.425 - 6.625 GHz band can be estimated as follows. Assuming that interference from this source must be at least 40 dB below the auxiliary-satellite received carrier power, and that the satellites can be located at the same orbital position, then

$$\left(\frac{C}{I}\right) = P_c - \left[EIRP + G_{o,R} - 201\right], \text{ dB} \qquad (8.3.7)$$

where P_c is the auxiliary-satellite carrier power at the LNA, $G_{o,R}$ is the satellite antenna gain, and EIRP is the spurious EIRP in a 16 kHz band from the fixed-satellite earth station. Rearranging this expression gives the maximum permissible EIRP in a 16 kHz band from a fixed-satellite earth station in terms of the on-axis gain of the auxiliary-satellite, i.e.

$$EIRP = 33 - G_{o,R}, \quad \text{dBW} \qquad (8.3.8)$$

For an auxiliary-satellite antenna gain of 45 dB the maximum permissible spurious EIRP is -12 dBW in a 16 kHz band. This level is much below the INTELSAT IV earth station out-of-band emission specification of 26 dBW/4 kHz (Reference 8.3/1). This specification is applicable to a 36 MHz FDM/FM carrier using an uplink EIRP of 95 dBW. Although spurious emission interference from this type of earth station is approximately 40 dB less severe than in the co-channel case, a satellite spacing on the order of two degrees could be necessary to protect the auxiliary service from the spurious emissions of high power fixed-satellite earth stations.

8.4 Interference Into a Fixed-Satellite Uplink

The case of co-channel interference in the 6.425 - 6.525 GHz band is considered first. For auxiliary-satellite earth stations operating in the coverage zone of the fixed-satellite, the uplink C/I ratio for a 40 kHz SCPC carrier being interfered with by an auxiliary-service earth station is given by

$$\left(\frac{C}{I}\right) = 36.2 - P_{AUX} + 25 \log \varphi - G_{0,R} \quad , \text{dB} \tag{8.4.1}$$

where P_{AUX} is the auxiliary-service uplink transmitter power per carrier, $G_{o,R}$ is the fixed-satellite antenna gain, and φ is the angle between the fixed-satellite and the boresight of the auxiliary-service earth station antenna. This equation assumes that 3 auxiliary-service carriers can enter the 40 kHz receiver bandwidth.

For a 24 channel FDM/FM uplink, 32 auxiliary-service carriers can act as interferers. The fixed-satellite uplink C/I in this case is given by

$$\left(\frac{C}{I}\right) = 51 - P_{AUX} + 25 \log \varphi - G_{0,R} \quad , \text{dB} \tag{8.4.2}$$

For a 960 channel FDM/FM uplink, 576 auxiliary service carriers can act as interferers. The C/I ratio in this case is given by

$$\left(\frac{C}{I}\right) = 58 - P_{AUX} + 25 \log \varphi - G_{0,R} \quad , \text{dB} . \tag{8.4.3}$$

Assuming that C/I ratios of 35 dB for the SCPC uplink, 40 dB for the 24 channel FDM/FM carrier, and 45 dB for the 960 channel carrier must be met, then the off-axis angle at the auxiliary-satellite earth station must exceed:

$$\log \theta_{min} = \begin{cases} \frac{1}{25}\left[P_{AUX} + G_{0,R} \right] - 0.048 \, , & \text{SCPC} \\ \frac{1}{25}\left[P_{AUX} + G_{0,R} \right] - 0.64 \, , & \text{24 channel} \\ \frac{1}{25}\left[P_{AUX} + G_{0,R} \right] - 0.52 \, , & \text{960 channel} \end{cases} \qquad (8.4.4)$$

These equations are plotted in Figures 8.4/1, 8.4/2, and 8.4/3. In general, the SCPC traffic is the most susceptible to interference and will determine the inter-satellite spacing required to protect this service.

For example, if the auxiliary-satellite antenna gain is 30 dB, and the earth station uses a 10 m antenna, then the auxiliary service uplink transmitter power is -5.5 dBW per carrier. If the fixed-satellite on-axis gain is also 30 dB, then the angle between the auxiliary service earth station antenna boresight and the fixed satellite must exceed 8.6, 2.2, and 2.9 degrees to protect the fixed-satellite SCPC, 24 channel FDM/FM, and 960 channel FDM/FM uplinks respectively.

In the case of the SCPC uplink, this mode of interference will determine the inter-satellite spacing, while interference into the auxiliary-satellite uplink from the fixed-satellite earth stations will determine the minimum spacing if 24 or 960 channel FDM/FM traffic shares the band with the auxiliary-satellite service.

Out-of-band emissions from an auxiliary service earth station will consist primarily of intermodulation distortion products. These products are typically 25 dB below P_{AUX} in any 16 kHz band in the auxiliary service band. Outside of the band, the emissions will depend on the level of output filtering provided in the earth station. If at least 40 dB of output filtering is provided, the emissions will be down at least 65 dB from the uplink carrier power. As a result, this mode of interference should not affect the operation of fixed-satellite receivers operating at frequencies outside of the 6.425 to 6.625 GHz band.

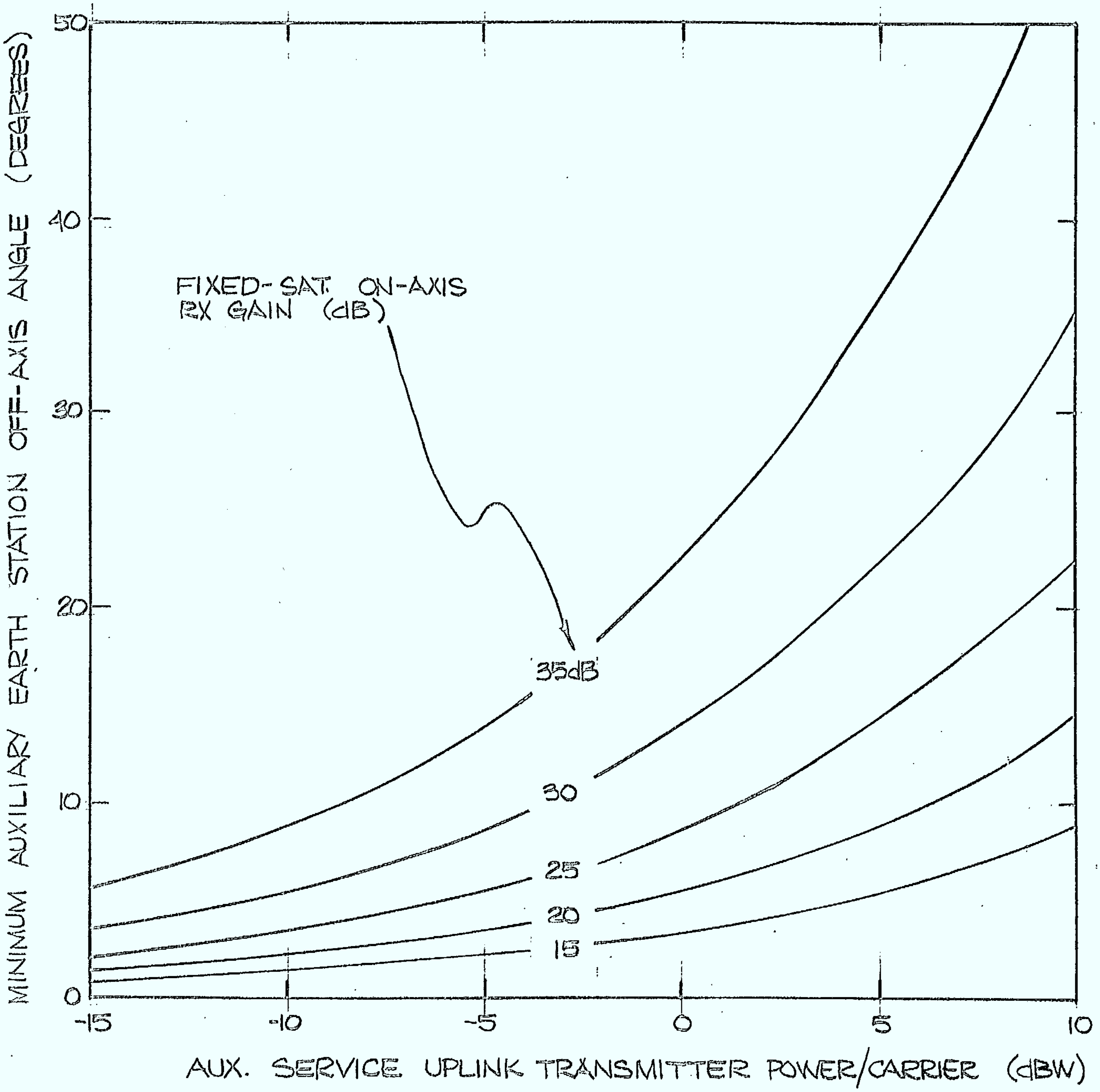


FIG. 8.4/1 MINIMUM AUX. SERVICE EARTH STATION OFF-AXIS ANGLE FOR WHICH THE (C/I) = 35 dB IN A SCPC FIXED-SAT. UPLINK AT 6.5 GHz.

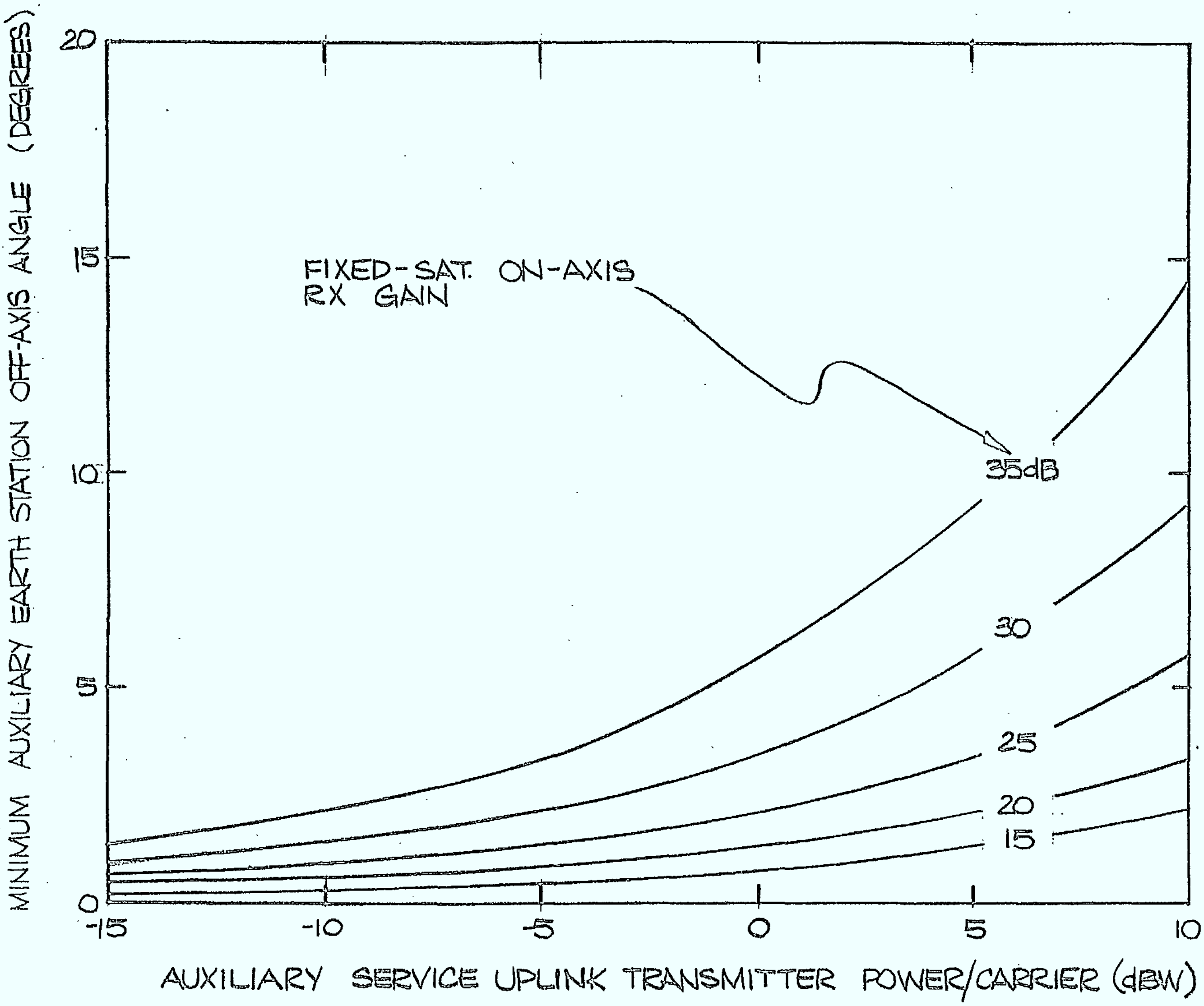


FIG. 8.4/2 MINIMUM AUX.-SERVICE EARTH STATION OFF-AXIS ANGLE FOR WHICH THE (C/I) = 40dB IN 24-CHANNEL FDM/FM FIXED-SAT. UPLINK AT 6.5 GHZ.

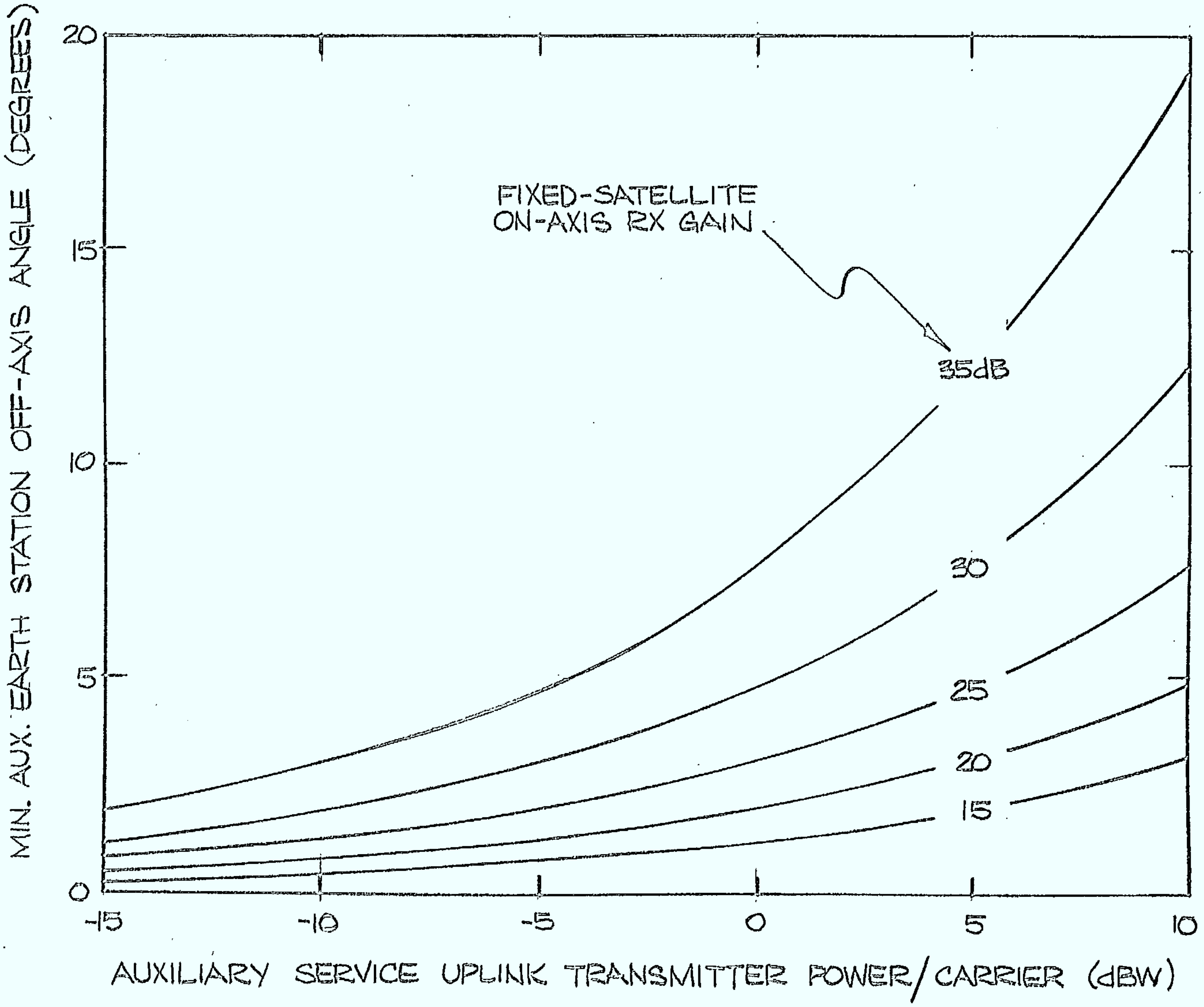


FIG. 8.4/3 MINIMUM AUX.-SERVICE EARTH STATION OFF-AXIS ANGLE FOR WHICH THE (C/I) = 45 dB IN A 960-CHANNEL FDM/FM FIXED-SAT. UPLINK AT 6.5 GHZ.

8.5 Summary

In this chapter, the sharing of uplink bands near 6 GHz by the fixed-satellite and the auxiliary-satellite services was investigated. It was found that in the case of co-channel operation, the auxiliary-service is subject to interference from earth stations in the fixed-satellite service and as a result, satellite separations on the order of 3 to 30 degrees may be necessary to permit sharing. The problem of auxiliary-service interference into a fixed-satellite uplink was also investigated. It was found that for high capacity fixed service traffic, smaller satellite separations can be obtained before the minimum interference levels are exceeded. For SCPC traffic, larger satellite separations are required than in the case of SCPC traffic interfering with the auxiliary-satellite uplink.

The effects of spurious emissions from fixed-satellite earth stations outside of the 6.425 - 6.625 GHz band was briefly considered. In general, out-of-band emissions could present a problem if an auxiliary service satellite is spaced less than $\approx$2 degrees from a fixed-satellite of the INTELSAT IV class.

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8.2/2 "The International Telecommunications Satellite Organization (INTELSAT)", M.B. Brown, Jr., in "Communication Satellite Systems: An Overview of the Technology", Edited by R.G. Gould and Y.F. Lum, IEEE Press, 1975.

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8.2/4 "Limitations on Off-Angle EIRP Density by Earth Stations in the Fixed-Satellite Service", CCIR Draft New Report, DOC. 4(53-E), 16 February, 1976.

8.3/1 "INTELSAT IV-A Transmission System Design", J. Dicks, M. Brown, Jr., COMSAT Technical Review, Vol. 5, No. 1, Spring, 1975.

9.0 FIXED-SATELLITE BANDS AT 10.7 -11.7 GHz

9.1 Introduction

The interference problem investigated in this chapter is concerned with the proposed use of the 10.7 - 11.7 GHz band by both fixed-satellite space-to-earth services (the current allocation), and fixed-satellite earth-to-space services. The proposed uplink traffic is FM/TV (ie, the feeder link to a broadcast-satellite). The feasibility of sharing this band depends on the levels of inter-system interference caused by:

- Downlink emissions from a satellite, interfering with a satellite receiving the uplink FM/TV signal
- Uplink FM/TV emissions from an earth station interfering with earth station receivers. This interference is assumed to be co-channel and is a very similar problem to that studied in Chapter 6.

9.2 System Characteristics

The uplink carrier is an FM/TV carrier feeding a broadcasting-satellite. The characteristics of the uplink, summarized in Table 9.2/1, are based on the recommendations in Reference 9.2/1 for a community broadcast service.

For an earth station at the edge of a satellite's coverage area, the EIRP required to provide a minimum uplink received power of -94 dBW is given by

$$(EIRP)_{up} = -94 - \left[(G_{o,SAT} - 3dB) - (L_{\substack{FREE\\SPACE}} + L_{LINK}) \right] \qquad (9.2.1)$$

$$= 120 - G_{o,SAT} \; , \; dBW .$$

Using equation 6.2.3 for the earth station's on-axis gain, substituting into 9.2.1 and rearranging gives the uplink transmitter power as a function of the earth station antenna diameter D (in metres), and the spacecraft on-axis gain, $G_{o,\ SAT}$ (in dB), ie:

$$P_{up} = 81.5 - 20 \log D - G_{o,SAT} \; , dBW . \qquad (9.2.2)$$

This equation is plotted in Figure 9.2/1 for a range of spacecraft antenna gains and earth station diameters. Comparison with equation 6.2.4 indicates that the transmitter power must be 4.2 dB higher at 11 GHz than at 4.5 GHz to provide the same uplink C/N.

The downlink traffic in the other fixed-satellite system consists of the same carriers studied in Chapter 6, ie, 24 and 960 channel FDM/FM signals. The characteristics of the downlinks are summarized in Table 9.2/2. The downlink on-axis satellite EIRP required

TABLE 9.2/1: Characteristics of the FM/TV uplink in the 10.7 - 11.7 GHz band

- Carrier = FM/TV
- Bandwidth = 23 MHz
- Required Uplink C/N = 27 dB, exceeded at least 99.9% of the time
- Free Space Loss (at 11 GHz) = 204.8 dB
- Uplink Clear Weather Attenuation = 0.5 dB
- Rain Margin = 3.5 dB, exceeded no more than 0.1% of the time
- Feeder Duplexer Losses = 2 dB
- Total Uplink Margin = 6 dB
- Uplink Noise Temperature = 2500 K
  - kTB = -121 dBW
- Minimum Required Carrier Power at LNA Input = -94 dBW
- Satellite Antenna Gain = 25 to 55 dB

Note: Rain margin is for southern Canada. Assumes 10 degree elevation angle, rain rate of 7 mm/hr (0.1% of time).

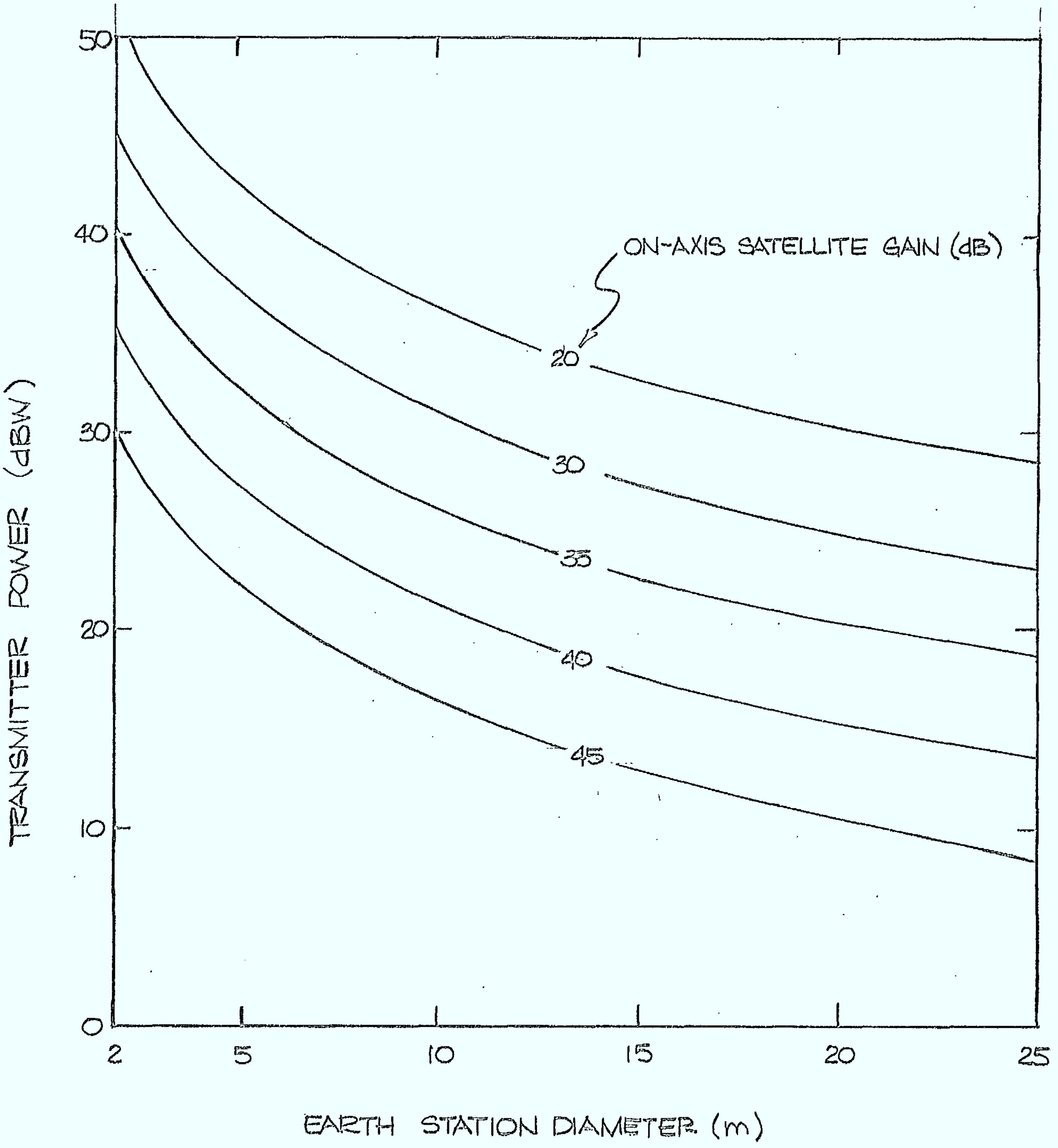


FIG. 9.2/1 MINIMUM UPLINK TRANSMITTER POWER FOR AN FM/TV CARRIER IN THE 10.7-11.7 GHZ BAND.

TABLE 9.2/2 Characteristics of Fixed-Satellite Downlink in 10.7 - 11.7 GHz Band

Carrier: 24 Channel FDM/FM

- Bandwidth = 2 MHz
- Required Downlink C/N = 13 dB, exceeded at least 99.9% of the time
- Earth Station LNA Noise Temp. = 120 K
  - Antenna Feeder Loss = 0.5 dB
  - Antenna Temperature = 150 K
  - System Noise Temp. = 285 K
  - kTB = -141 dBW
  - Minimum Required Carrier Power at LNA Input = -128 dBW

Carrier: 960 Channel FDM/FM

- Bandwidth = 36 MHz
- Required Downlink C/N = 18.4 dB, exceeded at least 99.9% of the time
- Earth Station LNA Noise Temp. = 60 K
  - Antenna Feeder Loss = 0.5 dB
  - Antenna Temperature = 150 K
  - System Temperature = 226 K
  - kTB = -129.5 dBW
  - Minimum Required Carrier Power at LNA Input = -111 dBW

Rain Margin = 6.4 dB, exceeded no more than 0.01% of the time

Total Downlink Margin = 8.4 dB

to provide the carrier-to-noise ratios shown in the table at stations at the edge of the coverage zone, is given by:

$$(EIRP)_{SAT} = P_{R,MIN} - G_{0,E} + 216.2 \quad , \text{dBW} \tag{9.2.3}$$

where $P_{R,MIN}$ is the minimum required carrier power at the input of the earth station LNA.

Expressing the earth station receiving gain $G_{o,E}$, in terms of the antenna diameter, and rearranging this equation gives the satellite transmitter power required for the downlink carrier.

$$P_d = 177.9 + P_{R,MIN} - G_{0,SAT} - 20 \log D \quad , \text{dBW} . \tag{9.2.4}$$

Comparison with equation 6.2.6 indicates that for comparable spacecraft antenna gains and earth station diameters, the satellite transmitter power in the 10.7 - 11.7 GHz band will be 5 dB higher than in the 4.4 - 4.7 GHz band for the same quality of service.

9.3 Interference Between Satellites

The first mode of inter-satellite interference to be studied involves closely spaced satellites. The level of received interference power at the broadcasting-satellite LNA is given by equation 6.3.1, and is shown in Figure 9.3/1 as a function of inter-satellite spacing for 0 dB spacecraft antenna gains.

If the permissible interference level is 10 dB below the uplink thermal noise, i.e., -131 dBW, the resulting C/I is 37 dB. For downlink carrier powers less than 10 dBW, a satellite spacing of 0.04 degrees would suffice. Comparison with the results in section 6.3 indicate that for the same C/I ratio, satellite spacings can be reduced by a factor of 2.8 from the values required in the 4.4 - 4.7 GHz band. If a C/I ratio of 45 dB is required and the sum of the antenna gains is increased by 10 dB, the minimum satellite spacing increases to 0.35 degrees (for a 10 dBW downlink carrier). As a result, this mode of interference should not impact the use of the 10.7 - 11.7 GHz band.

The other inter-satellite interference problem occurs when the two satellites are located in near-antipodal positions. The interference power, from Section 6.3, is given by

$$P_I = (EIRP)_{SAT} - (\Delta G_T + \Delta G_R) + G_{0,R} - 211.4 \text{ , dBW} \qquad (9.3.1)$$

where $(EIRP)_{SAT}$ is the fixed-satellite downlink EIRP, ΔG_T and ΔG_R are the antenna discriminations, and $G_{0,R}$ is the on-axis gain of the receiving antenna of the broadcasting-satellite. This equation is plotted in Figure 9.3/2. The on-axis gain of this antenna is assumed to be 52 dB, (i.e., 0.4 degree beamwidth). If a C/I ratio of 45 dB must be obtained, the downlink EIRP must be limited to values less than 26.4 dBW. If the minimum C/I ratio

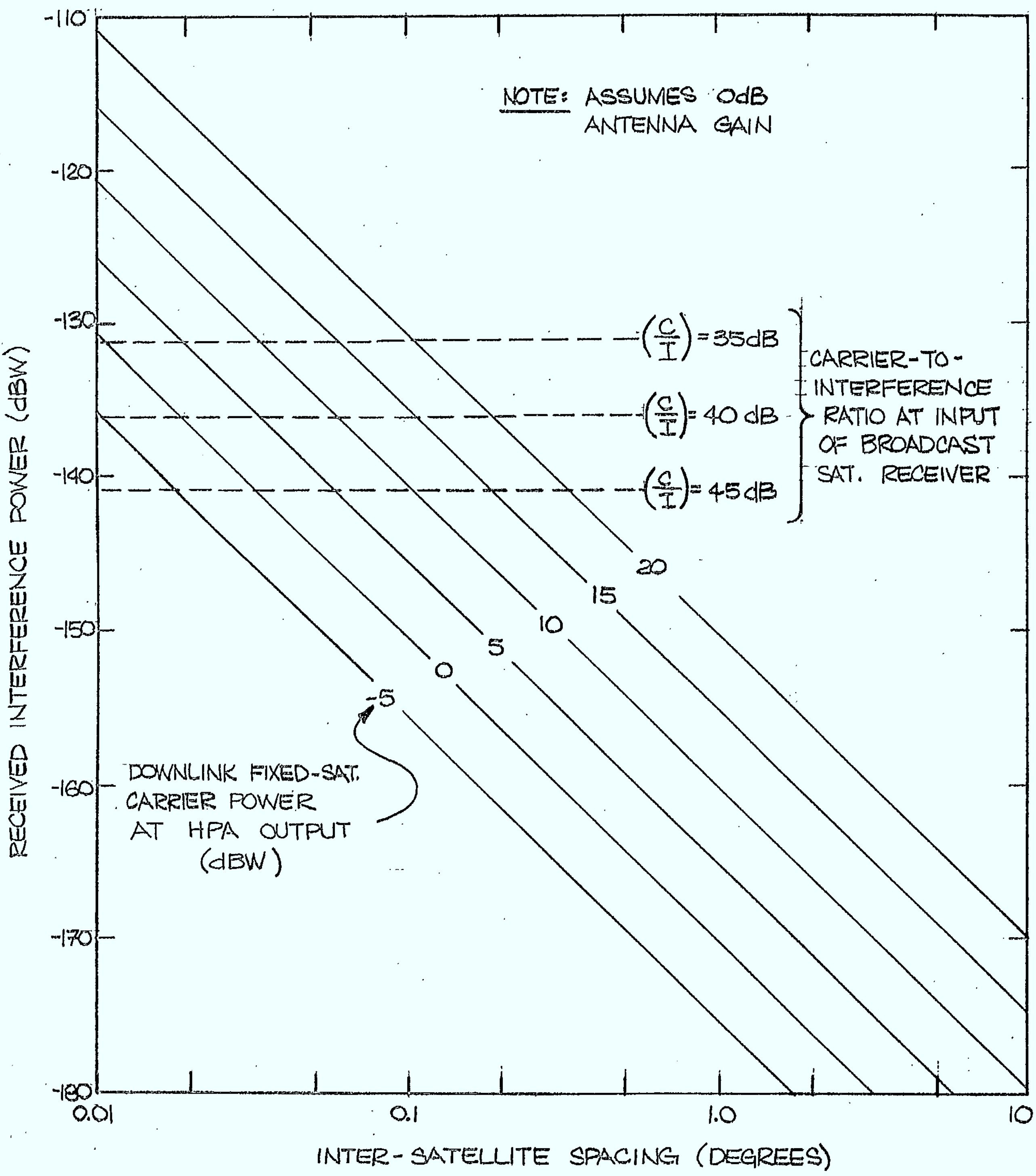


FIG. 9.3/1 INTERFERENCE POWER AT BROADCAST-SAT. RECEIVER FROM A COCHANNEL DOWNLINK CARRIER ON A CLOSELY SPACED SATELLITE IN THE 10.7-11.7 GHz. BAND.

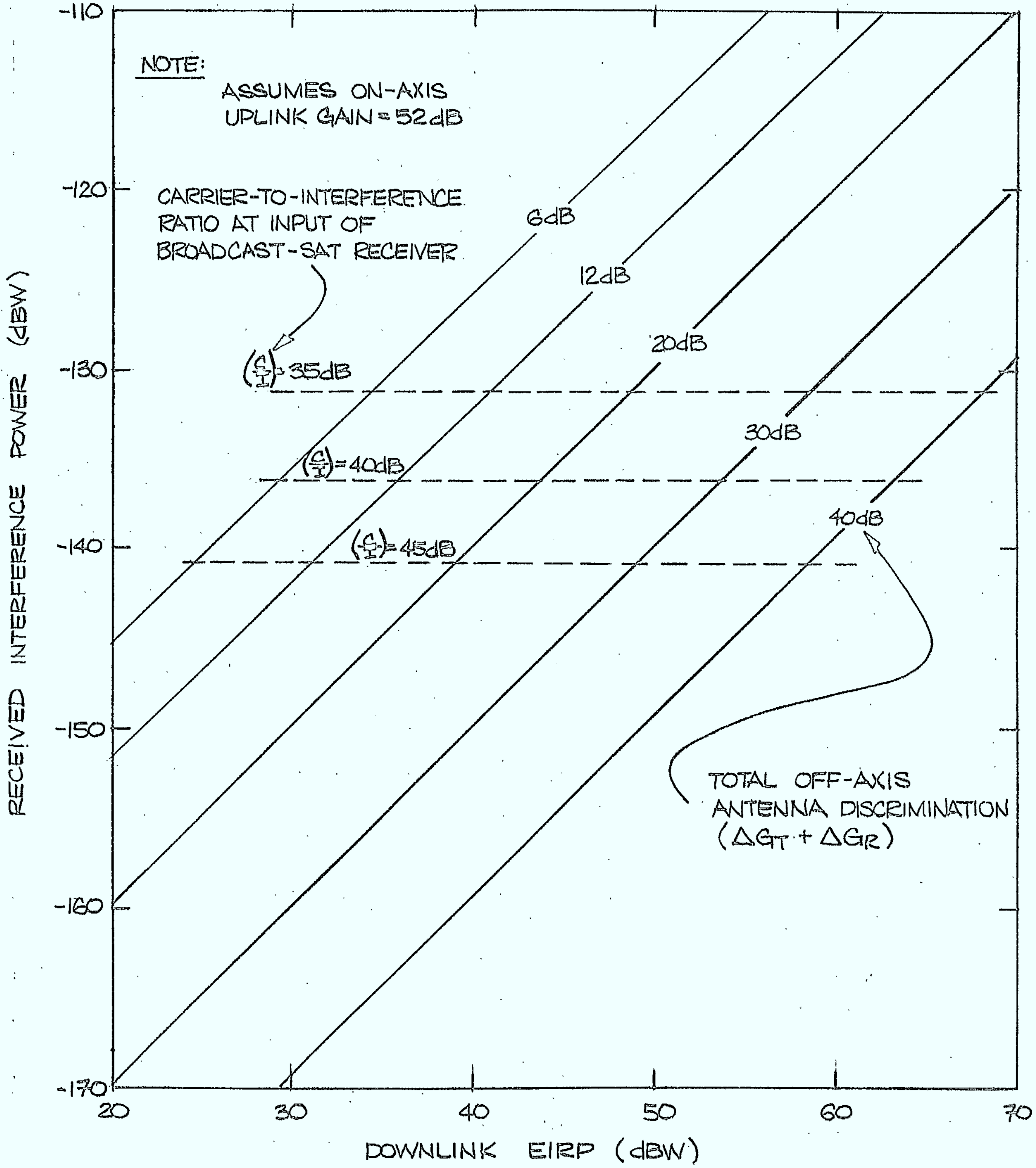


FIG. 9.3/2 ANTIPODAL SATELLITE INTERFERENCE AT 10.7 - 11.7 GHZ

is reduced to 35 dB, a downlink EIRP of 36.4 dBW can be tolerated. In general, however, coordination of the satellites would be required.

9.4 Interference Between Earth Stations

In this case, emissions from a fixed-satellite earth station feeding a broadcast-satellite may cause interference in the downlink of a fixed-satellite earth station. The interference power P_I, into the earth station receiver exceeded for less than 0.01% of the time is given by equation 6.4.1. The basic transmission loss used in this equation, L_b (0.01%) is shown in Figure 9.4/1 (from Reference 9.4/1) as a function of separation distance for a frequency of 11 GHz.

For the 24 channel FDM/FM downlink, the assumption is made that all of the power of the interfering FM/TV carrier falls in the 2 MHz receive band, and hence the minimum permissible transmission loss is given by

$$L_{MIN} = P_{up} - \left[-128\ \mathrm{dBW} - \left(\frac{C}{I}\right)_{0.01\%}\right], \mathrm{dB}. \tag{9.4.1}$$

where P_{up} is the uplink transmitted power of the FM/TV carrier. The G/I ratio exceeded for 99.9% of the time is 23 dB. Thus

$$L_{MIN} = P_{up} + 151, \mathrm{dB}. \tag{9.4.2}$$

For this carrier, the basic transmission loss must exceed

$$L_b(0.01\%) = P_{up} + 151 + G_T + G_R, \mathrm{dB}. \tag{9.4.3}$$

The uplink transmitter power for the FM/TV carrier will range from 10 to 40 dBW, as shown in Figure 9.2/1. For various earth station horizon gains, the corresponding minimum transmission loss is given in Table 9.4/1 as a function of the uplink transmitter power. Comparison of these values with those in Table 6.4/1 indicates that the minimum transmission loss is comparable to that required in the 4.4 - 4.7 GHz band for a given transmitter power. However, the separation distance

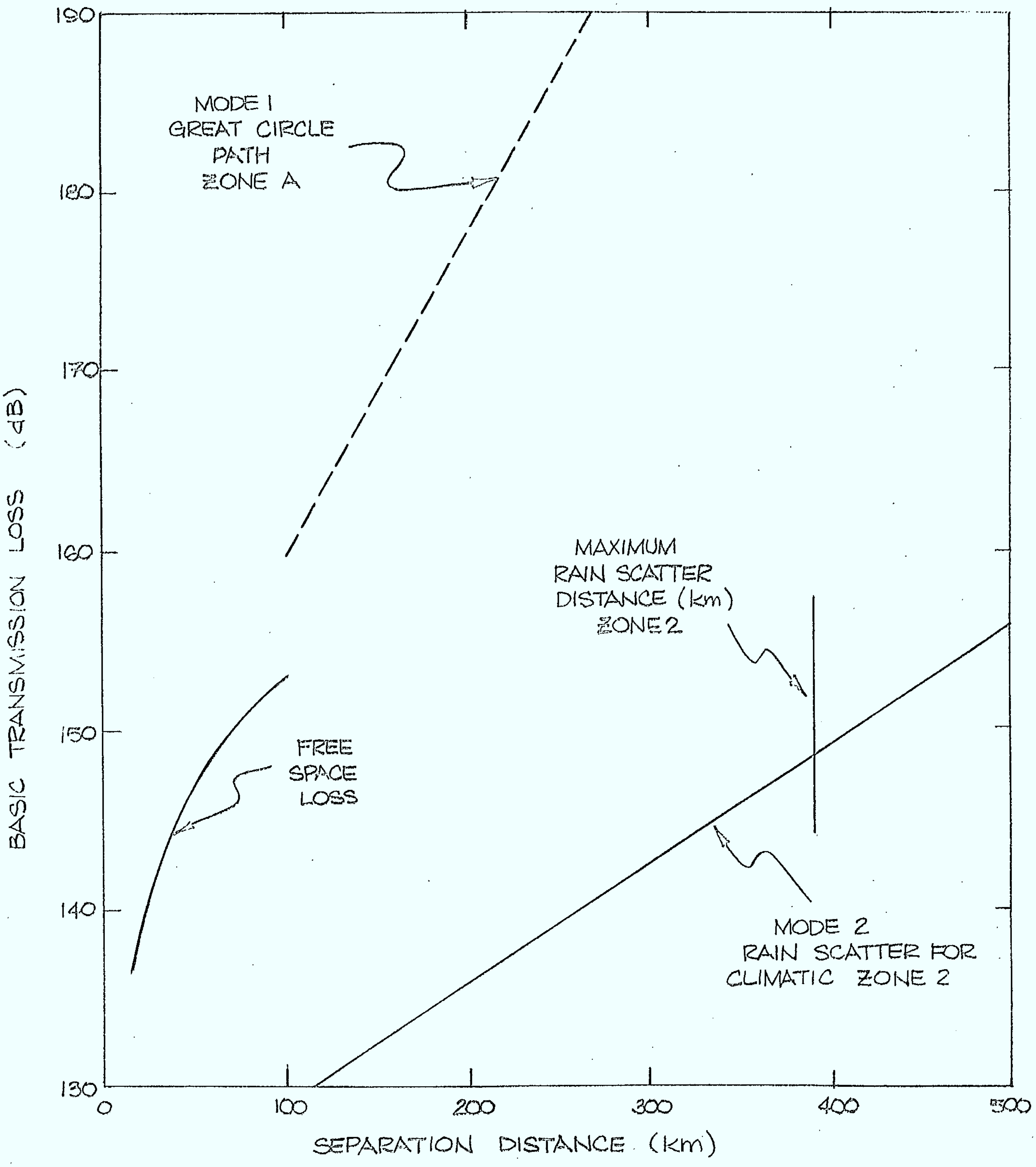


FIG. 9.4/1 TRANSMISSION LOSS BETWEEN TWO ISOTROPIC ANTENNAS AT 11 GHz, EXCEEDED FOR 0.01% OF TIME

TABLE 9.4/1 Minimum Basic Transmission Loss Required to Protect a 24 Channel FDM/FM Downlink at 11 GHz

(p = 0.01% of time)

Uplink TX Power (dBW)	Basic Transmission Loss (dB)		
	$G_T + G_R = -20dB$	$G_T + G_R = 0dB$	$G_T + G_R = 14dB$
5	136	156	170
10	141	161	175
15	146	166	180
20	151	171	185
25	156	176	190
30	161	181	195
35	166	186	200
40	171	191	205

corresponding to a given transmission loss is slightly less for Mode 1 propagation at 11 GHz than in the 4.4 4.7 GHz band.

Using a C/I ratio of 28.4 dB (99.99% of the time) for the 960 channel FDM/FM downlink carrier results in a minimum basic transmission loss given by

$$L_b(0.01\%) = P_{up} + 139.4 + G_T + G_R \text{, dB.} \tag{9.4.4}$$

Values of $L_b(0.01\%)$ for this carrier are given in Table 9.4/2. For the same uplink power and antenna gains, the transmission loss is 11.6 dB less in this case than for the 24 channel FDM/FM carrier.

TABLE 9.4/2 Minimum Basic Transmission Loss Required To Protect a 960 Channel FDM/FM Downlink at 11 GHz

(p = 0.01% of time)

Uplink TX Power (dBW)	Basic Transmission Loss (dB)		
	$G_T + G_R = -20$dB	$G_T + G_R = 0$ dB	$G_T + G_R = 14$dB
5	124.4	144.4	158.4
10	129.4	149.4	163.4
15	134.4	154.4	168.4
20	139.4	159.4	173.4
25	144.4	164.4	178.4
30	149.4	169.4	183.4
35	154.5	174.4	188.4
40	159.4	179.4	193.4

9.5 Summary

Inter-system interference between two fixed-satellite systems sharing up and downlink bands at 10.7 - 11.7 GHz has been examined in this chapter. The analysis and baseline system characteristics used in the analysis are similar to those used in Chapter 6, in which a similar interference problem in the 4.4 - 4.7 GHz band was investigated.

It was found that in general, coordination of the satellites and the earth stations will be required. The inter-satellite spacing for the uplink and downlink satellite will be on the order of 0.4 degrees, depending primarily on the satellite antennas' sidelobe responses and the downlink carrier power. This value indicates that this mode of interference will not be common and can easily be reduced to acceptable values by adjusting the satellites' locations slightly.

The other interference mode of concern occurs for near-antipodal satellites. In this case it was found that a severe interference problem could occur if the spacecraft antenna gains in the direction of the orbit arc are not carefully controlled. In the majority of cases, this mode of interference will not be significant as it depends on the occurrence of a rather unusual set of geometric circumstances.

Interference between earth stations can be a problem in this band. It was found that coordination contours on the order of 300 km may be required. As a result coordination of earth stations in the uplink and downlink services will be necessary at times. The problem will not be as severe as in the 4.4 - 4.7 GHz band however.

REFERENCES

9.2/1 "Broadcast-Satellite Service", DOC 10-11/1114-E, 16 March 1978, CCIR XIVth Plenary Assembly, Kyoto.

9.4/1 "Determination of Coordination Area", DOC. 4-9/1112-E, 28 March 1978, CCIR, Kyoto.

10.0 FIXED-SATELLITE AND BROADCASTING-SATELLITE BANDS NEAR 12 GHz

10.1 Introduction

In this chapter, several proposed frequency plans for the fixed-satellite and broadcasting-satellite services near 12 GHz are investigated. Intra-system interference in a broadcasting-satellite is investigated for two frequency plans involving the 11.7 - 12.5 GHz downlink, as shown in Figure 10.1/1 (plans 1 and 2). In addition to intra-system interference in such a system, inter-system interference is possible between systems using the broadcasting-satellite downlink 11.7 to 12.5 GHz and those using the fixed-satellite downlink at 11.7 - 12.2 GHz as shown in the figure as plan 3. The other inter-system interference mode which is studied is shown in the figure as plan 4. In this case, spurious emissions from downlink carriers in the broadcasting-satellite can cause interference into fixed-satellite receivers operating in the 12.5 - 13.25 GHz band.

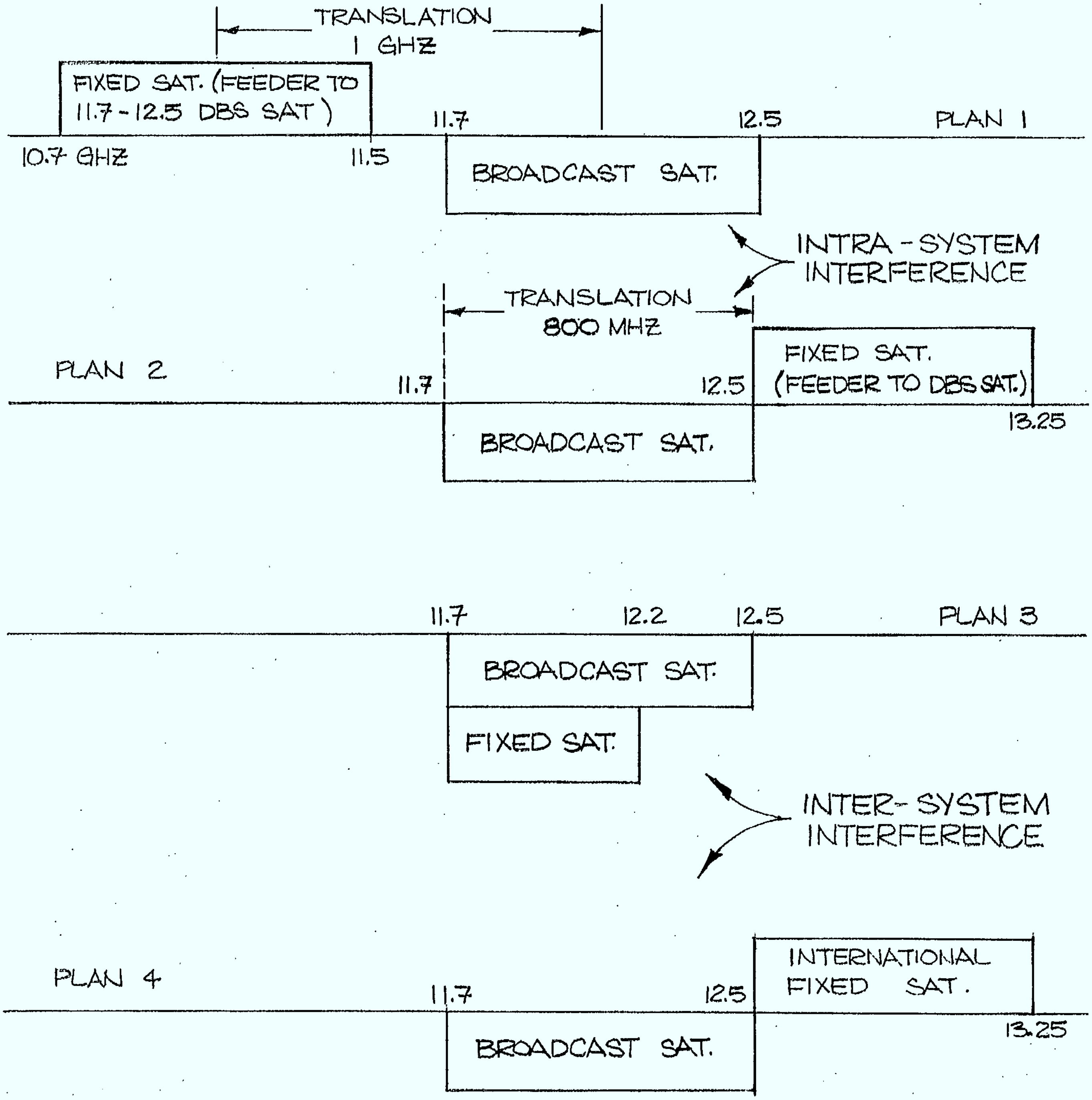


FIGURE 10.1/1 FREQUENCY PLANS FOR BROADCAST-SAT. AND FIXED-SAT. BANDS NEAR 12 GHZ.

10.2 System Characteristics

The characteristics and performance requirements of the broadcasting-satellite service in this band is summarized in Table 11.2/1. For the uplink band at either 10.7 - 11.5 GHz or 12.5 - 13.25 GHz, the characteristics are summarized in Table 9.2/1.

The only fixed-satellite uplink carrier considered explicitly in the analysis is a 40 kHz SCPC voice or data carrier with characteristics similar to Telesat's thin route and INTELSAT's SPADE carriers. The characteristics of this carrier are summarized in Table 10.2/1.

TABLE 10.2/1: Characteristics of Fixed-Satellite Uplink at 12 GHz

- Carrier: 40 kHz SCPC Voice or Data
- Required Uplink C/N = 24 dB, exceeded at least 99.99% of the time
- Free Space Loss = 206 dB
- Tropospheric Absorption = 0.5 dB
- Rain Attenuation = 6.4 dB, exceeded no more than 0.01% of the time
- Feeder, Duplexer, Pointing Loss = 2.0 dB
- Total Uplink Margin = 8.9 dB
- Satellite Receiving System Noise Temperature = 2,500 K
- kTB = -148.6 dBW
- Minimum Required Carrier Power at LNA input = -123.6 dBW

10.3 Intra- SystemInterference in the Broadcasting-Satellite

The feasibility of using the 10.7 - 11.5 GHz band as a feeder link to a broadcasting-satellite is considered first. A constraint on the use of this band as an uplink may exist if high levels of spurious, harmonically related emissions resulting from the up-conversion process in the satellite transponder, fall in the 11.7 - 12.5 GHz downlink band. The level of these emissions must be considerably below the thermal noise level of the link. A value of 40 dB below the carrier power in any 23 MHz band is assumed as the permissible level.

Spurious responses in a single conversion process at the output of the mixer can be estimated using the spurious response chart in Table 11.4/1. These responses occur at frequencies

$$f = n f_{RF} \pm m f_{LO} , \qquad (10.3.1)$$

where f_{RF} is the uplink carrier frequency and f_{LO} is the local oscillator frequency. For the 10.7 - 11.5 GHz band, $f_{LO} = 1$ GHz. The fundamental, or wanted emission occurs at $f = f_{RF} + f_{LO}$.

The only spurious emissions that need to be considered in the single conversion process occur for $n = 0,1,2,$ and 3. When $n=0$, the mixer spurious emissions occur at harmonics of the local oscillator frequency and will not be a problem.

For $n=1$, responses other than the fundamental occur at 10.7 - 11.5 GHz (carrier leakage, 30 dB down), 9.7 - 10.5 GHz (0 dB down, corresponding to $f_{RF} - f_{LO}$), 12.7 - 13.5 GHz (33 dB down) and at 8.7 - 9.5 GHz (33 dB down). As all of these are at least 200 MHz from the downlink band, these emissions should not impact the pairing of the 10.7 - 11.5 / 11.7 - 12.5 GHz bands.

For n=2, emissions fall in bands near 20 GHz and will not present a problem. Similarly, for n=3, spurious emissions fall in bands above 30 GHz.

The isolation requirements between the input and output sections of a broadcasting-satellite using these bands is considered now. A possible constraint on the use of these bands can occur as a result of intermodulation products and other spurious emissions from the satellite HPA falling in the 10.7 - 11.5 GHz uplink band. From Table 9.2/1, the thermal noise power in a 23 MHz bandwidth in the uplink band, referenced to the input of the LNA is approximately -121 dBW. If spurious emissions from the satellite HPA are to be less than -131 dB at this point, they must be attenuated by the HPA output filter. In addition to the isolation obtained by the output filter, approximately 30 dB of isolation can be obtained if orthogonally polarized transmit and receive antennas are used. For a 23 dBW downlink carrier power, and assuming that the spurious emissions at the HPA output are approximately 60 dB down from this value in the uplink band (Reference 10.3/1), then a total of 95 dB of isolation is required. As output filters with a roll off of 2 dB/MHz are feasible at 12 GHz (Reference 10.3/2) this isolation can be obtained without a requirement for additional guardbands in the downlink band. As a result this mode of intra-system interference will not impact the use of the 10.7 - 11.5 GHz uplink band as a feeder link to a broadcasting-satellite using the 11.7 - 12.5 GHz downlink.

The other mode of intra-system interference that must be considered occurs when intermodulation distortion products generated in the LNA fall in the 10.7 - 11.5 GHz receiving band. Equation 7.3.1 can be used to estimate the level of isolation that must be provided by the receiver input filter. Assuming an LNA gain of 40 dB, a third order intercept point of -10 dBW (at the output of the LNA) and a downlink transmitter power of 23 dBW, the input filter attenuation in the downlink band must exceed:

$$A_{IN} = \begin{cases} 100 \text{ dB, when co-polarized RX/TX antennas are used} \\ 70 \text{ dB, when cross-polarized RX/TX antennas are used.} \end{cases}$$

The transmitted carrier power at the LNA input will be less than -77 dBW after being attenuated by the input filter. At the output of a wideband LNA the carrier level would be -37 dBW. Since the 1 dB compression point of typical LNA's is approximately -20 dBW, the LNA will operate 17 dB below saturation. As a result, the isolation provided by the input filter to reduce IM noise generated in the LNA will also ensure that the receiver is not saturated by the downlink carrier.

If orthogonally polarized RX and TX antennas are used on the satellite, then an 11 pole Chebyshev filter would be required at the input of the LNA, assuming that the 3 dB points of the filter occur at 10.7 GHz and 11.5 GHz. At 11.7 GHz, the filter will attenuate signals by 76 dB. A 10 pole Chebyshev filter would be required at the HPA output. As a result, the pairing of these two bands is possible but will place constraints on the spacecraft design.

The feasibility of using the 12.5 - 13.25 GHz uplink band as a feeder link to the broadcasting-satellite is considered now. A portion of the downlink band from 12.45 - 12.5 GHz is used as a guardband between the uplink and downlink bands so that equal uplink and downlink bandwidths are obtained.

Spurious mixer products for a single conversion translation (f_{LO}= 800 MHz) can fall within 50 MHz of the downlink band. The emissions are at least 30 dB down however, and can be easily reduced to acceptable values by the spacecraft multiplexer filters. As a result it should be feasible to use a single conversion process to translate carriers in the 12.5 - 13.25 GHz band to the 11.7 - 12.45 GHz band.

The isolation that must be provided by the filter at the output of a 200 watt HPA, assuming that orthogonally polarized uplink and downlink signals are employed is 65 dB. The corresponding isolation that must be provided by the filter at the input of the satellite LNA is 70 dB. The practicality of using the 12.5 - 13.25 GHz uplink band with the 11.7 - 12.5 GHz downlink band depends to a large degree on the ease with which these filters can be realized. A 62 MHz guardband between the closest spaced transmit and receive channels is possible, made up of 50 MHz from 12.45 - 12.5 GHz, and 12 MHz corresponding to the guardband required by the C.C.I.R. (Reference 10.3/2) at the lower edge of the 11.7 - 12.5 GHz band.

The use of a bandpass filter with 3 dB points at 12.512 and 13.25 GHz and an attenuation of 70 dB at 12.45 GHz will be very difficult to achieve. If a 10 pole Chebyshev filter is used to provide an attenuation of 70 dB, 62 MHz beyond the 3 dB points of the filter, the 3 dB bandwidth of the filter must be 97 MHz. This will increase the complexity of the satellite as more input and output filters would then be required. As a result, the pairing of these bands will be difficult to realize.

The filtering requirements could be relaxed somewhat if more isolation were provided by other means. For example, if completely separate transmitting and receiving antennas and feeds are used, additional isolation could be obtained. This increase in spacecraft complexity could be traded off against lower filtering requirements. In any case, use of the 12.5 - 13.25 GHz band as an uplink to a broadcasting-satellite utilizing the 11.7 - 12.5 GHz band is not recommended on the basis of the intra-system interference, particularly when other uplink bands are available.

10.4 Inter-System Interference

As shown in Figure 10.1/1, the 11.7 - 12.2 GHz portion of the broadcasting-satellite downlink is shared by the fixed-satellite service. Two co-channel interference modes can occur in this instance:

- interference from a broadcasting-satellite into a fixed-satellite downlink
- interference from a fixed-satellite downlink into a broadcasting-satellite earth station receiver.

In the first case shown as plan 3 in Figure 10.1/1, it is generally accepted that narrowband SCPC downlinks are the most susceptible of the fixed-satellite carriers to interference from a broadcasting-satellite and that sharing of the band will be very difficult. Interference from fixed-satellite downlink carriers into the broadcasting-satellite earth station receiver is more severe for a "community-reception" station than for an "individual" broadcast receiver. As these problems have been studied elsewhere a similar analysis is not presented here.

The other interference mode, shown as plan 4 in Figure 10.1/1, occurs from spurious emissions from the broadcasting-satellite falling in the adjacent 12.5 - 13.25 GHz fixed-satellite uplink band. In this case, a guardband at the 12.5 GHz edge of the broadcast-satellite downlink is recommended (Reference 10.3/2) to protect the adjacent fixed-satellite band. This mode of interference can occur for closely spaced satellites and for satellites located in antipodal positions, and is investigated in the remainder of this section.

The uplink fixed-satellite carrier most susceptible to interference from spurious emissions from a broadcasting-satellite is a narrowband SCPC carrier. The interference power received in a 40 kHz band at the input of the fixed-satellite LNA, for closely spaced satellites, is given by:

$$P_I = P_T + G_T + G_R + 20 \log \left(\frac{\lambda}{4\pi R_G \theta_S} \right) , \text{ dBW} \quad (10.4.1)$$

where P_T is the spurious power at the output of the broadcasting-satellite HPA, G_T and G_R are the spacecraft antenna gains in the direction of one another, R_G is the radius of the geosynchronous orbit arc, and θ_S is the satellite spacing. Assuming 0 dB antenna gains gives:

$$P_I = P_T - 20 \log \theta_{S,deg.} - 171.3 , \text{ dBW}. \quad (10.4.2)$$

From Table 10.2/1, the minimum required carrier power at the fixed-satellite LNA input is -123.6 dBW for a 40 kHz SCPC carrier. The C/I ratio is then given by

$$\left(\frac{C}{I} \right) = 47.7 - P_T + 20 \log \theta_S , \text{ dB} . \quad (10.4.3)$$

From Reference 10.3/1, values for the out-of-band power can be estimated. At the edge of the RF bandwidth of a 200 watt FM/TV carrier, out-of-band emissions are on the order of -26 dBW in a 4 kHz band and fall off at a rate of 1 dB/MHz assuming no output filtering. In Region 2, the recommended guardband is 9 MHz at the upper edge of 11.7 - 12.5 GHz band, and is based on an output filter roll-off of 2 dB/MHz (Reference 10.3/2). The out-of-band emission level 9 MHz from the edge of the carrier bandwidth is -35 dBW in a 4 kHz band. After filtering, this level is reduced 18 dB, to -53 dBW in a 4 kHz band, or -43 dBW in a 40 kHz band. Assuming that the C/I ratio exceeds 30 dB for at least 99.99% of the time, results in a minimum satellite separation angle of 0.0009 degrees (from equation 10.4.3). At such a small separation, equation 10.4.3 is no longer valid as the separation angle is much less than the satellite station-keeping errors. If the satellites are separated by 0.2 degrees, to allow for station keeping errors, and a 9 MHz guardband is employed, then the C/I ratio is 77 dB. As a result, this mode of inter-satellite interference should not affect the operation of the fixed-satellite service in the 12.5 - 13.25 GHz uplink band.

The other inter-satellite interference mode occurs when the satellites are located in antipodal positions. In this case, the satellites are separated by 83000 km and free space propagation conditions apply. As a result, the interference power at the input of the fixed-satellite LNA is:

$$P_I = P_T + G_T + G_R - 212.4 \quad , \text{dBW} \qquad (10.4.4)$$

and the uplink C/I ratio for a SCPC channel is

$$\left(\frac{C}{I}\right) = 88.8 - P_T - G_T - G_R \quad , \text{dB} \qquad (10.4.5)$$

where G_R and G_T are the satellite antenna gains in each others direction. To achieve a 30 dB C/I ratio, given P_T = -43 dBW in a 40 kHz band (corresponding to a 9 MHz guardband), the sum of the antenna gains must not exceed 102.8 dB. As satellite antenna gains are not expected to exceed 45 dB, corresponding to a beamwidth of one degree, this mode of interference is also negligible. As a result, the 9 MHz guardband is sufficient to protect the fixed-satellite service at 12.5 - 13.25 GHz from out-of-band emissions from broadcasting-satellites.

10.5 Summary

In this chapter, intra-system interference in a broadcasting-satellite system was investigated to determine the feasibility of using uplink bands at 10.7 - 11.5 GHz or at 12.5 - 13.25 GHz as feeder links to the satellite. In both cases it was found that a single conversion process can be used to translate carriers from the uplink band to the downlink band but the implementation difficulty of a satellite using the 12.5 - 13.25 GHz uplink band with the 11.7 - 12.5 GHz downlink band could be prohibitive.

For the 10.7 - 11.5 GHz uplink band, it was found that the 200 MHz separation from the edge of the downlink band is sufficient to ensure that spurious emissions from the satellite's HPA do not cause interference in the uplink band. As the 12.5 - 13.25 GHz band is only 750 MHz wide compared to 800 MHz in the downlink, it was assumed that 50 MHz at the 12.5 GHz edge of the downlink band will be used as part of the 62 MHz guardband. This guardband is sufficient to isolate the satellite LNA from the transmit section. The use of a single wideband input or output filter will not be feasible in this band however. As a result, several filters could be required. As the design problems associated with the use of such closely spaced bands are many and solutions expensive, the use of the 12.5 - 13.25 GHz band as a feeder to a 12 GHz broadcasting-satellite is not recommended.

In the case of inter-system interference due to spurious emissions from the broadcasting-satellite transmitter into the 12.5 - 13.25 GHz fixed-satellite uplink band, it was found that the 9 MHz guardband suggested in Reference 10.3/2 is sufficient to protect the fixed-satellite uplink from the broadcasting-satellite.

REFERENCES

10.3/1 "Out-of-Band Emissions from Broadcasting-Satellite Space Stations Operating in the Band 11.7 to 12.2 GHz (12.5 GHz in Region 1)", CCIR Draft Report 11/479, DOC. 10-11/1110-E, 23 March 1978, Kyoto.

10.3/2 "Broadcasting-Satellite Service", DOC 10-11/1114-E, 16 March 1978, CCIR XIVth Plenary Assembly, Kyoto.

11.0 FEASIBILITY OF USING 4.4 - 4.7 (UPLINK) AND 12.2 - 12.5 GHz (DOWNLINK) BANDS BY THE BROADCASTING-SATELLITE SERVICE

11.1 Introduction

In this chapter, the feasibility of using the 4.4 - 4.7 GHz uplink band to feed a broadcast-satellite utilizing the 12.2 - 12.5 GHz downlink band is investigated. Amoung the constraints on the spacecraft design are:

- Spurious, harmonically related emissions resulting from the up-conversion of the FM/TV signals from the 4.4 - 4.7 GHz band to the 12.2 - 12.5 GHz band and the related filtering requirements in the satellite transponder.

- Satellite antenna configuration to permit use of such widely separated bands.

Although other factors also influence the use of this pair of bands, only the problems associated with the up-conversion and antenna configuration is studied in this chapter.

11.2 System Characteristics

The characteristics assumed for the uplink at 4.4 to 4.7 GHz are described in section 6.2. The uplink FM/TV carrier is assumed to have a 23 MHz bandwidth. For a Canadian-coverage system, the spacecraft receiving antenna gain, $G_{o,\ SAT}$, can be obtained from equation 6.2.4, i.e.,

$$G_{o,SAT} = 77.5 - 20 \log D - P_{up} \quad , dB \tag{11.2.1}$$

where P_{UP} is the earth station transmitter power (in dBW) and D is its antenna diameter (in metres). This equation is based on the assumption that the satellite antenna gain at the edge of the coverage area is 3-dB down from the on-axis gain. For a Canadian-coverage receiving antenna, an elliptically shaped beam approximately 4^{o} x 8^{o} is required, providing an on-axis gain of 30 dB. For a 10 m earth station, an uplink transmitter power of $\approx$ 560 watts will be required. These values are consistent with satellite systems operating in the 4/6 GHz bands and should not impose any constraints on the use of the 4.4 to 4.7 GHz band as an uplink to a broadcast-satellite system.

The characteristics of the downlink in the 12.2 - 12.5 GHz band are summarized in Table 11.2/1. The values contained in the table were obtained from Reference 11.2/1, and are intended for a community reception service operating in Region 2, (Rain climate zone 2). The required downlink EIRP can only be obtained through the use of satellite spot beams. A broadcasting-satellite serving Canada would typically use antenna gains of approximately 40 dB, corresponding to a 3-dB beamwidth of 1.6^{o}. The resulting coverage area in central Canada (assuming a spacecraft located due south) would be approximately 1000 km (E-W) by 2000 km (N-S).

TABLE 11.2/1: Characteristics of Broadcast-Satellite Downlink at 12.2 - 12.5 GHz (Community Reception)

- Carrier Bandwidth = 23 MHz
- Required Downlink C/N = 18 dB, exceeded 99% of the worst month
- System Noise Temperature = 800 K
  kTB = -126 dBW
- Free Space Loss = 205.8 dB
- Rain Margin (1% of worst month) = 2 dB
- Tropospheric Absorption = 0.5 dB
- Feeder, Duplexer, Pointing Loss = 3 dB
- Total Downlink Margin = 5.5 dB
- Minimum Required Carrier Power at LNA Input = -108 dBW

11.3 Spacecraft Antenna Considerations

The choice of spacecraft antenna for this service is probably restricted to a reflector type antenna utilizing an offset feed configuration. To obtain a 40 dB on-axis gain at 12.2 GHz, the reflector diameter must be approximately 1.10 m. The polarization of this antenna would probably be linear polarization. Although there is little superiority of linear over circular polarization in the band from the point of view of propagation phenomena, both the satellite and earth station segments of the system would be easier to implement using linear polarization, especially as high power and broadband characteristics are important, (Reference 11.3/1). Circular polarization is at a disadvantage in this system since a circular polarized feed horn requires a polarizer which changes a linearly polarized wave to a circularly polarized wave, adding to the weight and mechanical complexity of the satellite.

The spacecraft receiving antenna operating in the 4.4 - 4.7 GHz band would probably serve a larger area than that of a beam used for the downlink. If the uplink receive beam for a Canadian domestic system is similar to that currently employed in the ANIK series of satellites, then an offset feed would be employed. The size of the reflector utilized on ANIK is approximately 60 inches in diameter and dual feedhorns are utilized to obtain a beam pattern that is wider in the plane containing the feed axes than in the perpendicular (N-S) plane.

The possibility of using a common reflector for the uplink and downlink bands will now be considered. The gain of a parabolic antenna obtained at 4.4 GHz is plotted in Figure 11.3/1 as a function of the gain obtained at 12.2 GHz. A 9 dB difference exists between the gains at these two frequencies, and corresponding to a beamwidth ratio, ie. $(\varphi_{3dB,\ 4.4\ GHz} / \varphi_{3dB,\ 12.2\ GHz})$ of 2.8. As a result, sharing of the reflector would be feasible as the same paraboloid reflector would provide the appropriate gain for both the uplink and downlink bands. The use of a single reflector can also reduce the mechanical complexity and weight of the spacecraft.

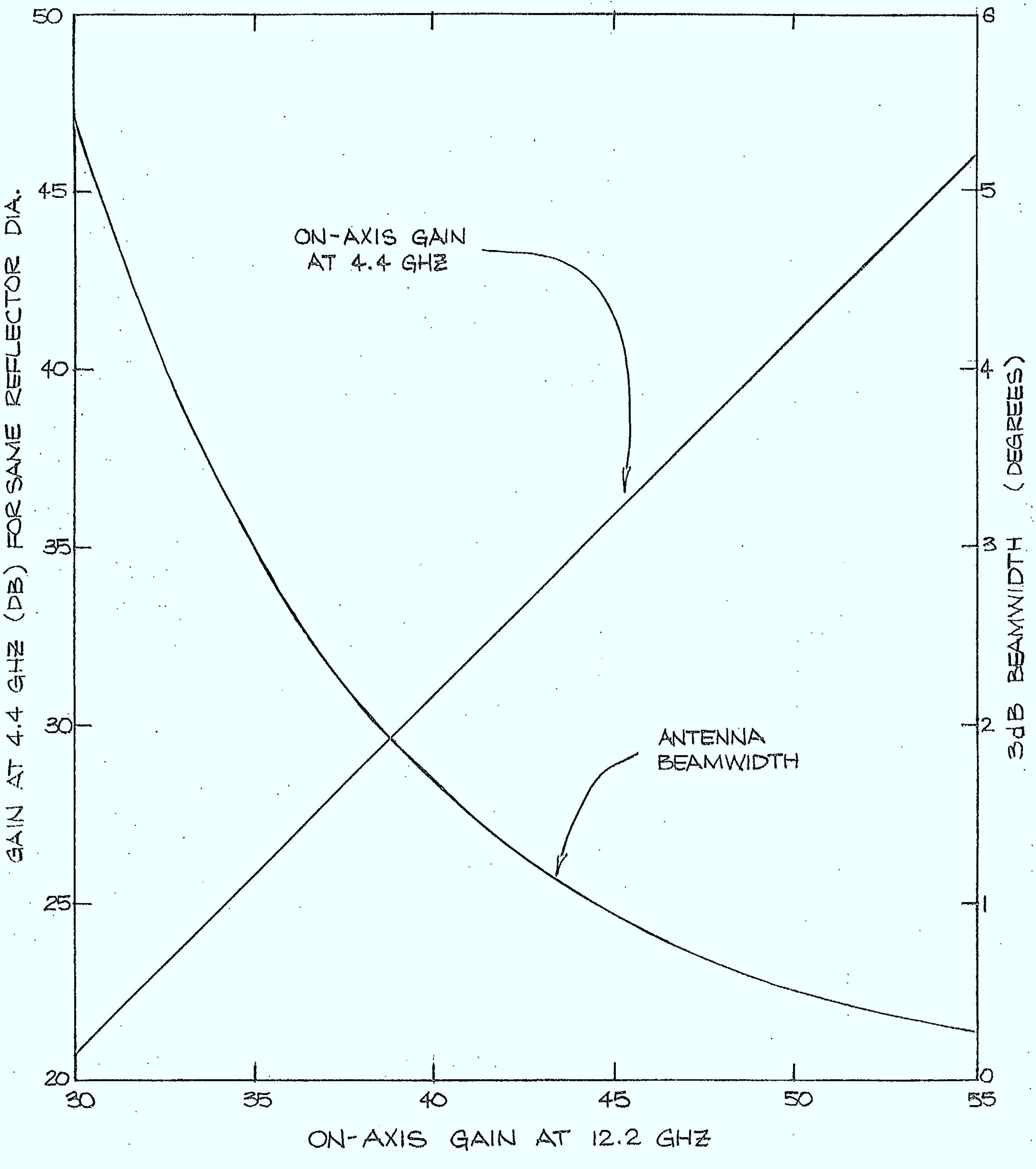


FIG. 11.3/1 ANTENNA GAIN FOR PARABOLIC REFLECTOR OPERATING AT DIFFERENT FREQUENCIES

As the use of a single feed horn with a bandwidth sufficiently wide to accomodate both the 4.4 - 4.7 and 12.2 - 12.5 GHz bands is not feasible, separate feedhorns will be required.

The main problem facing the spacecraft antenna designer will be the positioning of the feed horns. The problems will be fairly difficult for this type of service as multiple downlink spot beams are almost certainly a requirement. If steerable beams are used, the mechanical complexity of the feed structure may necessitate the use of separate uplink and downlink antennas. The reason for this is that if multiple feed horns are placed near the focal point of a parabolic antenna, comatic aberration will increase the sidelobe levels of those beams farthest from the rotation axis of the paraboloid (Reference 11.3/1). This may cause interference between downlink beams. To minimize this problem, caused by feed placement geometry, mechanical constraints may force the uplink feed horns to utilize a separate reflector.

11.4 Up- conversion

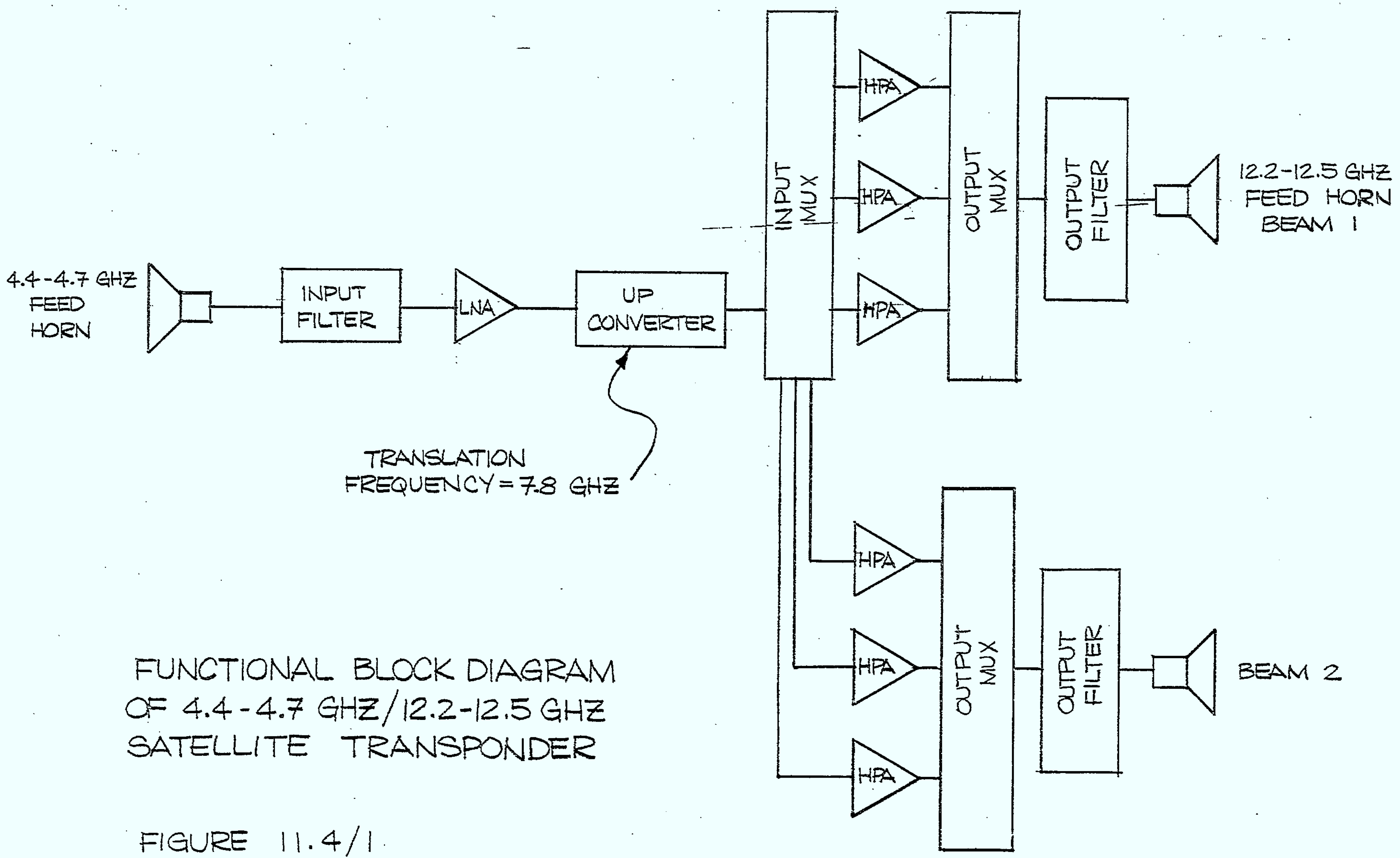
A block diagram of a satellite transponder utilizing the 4.4 - 4.7 and 12.2 - 12.5 GHz bands is illustrated in Figure 11.4/1. As high power TWTs are required to provide the required downlink EIRP, single carrier per HPA operation is assumed. This will minimize the out-of-band intermodulation distortion power at frequencies outside of the 12.2 - 12.5 GHz band. The input multiplexer is required to route the each upconverted FM/TV carrier to its associated TWT and the output multiplexer is required to route groups of amplified carriers to particular feed horns, (ie, assumes a multibeam configuration).

Two up-convertor implementations are possible. The first is a single conversion process requiring a balanced mixer and a 7.8 GHz local oscillator. The second approach is to use a double conversion implementation. In this case two mixing processes are required. A double conversion up-convertor allows the transponder designer more flexibility in filtering harmonically related emissions at the output of the first mixer. However, single conversion would be prefered on the basis of transponder weight and reliability (Reference 11.4/1).

The levels of spurious responses for a typical high performance double balanced mixer are shown in Table 11.4/1. Spurious responses will occur at multiples of the input frequency, f_{RF}, and the local oscillator frequency, f_{LO}, ie:

$$f = n f_{RF} \pm m f_{LO} \quad (11.4.1)$$

For single conversion, the emission spectrum at the output of the mixer is shown in Figure 11.4/2. For n, $m \leq 7$, only three spurious responses fall in the 12.2 - 12.5 GHz band.



FUNCTIONAL BLOCK DIAGRAM
OF 4.4-4.7 GHZ/12.2-12.5 GHZ
SATELLITE TRANSPONDER

FIGURE 11.4/1

TABLE 11.4/1 Mixer Spurious Response Chart

m n	0	1	2	3	4	5	6	7	8
0		35	40	46	54	54	55	56	55
1	30	0	33	13	35	35	42	35	45
2	60	70	70	65	80	60	73	70	98
3	70	60	65	70	70	55	75	55	75
4	85	80	95	85	95	85	95	85	90
5	85	80	85	70	90	67	92	65	85
6	97	90	95	90	97	95	100	90	100
7	99	95	100	90	95	99	100	85	95

Note:

- Responses referenced in dB below the desired signal at $f = f_{LO} + f_{RF}$
- frequency of spurious response = $nf_{RF} \pm mf_{LO}$
- f_{LO} = local oscillator frequency
- f_{RF} = frequency of input signal
- The values circled indicate that those products fall in the 12.2 to 12.5 GHz band.

FROM: ANZAC Model MD-113, Waltham, Mass.

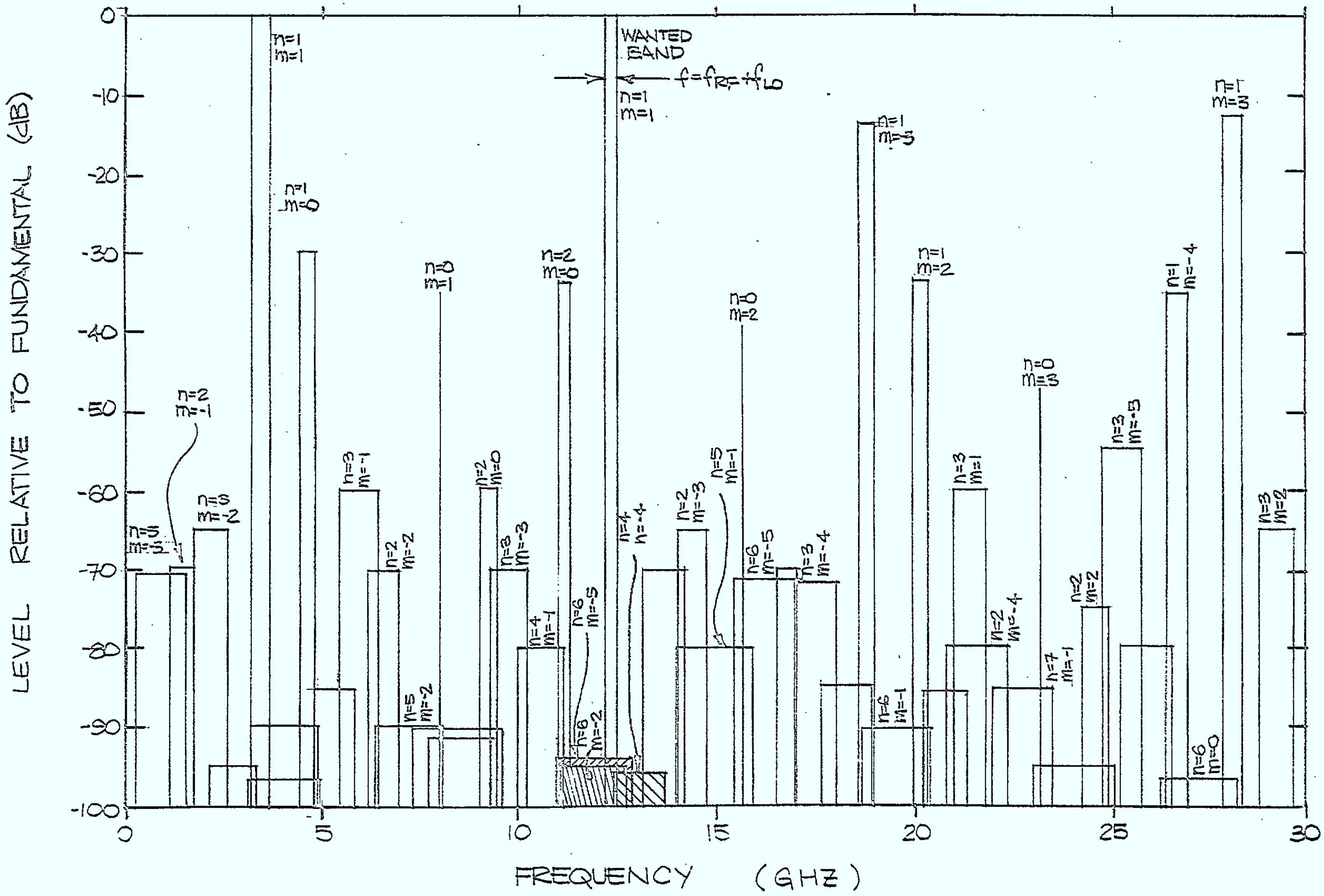


FIG. 11.4/2 SPECTRUM OF SPURIOUS OUTPUTS OF MIXER (LO=7.8 GHZ)

These responses are all down at least 95 dB relative to the fundamental and should not result in any degradation to the signal quality on the link. The remaining responses can be adequately filtered by the input multiplexer filters to negligible values, as 8-section Chebyshev filters are typical of this type of filter. The response of such a filter is typically 95 dB down, 40 MHz out from the channel edge (Reference 11.4/2). As a result, spurious responses from the single conversion mixing process can be effectively eliminated and will probably be the preferred approach if the 4.4 - 4.7 GHz band is used as an uplink to the 12.2 - 12.5 GHz downlink band.

11.5 Summary

The use of the 4.4 - 4.7 GHz uplink band with a 12.2 - 12.5 GHz downlink band should not pose any unique problems to system designers. The ratio of the downlink-to-uplink frequencies is such that for antenna plans particularly suited to a Canadian domestic system, a common spacecraft antenna reflector can be used. This should not be a particularly important factor in determining the use of these bands however, as in some cases, it will be preferable to use separate receiving and transmitting antenna structures, or possibly several of each, as is commonly done on existing 4/6 GHz spacecraft.

The choice of up-conversion technique was also studied. It was found that a single conversion process can be used as no high power spurious responses occur in the downlink band.

REFERENCES

11.2/1 "Broadcast- Satellite Service", DOC. 10-11/1114-E, 16 March 1978, CCIR XIVth Plenary Assembly, Kyoto.

11.3/1 "A Multi-beam SHF Satellite Communications System for Canada (1978 - 1985)", by Bell Northern Research, Ottawa, Study Contract No. PL 36100-0067 for DOC, Canada, October, 1972.

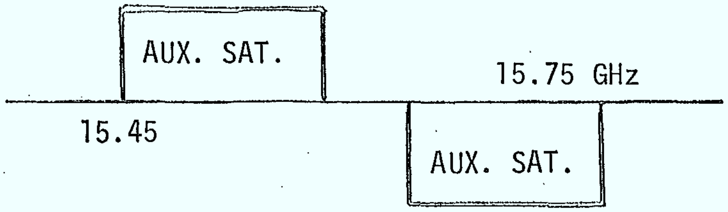
11.4/1 "A Super-High-Frequency Satellite Communications System for Canada (1977 - 1985)," Vol. 2, by Bell Northern Research, Ottawa, Study Contract No. PL36001-0-2945, for DOC, Canada, September, 1971.

11.4/2 "RCA Satcom, Satellite Technical Description," Prepared by RCA/ Government and Commercial Systems Astro-Electronics Division, Princeton, N.J. , for submission to the FCC, Dec. 7, 1973.

12.0 AUXILIARY-SATELLITE BANDS AT 15 GHz

12.1 Introduction

In this chapter, the proposed use of a band at 15.45 - 15.75 GHz to provide links between earth stations at fixed locations and satellites in the mobile-satellite service is investigated. The proposed frequency plan is shown below:



A potential intra-system interference problem exists in the spacecraft that will limit the available uplink and downlink bandwidths. The purpose of this chapter is to investigate this interference to estimate the maximum usable bandwidths that can be obtained for this type of service. Because of the close spacing of the uplink and downlink bands and the nature of the traffic (ie, narrow-band voice and data), intermodulation distortion generated in the satellite HPA will fall in the uplink band. The severity of this problem together with the characteristics of the spacecraft output and input filters will determine the bandwidths that can be obtained and the suitability of this band for this class of service.

The nature of the problem investigated in this chapter is very similar to that of Chapter 3. As a result, many of the analysis techniques and equations given in that chapter will be used in the following analysis.

12.2 System Characteristics

The uplink and downlink system characteristics and performance requirements are summarized in Tables 12.2/1 and 12.2/2. The downlink transmitted carrier power required to maintain a C/N of 25 dB (1% of the time, rain zone 1), at the edge of the coverage zone is given by:

$$P_d = 83.2 - G_{o,SAT} - G_{o,E} \text{ , dBW} \qquad (12.2.1)$$

where $G_{o,\ SAT}$ is the spacecraft on-axis gain and $G_{o,E}$ is the receiving earth station's on-axis gain. In terms of the earth station diameter, this power is given by:

$$P_d = 42.2 - 20 \log D - G_{o,SAT} \text{ , dBW} \qquad (12.2.2)$$

where D is in metres.

This equation is plotted in Figure 12.2/1 for a range of D and $G_{o,\ SAT}$. For a Canada-coverage beam, the downlink spacecraft gain is approximately 30 dB. For earth stations larger than 10m, the per carrier satellite transmitter power is less than -8 dBW. If a single transponder handles 200 active carriers, the total HPA output power requirement would be 10 log(200) - 8 = 15 dBW, or 32 watts, a reasonable value. The HPA would have to operate with a rather small output backoff (3 to 5 dB) and as a result, the intermodulation distortion products at the output of the HPA would result in a carrier-to-IM ratio of ≃ 20 dB (estimated from References 12.2/1 and 12.2/2). For a 25 kHz channel spacing and a 40% channel activity factor, the required transponder bandwidth is

$$B = (200/0.4) \times 25 \text{ kHz} = 12.5 \text{ MHz} . \qquad (12.2.3)$$

The intermodulation distortion spectrum at the output of the satellite HPA used in the subsequent analysis is shown in Figure 12.2/2.

TABLE 12.2/1 Characteristics of 15 GHz Auxiliary-Satellite Uplink

. Carrier: Narrowband Voice or Digital Data	
Bandwidth	= 16 kHz
. Required Uplink C/N	= 25 dB, exceeded at least 99% of the time
. Free Space Loss	= 208 dB
. Clear Weather Tropospheric Absorption	= 0.7 dB
. Rain Attenuation	= 5 dB, exceeded no more than 1% of the time
. Feeder, Duplexer, Pointing Losses	= 2.5 dB
. Total Uplink Margin	= 8.2 dB
. Uplink Noise Temperature	= 2500 K
kTB	= -152.6 dBW
. Minimum Required Carrier Power at LNA Input	= -127 dBW

Note: Rain margin is based on 10 degree path elevation angle

TABLE 12.2/2: Characteristics of 15 GHz Auxiliary-Satellite Downlink

- Bandwidth = 16 kHz
- Required Downlink C/N = 25 dB, exceeded at least 99% of the time
- Carrier-to-Intermodulation Noise Ratio = 20 dB
- Free Space Loss = 208 dB
- Clear Weather Tropospheric Absorption = 0.7 dB
- Rain Attenuation = 5 dB, exceeded no more than 1% of the time
- Feeder, Duplexer, Pointing Loss = 2.5 dB
- Total Link Margin = 8.2 dB
- Antenna Noise Temperature = 200 K (rain)
- Antenna Feeder Loss = 0.5 dB
- Earth Station LNA Noise Temperature = 150 K
- Downlink Noise Temperature = 340 K

  kTB = -161.2 dBW
- Minimum Required Carrier Power at LNA input = -136 dBW

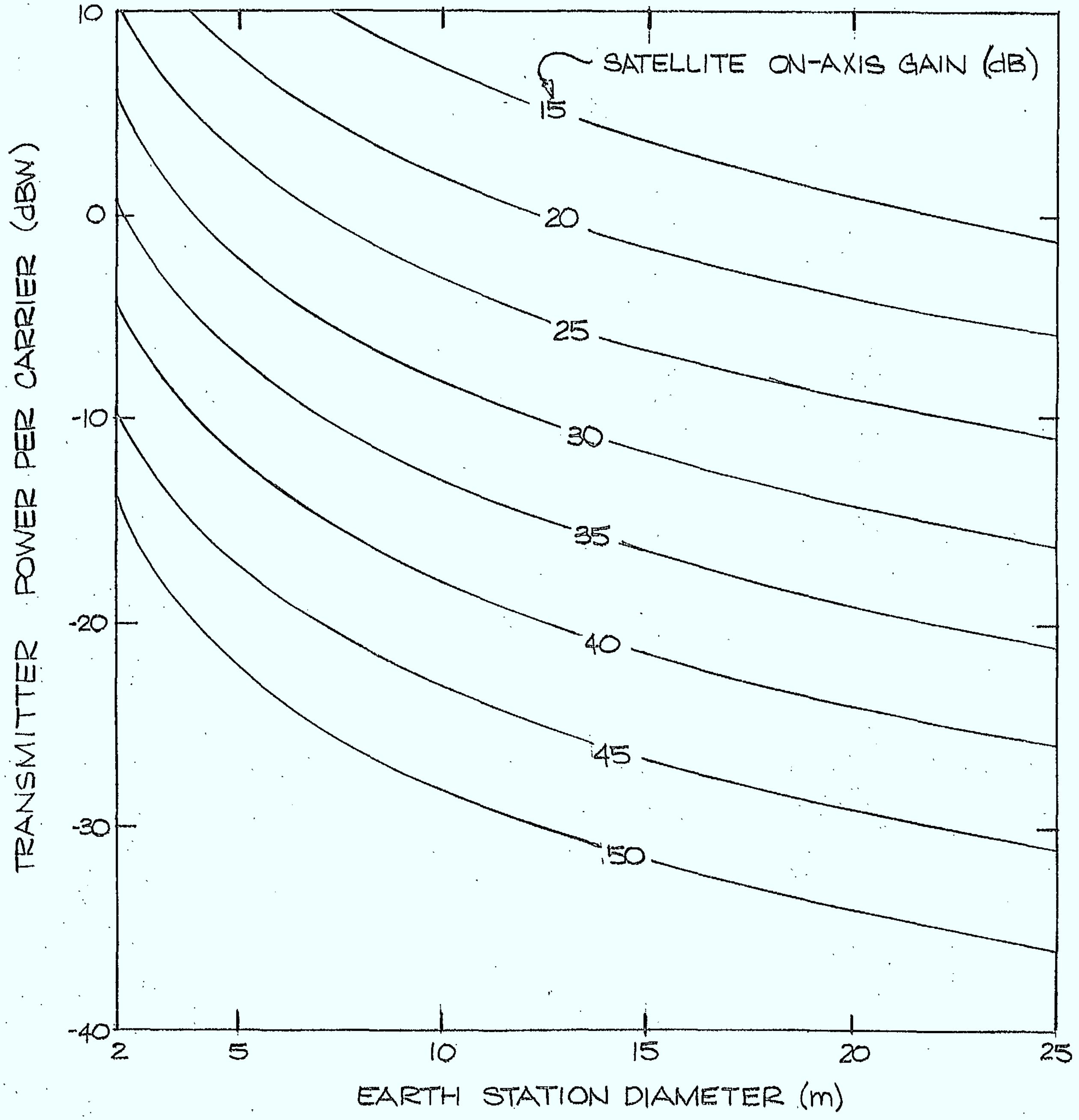


FIG. 12.2/1 SATELLITE TRANSMITTER POWER PER CARRIER VERSUS EARTH STATION DIAMETER FOR AUX.-SAT. SERVICE AT 15 GHZ.

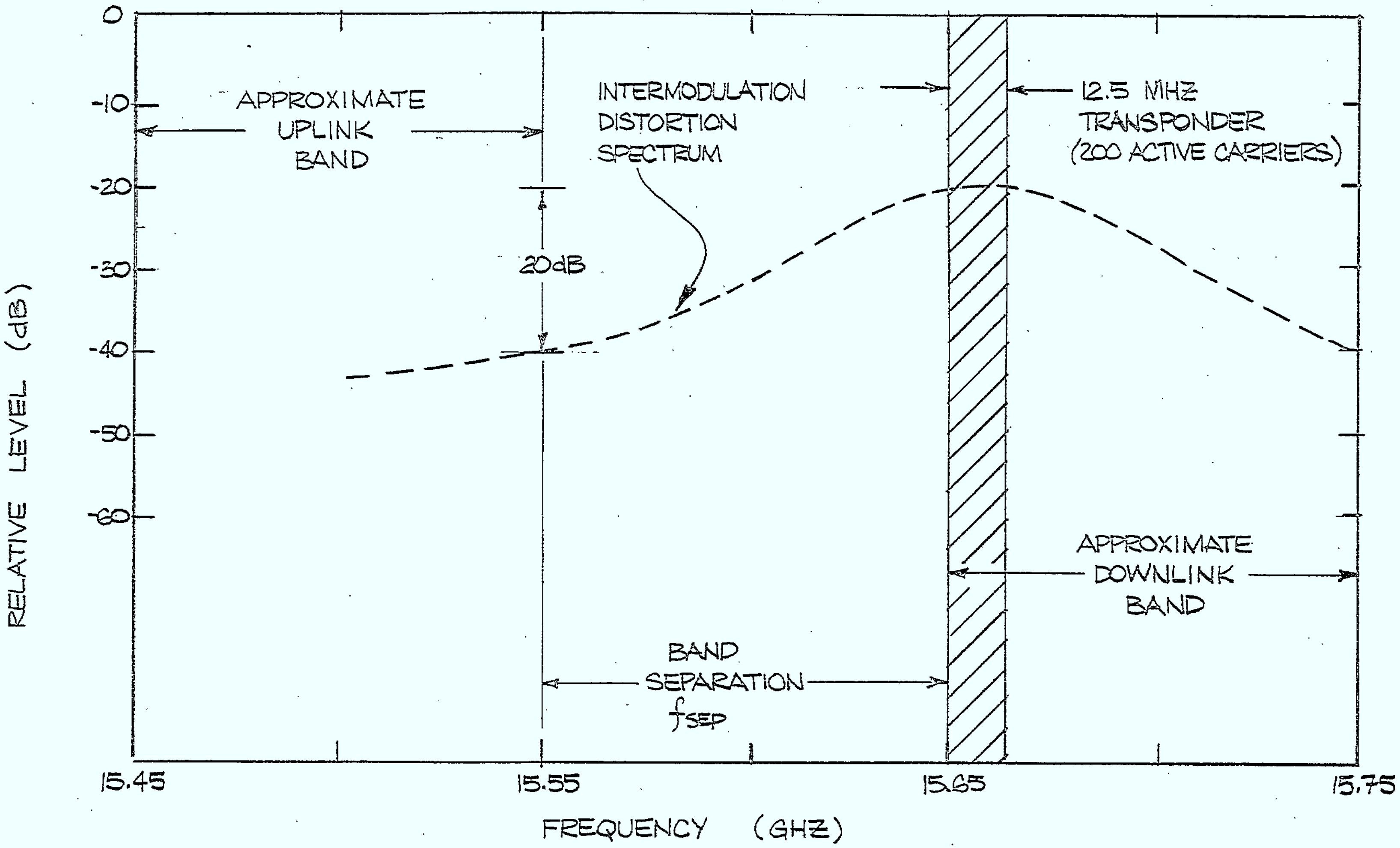


FIG. 12.2/2 INTERMODULATION DISTORTION SPECTRUM AT SATELLITE HPA OUTPUT (NO FILTERING)

In the uplink band, the IM power density should be down 20 dB from its value in the downlink portion of the band.

12.3 Satellite Filtering and Usable Bandwidths

The effects of IM distortion and filtering in the satellite will now be considered. Two intra-system interference modes must be considered. The first is caused by IM distortion products at the HPA output falling in the uplink receiving band. This interference, shown in Figure 12.2/2 is controlled by a filter at the output of the HPA. The second is caused by the generation of IM products in the wideband LNA due to the presence of the downlink transmitted carrier. An input filter in front of the spacecraft LNA must attenuate signals in the downlink band to levels at which they generate negligible IM power in the LNA. The choice of these filters will determine the usable uplink and downlink bandwidths and their minimum separation.

The HPA output filtering problem will be considered first. Assuming that IM products falling in the uplink band must be attenuated to levels at least 10 dB below the uplink thermal noise level, then the maximum allowable IM power in a 16 kHz band is -163 dBW. The isolation that must be provided by the output filter determined as follows:

Output Carrier Power (at HPA) = P_d, dBW

IM Level in RX Band = $P_d - 40$, dBW in a 16 kHz band

Max. Allowable IM = -163 dBW in a 16 kHz band

Required Isolation = $P_d + 123$, dB

Antenna Cross Polarization Isolation = 30 dB

Isolation By Output Filtering = $P_d + 93$ dB

The cross polarization isolation is obtained by using orthogonally polarized up and downlink signals.

The isolation that must be provided by the receiver input filter will now be determined. As in Chapter 3, the level of 3rd order intermodulation generated by the LNA in the uplink band from the carriers in the downlink band will be used to estimate IM generated via this mode. Following a derivation similar to that used to obtain equation 3.3.4, the isolation that must be provided by the input filter in this band is given by

$$A_{IN} \approx P_d - I_{CP} + G_{LNA} - \frac{1}{3}\left[2P_{IP} + P_{IM,MAX} + G_{LNA}\right] \text{, dB} \qquad (12.3.1)$$

where P_d is the carrier power level at the output of the HPA (in dBW), I_{CP} is the cross polarization isolation (30 dB), G_{LNA} is the gain of the LNA ($\simeq$ 40 dB), P_{IP} is the third order intercept point (-10 dBW) and $P_{IM, MAX}$ is the maximum allowable IM power in a 16 kHz band at the input of the LNA. Substituting the appropriate values into this equation gives

$$\begin{aligned} A_{IN} &= P_d - 30 + 40 - \frac{1}{3}\left[2(-10) - 163 + 40\right] \\ &= P_d + 58 \text{, dB}. \end{aligned} \qquad (12.3.2)$$

Due to the approximate nature of this calculation a 10 dB margin is added, to give the receive filter isolation across the downlink band of

$$A_{IN} = P_d + 68 \text{, dB}. \qquad (12.3.3)$$

This attenuation will also ensure that the LNA does not operate near saturation.

As the required output filter attenuation is approximately 25 dB higher than that of the input filter, the output filter will be the more difficult of the two to implement. Assuming that a single filter is used across the whole downlink band,(with 3-dB bandwidth BW,) and that the filter can be characterized as a Chebyshev filter, then the band separation frequency, f_{SEP}, is given by

$$f_{SEP} = 300 - 2\,BW \text{, MHz}. \qquad (12.3.4)$$

Using equations 3.3.5 and 12.3.4, equating the filter attenuation to P_d + 93 dB, and rearranging gives the usable bandwidth BW as a function of the downlink carrier power P_d and the filter order n,

$$BW = \frac{600}{3 + \exp\left\{\frac{(P_d + 93) + (12 - 4.2n)}{(9.6n - 2)}\right\}} \quad (12.3.5)$$

This equation is plotted in Figure 12.3/1. In this frequency band values of n = 7 to 8 are reasonable, resulting in a range of usable uplink/downlink bandwidths of 103 to 117 MHz for a Canadian coverage system. For a global coverage system, the downlink transmitter power per carrier is on the order of 0 dBW, resulting in a range of bandwidths from 97 to 107 MHz. A system utilizing a spot beam satellite antennas (2 degree beams, G_0 = 38 dB) would only require a downlink carrier power on the order of -20 dBW, resulting in usable bandwidths from 112 MHz to 120 MHz.

The assumption has been made in the above analysis that the usable downlink bandwidth can extend up to 15.75 GHz. Spurious emissions from the spacecraft at frequencies above this will consist primarily of intermodulation distortion products. The power density of these emissions will be approximately 23 dB below the per carrier transmitter power in a 16 kHz band at 15.75 GHz and be attenuated rapidly by the output filter at higher frequencies. If a 5m earth station antenna is the smallest utilized in the auxiliary-satellite service at 15 GHz, then the downlink per carrier EIRP will be less than 28 dBW. The EIRP of the spurious emissions in a 16 kHz band adjacent to and above the 15.75 GHz edge of the band will be ≃ 5 dBW. The flux density on the earth's surface will be -158 dBW/m^2 in a 16 kHz band. If this flux is received by an isotropic antenna, the power at the antenna terminals would be ≃ -203 dBW in a 16 kHz band, which would raise the antenna

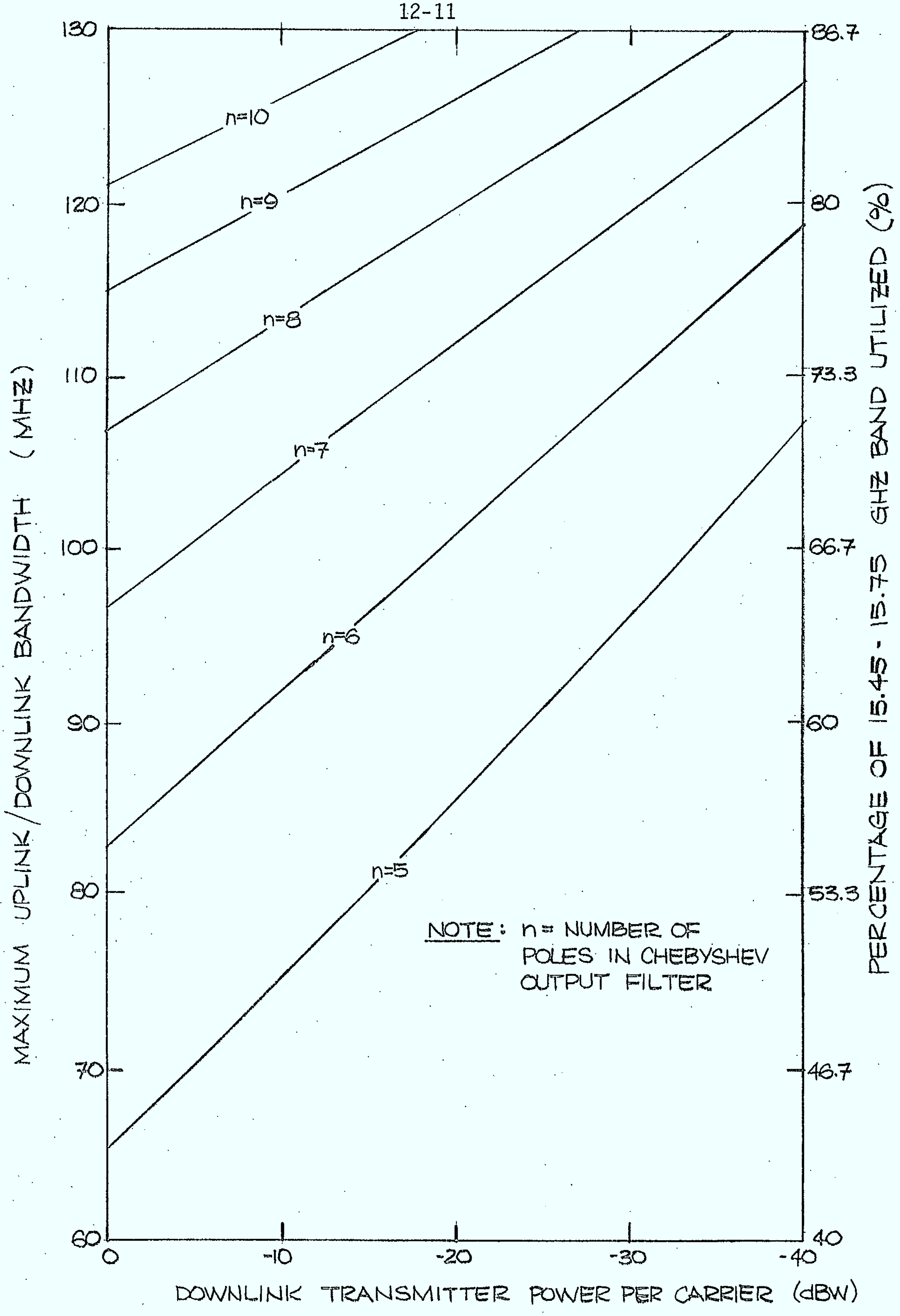


FIG. 12.3/1 USABLE UPLINK/DOWNLINK BANDWIDTH AS A FUNCTION OF SATELLITE TRANSMITTER POWER AND OUTPUT FILTER COMPLEXITY.

temperature by $\lesssim$ 0.025 K. For a higher gain antenna, this power could be a source of interference and hence additional filtering in the spacecraft, or coordination with the other receiving system would be required. In the majority of cases, however, the levels of spurious emissions will be small, allowing use of the band up to the 15.75 GHz edge.

Spurious emissions from earth stations at frequencies below 15.45 GHz may require investigation as a radio astronomy band at 15.35 - 15.4 GHz must be protected. Since prime power is not a constraint for an earth station, as it is for a spacecraft transmitter, the earth station HPA's can be operated in a more linear region, resulting in lower spurious emissions than from a spacecraft transmitter. Similarly, additional output filtering can be employed on earth stations in the vicinity of a radio observatory if spurious emissions require additional control. The 50 MHz band between the radio astronomy band and the proposed auxiliary-satellite band will also ensure that the spurious emissions can be reduced to negligible values.

12.4 Summary

The potential use of the 15.45 - 15.75 GHz band by the auxiliary-satellite service was investigated in this chapter. It was found that the major tradeoff involved in using this band is the complexity (i.e., number of poles) of the spacecraft output filter required to isolate the spacecraft receiver from spurious IM distortion products generated in the HPA. Depending on the earth station antenna diameter, and hence on the downlink transmitter power required for a given spacecraft antenna gain, a significant portion of the 300 MHz band could be utilized with a range of usable uplink/downlink bandwidths of 95 - 120 MHz. This bandwidth would be more than sufficient for this type of service.

Although the earth station filtering and distortion problem was not analysed, it is expected to place fewer constraints on the use of this band than the isolation requirements of the spacecraft.

REFERENCES

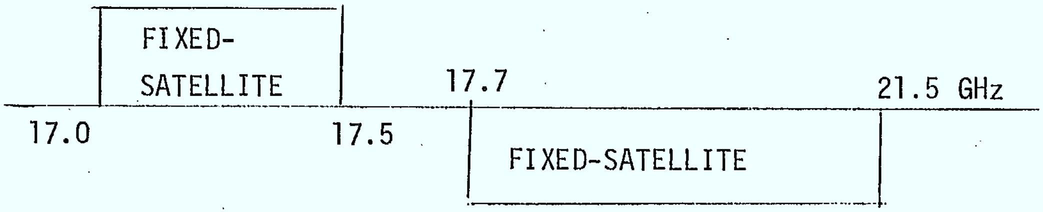
12.2/1 "SCPC Satellite Telephony with 4-D coded Quadrature Amplitude Modulation", G.R. Welti, COMSAT Technical Review, Vol. 7, No. 1, Spring 1977.

12.2/2 "UHF - SHF Satellite Communications Link Calculations", Study Contract No. PL 36100-4-00995 for DOC, Canada, by Bell Northern Research, July 1975.

13.0 FIXED-SATELLITE BANDS BETWEEN 17.0 AND 21.5 GHz

13.1 Introduction

In this chapter, inter-system interference between systems utilizing the uplink and downlink bands between 17.0 and 21.5 GHz is studied. Two frequency plans are considered. The first, consistent with Canada's Second Draft Proposal is shown below:



The other frequency plan involves moving the uplink band to 17.2 - 17.7 GHz. In both cases, out-of-band emissions from the downlink satellite transmitter into the satellite receiver using the uplink band is studied. Both closely spaced satellites and satellites located in an antipodal position are considered.

The other source of interference that may influence the use of these frequency bands occurs as a result of out-of-band emissions from earth stations operating in the uplink band falling into the downlink band used by other earth stations. This mode of interference is also investigated.

13.2 Baseline System Characteristics

Traffic on the uplink band is assumed to be either FM/TV (ie, the feeder link to a broadcast-satellite) or high capacity digital voice or data. Technical characteristics of the FM/TV uplink are given in Table 13.2/1 and are representative of a service intended for community reception. The characteristics should provide an overall quality similar to that recommended by the CCIR for a 12 GHz community broadcast service. (Reference 13.2/1). Other characteristics are similar to those used in Reference 13.2/2.

The recommended overall signal quality of the TV signal for a community broadcast system is approximately 17 dB C/N at least 99% of the worst month (approximately 99.75% of the time). If the uplink contributes 10 percent of the noise and the uplink availability is higher than that for the downlink, then the uplink C/N for 99.9% of the time is assumed to be 27 dB. At 17.5 GHz, the rain attenuation for southern Canada, exceeded less than 0.1 percent of the time is approximately 10 dB (for a 10 degree elevation angle path). Therefore, the uplink clear weather C/N for the FM/TV signal must exceed 37 dB.

The single carrier permissible interference into the spacecraft receiver is assumed to be 10 dB below the uplink thermal noise, or -135 dBW into the 23 MHz bandwidth of the carrier. This level of interference corresponds to a clear weather C/I ratio of 47.4 dB and a value of 37.4 dB for 0.1 percent of the time.

The EIRP of the FM/TV earth station required to provide a clear weather uplink C/N of 37.4 dB is given by

$$(EIRP)_{UP} = \left(\frac{C}{N}\right)_{CLEAR} - G_{R,SAT} + L_{\substack{FREE\\SPACE}} + L_{MISC} + L_{CLEAR} + 10\log\left(kT_{up}B\right), \ dBW \qquad (13.2.1)$$

TABLE 13.2/1 Characteristics of FM/TV Uplink at 17.5 GHz

- RF Bandwidth = 23 MHz
- Required Uplink C/N = 27 dB, exceeded at least 99.9% of the time
- Required Uplink C/I = 37 dB, exceeded at least 99.9% of the time
- Uplink Rain Margin = 10 dB, exceeded no more than 0.1% of the time
- Free Space Loss = 209 dB
- Misc Losses (pointing errors, duplexer, feeder loss) = 3 dB
- Clear Weather Propagation Loss = 1 dB
- Total Uplink Margin = 14 dB
- Satellite Receiving System Noise Temperature = 2000 K
- kTB = -122 dBW
- Minimum Required Carrier Power at LNA input = -95 dBW

where $G_{R,SAT}$ is the satellite RX antenna gain at the edge of its coverage zone, assumed to be 3 dB down from the on-axis gain, L_{MISC} is the loss due to earth station pointing errors, insertion losses, etc., (approximately 3 dB), and L_{CLEAR} is the clear weather tropospheric absorption on a low elevation angle path (approximately 1 dB). If $G_{0,SAT}$ is the on-axis spacecraft receiving antenna gain, then the uplink EIRP is given by

$$(EIRP)_{UP} = 131 - G_{0,SAT} \quad , \text{dBW} . \qquad (13.2.2)$$

The out-of-band emissions from the earth station can be estimated from information presented in Reference 13.2/3 and 13.2/4. An estimate the spectrum envelope of a worst case FM/TV carrier with no energy dispersal, filtered with a 4 pole Chebyshev filter (with a 3 dB bandwidth of 23 MHz) is shown in Figure 13.2/1. This spectrum is used to determine the out-of-band emissions for an earth station transmitting an FM/TV carrier.

The other uplink carrier considered is a high capacity 8-phase PSK carrier. Parameters of a representative 17.5 GHz uplink are summarized in Table 13.2/2. These parameters are similar to those used in Reference 13.2/2.

The link performance objectives are based on those recommended in Reference 13.2/5, for which the overall bit error probability must not exceed 10^{-6} (10 minute mean value) for more than 20 percent of any month, and 10^{-4} (one minute mean value) for more than 0.3 percent of any month (approximately 0.1 percent of the time). For southern Canada, 0.1 percent of the time corresponds to a rain margin of 10 dB (for a 10 degree elevation angle path). The noise budget assumed for the link is such that the uplink and downlink contribute equally to the overall signal degradation.

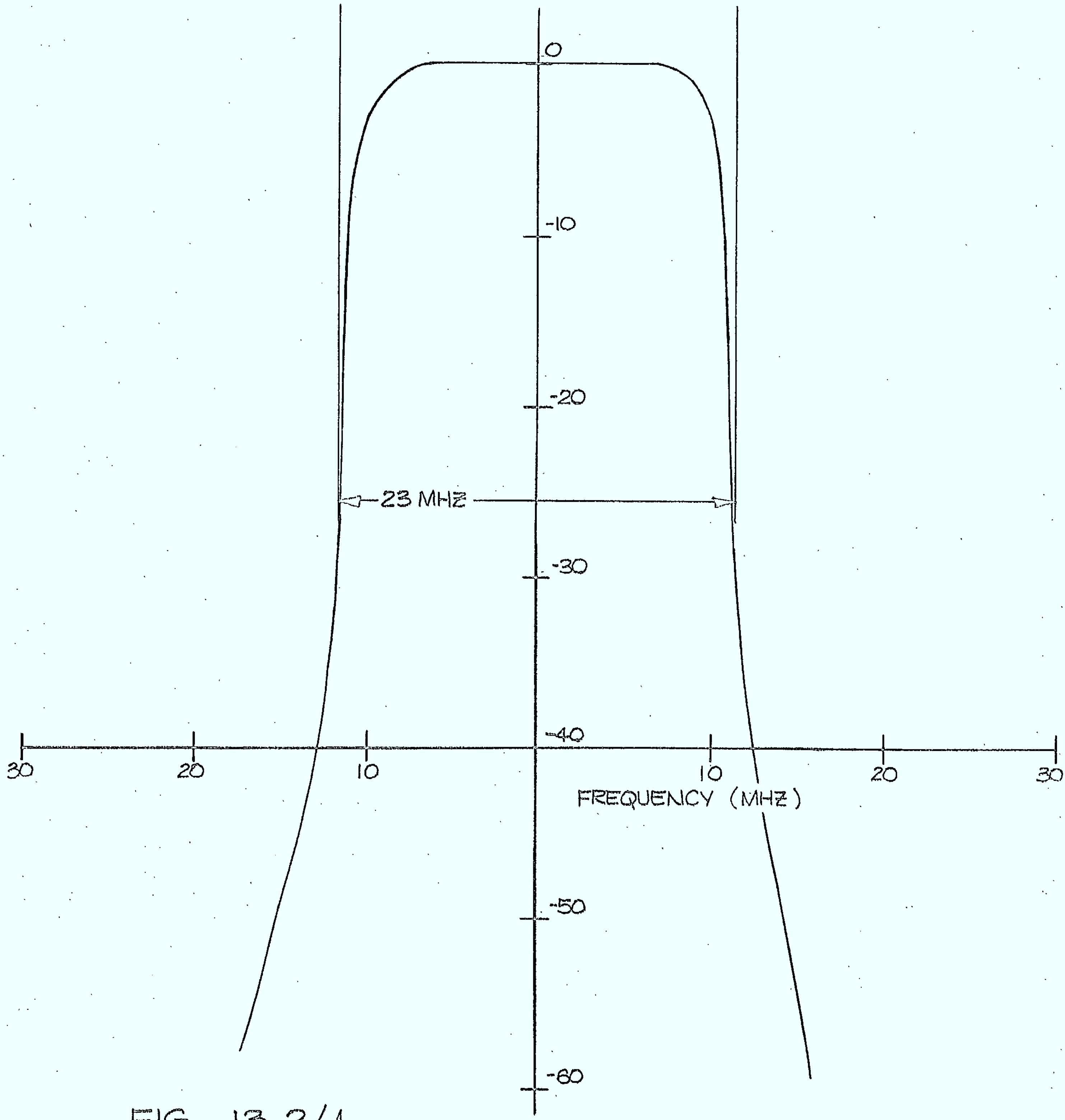


FIG. 13.2/1

23 MHZ FM/TV SPECTRUM ENVELOPE AFTER FILTERING BY A 4-POLE CHEBYSHEV FILTER

TABLE 13.2/2 Characteristics of PSK Uplink

- Signal: 8-phase PSK
- Bandwidth = 72 MHz
- Required Uplink C/N = 23 dB, exceeded at least 99.7% of any month
- Required Uplink C/I = 35 dB, exceeded at least 99.7% of any month
- Uplink Rain Margin = 10 dB, exceeded no more than 0.3% of a month
- Free Space Loss = 209 dB
- Feeder, Duplexer, Pointing Loss = 3 dB
- Tropospheric Absorption = 1 dB
- Total Uplink Margin = 14 dB
- Satellite Receiving System Noise Temperature = 2000 K
- kTB = -117 dBW
- Minimum Required Carrier Power at LNA input = -94 dBW

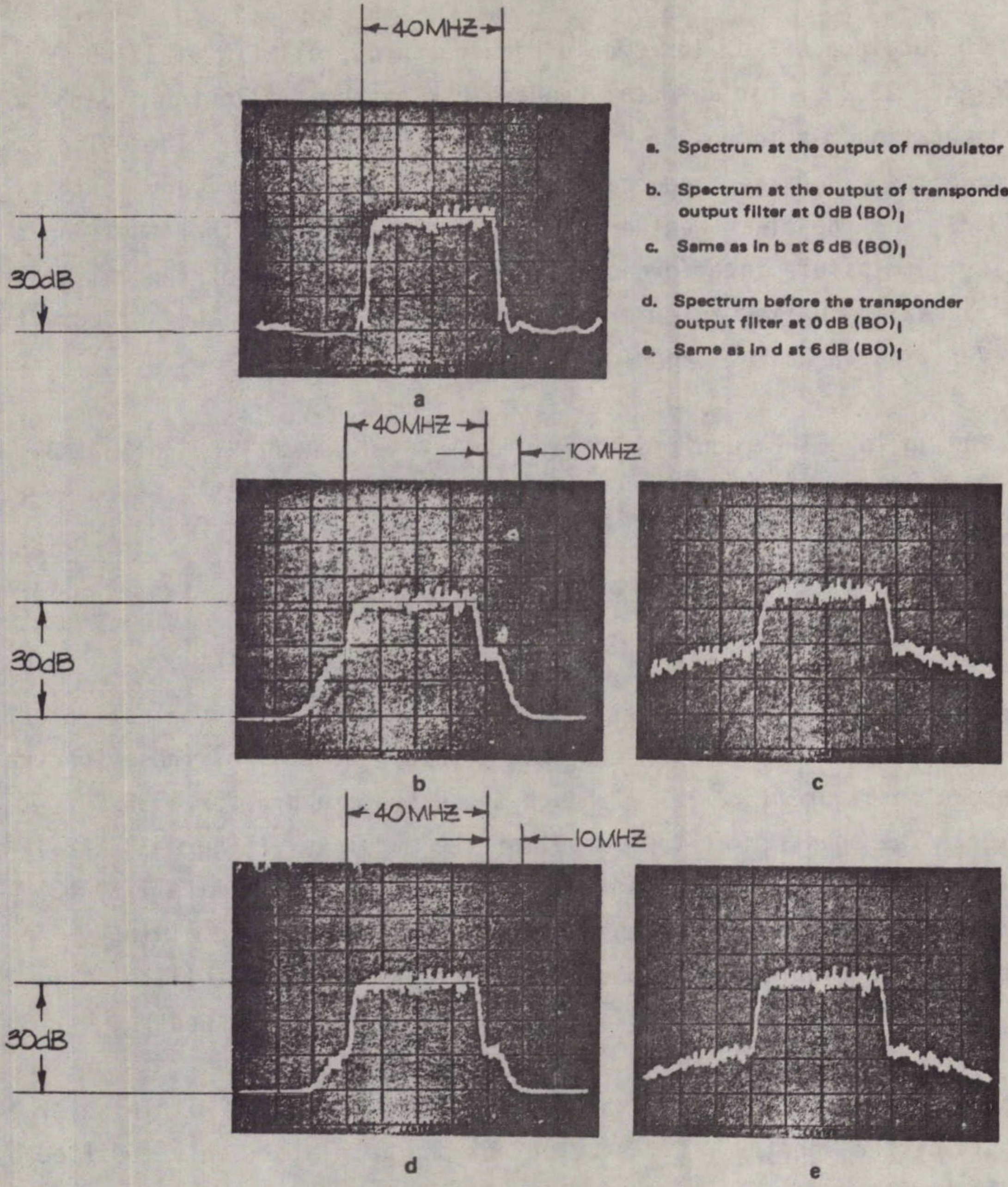
To obtain a BER of 10^{-4} would require an overall C/N of 17 dB (Reference 13.2/5) for an ideal 8-phase PSK system. Allowing a 3-dB implementation margin results in an overall C/N of 20 dB. The uplink and downlink C/N ratio exceeded for all but 0.3 percent of any month is 23 dB, and the clear weather C/N is 33 dB. Assuming that the single carrier permissible interference is 10 dB below the uplink thermal noise gives a maximum uplink interference power of -127 dBW at the spacecraft receiver (into a 72 MHz bandwidth).

The uplink EIRP required to provide a clear weather C/N of 33 dB is given by

$$(EIRP)_{up} = 132 - G_{e,SAT} \quad , \quad dBW . \qquad (13.2.3)$$

The out-of-band emissions from this earth station can be estimated from the spectra obtained in Reference 13.2/5. Several of these spectra are shown in Figure 13.2/2. Although these spectra are for a 36 MHz carrier. The spectrum at the output of the modulator (Figure 13.2/2a) is flat across the carrier bandwidth and drops by approximately 30 dB outside of the band, without any output filtering. The remaining spectra in the Figure were measured at the output of a satellite transponder simulator and are representative of downlink spectra.

The output spectrum from the earth station should be within several decibels of the spectrum at the output of the modulator, only modified by an output filter. Assuming that a 4 pole Chebyshev filter with a 3-dB bandwidth equal to 72 MHz is used as the output filter results in the spectra shown in Figure 13.2/3.



a. Spectrum at the output of modulator

b. Spectrum at the output of transponder output filter at 0 dB $(BO)_I$

c. Same as in b at 6 dB $(BO)_I$

d. Spectrum before the transponder output filter at 0 dB $(BO)_I$

e. Same as in d at 6 dB $(BO)_I$

FIG. 13.2/2 8-PHASE PSK SPECTRA
(scale X : 10MHZ/cm , scale Y : 10dB/cm)
(FROM REFERENCE 13.2/1)

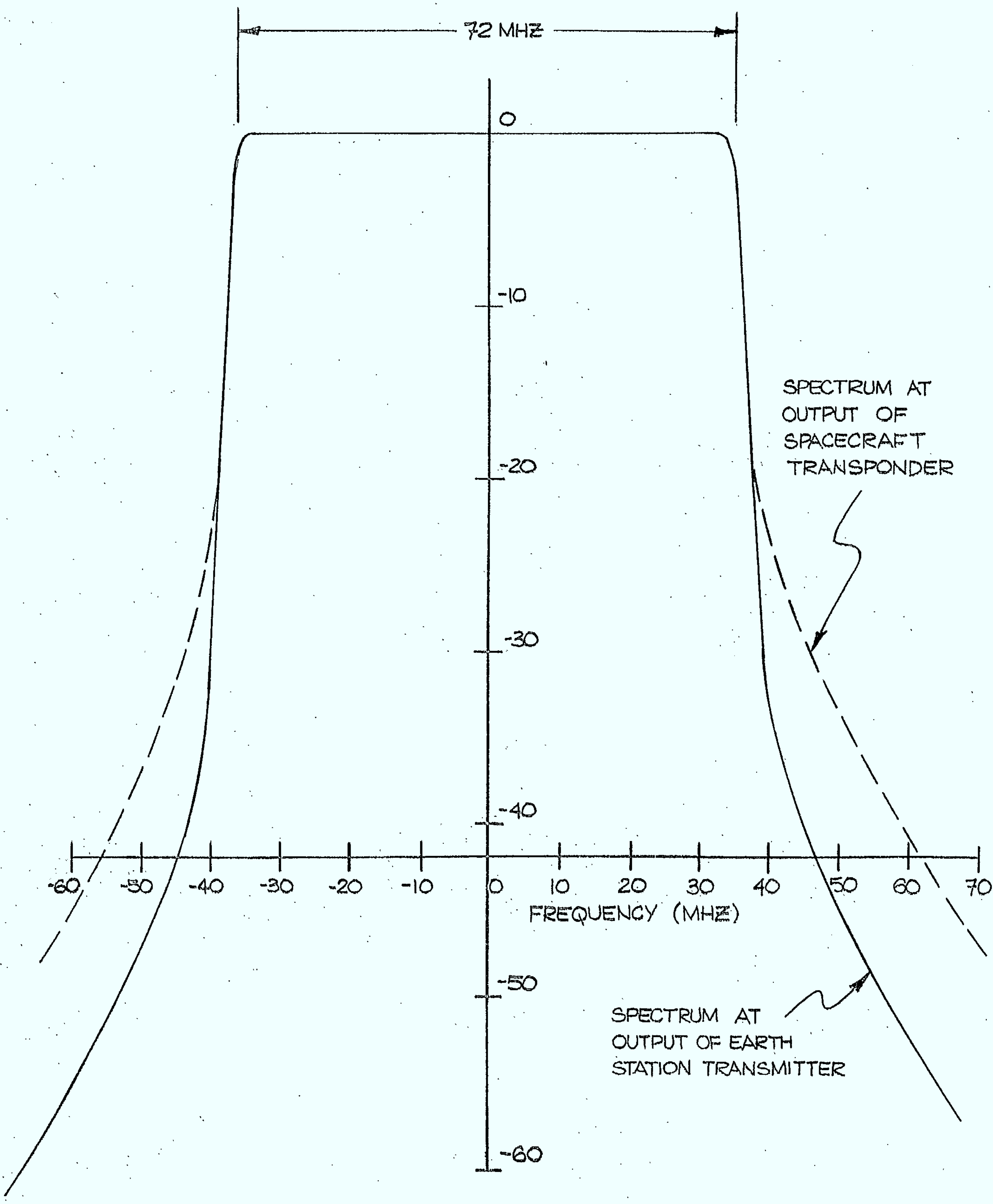


FIG. 13.2/3 72 MHZ 8-PHASE PSK SPECTRA AFTER FILTERING BY 4-POLE CHEBYSHEV FILTER

The other carrier that must be considered is the downlink carrier. A 72 MHz 8-phase PSK carrier whose characteristics are given in Table 13.2/3 is used in the subsequent analysis. As the assumption is made that the uplink and downlink contribute equally to the overall C/N, the downlink C/N must exceed 23 dB, for all but 0.3 percent of a month.

The downlink noise temperature will increase by approximately 4 dB whenever a rain cell intersects the mainbeam of the earth station antenna. Taking this into account and allowing a 10 dB rain margin results in a required clear weather downlink C/N of 37 dB. The permissible single carrier interference power on the downlink is assumed to be 10 percent of the clear weather downlink thermal noise, or -138 dBW (across the 72 MHz receiver passband), giving a C/I of 37 dB for all but 0.3% of any month.

The on-axis EIRP of the satellite required to maintain the required downlink C/N at the edge of the satellite's earth coverage zone is given by

$$(EIRP)_{SAT} = 124.7 - G_{0,E} \quad , \text{dBW} \tag{13.2.4}$$

where $G_{0,E}$ is the on-axis gain of the earth station antenna. This EIRP is restricted however, as a power flux density limit exists on downlink signals between 17.7 GHz and 22 GHz. For earth-space paths with elevation angles less than 5 degrees, the limit is -115 dBW/m^2 in any 1 MHz band. This places a constraint on the maximum permissible downlink EIRP and hence on the minimum permissible earth station antenna diameter. Assuming free space propagation, the power flux density at the earth's surface is given by

$$\begin{aligned} F &= EIRP - 162 \quad , \text{dBW}/m^2 \\ &= -(37.3 + G_{0,E}) \quad , \text{dBW}/m^2 \text{ in 72 MHz band.} \end{aligned} \tag{13.2.5}$$

TABLE 13.2/3 Characteristics of Fixed-Satellite Downlink at 17.7 GHz

- Signal: 72 MHz 8-phase PSK
- Required Downlink C/N = 23 dB, exceeded at least 99.7% of a month
- Required Downlink C/I = 37 dB, exceeded at least 99.7% of a month
- Downlink Rain Margin = 10 dB, exceeded no more than 0.3% of any month
- Free Space Loss = 209 dB
- Feeder, Duplexer, Pointing Losses = 3 dB
- Tropospheric Absorption = 1 dB
- Total Downlink Margin = 14 dB
- Earth Station Receiving System Noise Temperature = 373 K
- kTB = -124.3 dBW
- Minimum Required Carrier Power at LNA Input = -101.3 dBW

If the flux density limit of -115 dBW/m^2 in a 1 MHz band is extrapolated to a 72 MHz bandwidth (ie, -97 dBW/m^2 in a 72 MHz band), then the minimum earth station gain is 59.7 dB. At 17.7 GHz this corresponds to an earth station with an antenna diameter of 7 m. As a result the analysis will only consider earth stations larger than 7 m.

The downlink emission spectrum of the PSK signal is shown in Figure 13.2/3. This spectrum was obtained by extrapolating the spectrum of Figure 13.2/2 to that for a 72 MHz bandwidth and filtering with a 4-pole Chebyshev filter.

13.3 Interference Between Closely Spaced Satellites

The first mode of interference which will be considered occurs when out-of-band emissions from a downlink transmitter fall into the receiving band of an adjacent satellite. The geometry of the situation is sketched in Figure 13.3/1. The interference power in the satellite receive band at the LNA input is given by

$$P_I = P_T + G_T + G_R + 20 \log \left(\frac{\lambda}{4\pi R_G \theta_s} \right) , dBW \qquad (13.3.1)$$

where P_T is the out-of-band power falling in the receiving bandwidth (23 MHz for FM/TV and 72 MHz for 8-phase PSK) at the transmitting satellite's antenna terminals.

G_R, G_T are the antenna gains of the two satellite antennas in each others direction.

If $P_{I,\,MAX}$ is the maximum permissible interference power at the LNA, then the corresponding minimum allowable satellite spacing, θ_s is given by

$$20 \log \theta_S = P_{\alpha} + G_T + G_R - P_{I,MAX} - 210 . \qquad (13.3.2)$$

Converting to degrees gives

$$\log \theta_{s,deg} = \frac{1}{20} \left[P_{\alpha} - P_{I,MAX} + G_T + G_R \right] - 8.742 . \qquad (13.3.3)$$

For very closely spaced satellites, equation 13.3.3 no longer applies, as it is based on far field antenna gains. At 17.7 GHz, this limit is reached for separations less than 0.5 km. Spacecraft station-keeping

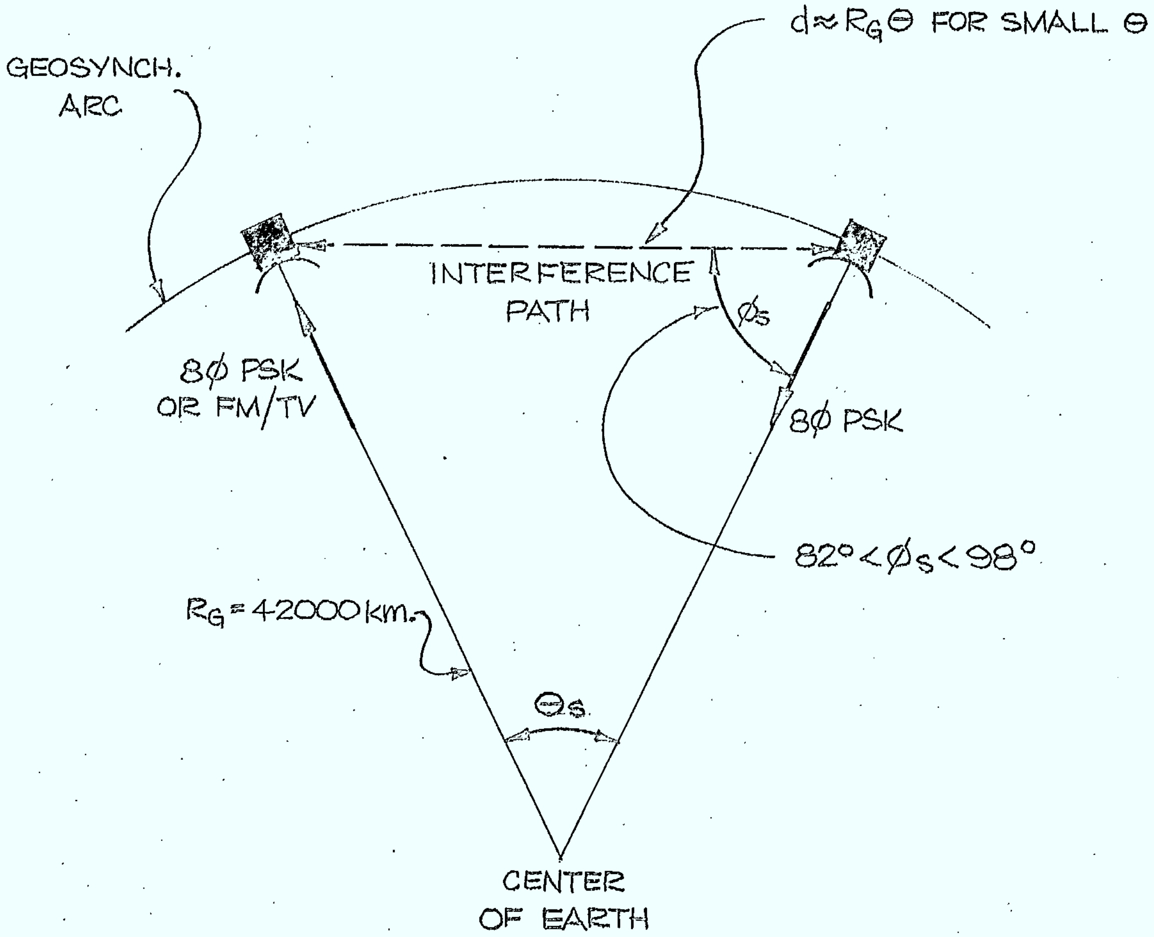


FIG. 13.3/1 CLOSELY SPACED SATELLITE GEOMETRY

also impacts the interference calculation for such closely spaced satellites, as it is then possible that one satellite may move out of the sidelobe pattern of the other into a region in which the antenna gain is much higher. For this reason, equation 13.3.3. should only be used for satellite separation angles greater than 0.2 degrees. For satellite spacings greater than 0.2 degrees, the off-boresight angles are approximately 90 degrees and the satellite antenna gains are below that of an isotropic antenna. Assuming 0dB gains, the out-of-band satellite transmitter power for a satellite separation angle of 0.2 degrees, must not exceed:

$$P_{T,MAX} = P_{I,MAX} + 160.9 \quad , \text{dBW}. \qquad (13.3.4)$$

For an FM/TV uplink carrier, $P_{I,\ MAX}$ = -132 dBW, resulting in a value for $P_{T,\ MAX}$ of 28.9 dBW.

For the 80 PSK uplink carrier, $P_{I,MAX}$ = -127 dBW, resulting in a value for $P_{T,\ MAX}$ of 33.9 dBW.

As the downlink transmitter power is smaller than these out-of-band values, this mode of interference will not affect the proposed use of the 17.2-17.7 GHz band as an uplink by the fixed-satellite service.

13.4 Antipodal Satellite Interference

Another mode of inter-satellite interference occurs when the satellites are in antipodal positions, as illustrated in Figure 13.4/1. The interference power in the satellites's receiving band is given by

$$P_I = P_T + G_T + G_R + 20 \log\left(\frac{\lambda}{4\pi \times 83000\,\text{km}}\right), \text{dBW} \qquad (13.4.1)$$

where P_T, G_T, and G_R are the same as in Section 13.3. The inter-satellite distance of 83000 km occurs on the grazing path and represents a worst case as the angles between the antenna boresights and the path are smallest on this path. The values of G_T and G_R are dependent on where the satellites earth coverage zones are located relative to the path. In the worst case, as sketched in Figure 13.4/1, the coverage zones of the uplink and downlink satellites are near the same side of the earth. It is assumed that G_T and G_R are only 3 dB down from their on-axis values in this case and that they operate using the same polarization. The interference power is then given by:

$$\begin{aligned} P_I &= P_T + G_{o,T} + G_{o,R} - 3 - 3 - 215.8 \\ &= P_T + G_{o,T} + G_{o,R} - 221.8, \text{ dBW} \end{aligned} \qquad (13.4.2)$$

where the subscript "o" indicates on-axis values.

The maximum allowable power, $P_{T,\,MAX}$ is plotted in Figure 13.4/2 for the two uplink carriers considered. Assuming that the downlink PSK carrier power is less than 20 dBW and that the maximum sum of the on-axis gains may reach 100 dB, implies that the uplink and downlink bands must be spaced sufficiently far apart so that P_T does not exceed -14 dBW in a 23 MHz band in the uplink band. For a 100 watt TWT, these out-of-band emissions must be 34 dB below the downlink carrier power (in a 23 MHz band). (Note only the FM/TV uplink is considered here as it is the more susceptible of the two). From Figure 13.2/3, this condition is met if the upper edge of the 23 MHz channel is a least 45 MHz from the center frequency of the downlink carrier. This will require a guardband of 9 MHz at the 17.7 GHz edge of the downlink. For the PSK uplink, a smaller guardband would be required.

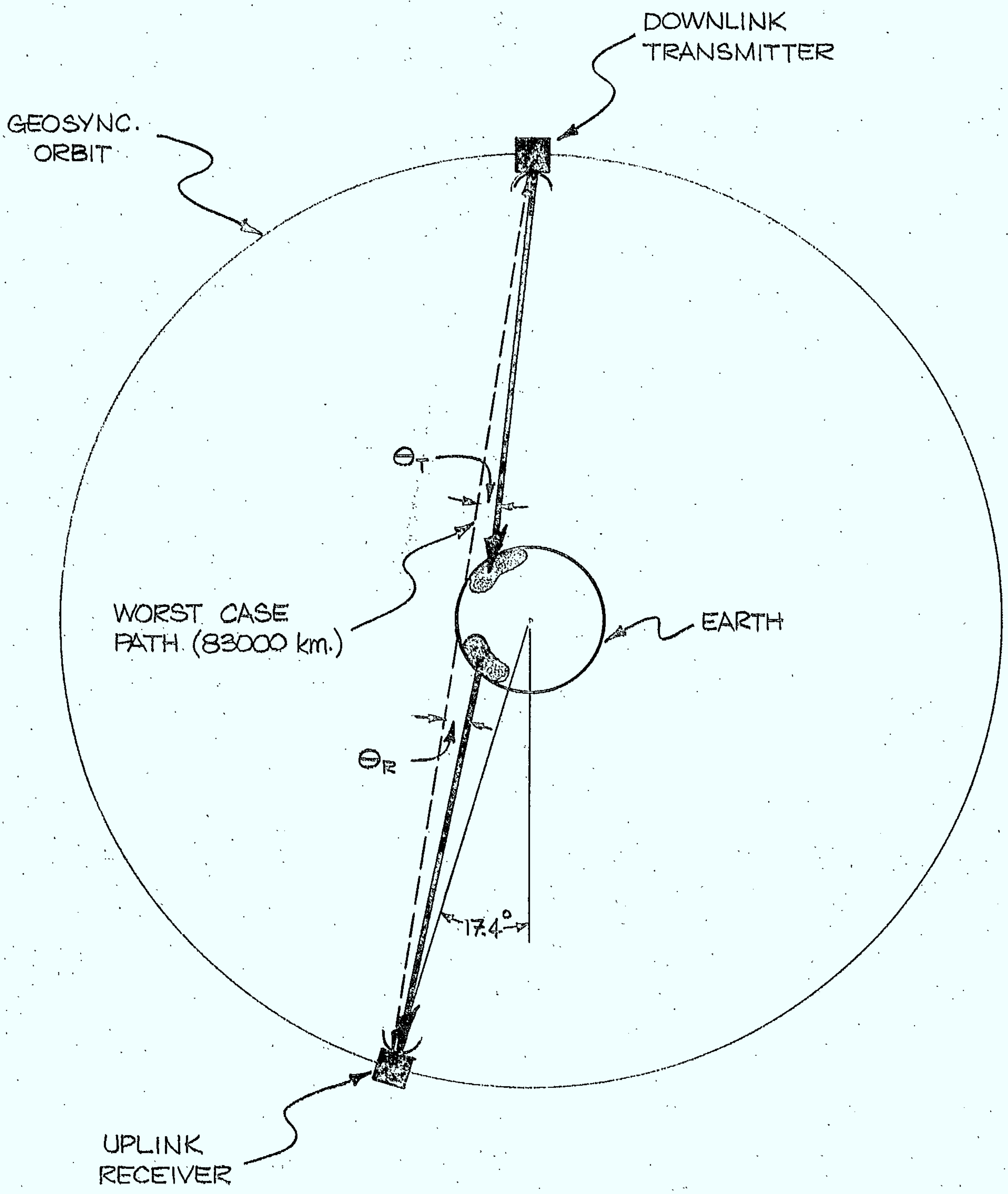


FIG. 13.4/1 ANTIPODAL SATELLITE GEOMETRY

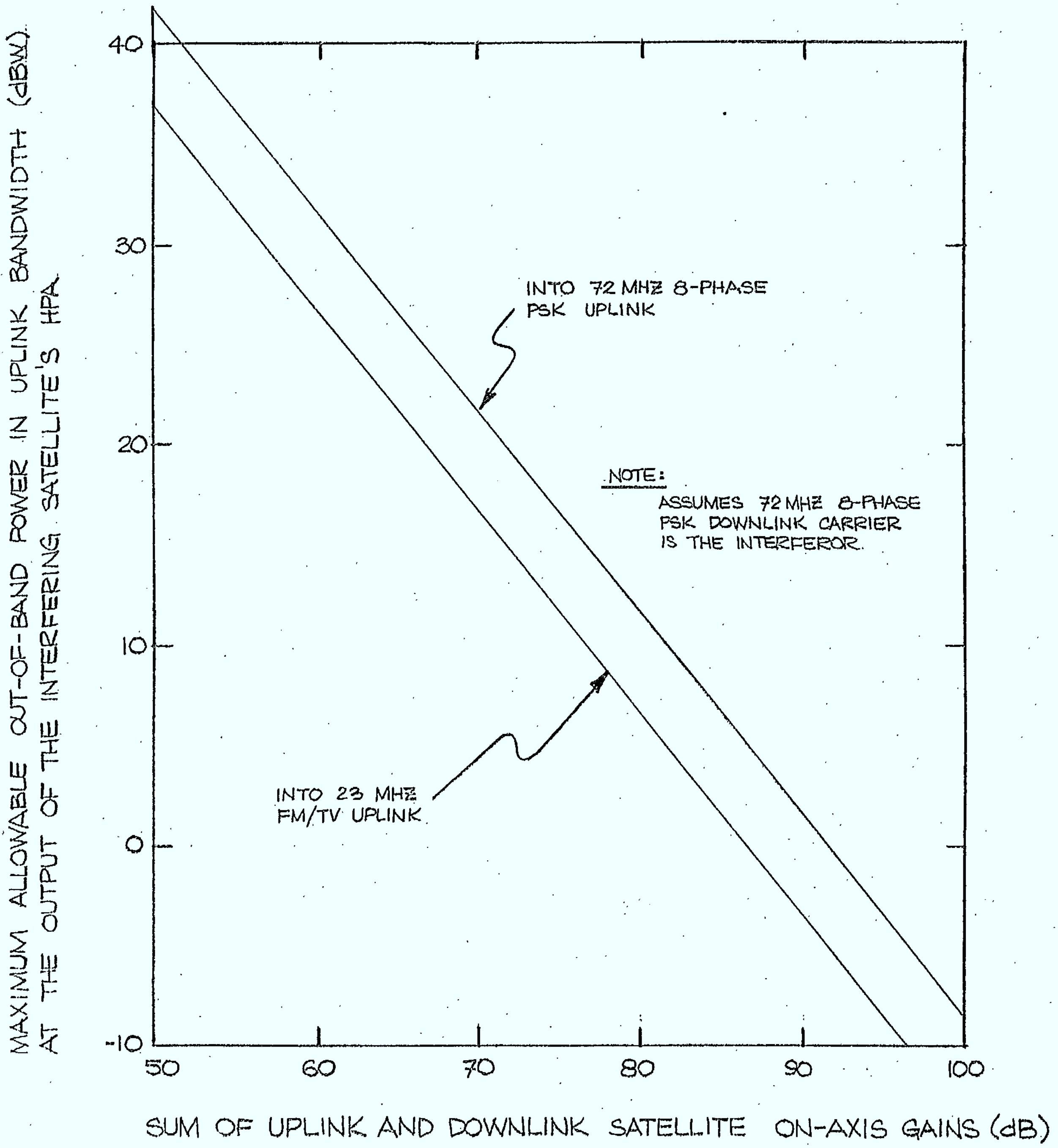


FIG. 13.4/2 MAXIMUM ALLOWABLE OUT-OF-BAND POWER, $P_{T,MAX.}$, FOR ANTIPODAL SATELLITE INTERFERENCE AT 17.7 GHz.

As a result, this mode of interference will not influence the use of the 17.0 - 17.5 GHz uplink band, but must be considered at the 17.7 GHz edge of the 17.2 - 17.7 GHz band.

The guardband required to protect the uplink carrier could be reduced if the spacecraft antenna gains were reduced in the direction of the orbit arc. The above analysis assumed that the antenna gains were only 3 dB down from their on-axis values. If the satellite antenna gains in the direction of the orbit arc are reduced to at least 20 dB below their on-axis values, then no guardband would be required to protect the uplink fixed-satellite carriers from this mode of interference.

13.5 Interference Between Earth Stations

Out-of-band emissions from earth stations transmitting at frequencies in the 17.2 - 17.7 GHz uplink band causing interference at earth stations receiving an 8-phase PSK downlink carrier are investigated in this section.

The interference power at the receiving earth stations LNA is determined by the level of out-of-band emissions from the uplink transmitter and the transmission loss between the two stations. It is assumed that the received interference power must be at least 10 dB below the receiving system thermal noise level. In a 72 MHz band, the maximum permissible interference power at the input of the LNA is -134.3 dBW. At the uplink transmitter output, the maximum permissible out-of-band power (in dBW) in a 72 MHz band is given by the sum of -134.3 dBW and the minimum required transmission loss between the stations. Assuming that the stations are separated by at least 1 km and that free space propagation occurs, then the minimum required transmission loss is:

$$L_T = G_T + G_R - 117 \ , \text{dB} \qquad (13.5.1)$$

where G_T and G_R are the gains of the earth stations in the plane of the horizon in each others direction.

For stations operating with boresight elevation angles greater than 10 degrees, the antenna gain in the horizon plane will be less than

$$G = 32 - 25 \log(10^\circ) = 7 \text{ dB} . \qquad (13.5.2)$$

As it is very unlikely that both stations will have antenna gains this high (ie, usually back lobe values of -10 dB will apply), the sum of G_T and G_R in equation 13.5.2 is taken to be 0 dB, resulting in a minimum required transmission loss of -117 dB.

The maximum out-of-band power at the earth station transmitter is then given by

$$P_{T,MAX} = -134.3 + 117 = -17.3 \text{ dBW in 72 MHz band.} \qquad (13.5.3)$$

The EIRP of the uplink carriers may be as high as 100 dBW (see equations 13.2.2. and 13.2.3), depending on the coverage area of the satellite receiving antenna. To achieve EIRP's this high will require transmitters with output powers possibly as high as 5000 watts (37 dBW). For an FM/TV uplink carrier, the out-of-band emission spectrum must be down approximately 55 dB relative to 37 dBW to ensure that the maximum interference level is not exceeded. From Figure 13.2/1, this implies that the upper edge of a 23 MHz uplink channel must be at least 5 MHz from the lower edge of the downlink channel.

For a 72 MHz PSK uplink carrier, the spectrum shown in Figure 13.2/4 is applicable. In this case, the spectrum must be down approximately 53 dB, requiring a 24 MHz guardband. As this guardband is larger than the guardband required to protect the receiving earth station from interference from FM/TV uplink carriers, and the guardband required to protect uplink carriers from interference from an antipodal transmitting satellite, the use of a 24 MHz guardband will ensure that the systems can co-exist without co-ordination.

13.6 Summary

The use of the 17.0 - 17.5 GHz band as an uplink band for the fixed-satellite service is not affected by fixed-satellite systems using the 17.7 to 21.5 GHz downlink band. However, use of a frequency band adjacent to the 17.7 GHz edge of the downlink band for fixed-satellite uplink service will place constraints on the use of the bands primarily due to:

- interference from antipodal satellites caused by out-of-band emissions from satellite transmitters, requiring a guardband of at least 9 MHz between the up and downlink bands.

- interference between earth stations caused by out-of-band emissions from the uplink transmitters, requiring a guardband of 24 MHz.

This guardband can be shared between the uplink and downlink bands or assigned to either the 17.7 GHz edge of the uplink or the downlink band.

The guardband could be reduced if the output filtering on the uplink earth station transmitter is improved. The guardband could also be reduced by employing higher gain spacecraft receiving antennas, since lower earth station EIRP's could be used.

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