NTIA REPORT 84-152

ASSESSMENT OF SATELLITE POWER FLUX-DENSITY LIMITS IN THE 2025-2300 MHz FREQUENCY RANGE

PART II

ANDREW FARRAR

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

David J. Markey, Assistant Secretary
for Communications and Information

JULY 1984

ACKNOWLEDGEMENT

The author acknowledges the contributions of M.J. Pagones of the Bell Telephone Laboratories and Paul Locke and Alan Rinker of Systematics General Corporation for extensive modification of the computer models used in the analysis. The technical discussions with Mr. James Scott of the National Aeronautics and Space Administration and the data on spacecraft he provided, were especially important in determining input parameters for the computer models used in the analysis.

ABSTRACT

The power flux-density (pfd) limits for satellites operating in the 2025-2300 MHz frequency range were calculated. Two computer models, one developed by the Bell Telephone Laboratories (BTL) and the other by the Systematics General Corporation (SGC), were used in the analysis. Modifications to these models were made in order to enhance their accuracy in the evaluation of the pfd limits in this and other bands. Distinctions were made between the satellites in geostationary satellite orbit and those in non-geostationary orbits. Two different sets of limits were calculated, one for the satellites in the geostationary satellite orbit and the other for the satellites in non-geostationary orbits. These limits were calculated using the technical characteristics of equipment in the 2025-2300 MHz frequency range and the criteria of noise due to interference from satellites set by the CCIR Recommendation 357-3. The pfd limits calculated here for the 2025-2300 MHz frequency range are applicable in the portions of this frequency range authorized for use by space services. These limits were compared with the existing limits in the NTIA Manual and the analysis indicated that the pfd limits for satellites could be relaxed.

KEY WORDS

Computer Models
Determination of Power Flux Density Limits
Electromagnetic Compatibility
Power Flux Density
Systems in Space and Fixed Service Sharing
2025-2300 MHz

TABLE OF CONTENTS

LIST OF TABLES

FIRST OF FIGURES

SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA), formed by Reorganization Plan No. 1 of 1977, is responsible, under Executive Order 12046, for managing the radio frequency spectrum used and/or allocated to the U.S. Federal Government and is in charge of formulation of telecommunication policy. In addition, the telecommunications policy concerning the promotion of efficiency and economy of Government operations states that, "...the basic guide to follow in the normal assignment of radio frequencies for transmission purposes is the avoidance of harmful interference..." In carrying out its responsibility and to ensure the compatibility in frequency sharing between the satellites and the systems in the Fixed Service, the NTIA has undertaken the spectrum resource assessment of power flux-density (pfd) limits in the 2025-2300 MHz frequency range. This study determines limits to protect systems in the Fixed and Mobile Services from interference from satellites in space services without placing undue burden on the design of these satellites. This report provides a technical base for calculated limits that may be recommended for inclusion in the NTIA Manual for future use in such functions as frequency sharing and granting spectrum support to satellites in the 2025-2300 MHz frequency range.

PRELIMINARY DISCUSSIONS

In an earlier report (Farrar, 1982) the origin of the pfd limits and two recent analytical models used in the derivation of these limits were discussed. A computer model, developed by the Bell Telephone Laboratories (BTL) and another by the Systematics General Corporation (SGC) were used in the analysis section of that report. Included in the report were a discussion of the algorithms and the assumptions used in the development of the two analytical models. The computer model developed by the BTL was for evaluation of pfd limits for satellites in geostationary orbit and will be referred to as geostationary model (GM) in this report. The SGC computer model was developed to determine the pfd limits for low orbit satellites and will be referred to as non-geostationary model (NGM) in this report. Farrar (1983) pointed out that modifications to these two computer programs were necessary in order to determine the pfd limits for the 2025-2300 MHz frequency range. The following is a summary of these modifications described in Part I of Farrar (1983).

1. The receiver transfer function used in both GM and NGM programs should be modified to take into account the technical characteristics of the equipment in the 2025-2300 MHz frequency range. A qualitative analysis conducted in Part I indicated that the characteristic of the equipment presently used or planned in this frequency range may have a serious effect on the relationship for the transfer function used in the models.

2. Long-term fading effects should be incorporated in the GM computer algorithm in order to determine satellite interference noise power into a radio-relay as a function of percentage of a month.

3. The effect of potential interference to radio-relay receivers from non-geostationary satellites in multiple orbits should be determined by modifying the NGM computer program.

4. Fading data measured in the United States should be incorporated in the NGM program. The current NGM program makes use of fading data measured in Germany.

5. In the calculation of pfd limits considerations should be given to the combined effects of interference from satellites both in geostationary and non-geostationary orbits for special cases when satellites in low orbits have low inclination angles.

Systems in the Mobile Service were assumed to be operationally less susceptible to interference from satellites than the systems in the Fixed Service. However, systems in Aeronautical Telemetry Mobile Stations used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof, were left for consideration in this follow-up analysis. Both GM and NGM computer models were developed for calculating the power flux densities which limit the interference from satellites to the systems in Fixed Service which share the same frequency range with satellites and use FDM/FM modulation and line-of-sight transmission. There are a large number of digital systems in the Fixed Service in the 2025-2300 MHz frequency range. An analysis was found necessary in this effort to determine if the pfd limits designed to protect the terrestrial analog systems were sufficient to provide compatible operation between terrestrial digital systems and spacecraft operating in the 2025-2300 MHz frequency range.

This report treats the modifications listed above in the computer models and the problems associated with the terrestrial digital systems using LOS techniques for the evaluation of the pfd limits in the desired frequency range. A review of the pfd limits given in the ITU and adopted in the NTIA Manual (1983) is also included.

OBJECTIVES

The overall objective of this task was to assess the pfd limits from satellites at the surface of the Earth in the 2025-2300 MHz frequency range. The following specific objectives were identified for this effort.

1. Determine pfd limits applicable to the United States for the satellites in geostationary and non-geostationary orbits that will not jeopardize the operations of the systems in the Fixed Service using line-of-sight transmission in the 2025-2300 MHz frequency range.

2. Review the existing pfd limits for space stations in the NTIA Manual, determine if those limits should be modified, and recommend the appropriate modification to these limits.

3. Review the power flux limit for systems using tropospheric transmission in the 2025-2300 MHz frequency range as given in the NTIA Manual.

4. Identify the problem areas which need more detailed analysis.

APPROACH

The interactions between services involved in the determination of pfd limits for the 2025-2300 MHz frequency range were analyzed and the existing interference criteria used in the calculation of these limits were reviewed. Information on the characteristics of space and terrestrial systems operating in this frequency range and given in Part 1 of this report were up-dated to determine the characteristics of typical systems in this frequency range.

Modification of the two computer models (GM and NGM) was necessary before the proper pfd limits for the desired frequency range could be determined. The following approach was used in carrying out the modifications of the GM and NGM computer programs.

The GM computer program in its original form did not consider fading of RF signals and the fading data used in the original design of the NGM program were data taken in Europe at 4 GHz. The fading data statistics for radio frequency (RF) signals measured by the Bell Telephone Laboratories (BTL) at different areas of the United States were incorporated in both the GM and NGM programs.

1. The NGM program was designed to carry out the computation of pfd limits for satellites in one orbit at a time. The program was modified to take into account the effects of satellites in different orbits in the computation of the pfd limits.

2. Combined effects of interference from satellites in both geostationary and non-geostationary orbits in the calculation of pfd limits were considered.

3. The expression for the radio-relay receiver transfer function used in both GM and NGM program was modified to take into account the characteristics of the equipment used in the 2025-2300 MHz frequency range. A new transfer function for this frequency range was derived and incorporated in the computer programs.

4. The assumption of on-tune interference from a satellite to all the receivers in a trendline was used originally in both GM and NGM programs. This assumption was not applicable to the terrestrial systems in the desired frequency range. Modifications to the programs were made to determine the pfd limits for this frequency range based on different applicable frequency-engineering-plans for a trendline.

The approach outlined above was for the determination of pfd limits considering the characteristics of FDM/FM analog radio receivers in the 2025-2300 MHz frequency range. The approach used in evaluating the adequacy of these limits for the digital radio receivers is as follows. Frequency Shift Keying (FSK), Phase Shift Keying (PSK), and Amplitude Shift Keying (ASK) were assumed to be representative types of digital modulation for the analysis. Three computer programs were prepared to calculate probability of bit-error-rate (Pe) for the three different kinds of modulation in the presence of

Gaussian noise. Using these computer programs plots of Pe vs Signal-to-Noise (S/N) ratio were obtained for the three types of modulation. The curves in these plots were used to assess the effect of analog pfd limits on trendlines using digital systems.

The effect of each modification listed above on the determination of pfd limits was determined separately. The final values of pfd limits found as a result of the analysis given here include the contributions made by all the modifications. The pfd limits for the 2025-2300 MHz frequency range were calculated after the modifications were incorporated in the computer models.

The historical basis used in establishing existing level of power density from satellites for systems using tropospheric propagation was reviewed in order to provide insight for its application. In addition, the non-compliance of the U.S. Satellites with the ITU limit for systems using troposhperic propagation was reviewed.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

This investigation is a continuation of Part 1 of the study on pfd limits for satellites that operate in the 2025-2300 MHz frequency range (Farrar,1982). A review of the spectrum use in the United States in this frequency range is made and the rules, criteria, and guidelines set by the ITU and CCIR pertinent to the determination of the pfd limits are studied. The limits developed here are appropriate for the United States and the assumptions used in their derivation should be reviewed for use by other administrations. The pfd limits for the satellites in the frequency ranges 13.4-14.0 GHz and 14.5-15.35 GHz are not treated in this analysis. However, the methodology developed in this analysis is applicable in treating pfd limits in these frequency ranges.

The pfd limits protecting the Fixed Service using line-of-sight techniques in the 2025-2300 MHz frequency range are included in the ITU Radio Regulations (RR) and are described in Article 28, Section IV, Nos. 2556 and 2557 (RR, 1982). Nos. 2556 and 2557 are as follows:

> "2556 (2) Power flux-density limits between 1525 MHz and 2500 MHz."
>
> "2557 (a) The pfd at the Earth's surface produced by emissions from a space station, including emissions from reflecting satellite, for all conditions and for all methods of modulation, shall not exceed the following values:
>
> -154 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
>
> $-154 + 0.5\ (\delta-5)$ dB(W/m^2) in any 4 kHz band for angles of arrival (in degrees) between 5 and 25 degrees above the horizontal plane;
>
> -144 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane."

These limits relate to the pfd which would be obtained under assumed conditions. These same limits are contained in the NTIA Manual for systems in line-of-sight operation. No. 2559 of the ITU Radio Regulations specifies that the limits in No. 2557 are applicable to the frequency range 2290-2300 MHz. However, ITU footnotes 747 and 750 specify that these limits are also applicable to the bands 2025-2110 MHz and 2200-2290 MHz.

Two computer models, the Geostationary Model (GM) and the Non-Geostationary Model (NGM), developed earlier for the determination of the pfd limits in the frequency bands shared between systems in the Fixed Service and satellites were found useful for this analysis. The models were modified extensively in order to conduct the analysis and to determine the pfd limits in the frequency range 2025-2300 MHz. Modifications to these computer models were identified in Part 1 of this analysis. The computer models may be used to determine pfd limits for any shared band; however, the preparation of the input parameters for these models requires a careful assessment of the usage of the spectrum and the technical characteristics of the systems.

The following are the conclusions and recommendations which resulted from a detailed analysis of the pfd limits in the frequency range 2025-2300 MHz.

GENERAL CONCLUSIONS

Effects of each modification to the computer models on the value of the pfd limits were determined separately. Some of the effects were significant. A summary of the modifications and their separate effects on pfd limits is as follows:

1. An approximate formula for the transfer function of typical radio receivers in the 2025-2300 MHz frequency range was evaluated. Based on modulation indices and emission spectrums of typical systems in this frequency range, the analysis indicated that the transfer function allowed the pfd limits to be relaxed by 3 dB as calculated by the GM or NGM computer models.

2. Data on fading obtained in the United States were incorporated in both the GM and NGM computer models. The results indicated that the use of this fading data in the computer models did not show any significant change (less than 1 dB) in the pfd limits.

3. A modification was made to the NGM computer model in order to be able to calculate pfd limits when interfering satellites are in different orbits. This modification simulated a more realistic method of operating satellites and the results indicated an increase of approximately 1-3 dB in the interference power received from satellites in non-geostationary orbits.

4. The pfd limits which protect the analog systems in terrestrial services should also protect the digital systems operating in the same frequency range. The results of calculations show that for an operating condition simulated by typically "worst case" Gaussian noise interference, the bit-error-rate is less than 10^{-3} for practical signal-to-noise ratios used in the design of terrestrial microwave systems. Hence, the digital systems are generally less susceptible to interference than their analog counterparts.

5. Single hop aeronautical telemetry mobile systems with very sensitive receivers and relatively high gain receive antennas (gain greater than 30 dBi) temporarily pointed toward satellites in geostationary or low orbits may occasionally experience potential interference. Analysis shows that the probability of potential interference from satellites in low orbits to these telemetry systems is approximately $1x10^{-3}$ and the duration of interference is a few seconds.

6. Potential interference from satellites to aeronautical telemetry systems was found to be manageable by using frequency management, coordination, antenna reorientation or scheduling. The report by ECAC

(White, 1977) documents the frequency management techniques that are used presently for coordination at the eastern and western test ranges.

SPECIFIC CONCLUSIONS

1. Potential interference from satellites in the geostationary orbit to terrestrial systems in the Fixed Service increases as the terrestrial systems are moved in latitude from the equatorial to approximately 50 degree latitude. The potential interference to terrestrial systems then decreases to 83 degree latitude. The worst interference occurs when the trendline for a terrestrial system is pointed toward the geostationary orbit. (a)

2. Analysis shows that for a given pfd, regardless of the altitude of low orbit satellites, the interference to terrestrial receivers generally increases as the inclination angle decreases as shown in Figures 13-16.

3. Analysis indicates that pfd limits for geostationary satellites may be considered separately from those for non-geostationary.

4. The results of analysis based on spectrum use and the characteristics of systems in the terrestrial and space services in the United States indicate that the the pfd limits for 2025-2300 MHz frequency range may be relaxed without degrading the operation of line-of-sight terrestrial systems. PFD limits for geostationary satellites should be changed to the following values:

-144 dB(W/m^2) in any 4 kHz for angles of arrival between 0 and 5 degrees above the horizontal plane;

$-144 + 0.5\ (\delta-5)$ dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 5 and 25 degrees above the horizontal plane;

-134 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizonal plane.

PFD limits for satellites in low orbits are similar to those given above except that they may be relaxed an additional 6 dB.

5. In the United States, the Government Fixed Service allocation in the sub-band 2200-2290 MHz is for line-of-sight transmission. Internationally, the band may be used by systems designed for tropospheric scatter transmission. Noise criteria due to interference from satellites to systems using tropospheric transmission has not yet been recommended by the CCIR. The pfd limits for satellites to troposcatter systems have not been determined.

Note a. A trendline consists of communication line between two points connected by a number of repeaters.

RECOMMENDATIONS

The following are NTIA staff recommendations based on the technical findings contained in this report. Any action to implement these recommendations will be accomplished under separate correspondence by modifications of established rules, regulations, and procedures. It is recommended that:

1. The pfd limits, given in conclusion 4 above for satellites in geostationary and non-geostationary orbits, be adopted by the NTIA in the 2200-2300 MHz frequency range.

2. Footnote US90 be modified as suggested below:

   US90-In the band 2025-2110 MHz earth-to-space and space-to-space transmissions may be authorized in the space research and earth exploration-satellite services subject to such conditions as may be applied on a case-by-case basis. Such transmissions shall not cause harmful interference to non-Government stations operating in accordance with the Table of Frequency Allocations. All space-to-space transmission reaching the earth's surface from satellites in geostationary orbit shall adhere to a power-flux-density of between -134 and -144 $dBWm^2/4$ kHz depending on angles of arrival discussed in ITU Radio Regulations No. 2557. All space-to-space transmission from satellites in non-geostationary satellite orbits reaching the earth's surface shall adhere to a power-flux-density of between -128 and -138 $dBW/m^2/4$ kHz depending on angles of arrival stated in ITU Radio Regulations No. 2557.

3. The pfd limits in the frequency ranges 13.4-14.0 GHz and 14.5-15.35 GHz discussed in Part 1 be reviewed using the approach used in this investigation.

4. Similar analysis should be undertaken to develop pfd limit in the 2025-2300 MHz frequency range appliable to other ITU administratons.

5. The power density-limit for systems using troposcatter transmission be determined after permissible noise levels due to interference from satellites to these systems have been recommended by the CCIR.

6. Coordination among NASA, DOD and DOE in the 2200-2290 MHz frequency range be continued and enhanced to mitigate potential interference from satellites to telemetry systems in the Aeronautical Mobile Service in conjunction with the adoption of the new pfd limits in Recommendation 1.

SECTION 3

ALLOCATIONS AND CRITERIA

GENERAL

The spectrum usage and the types of services allocated in the 2025-2300 MHz frequency range were among the key factors that had to be considered in the determination of pfd limits. A brief review of the National and International Tables of Frequency Allocations will be given in this section in order to highlight the different types of services which have allocations in the 2025-2300 MHz frequency range. A careful examination of these services and their implementation both within, and to some extent, outside the United States are discussed in this section. An understanding of such implementation is essential in the determination of pfd limits in the 2025-2300 MHz frequency range. The existing pfd limits and criteria used in their derivation will also be discussed in this section.

ALLOCATIONS AND ASSIGNMENTS

Internationally, the frequency range 2025-2300 MHz, shown in Table 1, is allocated to Fixed and Mobile Services with the exception of the last 10 MHz (2290-2300 MHz) which is allocated to Space Research (deep space) and Fixed Services. Footnotes 747, 748, and 750 permit Space Research, Earth Exploration Satellite, and Space Operations Services in the 2025-2110 MHz worldwide. A majority of the ITU member adminstrations use the International Table of Allocations as their national table of frequency allocations. A majority of the countries in Region 2 are among these administrations.

For these administrations, the frequency band 1710-2300 MHz (590 MHz) is allocated to systems in the Fixed Service. However, despite the availability of more spectrum, the use of this frequency range varies from one country to another depending upon the Government structures. In some countries like Brazil, Argentina, Canada, and Mexico frequency planning is necessary and yet there are others where extensive band planning is not that critical. Information on the use of this frequency range is scarce and sometimes not accurate for the majority of these and other countries in Region 2, except the United States and Canada. Excerpts from the ITU File shown in Table 2 show the number of assignments recorded by the International Frequency Registration Board (IFRB). This ITU File is updated once a year and the member administrations are not required to register their frequency assignments for every system with the IFRB. Marketing information received from the U.S manufacturers indicates that the equipment sold in this frequency range to the countries in South and Central America as well as Canada are similar in characteristics as those used in the United States. If similarity of equipment characteristics may be used as a measure of the band usage, it may be stated that at least in Region 2 the proliferation of high capacity systems with large tuning range such as those used in the 4 and 6 GHz communication bands is not likely to occur in the above noted frequency range. As a result, one may state that even though spectrum for the Fixed Service is made available by the ITU, the typical usage by the systems similar in characteristics to those used in the United States dominates the frequency range. A survey made by the European Space Agency indicated that in Europe some "long-haul" communications exist in the Fixed Service in this frequency

TABLE 1

EXCERPTS FROM THE INTERNATIONAL TABLE OF FREQUENCY ALLOCATIONS (1710-2300 MHz)

MHz
1 710 — 2 290

Allocation to Services		
Region 1	Region 2	Region 3
1 710 — 2 290 FIXED Mobile 722 744 746 747 748 750	**1 710 — 2 290** FIXED MOBILE 722 744 745 746 747 748 749 750	
2 290 — 2 300 FIXED SPACE RESEARCH (deep space) (space-to-Earth) Mobile except aeronautical mobile	**2 290 — 2 300** FIXED MOBILE except aeronautical mobile SPACE RESEARCH (deep space) (space-to-Earth)	

Footnotes applicable to the analysis in this report

747 Subject to agreement obtained under the procedure set forth in Article **14**, the band 2 025 — 2 110 MHz may also be used for Earth-to-space and space-to-space transmissions in the space research, space operation and earth exploration-satellite services. The services using space-to-space transmissions shall operate in accordance with the provisions of Nos. **2557** to **2560** and shall not cause harmful interference to the other space services.

748 Subject to agreement obtained under the procedure set forth in Article **14**, the band 2 110 — 2 120 MHz may also be used for Earth-to-space transmissions in the space research (deep space) service.

750 Subject to agreement obtained under the procedure set forth in Article **14**, the band 2 200 — 2 290 MHz may also be used for space-to-Earth and space-to-space transmissions in the space research, space operations and earth exploration-satellite services. These services shall operate in accordance with the provisions of Nos. **2557** to **2560**; the space-to-space transmissions shall not cause harmful interference to the other space services.

TABLE 2. EXCERPTS FROM THE INTERNATIONAL FREQUENCY REGISTRATION BOARD FILE.

(2025-2300 MHz)

NAME OF COUNTRY	NO. OF ASSIGNMENT
Argentina	169
Bahamas	2
Dominican Republic	1
Guatemala	41
Greenland	14
Guyana	22
British West Indies	6
Mexico	393
Martinique	29
Republic of Panama	1
Paraguay	12
Puerto Rico	13
Uruguay	8
Canada	198
Panama Zone	2
TOTAL	911

range. But the term "long-haul" in Europe compared with the geographical boundaries could imply any microwave transmission no further than a few hundred miles.

Generally, in the United States the allocation table for the frequency range 2025-2300 MHz is planned to be responsive to higher demand on spectrum. The Canadian Department of Communication has made an attempt to bring a greater agreement between the U.S. planning of the 2025-2300 MHz frequency range and that which is used in Canada. Similar statements may be made about Mexico. A U.S. marketing office involved in the sale of 2 GHz equipment to Latin American countries stated that industrial use of the spectrum in the 1710-2300 MHz frequency band has been the trend so far. The sketchy description of the use of the frequency band internationally leads to no general conclusions except that the determination of the international usage of the band is complex and that from the equipment point of view the band usage may follow that which has been adopted by the United States.

The U.S. frequency-range planning referred to above is shown in Figure 1. Note that the non-Government portion of the frequency range, 2025-2300 MHz, has been divided by the FCC for use by different station classes defined by the FCC Rules and Regulations. This usage, which impacts the assumptions used in the computation of pfd limits, are discussed below.

The FCC divided the 175 MHz non-government band, which spans the frequency range 2025-2200 MHz, into two parts. The first part is 85 MHz wide beginning at 2025 MHz and is for use by the Auxiliary Broadcast Station which is described in part 74 of the FCC Rules and Regulations (Code of Federal Regulations: 47CFR74.601). Classes of Television Auxiliary Broadcast Stations presently defined by these regulations are as follows:

> "(a) TV pickup station. A land mobile station used for the transmission of television program material and related communications from the scenes of events occurring at points removed from the station studios to TV broadcast and low power TV stations.
>
> (b) TV STL station (studio-transmitter link). A fixed station used for the transmission of television program material and related communications from the studio to the transmitter of a TV broadcast or low power TV station.
>
> (c) TV intercity relay station. A fixed station used for intercity transmission of television program material and related communications for use by TV broadcast and low power TV stations.
>
> (d) TV translator relay station. A fixed station used for relaying programs and signals of TV broadcast stations to LPTV, TV translator, and other communications facilities that the FCC may authorize."

These stations in the Auxiliary Broadcast, may be fixed or mobile. It should be pointed out that these systems have no more than several channels and are not used for transmission of information (voice and picture) beyond several repeater stations.

UNITED STATES TABLE		FCC USE DESIGNATORS	
GOVERNMENT	NON-GOVERNMENT		
Allocation MHz (4)	Allocation MHz (5)	RULE PART(s) (6)	Special-Use Frequencies (7)
1 990 - 2 110 US90 US111 US219 US222	1 990 - 2 110 FIXED MOBILE US90 US111 US219 US222 NG23 NG118	AUXILIARY BROADCASTING (74)	
2 110 - 2 200 US111 US219 US222 US252	2 110 - 2 200 FIXED US111 US219 US222 US252 NG23	DOMESTIC PUBLIC FIXED (21) PRIVATE OPERATIONAL-FIXED MICROWAVE (94)	
2 200 - 2 290 FIXED MOBILE SPACE RESEARCH (space-to-Earth) (space-to-space) G101	2 200 - 2 290		
2 290 - 2 300 FIXED MOBILE except aeronautical mobile SPACE RESEARCH (space-to-Earth) (deep space only)	2 290 - 2 300 SPACE RESEARCH (space-to-Earth) (deep space only)		

Figure 1: Excerpts from NTIA Allocation Table and FCC Rules and Regulations

Footnotes for Figure 1 are given on the next page

Footnotes from Figure 1:

G101—In the band 2200–2290 MHz, space operations (Space-to-Earth) and (Space-to-space), and earth exploration-satellite (Space-to-Earth) and (Space-to space) services, may be accommodated on a co-equal basis with fixed, mobile and space research service.

US90—In the band 2025–2110 MHz earth-to-space and space-to-space transmissions may be authorized in the space research and earth exploration-satellite services subject to such conditions as may be applied on a case-by-case basis. Such transmissions shall not cause harmful interference to non-Government stations operating in accordance with the Table of Frequency Allocations. All space-to-space transmission reaching the earth's surface shall adhere to a power flux density of between -144 and -154 dbw/M^2/4 kHz depending on the angle of arrival per ITU Radio Regulation 2557 and shall not cause harmful interference to the other space services.

US252—The bands 2110–2120 and 7145–7190 MHz, 34.2–34.7 GHz are also allocated for earth-to-space transmissions in the Space Research Service, limited to deep space communications at Goldstone, California.

The second part of the non-Government band in the 2025-2300 MHz frequency range is 90 MHz wide starting with 2110 MHz and is divided into four bands for use by two different services as shown in Figure 1. These services are Domestic Public and Private Operational Fixed Microwave. These two have been allocated two non-adjacent segments of the spectrum which separate the transmitter and receiver frequencies at any given site. This point is discussed in more detail in the analysis section of the report.

The operation and licensing requirements for the systems in the Fixed Service, that operate in various segments of the 90 MHz, are given in the FCC Rules and Regulations (94CFR 94.61 and 21CFR). Generally, the licensing requirements and compliance with the FCC Rules and Regulations make it necessary for these systems to be operationally narrow band with a limited number of repeaters. As a result, it is unlikely for the 2025-2200 MHz non-Government use to expand in the United States in the manner which presently exists in the communication bands near 4 and 6 GHz.

A review of the allocations in the 2025-2120 MHz frequency range is important. The three space services in Figure 1 are permitted by footnote to operate in the 2025-2110 MHz frequency range. These services are: Space Research, Space Operation, and Earth Exploration Satellite. These services share the frequency range allocated to non-Government users shown in Figure 1. The non-Government users are Auxiliary Broadcast and Domestic Public. Systems in the Auxiliary Broadcast, in general, consist of a few hops and are narrow band. The deep space Earth-to-space transmission in the 2110-2120 MHz frequency range is authorized by Footnote US252. Hence, systems in the Domestic Public are not affected by the Space Services in the non-Government portion of the desired frequency range.

The above discussion on the allocations and usage in the 2025-2300 MHz frequency range indicates that:

1. The 2025-2300 MHz frequency range planning in the United States is different from that in other countries.

2. Because of the spectrum planning described above, the spectrum is more for commercial applications and, so far, systems such as those in 4 and 6 GHz communication bands have not been developed for this frequency range. For example, FCC has allocated 120 MHz (1990-2110) to Auxilary Broadcast which by CCIR definition is not a long-haul communication system. Lesser spectrum, only 100 MHz (2200-2300), is allocated to Fixed and Mobile Services in the Government portion of the frequency range.

3. The pfd limits in the 2025-2300 MHz should be determined in a manner to protect the systems in the Auxiliary Broadcast operating in the 2025-2110 MHz and the systems in the Fixed and Mobile Service in the 2200-2290 MHz frequency range.

4. In Region 2, which includes the United States, the band usage varies according to economic condition and the spectrum allocations for the countries in this region. Generally speaking, Fixed and Mobile Services have more spectrum available to them in countries other than the United States.

SUMMARY OF INTERFERENCE CRITERIA

The following discussion of the interference criteria applicable to the pfd analysis is based on CCIR Recommendations 393-3 and 357-3. The interference criteria given in these recommendation and used in the calculations of pfd are for analog systems in the Fixed Service. The criteria given by the CCIR are applicable to a Hypothetical Reference Circuit (HRC) defined in CCIR Recommendation 390-3. HRC is a necessary element in the study of certain characteristics of long-distance circuits. Operational circuits may be shorter or longer than the HRC defined by the CCIR. In practice the HRC was intended only as a guide in the planning of carrier systems in the Fixed Service. The HRC used by the CCIR in establishing the noise due to interference from satellites to a system in the Fixed Service represents a trendline 2500 km long consisting of fifty equal hops. Thus far, the criteria for noise power from satellites set forth by the CCIR pertain to the protection of analog systems using FDM/FM modulation. The criteria for the protection of digital systems have been under study and the CCIR has not yet recommended a criteria for the protection of digital systems used in the Fixed Service.

Analog Systems (Line-of-Sight)

The noise due to interference from satellites is equal to a fraction of the total allowable noise power in a HRC. One of the objectives of noise power limits, set by the CCIR for radio-relay systems, was to have comparable noise power for both radio and cable systems. The maximum allowable noise in a HRC is given in CCIR Recommendation 393-3. This recommendation defines the maximum allowable noise power as follows:

> "1. that the noise power at a point of zero relative level in any telephone channel on a 2500 km hypothetical reference circuit for frequency-division multiplex radio-relay systems should not exceed the values given below, which have been chosen to take account of fading:
>
> 1.1 7500 pWOp, psophometrically-weighted one-minute mean power for more than 20 percent of any month;
>
> 1.2 47,500 pWOp, psophometrically-weighted one-minute power for more than 0.1 percent of any month;
>
> 1.3 1,000,000 pWOp, unweighted (with an integrating time of 5 ms) for more than 0.01 percent of any month;
>
> 2. that in a part of the hypothetical reference circuit consisting of one or more of the homogeneous sections defined in Recommendation 392, the one-minute mean noise power not exceeded for 20 percent of the month shall be considered to be proportional to the number of sections involved."

It should be pointed out that the CCITT allows 2500 pWOp mean value for the frequency-division multiplex equipment in a Hypothetical Reference Circuit and this noise power is not included in the noise levels given above. A graphical presentation of the above noise levels is given in Figure 2. The circled points on the graph are the noise levels given by the CCIR. The interpolation between these points follow an example of possible interpolation used by the CCIR in Recommendations 357-3 and 356-4. Recommendation 357-3 defines the maximum noise power levels allowable from satellites in the Fixed Satellite Service to a radio-relay system using line-of-sight transmission.

The following excerpt from Recommendation 357-3 is important to the analysis of the pfd limits given in this report:

> "1. that systems in the Fixed Satellite Service and line-of-sight analogue angle-modulated radio-relay systems which share the same frequency bands, should be designed in such a manner, that in any telephone channel of a 2500 km channel Hypothetical Reference Circuit for frequency-division multiplex analogue angle-modulated radio-relay systems, the interference noise power at a point of zero relative level, caused by the aggregate of the emission of Earth stations and space stations of the systems in the Fixed Satellite Service, including associated telemetering, telecommand and tracking transmitter, should not exceed:
>
> > 1.1 1000 pWOp psophometrically-weighted one-minute mean power for more than 20 percent of any month;
> >
> > 1.2 50 000 pWOp psophometrically-weighted one-minute mean power for more than 0.01 percent of any month.
>
> 2. that the following Note should be regarded as part of the Recommendation.
>
> Note -- The way in which the above values are to be taken into account in the general noise objective for radio-relay systems is defined in Recommendation 393-3."

The two circled points in the lower curve in Figure 2 show the noise levels set by the CCIR in Recommendation 357-3. The distribution of noise between the two points follows from the example of possible interpolation given by the CCIR in Recommendation 357-3. This pattern of distribution by the CCIR is not unique to Recommendation 357-3. This same distribution was also used in Recommendation 356-4 which pertains to the maximum allowable interference from line-of-sight radio-relay systems to a telephone channel of a system in the Fixed Satellite Service employing frequency modulation when both systems share the same frequency bands.

The pfd limits which were adopted by the CCIR were derived using 1000 pWOp noise power level given in Recommendation 357-3. These limits in the 2025-2300 MHz frequency range are included in Section IV, Article 28, of the ITU Radio Regulations, Edition 1982.

Provisions in Nos. 2556-2559, which are applicable to line-of-sight systems in the 2025-2300 MHz frequency range, are reproduced here for easy reference.

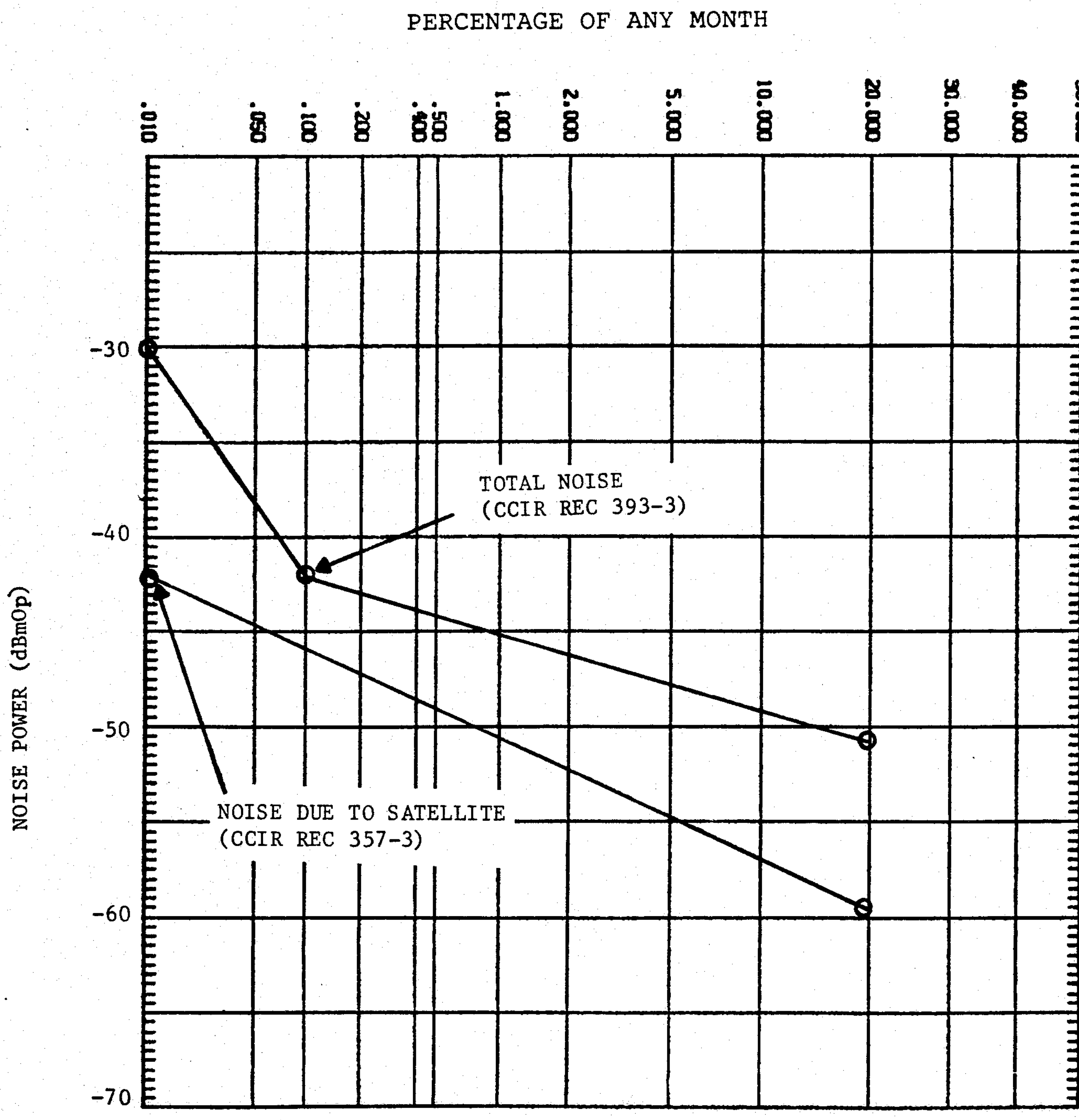


Figure 2. A Plot of CCIR Noise Power Level Criteria.

2556 (2) Power flux density limits between 1525 MHz and 2500 MHz.

2557 (a) The power flux density at the Earth's surface produced by emissions from a space station, including emissions from reflecting satellites, for all conditions and for all methods of modulation, shall not exceed the following values:

> -154 dB(W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;
>
> $-154 + 0.5(\delta-5)$dB(W/m^2) in any 4 kHz band for angles of arrival δ (in degrees) between 5 degrees and 25 degrees above the horizontal plane.
>
> -144 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane.

These limits relate to the power flux density which would be obtained under assumed free-space propagation conditions.

2558 (b) The limits given in No. 2557 apply in the frequency bands listed in No. 2559 which are allocated to the following space radiocommunication services:

- meteorological-satellite service (space-to-Earth)
- space research service (space-to-Earth)
- space operation service (space-to-Earth)

for transmission by space stations where these bands are shared with equal rights with the Fixed or Mobile Service.

2559	1525 - 1530 MHz	(for Regions 1 and 3)
	1530 - 1535 MHz	(for Regions 1 and 3, up to January 1990)
	1670 - 1690 MHz	
	1690 - 1700 MHz	(on the territory of the countries mentioned in Nos. 740 and 741)
	1700 - 1710 MHz	
	2290 - 2300 MHz	

In addition to the frequency ranges given in No. 2559, the pfd limits given in 2557 are applicable to transmissions from satellites in the 2025-2110 MHz and 2200-2290 MHz frequency ranges by Footnotes 747 and 750 of the International Table of Frequency Allocations.

The pfd limits given in the ITU Radio Regulations have been adopted by the United States and are now in Chapter 8 of the NTIA Manual. Neither ITU Radio Regulations nor the NTIA Manual make a distinction between the satellites in geostationary and non-geostationary orbits. Hence, the pfd limits noted above have been used to determine the compliance of any satellite emission on the surface of the Earth.

Analog System (Troposcatter)

Tropospheric scatter propagation is in use outside the United States in the 2025-2300 MHz frequency range. Systems designed to use this mode of propagation are recommended to conform to appropriate CCIR Recommendation noise power levels set by the CCIR for these systems. Definition of Hypothetical Reference Circuit for transhorizon radio-relay systems and their noise power criteria are given in Recommendations 396-1 and 397-3. Extracts from Recommendation 397-3 were given in Part 1 of this report (Farrar, 1982) and are reproduced here.

> CCIR distinguishes between two classes of troposcatter systems:
>
> > Class I. Systems operating between points capable of linkage by line-of-sight radio-relay or underground cable without excesssive difficulty.
> >
> > Class II. Systems operating under conditions precluding alternative means of communication.
>
> The authorized noise power allowances extracted from CCIR Recommendations 397-3 and 393-3 for a CCIR hypothetical reference circuit for the two classes are given in Table 3.

According to CCIR Recommendation 397-3, Class II systems in which the noise power levels are in agreement only with the level given for 20 percent and 0.5 percent of any month are excluded from the main international and intercontinental routes. As a result, in a worldwide connection a maximum of one or two circuits of medium length will be encountered which comply with the noise power level allowed for 0.05 percent of any month.

The noise power levels indicated in Table 3 are the allowable noise power in a Hypothetical Reference Circuit for any transhorizon radio-relay system using FDM/FM modulation. Unlike the systems in line-of-sight operation, CCIR has not yet determined specific values of noise power levels from satellites for the protection of systems using troposcatter propagation. However, to protect the systems using tropospheric propagation, certain criteria have been established by the provisions in No. 2560 of the ITU Radio Regulations. Provisions in No. 2560 given below are to mitigate interference between a transhorizon radio-relay system and a satellite emitter.

> 2560 c) The pfd values given in No. 2557 are derived on the basis of protecting the Fixed Service using line-of-sight techniques. Where a Fixed Service using tropospheric scatter operates in the bands listed in No. 2559, and where there is insufficient frequency separation, there must be sufficient angular separation between the direction to the space station and the direction of maximum radiation of the antenna of the receiving station of the Fixed Service using tropospheric scatter to ensure that the interference power at the receiver input of the station of the Fixed Service does not exceed -168 dBW in any 4 kHz band.

TABLE 3

ALLOWABLE NOISE POWER IN THE CCIR HYPOTHETICAL REFERENCE CIRCUIT FOR TELEPHONY USING FREQUENCY DIVISION MULTIPLEX

DESCRIPTION	NOISE POWER (pW)	
	CLASS I	CLASS II
One minute mean power not to exceed 20% of any month	7,500[a]	25,000[a]
One minute mean power not to exceed 0.1% of any month	47,500[a]	
One minute mean power not to exceed 0.5% of any month		63,000[a]
Power not to exceed .01% of any month	1,000,000	
Power not to exceed .05% of any month		1,000,000

a. This is CCIR psophometrically weighted noise level which reduces all uniform noise powers in a 3.6 kHz band by 2.5 dB.

In the 2025-2290 MHz frequency range, the provisions of No. 2560 are not applicable to the United States, since the Government portion of this frequency range is for line-of-sight operation only and troposcatter transmission in the non-Government portion has not been employed by industry. The compliance of the emissions of spacecraft with the limit set by these provisions is examined by the IFRB for every satellite system submitted for the ITU registration. In cases of non-compliance with this limit, the United States has not yet been required to operate such assignments on a non-interference basis. However, some of the concerned ITU member administrations have required detailed data and analysis before submitting their agreement to such assignments under Article 14 of ITU Radio Regulations.

Criteria For Digital Radio-Relays

On a long distance system experiencing fading, CCIR Report 378-3 indicates that the performance and design of a digital radio-relay system is partially controlled by the need not to exceed an error-rate given in CCIR Report 779 ranging from approximately 10 to 10 for a small percentage of time. Efforts have been made by the CCIR to recommend a unanimously agreed upon criterion for the digital systems. The noise levels from satellites to a Hypothetical Reference Circuit for digital system have not been identified as distinct from those given by the CCIR for comparable analog systems. Digital systems are relatively new and perform in an electromagnetic environment originally planned by the CCIR for the operation of their analog counterpart.

A number of papers in the CCIR treat the problem of probability of bit-error-rate for digital systems. For the protection of high-capacity terrestrial radio-relay systems employing digital modulation techniques the following Recommendations typical for digital receivers, were submitted (CCIR Doc. 4/347-E, 1981):

> "...the percent of any month for which a bit error rate of 1×10^{-3} is exceeded should not be increased by more than 0.1.
>
> "...the percent of any month for which a bit error rate of 1×10^{-7} is exceeded should not be increased by more than 0.005."

CCIR has not yet adopted definite criteria for the bit-error-rate, although there is interest for the protection of terrestrial radio-relay systems using digital modulations.

SECTION 4

CHARACTERISTICS OF REPRESENTATIVE EQUIPMENT IN THE 2025-2300 MHz FREQUENCY RANGE

INTRODUCTION

The technical characteristics of the operational and planned equipment in the 2025-2300 MHz frequency range were given in Part 1 of this report (Farrar, 1982). A summary of the typical data for terrestrial systems using line-of-sight transmission will be duplicated here for easy reference. The characteristics of the U.S. and non-U.S. satellites given in Part 1 were updated and additional information on the operation of these satellites, which was pertinent to the analysis given here, was obtained. The updated characteristics of satellites are discussed here and typical data representative of systems in space services in the 2025-2300 MHz frequency range are given in this section. The typical data representing the systems in both terrestrial and space services were used in the analysis section to prepare the input parameters for the computer programs used in the calculation of pfd limits.

SYSTEMS IN TERRESTRIAL SERVICES

Some of the recommended technical characteristics of the HRC defined by the CCIR cannot be applied readily to a majority of the communication trendlines operating in the 2025-2300 MHz frequency range in the United States. For example, long-haul communications, noise criteria for international connections, and intercontinental telephony are not applicable to most of the systems operating in this frequency range in the United States. On the other hand, it will be futile to determine pfd limits based on unique usage of the spectrum for any specific system. For example, a mobile telemetry system used in a Government test range temporarily pointing its antenna toward geostationary orbit describes a specific and limited use of the spectrum. Also, a single hop communication by an Auxiliary Broadcast system cannot be accepted as representative for pfd limits calculations. However, since the majority of the systems in the 2200-2290 MHz frequency range are in Mobile Service, the effect of the pfd limits on these systems should be treated in the analysis.

Basic premises of communication requirements such as direction of antennas, noise criteria due to interference from satellites, hop length, and number of hops in a trendline, should be selected carefully in the determination of pfd limits. The limits should protect the terrestrial users now and in the forseable future, and yet, not restrict unnecessarily the operation of satellites.

Fixed and Mobile Services constitute the terrestrial services in the 2025-2300 MHz frequency range. Of particular interest to this analysis are the characteristics of commercial equipment used in auxiliary broadcast station in the 2025-2300 MHz frequency range, systems in telemetry mobile, and fixed point-to-point communication in the 2200-2300 MHz frequency range. Technical characteristics typical of representative systems for the three categories of equipment listed above are as follows:

Auxiliary Broadcast Stations

Typical characteristics of systems for this category are as follows:

Number of hops......................	1-5
Transmitter Power...................	2-12 Watts
Antenna Gain........................	20 dBi
Receiver Noise Figure...............	4-8 dB
IF Bandwidth........................	8-30 MHz
Frequency Range.....................	1.99-2.11 GHz
Receiver Threshold (33dB S/N).......	-88 dBm

The above data for equipment in Auxiliary Broadcast Station were obtained through interview and published literature received from the U.S. manufacturers.

In addition to the frequency range used by the Auxiliary Broadcast Station, the space services also share the 2200-2300 MHz frequency range with the Fixed and Mobile Services allocated to the Government users. The functions of the Government systems are primarily for telemetry mobile and fixed point-to-point communications. Characteristics of these systems appropriate to the analysis are summarized below.

Telemetry Mobile

In this category, technical characteristics for the systems in aeronautical telemetry systems are most sensitive to potential interference from spacecraft in the 2200-2300 MHz frequency range. Of particular interest to the analysis are the equipment associated with station class MOEB defined by the NTIA Manual.

Function............................	Air-to-Ground Telemetry
Area of Operation...................	Government test ranges
Transmitter Power	0.4-20 watts
Transmitter Antenna Gain	0.0-10 dBi
Receiver Antenna Gain...............	1-45 dBi
Signal-to-Noise Ratio	28 dB

Systems in MOEB class are used for telemetering from a ballon; from a booster or rocket, excluding a booster or rocket in orbit about the Earth or in deep space; or from an aircraft, excluding a station used in the flight testing of aircraft. The systems in this class are located at specific military test ranges. The tests conducted by such systems can be scheduled and persist for a relatively short time.

Fixed Point-to-Point Communication

Typical characteristics identified here are representative of the U.S. systems and the band usage in the United States. The analysis data for the determination of pfd limits which are applicable to equipment in the Fixed Service is given in Table 4.

TABLE 4
SOME TECHNICAL CHARACTERISTICS OF REPRESENTATIVE
RECEIVERS IN FIXED SERVICE (2200-2300 MHz)

DESCRIPTION	U.S. DATA	CCIR DATA
Receiver Noise Temperature (K)	1200	750
Number of Stations in a Trendline	40	50
Maximum Antenna Gain (dBi)	36	42
Receiver Interference Threshold (dBrnco)	14	14
Feeder Loss (dB)	3	3
Branching Loss (dB)	0	0
Antenna Pattern	CCIR Rpt. 614-2	Rpt. 614-2
Receiver Signal Modulation	FDM/FM	FDM/FM

The rationale for the selected values given in Table 4 will now be discussed. The future needs for the systems in the Fixed Service were a factor in the selection of the typical antenna gain and the receiver noise temperature for these systems. In the pfd analysis given in CCIR Reports Nos. 387-1 and 387-3 receiver noise temperatures were 750 and 1750 Kelvin depending upon the type of receiver and the operating frequency for which it was designed. The analysis in CCIR Report 387-3 assumed the receiver noise temperature to be 750 Kelvins for a high sensitive type receiver operating at 2500 MHz. The noise temperatures for the system discussed in Part 1 varied from 440 to 2000 Kelvins. Data received from the manufacturers indicated that for the majority of the equipment the noise temperature is in the range of 880 to 2000 Kelvins. Hence, 1200 Kelvins for the noise temperature of a typical receiver in the 2200-2300 MHz frequency range is representative for the systems in this frequency range.

The receiver interference threshold level equal to 14 dBrnco corresponds to 25 pw thermal noise (psophometrically weighted) which has been used in CCIR Report No. 387-1. The separation distance of 30 km between stations in a trendline and 40 stations in a trendline for the operational system were typical for this frequency range. The assumption of 40 hops in a trendline is conservative. In the 2025-2110 MHz frequency range which the Space Research, Space Operation, and Earth Exploration satellites may operate, the usage of the frequency range is limited to television pickup and television intercity relay operations. The trendlines for such operations generally consist of a few hops (well below 40). Discussions with U.S. manufacturers indicate that estimated number of hops in the frequency range of interest will not be greater than 40. Three dB feeder loss listed above includes the loss for 40 meters of rigid waveguide and 0.5 dB connector loss. Branching loss was assumed to be equal to zero and space diversity was not considered in the analysis.

SYSTEMS IN SPACE SERVICES

There are three space services which have allocations in parts of the 2025-2300 MHz frequency range. These services are: Space Research, Space

Operations, and Earth Exploration Satellite. It will not be accurate to define typical characteristics based on the typical parameters associated with these services. Despite definitions and attempts by the CCIR to characterize these services, it is very difficult to relate the functions of satellites to these services. Hence, it is more meaningful to consider the characteristics of the operational satellites regardless of the services in which they operate. Typical characteristics for the satellites were derived using the information given in Table 5. Table 5 describes the appropriate parameters for U.S. satellites and Table 6 lists the parameters for non-U.S. satellites. Note that there are 42 satellites in Table 5 as compared to 23 satellites in Table 6. The characteristics of the U.S. satellites given in Table 5 were used in the preparation of the typical parameters for space services employed in the analysis given here.

The proliferation of U.S. satellites in the 2025-2300 MHz frequency range is related to the unique requirements of the Manned Space Program and the development of a space communication system in the 2 GHz band. The signal structure of spacecraft in the 2025-2300 MHz frequency range is complex and diversified. A careful study is necessary to determine the effective bandwidth for the emissions from these satellites. The term "effective bandwidth" is intended only for the analysis given here and it implies the bandwidth where the energy concentration is highest. For all practical purposes, in systems with smooth spectrum density, bandwidth at 3-15 dB is all that is necessary for the determination of the pfd limits. When spectrum density looks like a series of disconnected peaks it is difficult to define an effective bandwidth for that spectrum. In estimating an effective bandwidth for a satellite transmitter, it is important not to include in this bandwidth portions of spectrum between high peaks where negligible amount of energy exists as compared to the energy under the peaks. An appreciation of effective bandwidth is important for the analysis given in Section 5.

In a strict sense, signal structure and spectrum density of any satellite system is one of a kind. Yet for a tractable analysis it is desirable to categorize the spectrum densities of satellites in 2025-2300 MHz frequency range. The analysis results, as shown later, are not sensitive to the detailed signal structure of satellites. The envelope of a signal spectrum density, to a greater extent, and the positions of nulls around the main peaks of the spectrum, to a lesser extent, are all that is necessary for the analysis given here.

A rather coarse categorization of satellite spectrum density may be achieved by considering two types of spectrum used by satellites. These two types of spectrum are those used by TDRSS and Landsat-4. The power density spectrum for satellites in this frequency range generally is similar to these two types. Sometimes a satellite may be capable of transmitting both types. Examination of these two types of signal structure and their respective power density spectrum are as follows:

Landsat-4 Type Power Spectrum Density

This type of spectrum was originally used in the design of Unified S-Band (USB) system (as designed for Apollo) used subcarriers and a PN signal. The PN signal for this system was later modified to distribute the power more evenly over a wider band for use in TDRSS design. The USB signal consisted of

TABLE 5

U.S. SATELLITES PLANNED OR OPERATIONAL IN 2025-2300 MHz FREQUENCY RANGE

ORBIT	SPACE SYSTEM	NATIONAL STATUS	IFRB STATUS	OPERATIONAL STATUS	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	SPECTRUM TYPE
HE	AMPTE	SR(3)	AP(Prep)	Planned	Elliptical	28.5	2271.	1
LO	COBE (TDRSS)			Planned	900 x 900	99	2287.5	3
HE	DE-A	SR(3)	AP	Active	Elliptical	89.7	2214.	1
LO	ERBS(TDRSS)	SR(Prep)	AP(Prep	Planned	610 x 610	46	2287.5	3
LO	EUVE(TDRSS)			Planned	550 x 550	28.5	2287.5	3
DS	Galileo	SR(3)	AP(Prep)	Planned	Deep Space		2295,2296.4815	1
G	GOES-3			Active	Synch	0.0	2031.1, 2034.2	1
G	GOES-4 (D)			Active	Synch	0.0	2034.9, 2209.086	1
G	GOES E,F			Planned	Synch	0.0	2214,2033	3
LO	GRO(TDRSS)	SR(3)	AP(Prep)	Planned	400 x 400	28.5	2287.5	1
LO	IRAS	SR(3)	AP(Prep)	Planned	900 x 900	99	2253	1
HE	ISEE-1 (A)	SR(3)	AP	Active	Elliptical	27.5		1
HALO	ISEE-3(C)	SR(3)		Active	Elliptical	24.3	2215.5, 2264.8	
RE	IUE		AP	Active	Elliptical	28.7	2249.8	1
LO	LANDSAT-D(TDRSS)	SR(3)	AP	Active	705 x 705	98.2	2287.5, 2265.5	3
LO	NIMBUS-7 (G)		AP(Prep)	Active	960 x 945	99	2211,2273.5	1
DS	OPEN			Planned				1
DS	PIONEER 6-11		REG	Active	Deep Space		2294.26, 2293.89	3
LO	SME(TDRSS)	SR	AP	Planned	530 x 530	97.5	2287.5	3
LO	SMM(TDRSS)	SR(3)	AP REG(Prep)	Active	574 x 574	33	2287.5	3
LO	ST	SR	AP	Planned			2255.5, 2287.5	3
LO	STS(TDRSS)	SR(2)	AP(Prep)	Planned	Variable		2217.5,2250,2287.5	3
G	TDRSS-E,W,C	SR(3)	AP,REG(Prep)	Planned	Synch		2211,2106.4	3
LO	UARS-A+B			Planned	600 x 600	57		3
DS	Viking 1 Land	SR(4)	AP(REG)	Active	Deep Space		2293.15,2294.63	
DS	Voyager 1	SR(3)	REG	Active	Deepspace		2295, 2296.48	
DS	Voyager 2	SR(3)	REG	Active	Deepspace		2113.31, 2295	
G	GSP/NAVSTAR	SR(4)	AP REG	Active	Synch	0.0	2227.5	1
G	IRV	SR(2)		UNKNOWN	Synch	0.0		1
G	LES 8	GMF		Active	Synch	0.0		1
LO	P78-1	SR(4)	AP COORD*REG*	Active	593 x 593	97.7	2247.5, 2252.5	1
LO	P78-2	SR(4)	AP COORD REG	Active	43 x 28	8.3	2222.5	1
LO	P80-1	SR(3)	AP COORD	Planned 11/82	740 x 740	72.5	2212.5-2207.5	1
	SAMS026-70			UNKNOWN				1
G	DSCS II IND OCN			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II ATL			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II EPAC			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II WPAC			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS III INDOCN	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCSIII ATL/MID	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCS III EPAC	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCSIII WPAC	SR(4)		Planned	Synch.	0.0	2257.5, 2277.5	1
G	FLTSATCOM INDOCN			Active	Synch	0.0		
G	FLTSATCOM ATL			Active	Synch	0.0		
G	FLTSATCOM EPAC			Active	Synch	0.0		
G	FLTSATCOM WPAC			Active	Synch	0.0		
G	FLTSATCOM INDOCN	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM ATL	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM EPAC	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM WPAC	SR(4)		Planned	Synch	0.0		
LO	BLOCK-5D(DMSP)	SR(4)	AP	Active	752 x 724	98	2207.5, 2252.5 2237.5, 2267.5	1

Notes for Table 5 are given on the next page.

NOTE 1: The abbreviations used in this table are as follows:

SR( )	=	System review (stage of review)
GMF	=	Frequency Assignment in GMF
AP	=	Advanced Publication
COORD	=	Frequency assignments coordinated with other administrations
REG	=	Frequency assignments in the Master Register of IFRB
(Prep)	=	Documents in question prepared but not submitted or action not completed.
*	=	Only some of the necessary actions with the IFRB have bee completed.
LO	=	Low Orbiting
HE	=	Highly Elliptical
G	=	Geostationary
DS	=	Deep Space

NOTE 2: TDRS and Landsat represent two types of spectrum used in this frequency range. Type 1 in Table 5 represent a spectrum similar to that used by Landsat Satellite and Type 3 represents a satellite transmitter that is capable of producing Landsat and TDRS types signals.

NOTE 3: Frequencies shown in Table 5 are satellite transmit and receive frequencies. All the frequencies in the 2025-2120 MHz frequency range are satellite receive frequencies with the exception of those for TDRS which may transmit on any frequency in the 2025 to 2120 MHz frequency range.

TABLE 6

SOME OF THE NON-U.S. SATELLITES IN 2025-2300 MHz FREQUENCY RANGE

ORBIT	SPACE SYSTEM	COUNTRY	IFRB STATUS	DATE OF USE	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	
							UPLINK	DOWNLINK
HE	EXOS	FRANCE	AP	Dec, 1981		72	2260.8	
G	L-SAT	FRANCE	AP	1985			2201	
LO	SPOT	FRANCE	AP	June, 1984	822 x 822	98.7	2205.93	
LO	SPOT-2	FRANCE	AP	June, 1985	829 x 813	98.7	2206.53	
G	TDF-1	FRANCE	AP	1984			2204.73	
G	TELECOMM 1C	FRANCE	AP				2203.5-2208.5	
HE	IC2	FRANCE	AP	1977			Unknown	
LO	[illegible]S	FRANCE		Planned	700 x 900	Polar	Unknown	
G	TV-SAT	GERMANY	AP	1984			2200.24	
LO	ASTRO-A	JAPAN	AP	1981	640 x 480	31	2280.5	
LO	ASTRO-B	JAPAN	AP	1983	650 x 550	31	2280.5	
G	BS-2	JAPAN	COORD	Feb, 1984			2276.99,2280.7	
G	CSE	JAPAN	AP	Feb, 1977			2110-2120	2200-2290
G	CS-2A	JAPAN	COORD	Feb, 1983			2286.5	
G	CS-2B	JAPAN	COORD	Nov, 1983			2286.5	
HE(1)	ETS-IV	JAPAN	AP	1981			2208.706	
G	TELE-X	SWEDEN	AP	1986			2027-2035	2202-2210
G(2)	PROGNOZ 1	USSR	COORD	1982				
G(2)	PROGNOZ 2	USSR	COORD	1982				
G(2)	PROGNOZ 3	USSR	COORD	1982				
G(2)	PROGNOZ 4	USSR	COORD	1982				
HE	VIKING	SWEDEN	AP	2nd half 1984	822 x 15,000	98.7	2033.35	2208.1629
G	MSAT	CANADA	AP	1987			2090.15	2269.85
G	DFS-1	FRG	AP	1987			2028	2202.35
G	DFS-2	FRG	AP	1988			2028	2202.35
HE	AMPTE-UKS	BRITIAN	AP	Aug, 1984	547 x 112,891	28.5	2093.75	2273.76
HE	AMPTE-IRM	FRG	AP	Aug, 1984	500 x 121,000	85	2103.6	2284.5
G	APEX	FRANCE	AP	1986			2029-2033.6	2203.5-2208.5
G	F-SAT 1	FRANCE	AP	1987			2025-2110	2200-2290
G	F-SAT 2	FRANCE	AP	1986			2025-2110	2200-2290
(3)	GIOTTO	FRANCE	AP	July, 1985			2116.723	2298.704
G	HIPPARCOS	FRANCE	AP	1988			2063.59	2241.00
(4)	ISPM	FRANCE	AP	May, 1986			2111.607	2293.148
G	VIDEOSAT-1	FRANCE	AP	1987			2025-2110	2200-2290
G	VIDEOSAT-2	FRANCE	AP	1987			2025-2110	2200-2290
LO	EXOS-C	JAPAN	COORD	Feb, 1984	320 x 1,000	73	2108.557	2280.5
G	GMS-3	JAPAN	AP	Aug, 1984			2025-2110	2200-2290
(5)	MS-T5	JAPAN	AP	Jan, 1985			2111.607	2293.148
(3)	PLANET-A	JAPAN	AP	Aug, 1985			2112.289	2293.8889
G	HELVESAT-I	SWITZERLAND	AP	1986			2025-2110	NONE
G	UNISAT I	BRITIAN	AP	1986			2025-2110	2200-2290

1 - Earth-so-Space -- 2116.6 MHz. Space-to-Earth -- 1705. MHz
2 - All PROGNOZ Type satellite Operation on These Bands: 2131, 2151, 2191, 2211, 2231, 2251 MHz, (all ± 10 MHz) 2277, 2289 MHz (both ± 6 MHz).
3 - Will observe Halley's Comet.
4 - Earth-to-Jupiter mission
5 - Interplanetary mission

a carrier and standard subcarriers which were 1.024 MHz and 1.25 MHz (used for telemetry and voice) away from carrier frequency. This, of course, resulted in energy concentrations in certain segments of the spectrum, depending upon the number of subcarriers used. The USB as used today (May, 1983) operates in very much the same way as it did for Apollo.

Landsat-4 has a power spectrum density similar to that used by USB. A variety of Landsat-4 type signals have been used by satellites other than TDRSS. A detailed description of Landsat-4 type spectrum given below is of interest.

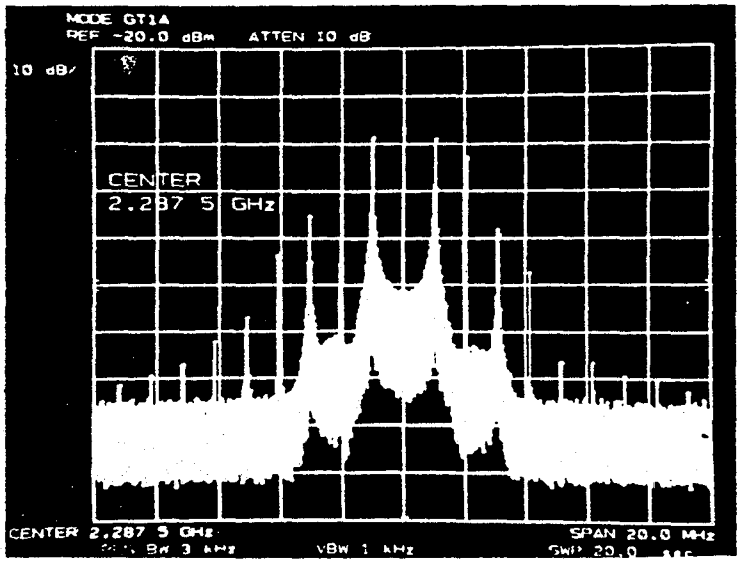
Landsat-4 has an S-band transponder that is capable of working in either the TDRSS or USB (Unified S-band) mode. In the USB mode, it is capable of operating in four different "sub-modes" as follows:

Mode	Modulation	Data Rate (Bio-S)	Mod Index
1 (GT1A)	PCM/PSK/PM	8 kpbs	1.6 rad
2 (GT2A)	PCM/PSK	8 kbps	0.8 rad
	PCM/PM	32 kbps	1 rad
3 (GT3A)	PCM/PSK	8 kbps	0.8 rad
	PCM/PM	256 kbps	1 rad
4 (GT4A)	PCM/PSK	8 kbps	0.8 rad
	Tone PM		0.39 rad

These modes all use the basic 5 watt transmitter and subcarriers are detuned by 1.024 MHz from the carrier. Note that the relatively low modulation indices imply most of the energy is in the close-in sidebands. These modes will now be examined in greater detail.

The first mode, GT1A, is a mode with an 8 kbps, bi-phase signal modulated (PSK) on the 1.024 MHz subcarrier which is in turn phase modulated on the carrier (2287.5 MHz). The carrier level is down about 6.9 dB from total power (5 watts or 7 dBW) or about 1 watt. Note that the peaks in Figure 3 are well separated and that their amplitudes decrease rapidly.

Now consider the GT2A mode in Figure 4. The power level of the carrier is about the same because of a change in the modulation index (see tabulation above). The oscillogram in Figure 4 shows the effect of modulating a 32 kbps bi-phase random wave on the carrier. Significant energy is located at plus or minus 32 kHz from the carrier, about 8 dB below the carrier (160 mw). There is a null at 64 kHz from the carrier but, again, significant energy at about 100 kHz (3 x 32 kHz). This is about -15 dB below the carrier (30 mw). Clearly, except for the carrier, the energy is "bunched" every 64 kHz. An expansion of Figure 4 is shown in Figure 5 which shows a 2 MHz portion of the same spectrum. Note that the 1.024 MHz carrier is down about 8 dB from total carrier power (-8 dBW or about 160 mw). This is lower than that for mode GT1A because of the lower modulation index (1 radian vs 1.6 radian). Modes GT3A and GT4A are similar to mode GT2A.



LANDSAT-4

H 2 MHz/div

V 10 dB/div

BW 3 KHz

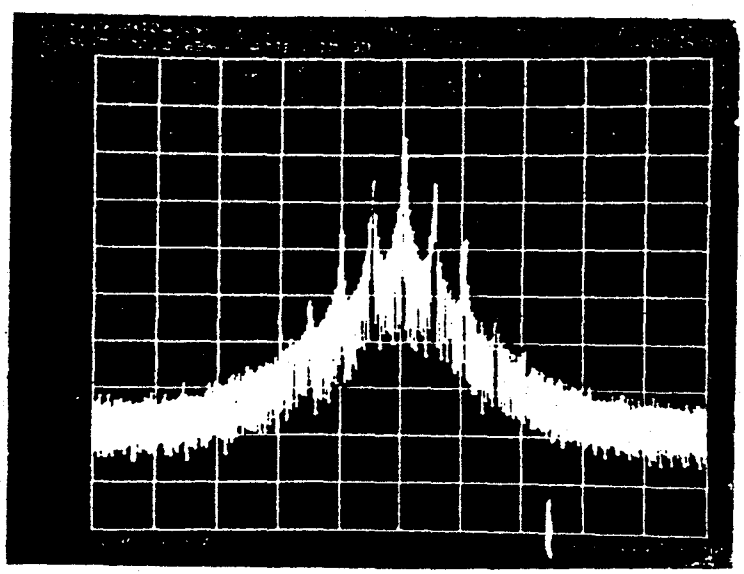
SWP 20 sec

CF 2287.5 MHz

Photo 1

Mode GT1A

Figure 3 Mode GT1A emission from LANDSAT-D



LANDSAT-4

H 2 MHz/div

V 10 dB/div

BW 10 kHz

SWP 6.0 sec

CF 2287.5 MHz

Photo 2

Mode GT2A

Figure 4 Mode GT2A emission from LANDSAT-D.

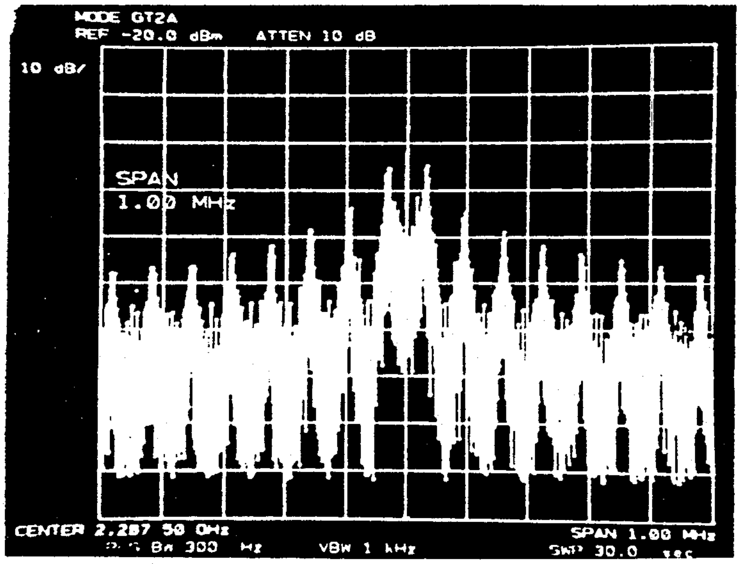
Landsat-4 has a second S-band transmitter (transmit frequency 2265.5 MHz) which is used to transmit wideband data at a power level of 10 watts (total transmit power). This signal is PCM/FM on the carrier at 15 Mbps. Examination of the power spectrum for this operation shows that the energy is distributed with some degree of uniformity (within 10 dB) over a bandwidth in excess of 15 MHz. It is reasonable to assume that most of the power (10 W) is in this bandwidth.

TDRSS Type Power Spectrum Density

An oscillogram of emission spectrum for Landsat-4 operating in the TDRSS mode is shown in Figure 6. The signal structure in Figure 6 is typical of both the TDRS forward link transmit signal (to the user) and the return link signal transmitted by the user to the TDRS. TDRS is a product of the latest technology developed by NASA. Briefly, TDRS, as envisioned by NASA, is a consolidated system which provides at once communication requirements for the near-earth unmanned systems (previously performed at VHF frequencies) and for the USB system which operated at S-band. The USB was used for Apollo and other manned spacecraft. Hence, TDRS is a satellite network which provides communication functions for both manned and unmanned space programs. Oscillogram of the emission spectrum for TDRS is shown in Figure 6. The data in Figure 6 shows a direct sequence spread spectrum signal in which the spreading chip rate is about 8 megabits per second. Note that power density spectrum shown in Figure 6 is of the $(\sin x/x)^2$, with nulls above and below the center frequency and with a null-to-null bandwidth of about 6 MHz. It is estimated that about 80% of the power is in the region defined by $\pm$ 1.6 MHz. Considering the spectrum shown in Figure 6 a bandwidth of $\pm$ 1.6 MHz is close to 8 dB points on the spectrum and at 20 dB below the peak where the first nulls appear are at $\pm$ 3 MHz points.

As noted, the spectrum in Figure 6 is typical of the TDRSS associated spectrum for most spacecraft. The spreading signal, a PN code, can also be used for ranging and/or data transmission purposes. In the past the satellite technology used by NASA was such that the spectrum for every satellite was generally custom designed based on the mission of satellite. This mode of operation also required a number of earth stations which NASA had to maintain overseas. However, it should be pointed out that with the advent of TDRS, the future satellites should be designed in conformity with the spectrum presently designed for TDRS. Most of the Earth stations overseas are being phased out and data transmission and collections by the satellites will be carried out through TDRS systems. Landsat-4 has a transmitter with a spectrum compatible to TDRS that may be activated by remote control. The changeover should take place when TDRS is fully operational.

The discussion on TDRSS pertains to plans envisioned by NASA which is a major user of the spectrum in space services in the 2025-2300 MHz frequency range. Other U.S. agencies such as Department of Defense may continue to design satellites with a spectrum similar to those used by LANDSAT-4 or a variety of other types. However, for the purpose of pfd analysis it is more desirable to use a typical spectrum rather than a variety or even the worse case one.



LANDSAT- 4

H 100 kHz/div

V 10 dB/div

BW 300 Hz

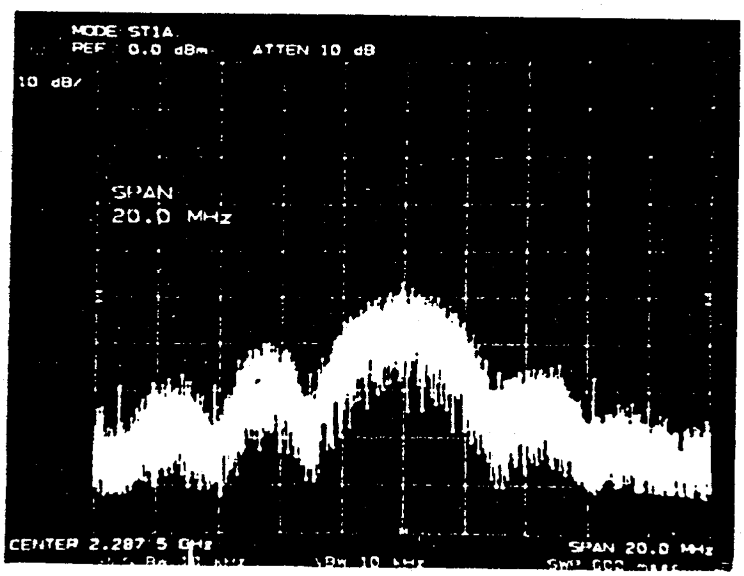
SWP 30.0 sec

CF 2287.5 MHz

Photo 3

Mode GT2A

Figure 5 Expanded data shown in Figure 4.



LANDSAT- 4

H 2 MHz/div

V 10 dB/div

BW 10 kHz

SWP 600 msec

CF 2287.5 MHz

Photo 45

Mode ST1A

Figure 6 Emission spectrum of TDRSS down path transmission $(\sin x/x)^2$.

A review of the available emission spectrums used often by the spacecraft in the 2025-2300 MHz frequency range indicate that the systems in the space services are relatively narrowband and that an effective bandwidth of 0.5 to 4 MHz is a reasonable range for the analysis. A bandwidth of 4 MHz accounts for nearly 90 percent of the power emitted from a wideband satellite in this frequency range. A bandwidth of 2 MHz was considered typical for emissions from spacecrafts in 2025-2300 MHz frequency range.

The types of power spectrum density described above are representative of the non-military spacecraft in the 2025-2300 MHz frequency range. However, military spacecraft such as those used in the Space Ground Link System (SGLS) generally have power density spectrums similar to that used by Landsat-4. SGLS has two carriers. Carrier 1 has 10 Mbps modulating code with modulation indices from 0.125 or 3 radians. Subcarriers for Carrier 1 are at 1.024 MHz and 1.7 MHz away from carrier. The modulating signal on the first subcarrier is 7.8 bps to 128 kbps and the modulating signal for the second subcarrier has a rate ranging from 125 bps to 512 kbps. Carrier 2 is PCM modulated with a 128 kbps to 1.024 Mbps signal. Note that the concept of carrier and subcarriers used in SGLA is not different from that used in Landsat-4. Frequency separation between carrier and subcarrier in addition to the rate of modulating signal varies among the satellites. These variations affect only position of peaks and nulls in the power spectrum density of a satellite. Such variations especially at sections of spectrum which are 10 dB or more below the peaks have little effect on the determination of pfd limits. Hence it was assumed that the two types of the spectrum density described above are sufficient for the analysis given here.

TYPICAL CHARACTERISTICS OF SATELLITES

The technical parameters used in the analysis of the satellites in low and geostationary orbits are as follows:

1. Geostationary orbit

   Separation between satellites (deg.)....................10-20

2. Non-Geostationary orbit

   Satellite orbit altitude (km)...........................300-1200
   Number of satellites visible to receivers...............8
   Satellite inclination angles (deg)......................10-99

The above data were extracted from the information obtained from the NASA, the GMF, and the system review files at NTIA. The input parameters for the computer models used in the analysis were extracted from the technical characteristics noted above.

A breakdown for the majority of the satellites in Table 5 is given below:

ORBIT	NUMBER OF SATELLITES	ACTIVE	PLANNED
Low Orbit	15	6	9
Geostationary	15	8	7
Deep Space	6	4	2
Highly Elliptical	4	3	1

The above data indicate that nearly 50 percent of the satellites in the frequency range 2025-2300 MHz are not yet active. The life expectancy of any of the active satellites in the frequency range is less than 10 years. The low orbit satellites in this frequency range operate at altitudes between 300 to 1200 km. The active low orbit satellites in the frequency range are launched in several orbits. In the computation, eight satellites were assumed to operate co-channel with radio-relays in a trendline and the satellites were distributed evenly in the orbits 300, 500, 800, and 1200 km. The inclination angles for approximately 50% of low orbit satellites range from 90 to 99 degrees. There are approximately eight U.S. satellites in the frequency range 2025-2300 MHz which may have inclination angles as low as 28 degrees. The majority of satellites in the frequency range 2025-2300 MHz use digital modulation each with the capability to operate with multiple modes.

SECTION 5

ANALYSIS

PROBLEM DEFINITION

Before we proceed with the analysis a problem definition is necessary. As was pointed out earlier the method of usage implemented by the systems in the 2025-2300 MHz frequency range is an important factor in the determination of pfd limits. Internationally, as was discussed earlier, all systems in the Fixed and Mobile Services operating in the 2025-2300 MHz frequency range are protected against interference from satellites in this frequency range. The data on the implementation of this frequency range by the ITU member administrations other than the United States are not readily available. A discussion was included in Section 3 of this report which treated the assignments in this frequency range in some countries in Region 2. A detailed treatment of the usage of this frequency range by all the member administrations is beyond the objectives of this analysis. A worse case analysis will result if an assumption is made that the usage by the systems in the Fixed and Mobile Services is similar to that in the communication bands near 4 or 6 GHz. Even with such a conservative assumption, one should not draw a hasty conclusion that the pfd limits for the desired frequency range (2025-2300 MHz) should therefore be identical to that used in the bands near 4 or 6 GHz. The reason for this will become clear after the pfd limits for the United States have been treated. Interactions between the Space and Terrestrial Services deduced from the information given in Figure 1 may be summarized as shown in Table 7.

For determination of pfd limits only space-to-space and space-to-Earth transmissions need to be considered. In addition, operational and technical characteristics of the systems used in implementing Auxiliary Broadcast Station are less restrictive than those for systems in the Fixed Service that resemble the Hypothetical Reference Circuit defined by the CCIR. The number of hops and the antenna gain for the systems in the Auxiliary Broadcast Station are less than those for the systems used for long-haul communication. As an example, consider an Auxiliary Broadcast Station consisting of a single hop. As was mentioned before, the system may have an antenna with 20 dBi gain. Since the possibility of main beam coupling between the receiver and satellite transmitter antennas is small, assume that the receiver has 10 dBi gain in the direction of a satellite transmitter. The 10 dBi gain corresponds to an effective aperture area of approximately -17 dB(m^2). Assuming -154 dBW/m^2/4 kHz interference level from satellite and an IF bandwidth of 20 MHz for the receiver, it is easy to show that the interference level in the receiver, is approximately 16 dB below the -88 dBm receiver noise threshold.

$$-154 + (-17.4) + 10 \log (20x10 /4000) + 30 = -104 \text{ dBm}$$
$$88-104 = -16 \text{ dB}$$

Hence, Auxiliary Broadcast systems were not considered to be relevant to the determination of pfd limits for the 2025-2300 MHz frequency range.

TABLE 7. GOVERNMENT AND NON-GOVERNMENT SERVICES IN 2025-2300 MHz FREQUENCY RANGE

FREQUENCY RANGE (MHz)	SPACE SERVICE	SPACE TRANSMISSION LINK	TERRESTRIAL SERVICE
2025-2110 (NG)	Space Research Earth Exploration Satellite (EES)	Space-to-Space Earth-to-Space	Auxiliary Broadcast
2110-2120 (NG)	Space Research (deep space)	Earth-to-Space	Domestic Public
2200-2290 (G)	Space Research, EES, Space Operation Satellite	Space-to-Earth Space-to-Space	Fixed and Mobile
2290-2300 (G) & (NG)	Space Research (deep space)	Space-to-Earth	Fixed and Mobile

NG: Denotes Non-Government
G: Denotes Government

Considering the information given in Table 7 and the characteristics of the systems in the terrestrial services, the worst case interaction may occur in the 2200-2300 MHz frequency range between systems in space and those in the Fixed and Mobile Services. Hence, the problem may be defined as the determination of pfd limits to protect the terrestrial systems in the Fixed and Mobile Services operating in the 2200-2300 MHz frequency range.

The CCIR Study Groups 8 and 9 have treated a number of sharing conditions related to systems in the Mobile and Fixed Services, respectively. Sharing conditions required for the protection of systems in the Fixed Service against the potential interference from systems in the Fixed-Satellite Service were analyzed by the CCIR study group 9. In the determination of the pfd limits by the CCIR, only the characteristics of the system in the Fixed Service were considered. Except for a related analysis given in CCIR Report 927, no parallel study has been conducted within the CCIR in order to assess appropriate pfd limits for systems in Mobile Service. The analysis given here treats the determination of pfd limits considering the technical characteristics of systems in the Fixed Service operating in the 2025-2300 MHz frequency range.

Except for some of the systems in the aeronautical telemetry class (ATC), operational and often technical characteristics of the systems in Mobile Service are less stringent than the characteristics of the system in the Fixed Service. Operational requirements may necessitate the antennas of a system in ATC to be pointed toward satellite transmitters in orbits. Thus, the impact of pfd limits during the mainbeam-to-mainbeam coupling between antennas of the satellite in orbit and the system in ATC is of interest.

Telemetry systems are used by the DOD, NASA, and DOE. These systems primarily provide real-time data from remotely piloted vehicles, drones, and missiles. Locations of these systems are somewhat diverse but the majority are on military test ranges in the Southwest U.S. and on the East Coast. The overall usage of each of these systems at any location is quite fluid. The interaction between aeronautical telemetry and spacecraft in the 2200-2300 MHz band has been recognized to be manageable (Flynn, 1980). A number of instruments for coordination between agencies involved in telemetry and space activities exist to provide the necessary aids for frequency management in locations where telemetry systems are used. The report by ECAC (White, 1977) documents the frequency management techniques that are presently used for coordination in the eastern and western test ranges. The following discussion indicates that the probability of potential interference from satellites to the ATC systems is rather small, however, the necessity for coordination as discussed below is essential in order to provide protection for these systems.

The probability of interference from satellites in low orbits was calculated and it was found to be varying approximately from $3x10^{-3}$ to from $3X10^{-5}$. This probability is a function of satellite inclination angle and the beamwidth of the antenna for the ATC receiver. In the calculation of the probability values given here, it was assumed that the antenna gain for the telemetry receiver was near 42 dB (beamwidth 1.6 degrees) and the inclination angles for non-geostationary satellites varied from 10-99 degrees. The telemetry antenna was assumed to scan from horizon (zero degree) to 90 degrees in vertical plane. Thus worst case conditions were assumed in the calculations. The point which must be made here is that the probability of potential interference is rather small. Other values for this probability may also be calculated depending on the geometry and assumptions used. The results given here represent the probability of mainbeam-to-mainbeam coupling. The threat to critical data collected by a telemetry receiver is even smaller, since other conditions such as timing, location, missile geometry, and fading all have to be considered in the computation of this threat. Small relaxation in the pfd limits such as that found by the analysis given here may not increase the probability of harmful interference beyond the range indicated above. The threat evaluation is beyond the scope of this report. The fact is that this probability remains to be small for the narrow beamwidth antennas used in long range telemetry. For wider beamwidth the probability increases, but wider beamwidths are used in systems with shorter tracking in which high gain antennas are not needed. Regardless of the magnitude of the probability of interference, there is a need for coordination in order to protect data collected by a telemetry receiver.

The interaction between telemetry receivers and satellites in geostationary orbit can be mitigated through proper orientation of antennas and frequency separations. These functions should be worked out by the agencies involved through the coordination activities noted above.

Based on the above discussion, systems in the Mobile Service often have less stringent characteristics than the systems in the Fixed Services. In case of aeronautical telemetry coordination may be used to mitigate potential interference from satellites to telemetry receivers.

GENERAL DISCUSSIONS

A literature search and analysis described in Part 1 of this report (Farrar, 1983) indicated that the two analytical models referred to as GM and NGM had to be modified in order to determine the pfd limits in the 2025-2300 MHz frequency range. These modifications were found necessary, since the technical and operational characteristics of the equipment in this frequency range were not consistent with the original assumptions used in the development of the models. The following topics treated in this section include the modifications of the computer models which were proposed in Part 1 of this report.

a. Frequency engineering of radio-relay systems
b. Fading and diversity considerations
c. Multiple orbit effects
d. Systems using tropospheric transmission
e. Protection of digital radio-relay receivers
f. Transfer function for a radio-relay receiver

In addition, this section includes the determination of pfd limits for geostationary and non-geostationary satellites. The pfd limits derived here include the effects of the modifications in the computer models and are applicable to the United States. A discussion is included which may be useful in the preparation of proposed pfd limits for adoption internationally. The analysis results given here show the effects of different variables involved in the computation of pfd limits for the desired frequency range. The proposed limits are based on the most probable scenario considered to be representative for the frequency range analyzed here.

FREQUENCY ENGINEERING OF RADIO-RELAY SYSTEMS

A microwave communication circuit is defined by a trendline which generally consists of a number of repeater stations (radio-relays). In spite of the highly directive antennas now available in the commercial market and even used in some of the trendlines, a certain fraction of transmitter power from many stations may radiate in directions other than that for which it was intended. This undesired radiation is even worse when the directivity of the antennas used in a trendline is reduced. The cost considerations often make it necessary for less directive antennas to be used in the design of a system in the 2025-2300 MHz frequency range. The undesired radiation from any one station in a trendline is a potential source of interference to the other stations in the same trendline that operate on the same frequency. Depending upon the coupling mechanisms used in the reception of the undesired radiation, such interferences are called over reach, adjacent section, and same section interference. Figure 7 illustrates the various types of interference that may exist in a typical trendline. Note that at every repeater site transmitter and receiver frequencies are separated by f_{Δ} (Δf is often larger than 40 MHz). Frequency engineering techniques are generally used in conjunction with the selection of an appropriate antenna in order to mitigate harmful results of these types of interference.

In the 2025-2300 MHz frequency range the frequency plans for a trendline are rather limited. Nationally, only 100 MHz bandwidth (2200-2300 MHz) is available to the Government systems in the Fixed and Mobile Service. This relatively limited bandwidth discourages the deployment of multiple radio frequency channel communication systems. Despite the limited available spectrum however, in this frequency range the present systems on the market can handle as many as six radio channels with 192 baseband channel capacity. As the number of radio frequency channels in a system grows, the number of frequency reuse decreases. For example, in a trendline which is designed with a two-frequency plan, generally half of the stations in the trendline operate on one frequency and the other half operate on the other frequency. When a four-frequency plan is used in a trendline, only one quarter of the stations in the trendline remain co-channel.

The selection of a frequency plan in the design of a microwave trendline is a result of a trade-off among various factors such as: economy, quality of performance, and desired interference levels. Above all, the impact of the potential interference from satellites to the stations in a trendline is a function of the frequency plan used in the design of the trendline. The use of a single frequency in the design of a multihop trendline is not practical. For an acceptable performance, highly directive antennas are needed in a trendline which is designed to operate with a two-frequency plan. Four- and six-frequency plans are in common use in the 2025-2300 MHz frequency range by both Government and non-Government users.

In Part 1 of this report, it was pointed out that in the calculations of the existing pfd limits for space services, one of the assumptions was that all the stations in the trendline remain co-channel with all the satellites in the orbit visible to the trendline. This assumption is not appropriate for calculations of the pfd in the 2025-2300 MHz frequency range. The emission bandwidths for satellites in the space services are less than the frequency separations used in the radio-frequency channels planned in a trendline. As a

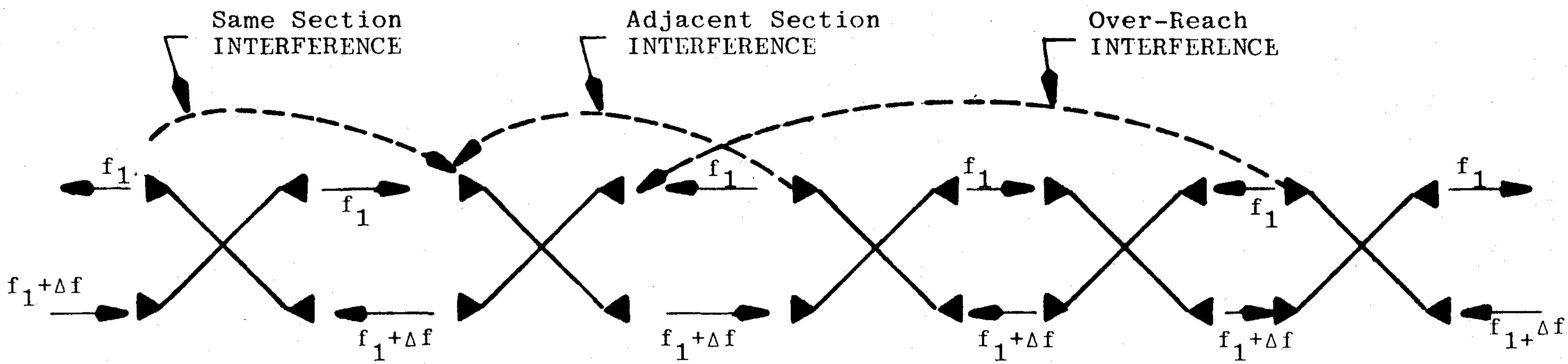


FIGURE 7. Types of Interference in a Microwave Radio-relay Communication System

result, these satellites may operate co-channel only with one of the radio-frequency channels used in a trendline. Therefore, as far as the potential interference is concerned, a worst case combination occurs when a two-frequency plan is used in the design of a microwave trendline. However, this is a combination which occurs only rarely.

In this analysis, the pfd limits were calculated considering the effects of frequency plans used by radio users. In a two-frequency plan, every other receiver in a trendline is tuned to the same frequency. Similarly, receivers tuned to the same frequency in a trendline designed with a four-frequency plan, are separated by three hops. In order to consider the effect of such frequency plans, the simulation models (GM and NGM) were modified to sum the calculated interferences to only half of the receivers in a two-frequency plan. An extension of this algorithm was used for calculation of interference to a trendline using a four-frequency plan.

To demonstrate the significance of the frequency plan of a trendline in the computation of pfd limits, the GM computer program was used to calculate the change in the pfd as a function of the type of frequency plan used in a trendline. The results of such calculations are shown in Table 8.

The entries in Table 8 were calculated using the computer input parameters described in Section 4 of this report. These parameters were representative for the systems in the Fixed and space services operating in the 2025-2300 MHz frequency range. Interpretation of the data in Table 8 is as follows. To determine a pfd limit from the information given in Table 8, one should add -154 to the data given in the table. For example, for a four-frequency plan if the trendline starts at 50 degrees latitude the pfd limit will be $-154 + 6.5 = -147$ dB(W/m^2). Note that as the number of frequency reuse in a trendline decreases the calculated pfd limit for that trendline increases, that is, the pfd limits are less stringent. The reason for this is that the number of frequencies used in the trendline increases and hence, there is less likelihood of co-channel operation with satellites in the orbit visible to the radio-relays in the trendline.

In the non-Government part of the frequency range (2025-2110 MHz), the Auxiliary Broadcast systems must be protected against potential interference from satellites. And in the Government part of the band (2200-2300 MHz) the system in the Fixed and Mobile need to be protected. The representative parameters used in the above calculation are for the systems used in the Fixed Service and are quite conservative as far as the protection of the Auxiliary Broadcast systems are concerned. As was mentioned before, the systems in this service generally consist of a few hops and are different from the definition of the Hypothetical Reference Circuit given by the CCIR for long-haul communication systems which may exist in the Fixed Service. Considering the usage of the band in the United States and the fact that the four-frequency plan is the most popular among systems in the Fixed Service, data in Table 8 shows that a change in the pfd limits approximating 6 to 14 dB is possible in the 2025-2300 MHz frequency range.

TABLE 8. CHANGE IN pfd LIMITS DUE TO FREQUENCY PLANNING OF MICROWAVE RADIO-RELAY TRENDLINE (2025-2300 MHz)

LATITUDE (deg.)	CHANGE IN DB		
	1[a]	2[b]	4[c]
20	4.6	9.6	14.0
30	3.9	9.2	13.2
40	3.8	7.0	8.2
50	2.6	3.9	6.5

a, b, and c Represent one, two, and four- frequency plan respectively.

FADING AND DIVERSITY CONSIDERATIONS

General

Communication trendlines considered in this analysis consist of links (paths, hops) that are approximately 30 to 40 km long. Transmission on most hops is line-of-sight, with antennas mounted on towers that vary in height from 30 to 80 meters depending upon the terrain over which the microwave energy is transmitted. On rare occasions, when line-of-sight transmission between successive towers is not practical, passive repeaters are used. Tower sites are selected to avoid ground reflections and scattering. Despite such care in site selection, multipath effects, especially for long-haul communication, are not avoidable.

Multipath transmission during certain atmospheric conditions produce destructive interferences at receiving antennas in a trendline. The phenomenon referred to as "fading" causes a desired signal to fluctuate and a system for several seconds. Since the protection of this signal against interference from satellites is of interest, fading effects need to be considered in the calculation of pfd limits. But prior to this calculation a careful look at the design margin of a radio-relay trendline is necessary in order to gain more detailed insight into the impact of interference noise from satellites on systems in the Fixed Service.

Design Margin

Space diversity is often used in the design of microwave transmission in order to mitigate or even eliminate the effects of fading. Vertically separated antennas on a single tower provide an economical space-diversity which can protect the desired signal during fade. Use of space-diversity is increasing. One reason for this (apart from spectrum conservation) is that, in areas where deep fading is common place, frequency diversity alone can not provide the needed protection for the desired signal. Federal Communication Commission's Rules and Regulations prohibit the use of frequency diversity in the 2025-2200 MHz frequency range. This is consistent with spectrum conservation policy pursued in the United States. Of importance to the analysis given in this report are the number and duration of fades in this frequency range. These parameters are well known and the empirical relationships developed by Barnett (1972) may be used to calculate the "time below level" in a heavy fading month for transmission at 2 GHz frequency. The sum of the duration of all fades of a particular depth is called "time below level" and it is represented here by T. T is proportional to fade depth L and fade occurrence factor r:

$$T = rT_oL^2 \qquad \text{for} \qquad L < .1 \qquad (1)$$

where;

T_o = time period over which the summation of fade duration is made (a month, for example)

r = fade occurrence factor for heavy fading month and is given by the expression

$$r = c\,(f/4)D^3\ 10^{-5}$$

where;

$$c = \begin{cases} 4 & \text{over water and Gulf coast} \\ 1 & \text{average terrain and climate} \\ \frac{1}{4} & \text{mountains and dry climate} \end{cases}$$

f = frequency in GHz

D = path length in miles

L = ratio of faded to unfaded signal

Equation (1) was used to determine the time below level in a heavy fading month for transmission at 2 GHz. The results of the calculations are shown in Figure 8. Curve A in Figure 8 indicates that the time-below-level corresponding to a −20 dB fade margin is 2000 seconds (less than one hour) and for a −40 dB fade margin is 20 seconds for a heavy fading month. Depending on system requirements and the probability of occurrence of these fades, data such as those shown in Figure 8 may be used to determine if space-diversity should be used in the system design. The design margin for a typical microwave hop is illustrated by the following example given below.

The use of space diversity in the design of microwave systems helps the systems tolerate the potential interference from satellites. Let us consider an example by following the design criteria used by the Bell Systems. (Vigants, 1974). For long-haul microwave communication system (250 miles or more) the objective for time-below-level is approximately .02 (two-way) percent in any year. Half of this is allocated for equipment failure. Hence, the allocation to fading is .01 percent (two-way) annually. Fading due to obstruction is not very serious because of the design trend toward increased clearances in the installation of antenna towers. Consequently, no allocation to obstruction fading is made. The entire .01 percent two-way annual fading allocation is then applied to multipath fading only. Based on this objective one way fading allocation will be .005 percent in a year or approximatley 1600 seconds per year. The corresponding allocation to a hop 40 km long will be 1600 x 40/(250 x 1.6) seconds per year (160 seconds per year for an average 40 km hop in the 2025-2300 MHz frequency range).

Using a geographic average the value of time-below-level for annual fade may be obtained by multiplying the time shown by curve A in Figure 8 by a factor of 3. In other words, in space diversity engineering, the values of time-below-level for a year is equivalent to three times the value for a heavy fading month. The annual time-below-level obtained in this manner is shown by Curve B in Figure 8. For a terrestrial system in the Fixed Service in the 2025-2300 MHz frequency range, the value of signal-to-noise ratio is 66 dB on the average under no fade conditions. Assuming 55 dBrnco to be the intolerable level of noise in a system (this level is in common use by the Bell system), we obtain a corresponding S/N = 33 dB (GTE Lenkurt, 1970). This allows 33 dB fade margin. Data in Figure 8 indicate that 33 dB fade margin corresponds to 300 seconds a year. Since the time-below-level should not exceed 160 seconds, space-diversity must be used to reduce the calculated 300 seconds a year. With the application of space-diversity it is possible to achieve 20 dB improvement (Vigants, 1974). Curve A in Figure 9 shows estimated signal-to-noise ratio for such a system employing space-diversity. The recommendations for noise power in a Hypothetical Reference Circuit given in

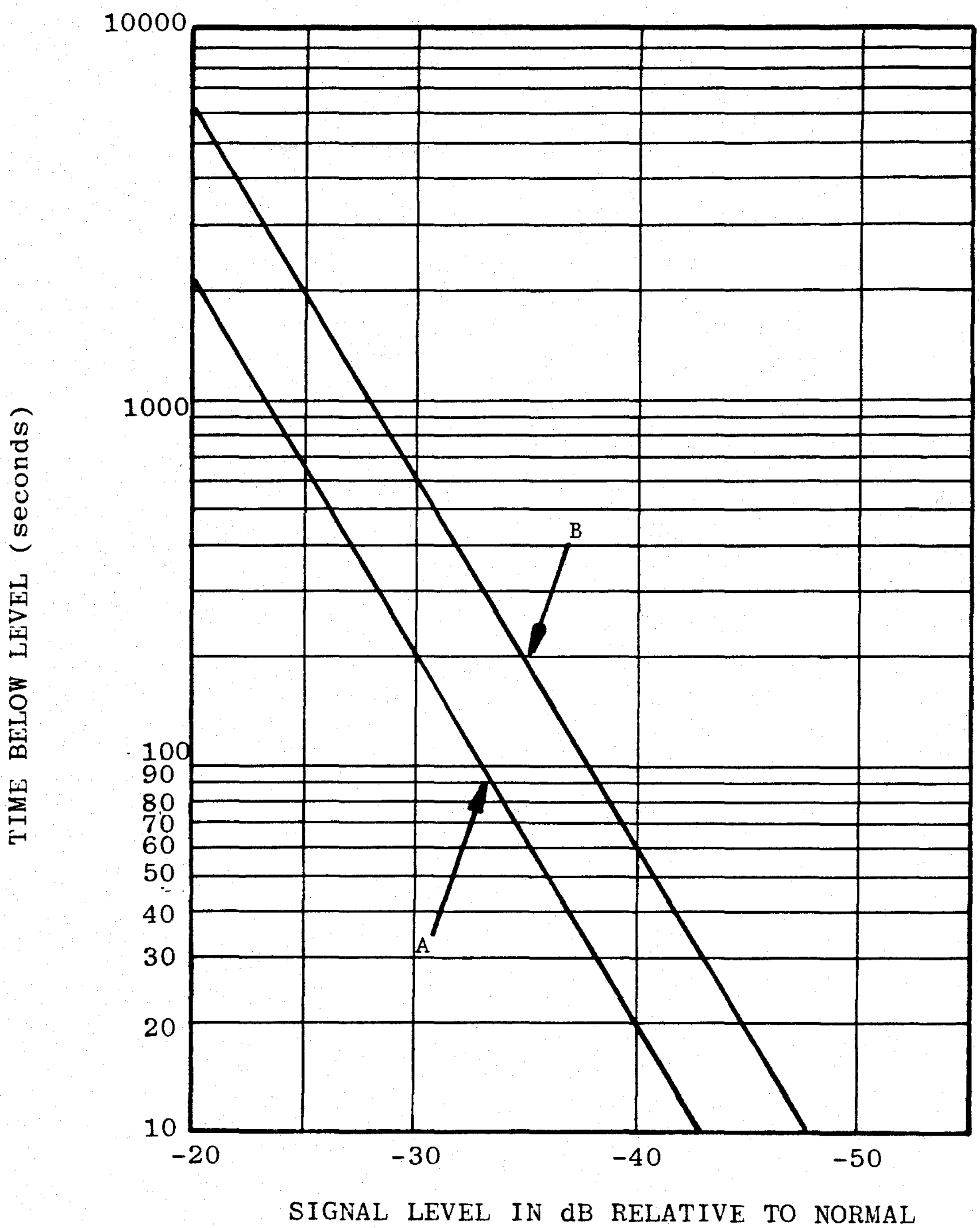


Figure 8 Time Below Level: A) Heavy Fading Month, B) Annual Fading (D=40 km, C=1, T_o=31 days= 2.68×10^6 seconds).

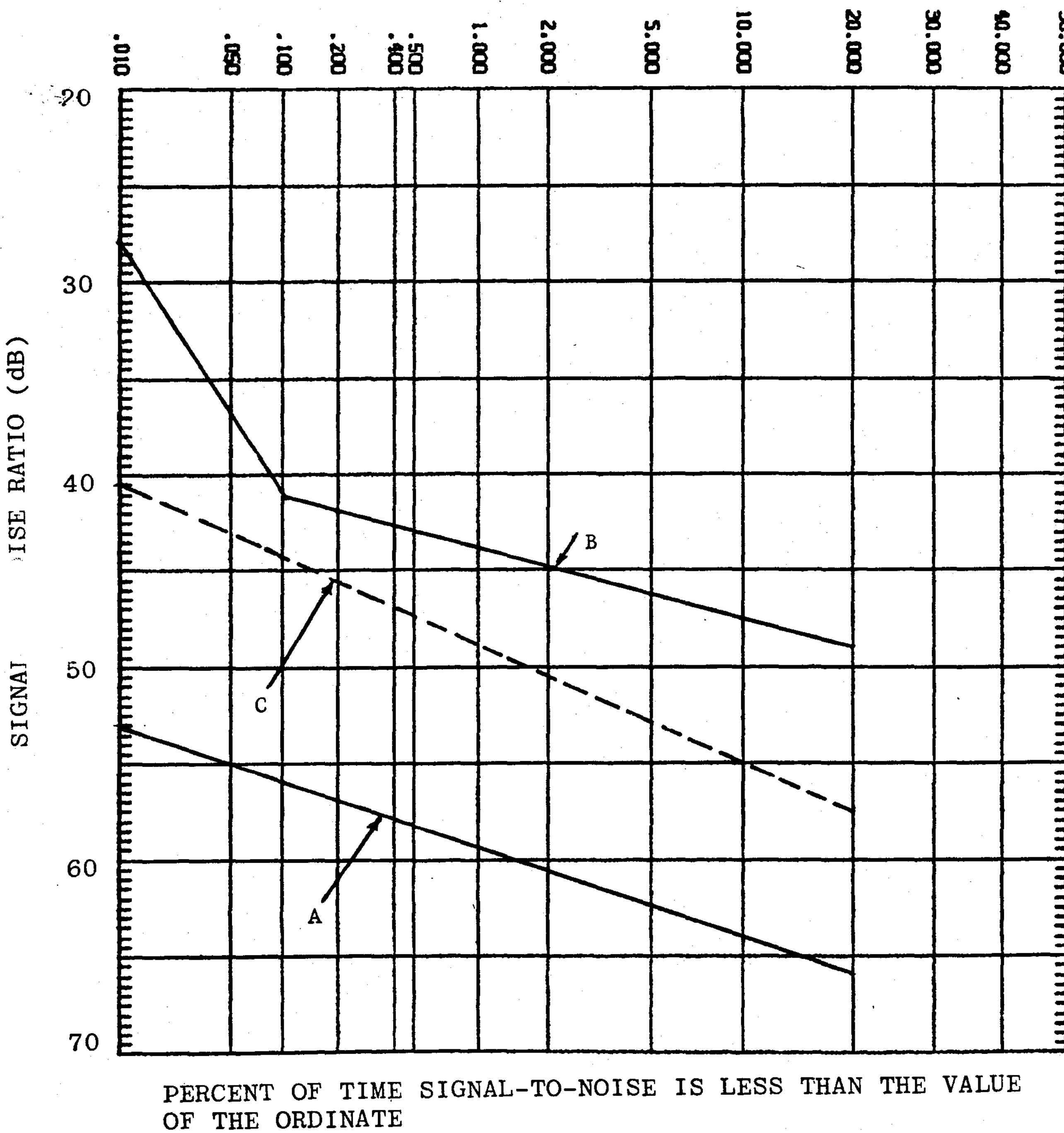


FIGURE 9 SIGNAL-TO-NOISE RATIO - For a 250 Mile (400 km) Microwave Multihop System Fixed Service Using the Fading Data for 2025-2300 MHz Frequency Range.

CCIR Recommendations 393-3 are given by curve B in Figure 9. Curve C in Figure 9 shows the degradation in signal-to-noise ratio of the system in the example given here when the effect of potential noise power interference from satellites in the Fixed Service given in CCIR Recommendations 357-3 was added. A plot of noise power levels recommended in CCIR Rec. 357-3 was given in Figure 2. The results of the analysis show that the addition of the interference noise from satellites is far from degrading the microwave system to the presumably unacceptable level of S/N=33 dB. Note that the values of signal-to-noise ratio in curve C are better than those recommended by CCIR Recommendation 393-3 shown in curve B in Figure 9. The example described above was an illustration of microwave systems in the Fixed Service in the 2025-2300 MHz frequency range. The results shown in Figure 9 support the statement made earlier that these systems are generally designed to operate in an electromagnetically hostile environment and the addition of the satellite interference power described in CCIR Recommendation 357-3 may not make such systems operationally unacceptable. The above illustrative example is not intended to suggest that the design margin of safety generally built into a microwave radio-relay system should be used to accommodate interference noise from satellites. However, an understanding of the ruggedness inherent in the design of a microwave system in the Fixed Service was deemed essential in assessing the impact of power flux densities from satellites on terrestrial microwave systems.

Impact of Fading on pfd limits

Originally fading statistics of radiowave signals were not considered in the GM computer model. In fact, the GM model computes the pfd limits on the basis of percentage of trendlines in which the 1000 pw noise limit, allowed by the CCIR, is exceeded. This method of computation was discussed in Part 1 of this report (Farrar, 1983). This computation did not take into account the effect of the duration of interference. The limit of 1000 pw given by CCIR Recommendation 357-3 was for no more than 20 percent of any month. The fading statistics data used in the NGM computer model were from the information given in CCIR report 338-3. The data in the CCIR report were based on measurements performed in Europe.

Since the CCIR report and the earlier work by Bullington (1957), much data on fading were collected over the years by the Bell Telephone Laboratories in at least two locations in the United States. Equation (1) is a mathematical representation of this data. Equation (1) describes the fading characteristics of the radio wave signals for line-of-sight transmission and is valid only for $L<.1$.

Since the calculation of pfd limits required an expression valid for high values of L, the results obtained using Equation (1) were compared with the results reported by Bullington (1957). Bullington published his results on typical fading characteristics in the worst month from the data collected in the United States. The results of the comparison are shown in Figure 10. Because of the good agreement found by this comparison, the data by Bullington were considered to be accurate for the analysis given here. The NGM program was modified and the fading data obtained in the United States were used in the sample calculation of the pfd limits for satellites in polar orbits at altitudes of 1200 km.

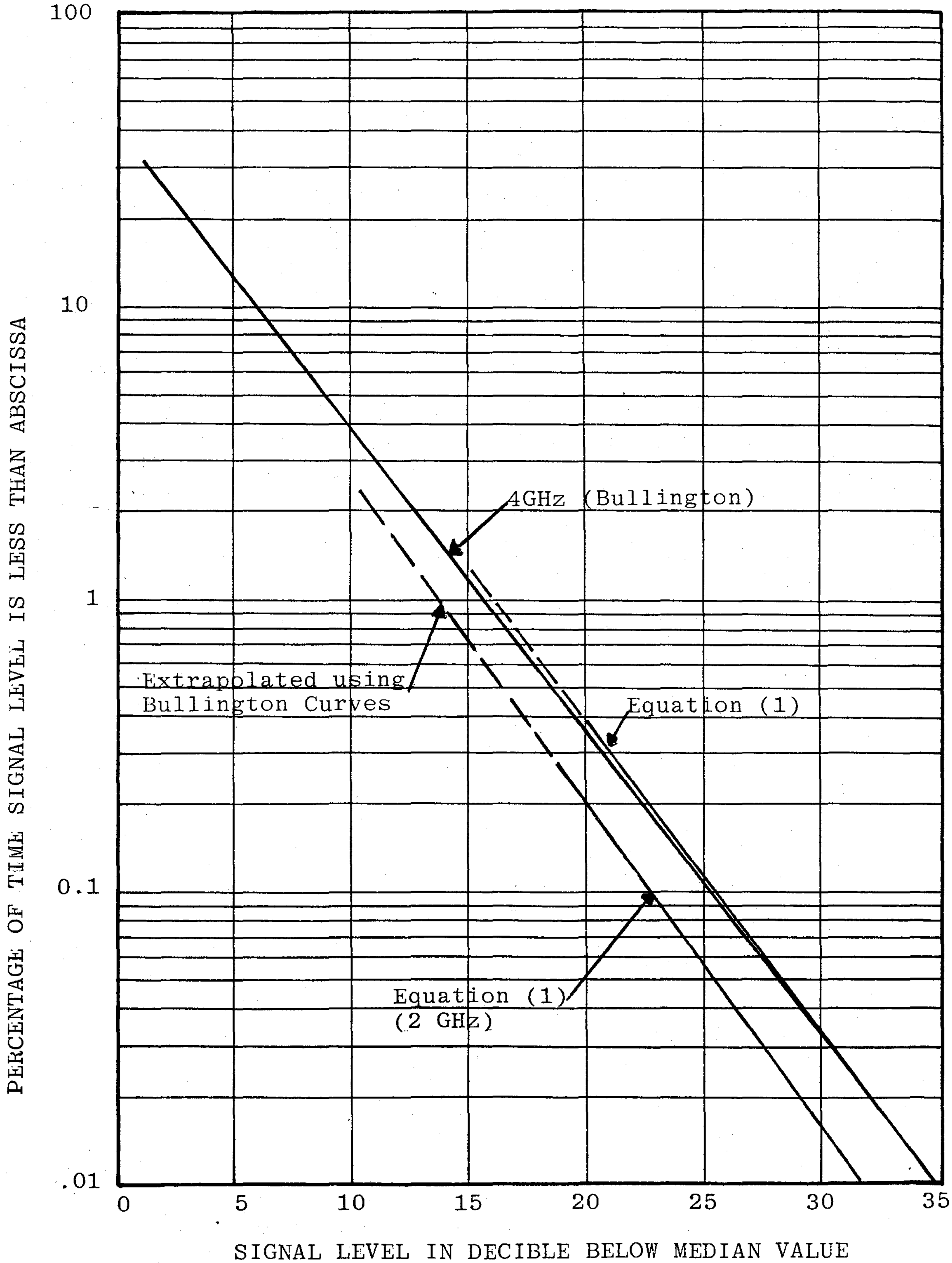


FIGURE 10: Comparison of Bullington results with data given by Equation (1)

The results of these calculations are shown in Figure 11. The curve marked by letter B in Figure 11 indicates the results obtained using the fade data taken in Europe and curve C refers to the result obtained using the data reported by Bullington (1957). These modifications did not significantly change the pfd limits calculated using the data taken in Europe. However, the data in Figure 11 indicate that for values larger than 2 percent the noise power levels in a terrestrial radio receiver may be lower by as much as 2 dB. Curve A in Figure 11 shows the calculations of pfd limits for the case when fade statistics were excluded. Inclusion of the fade statistics in the calculation of pfd limits is more practical and should not be ignored.

To achieve consistency and to simulate a more practical environment in the calculation of the pfd limits for satellites in the geostationary orbit, the GM computer model was modified and the fading statistics were incorporated in the GM model. An identical algorithm was used in both the modified GM and NGM programs in order to incorporate fading statistics in the calculation of pfd limits. The algorithm for fading used in the modified GM program is as follows. In the original GM model a transfer function relating the ratio of input interference-to-noise ratio to output interference-to-noise ratio was used. The effect of fading on desired signal in a radio-relay channel was simulated by assuming that the noise in the channel fluctuates by fading in a manner similar to that experienced by a desired signal. Hence, the amplitude of the noise in a channel was considered to have a distribution similar to that for fading. For a calculation typical of the systems in the 2025-2300 MHz frequency range, it was assumed that 30 percent of the hops in a trendline experience simultaneous deep fading (Panter, 1972). This is considered to be an extremely conservative approach. In a sample calculation 40 trendlines were used and the results of the calculation are shown in Figure 12.

The results shown in Figure 12 are for radio-relay trendlines at 50 degree latitude. The United States is located between the 20 degree and 50 degree latitudes. Previous calculations given in Part 1 of this report showed that the interference from satellites in geostationary orbit to terrestrial radio-relay trendlines increases as the trendlines move from 20 to 50 degree latitudes. The data in Figure 12 are for the severe case of 50 degrees latitude indicating that approximately a 5 dB relaxation in pfd limits is possible due to fading effects of the desired signal. This 5 dB relaxation shown in Figure 12 is subject to fluctuation for different trendlines. The results of the analysis indicated that the 1000 pw noise level shown by a circle in Figure 12 is the limiting valve in the calculation of pfd limits for satellites in geostationary orbit.

MULTIPLE-ORBIT AND INCLINATION ANGLE EFFECTS

Satellites in non-geostationary orbits are used for a variety of different missions. The altitude and the inclination angle of such satellites depend on their missions. For example, satellites in the Earth Exploration Service are generally at higher altitudes than those in the Space Research Service. The NGM computer program was designed to assess the pfd limits for a finite number of satellites in a single orbit. Since in practice satellites are in different orbits, the computation of the pfd limits could not be performed adequately by using a model with a single orbit capability. Hence, there was a need for a model with multiple-orbit capability. This was achieved by modifying the NGM computer model.

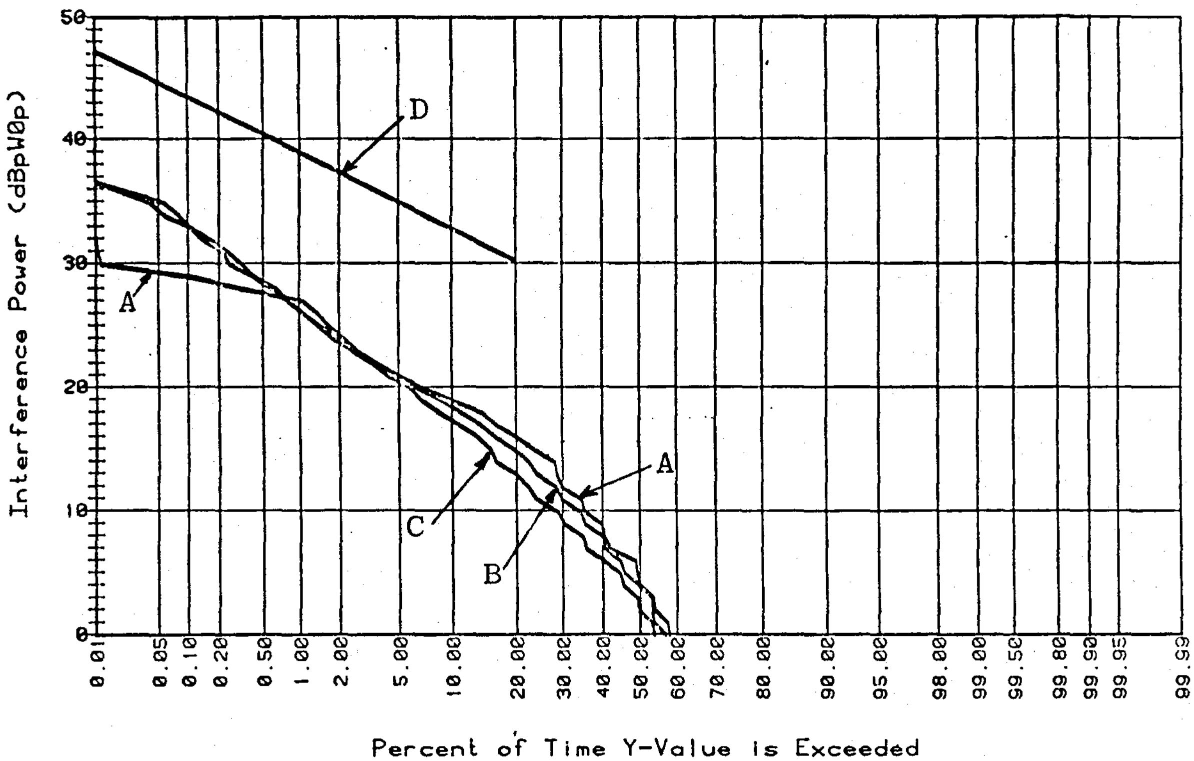


Figure 11. Inclusion of Fade Statistics in the Computation of pfd Limits for Satellites in non-geostationary Model. A) No fading statistics, B) Fading Data from Europe, C) Fading Data reported by Bullington, D) CCIR Noise Criteria Rec. 357-3.

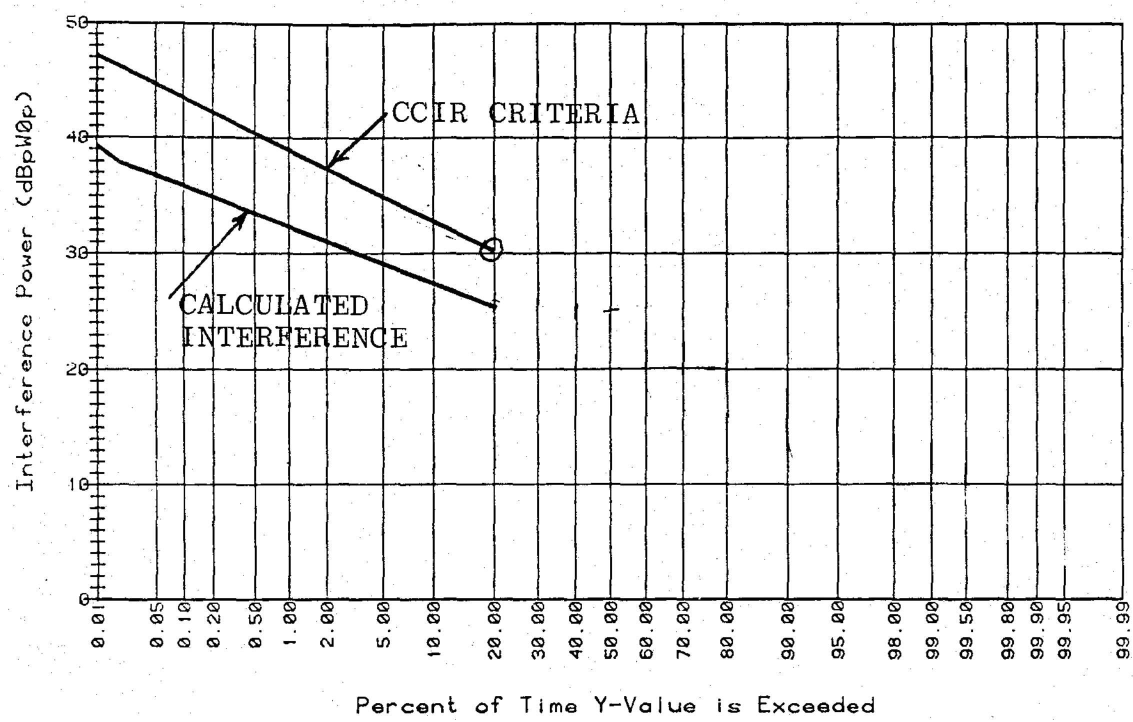


Figure 12. Inclusion of Fade Statistics in the Computation of pfd Limits for Satellites in Geostationary Orbit.

In this assessment the effects of inclination angles and orbit altitudes on pfd computation were investigated separately. The results of these calculations for a single satellite are shown in Figures 13 through 16. The curves marked A, B, C, and D in these figures represent orbit altitudes 300, 500, 800, and 1200 km, respectively. Curve E in these figures represents the CCIR interference noise criteria for systems in the Fixed Service. The results shown indicate that, regardless of orbit altitude, the interference from satellites to radio-relays in the Fixed Service is more serious at low inclination angles. Also the level of interference increases as the altitude of satellite orbit increases. Since the curves shown in Figures 13 through 16 do not cross each other at least in the important region above 0.1 percent of time, it may be stated that the effects of orbit altitudes and orbit inclination angles are independent. Based on these results, worst case interference to radio-relays in the Fixed Service from a low orbit satellite occurs when it is in an orbit with high altitude and low inclination angle. However, the increase in interference level due to low inclination angles occurs in the region of the interference curve which has no effect on the determination of pfd limits.

A glance at Figures 13 through 16 indicates that the separation between the criterion curve E and the interference curves A, B, C, and D is larger for higher percentages of time. This is true for all the inclination angles and the various orbit altitudes used in the calculations of the data in Figure 13 through 16. This result is significant and leads to the fact that the interference from the satellites in low orbit is more pronounced at low inclination angles. The data shown in Figures 13 to 16 were for the hypothetical case where one satellite was assumed to be in orbit. The purpose of the data was to show the effect of inclination angle on the interference received from satellites in non-geostationary orbits. A significant point to be made is that interference received from satellites in non-geostationary orbit is negligible for percentage of time greater than 5%.

Now consider the case of a trendline that experiences interference from satellites in the geostationary and non-geostationary orbits. Clearly, the effect of interference from satellites in both geostationary and non-geostationary orbits is more serious when satellites in non-geostationary orbits have low inclination angles. Assuming that a trendline located at 40 degrees latitude is experiencing 1000 pW of interference from satellites in geostationary orbit, the interference from satellites in non-geostationary orbits was calculated and the results was added to the 1000 pw of interference. The results found for this combination are shown graphically in Figure 17. In this calculation eight satellites were assumed to be divided evenly in four non-geostationary orbits with 20 degrees inclination angle. The four orbits each having two satellites were in altitudes 300, 500, 800, and 1200 km. The data in Figure 17 shows that the effect of interference from satellites in non-geostationary orbits is negligible for percentage of time greater than 5%.

An examination of the data in Figure 17 suggests that the pfd limits for satellites in non-geostationary orbit may be raised by only 8 dB (the dB difference between CCIR curve and the curve showing the calculated interference at 0.5% of time). But in reality, this is not the case. Figure 18 shows the interference received by the same trendline from satellites in

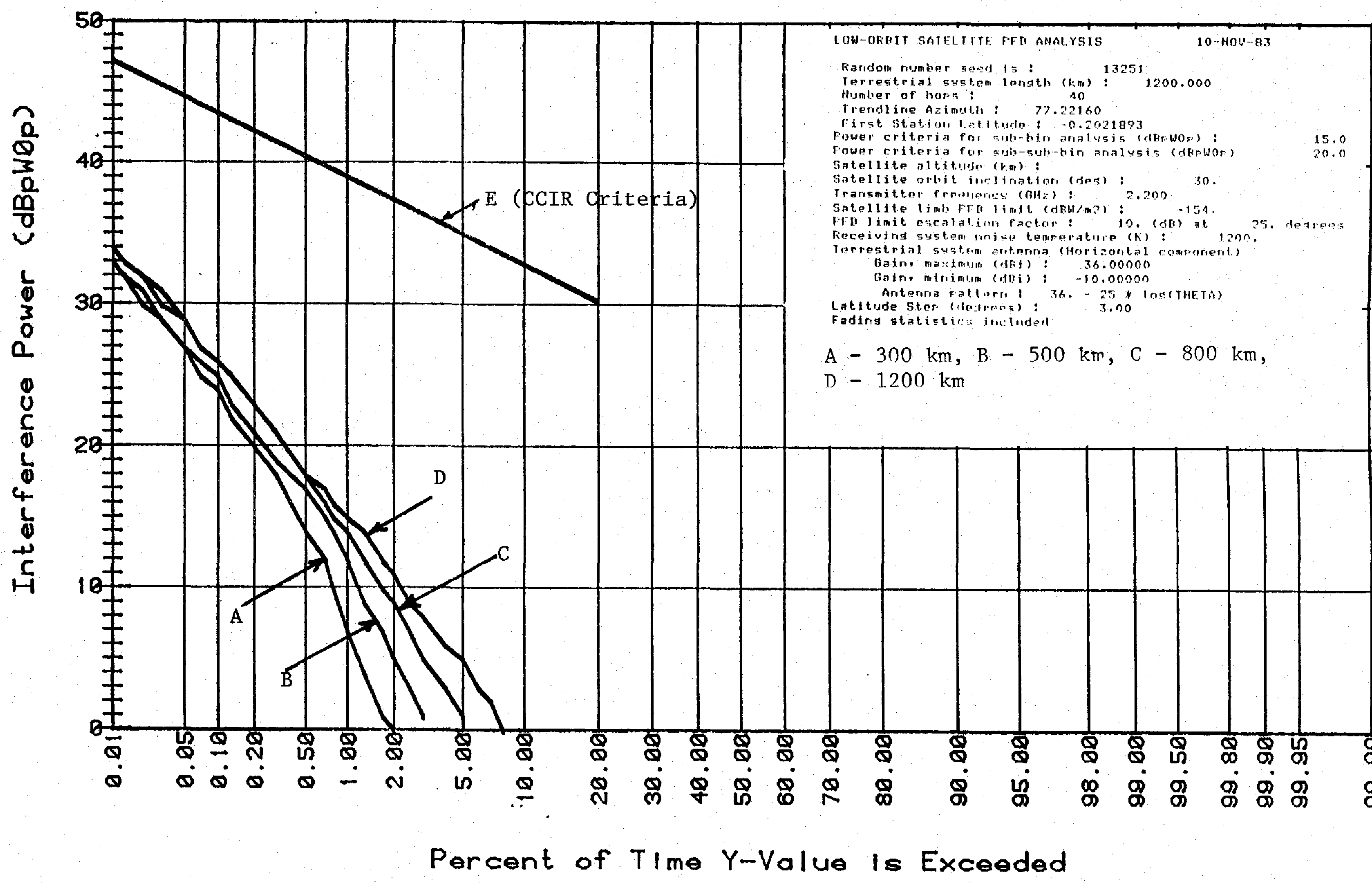


Figure 13 Interference Calculcation for Inclination Angle Equal to 10 Degrees

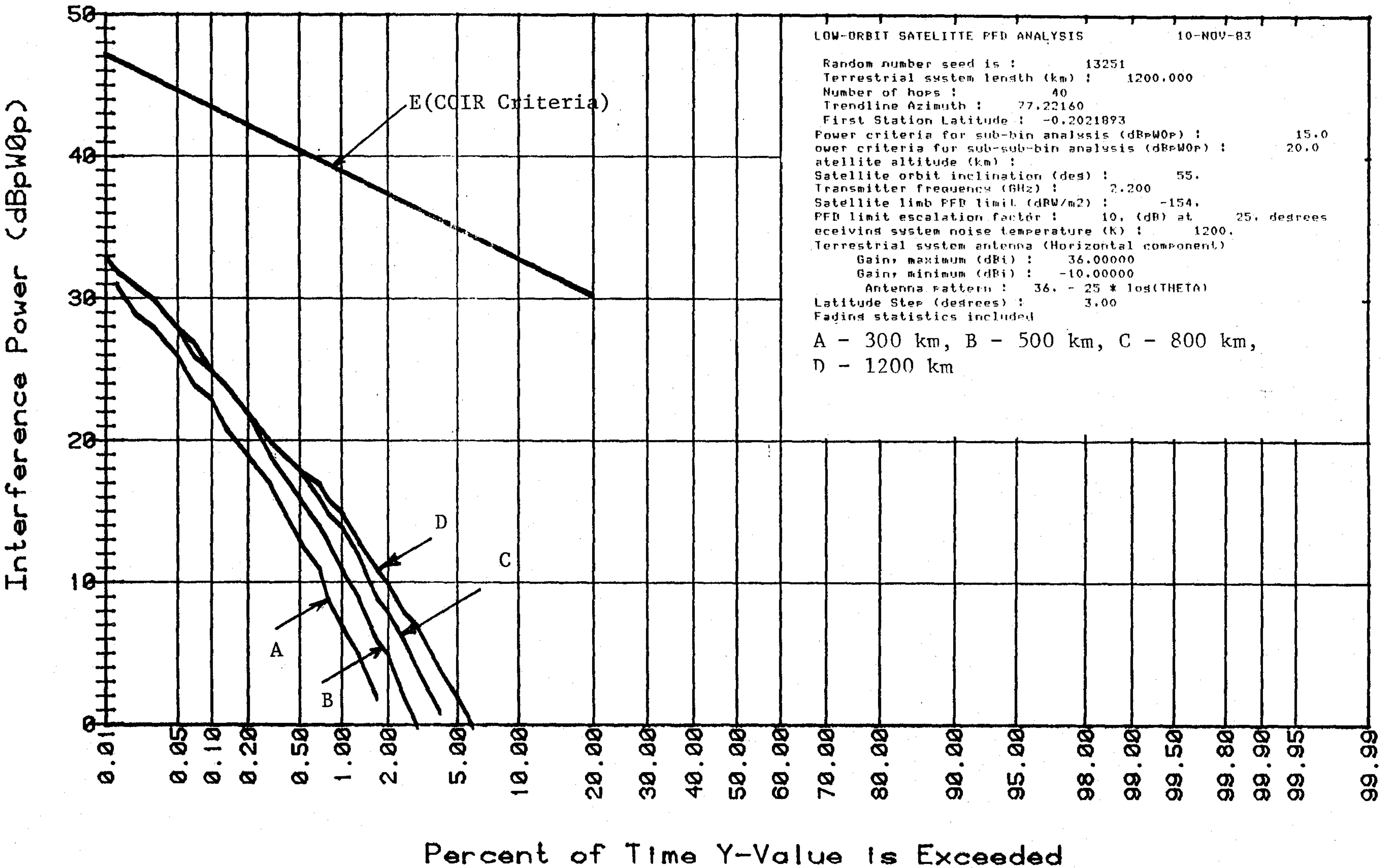


Figure 14 Interference Calculation for Inclination Angle Equal to 30 Degrees

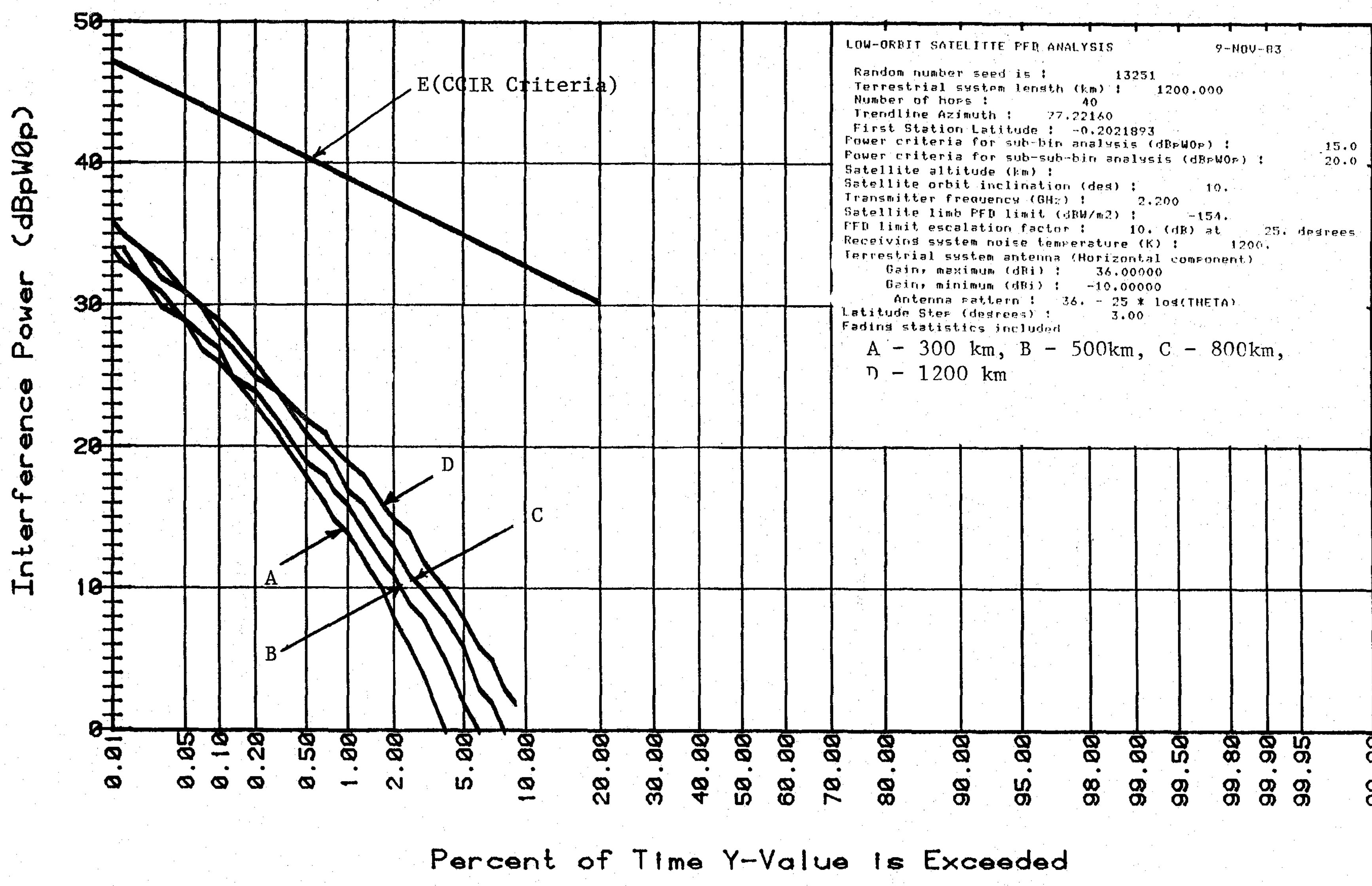


Figure 15 Interference Calculation for Inclination Angle Equal To 55 Degrees

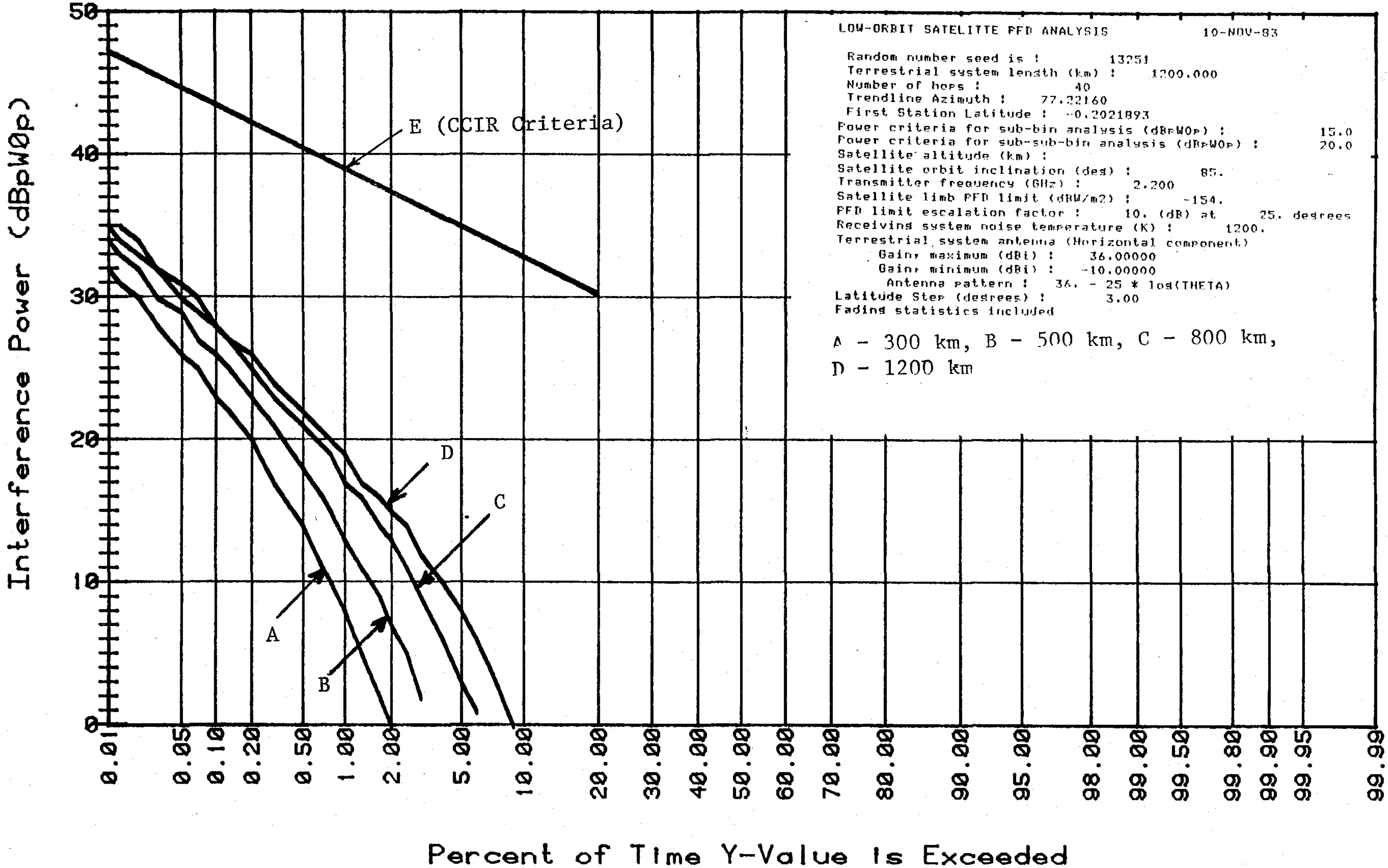


Figure 16 Interference Calculations for Inclination Angle Equal to 85 Degrees

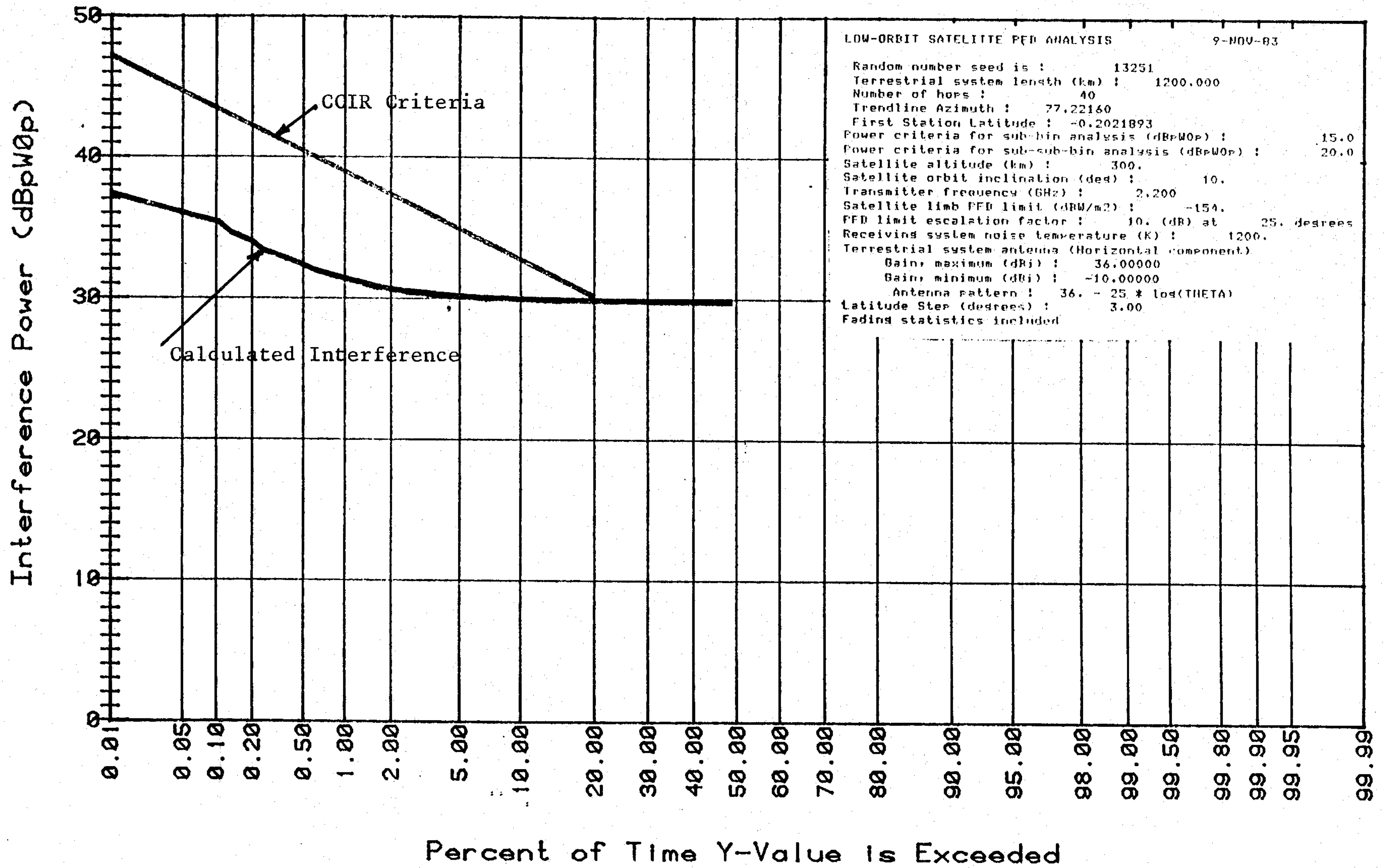


FIGURE 17: Combined Interference from Satellites in Both Geostationary and Non-Geostationary Orbits

Figure 17 except that in the latter 1000 pW of interference from satellites in the geostationary orbit was not added to the results. Note that again the results in Figure 17 shows that this time the pfd limits from satellites in non-geostationary orbit may be raised by 14 dB (again considering the level of interference at 0.5 percent of time). Had we added 14 dB to pfd limits and included 1000 pW of interference from geostationary orbit, the results would have been 40.4 dB compared with 40 dB recommended by the CCIR. Therefore, the combined curve for interference shown in Figure 17 should be interpreted correctly and care should be exercised in using this curve for calculating pfd limits for satellites in non-geostationary orbits. The results in Figures 17 and 18 indicate that pfd limits for satellites in non-geostationary orbits may be thought of as being independent from the limits for satellites in geostationary orbit and can be calculated separately.

As was mentioned above, to determine multiple-orbit effects on pfd limits, the NGM computer program was modified to conduct the analysis using satellites in various orbits of different altitudes. To calculate these effects it was assumed that there were a total of eight satellites visible simultaneously by the radio-relays in the Fixed Service in 2025-2300 MHz frequency range. This assumption is consistent with the results given in Part 1 of this report. Since the orbit altitudes in this frequency range vary from 300 to 1200 km, for the computational purposes it was assumed that there are two satellites in each of the four orbits with the altitudes of 300, 500, 800, and 1200 km. The eight satellites were evenly divided among the four orbits. Curve E in Figure 18 represents the interference noise criteria established by the CCIR (Rec. 357-3). Data in Figure 19 shows that the pfd limits for satellites in non-geostationary orbits may be raised by 14 dB. This method of calculation is more realistic and the assumption that all the satellites remain in the highest orbit visible to terrestrial radio-receivers is very conservative and results in more restrictive pfd limits.

SYSTEMS USING TROPOSPHERIC TRANSMISSION

Internationally, there are several systems which use tropospheric transmission in or near the 2025-2300 MHz frequency range. However, in the United States the use of the 2200-2290 MHz band is limited to line-of-sight transmission for Government users and the 2290-2300 MHz band is not sufficient for accommodating any long-haul tropospheric transmission in other administrations. But the emissions from U.S. satellites are not always confined to the U.S. boundaries and power flux limits are required to protect the systems using tropospheric transmission in other administrations. Provisions in No. 2560 of the ITU Radio Regulations specify limits for the protection of the systems which are designed to operate using tropospheric transmission. Transhorizon receivers generally have lower noise temperatures than the receivers used in line-of-sight operation. Transhorizon systems use very high gain antennas with narrower beamwidth and low off-axis gain. Compared to systems using line-of-sight transmission, transhorizon systems use fewer receivers in a trendline of similar length. Hence, there are fewer interference entries in a transhorizon system.

A realistic power flux limit for the protection of transhorizon system was not determined here. There exists no recommendation by the CCIR for the noise power level to transhorizon systems from the systems in the Fixed Satellite Service. The derivation of -168 dBW in any 4 kHz bandwidth was

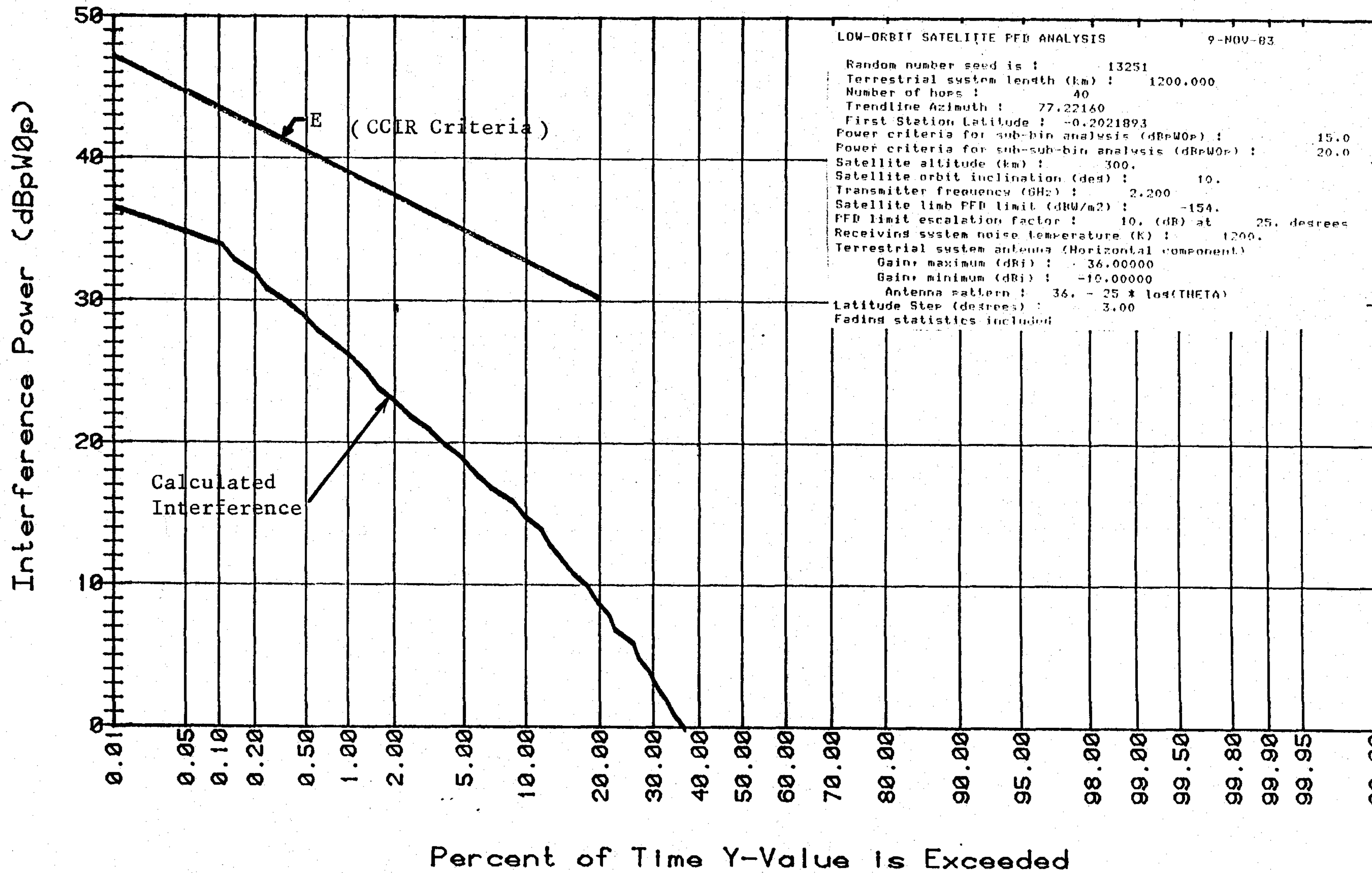


FIGURE 18: Interference from Satellites in Non-Geostationary Orbits.

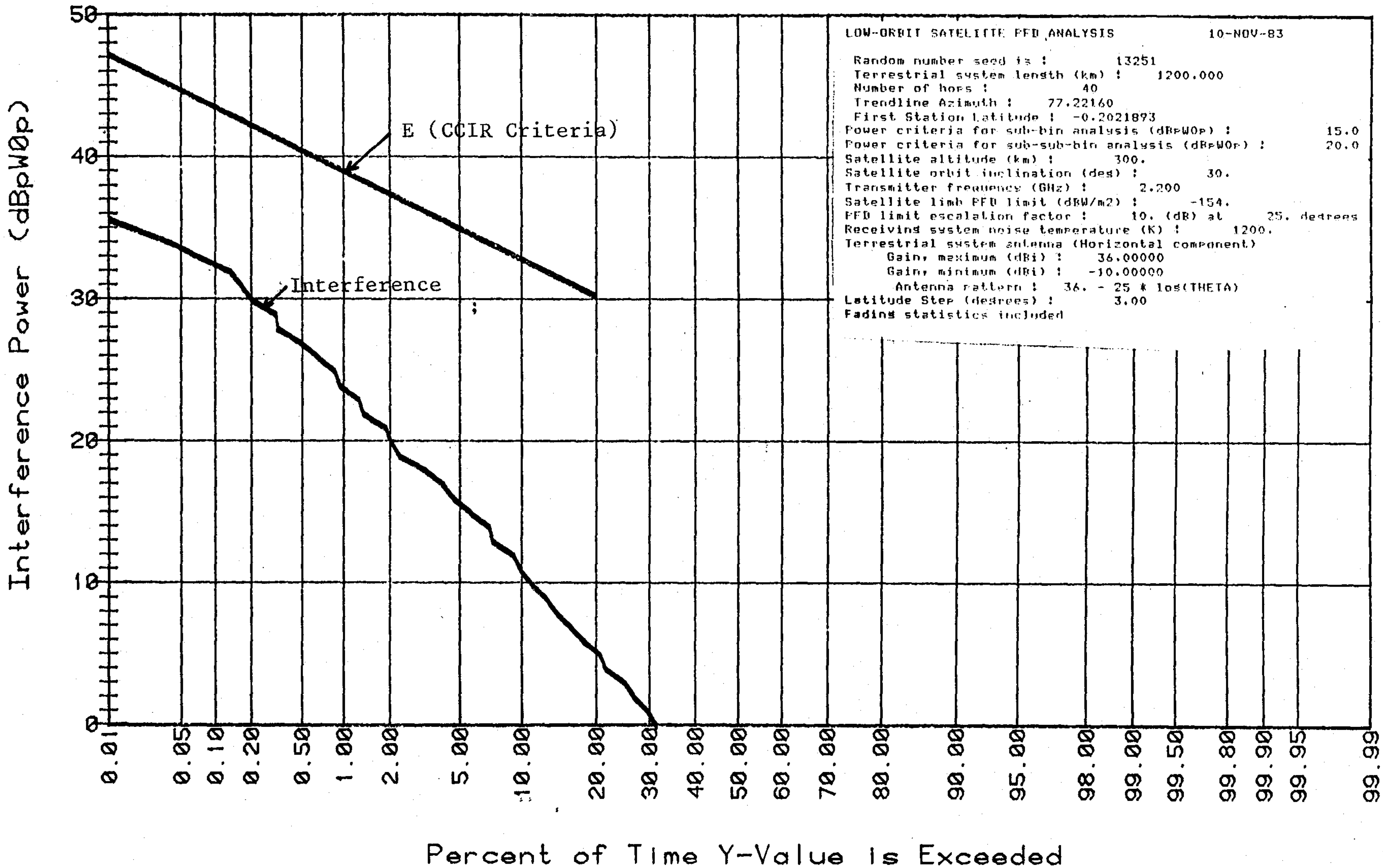


FIGURE 19: Interference Curve for 8 Satellites in Low Orbits Varying in Altitudes from 300-1200 km

considered both in Annex 6-2D and Annex 8-4B of the CCIR Report of the Special Joint Meeting of 1971, Part II. Annex 6-2D is discussed by Watson (McHugh E, Watson) as follows.

"INTERFERENCE FROM ERS SPACE STATIONS TO
TRANS-HORIZON RADIO-RELAY RECEIVERS (M/227)

"The following hypothetical example at 8 GHz is developed to illustrate some aspects of sharing between trans-horizon radio-relay systems and low altitude inclined orbit satellite systems such as an ERS system.

Trans-horizon radio-relay systems have system noise temperatures as low as 300 K. To protect the most sensitive receiver, under the assumption that interference is allowed to equal thermal noise, the maximum allowable interference level at the receiver input will be -167.3 dBW in 4 kHz."

A summary of derivation of -167.3 dBW in 4 kHz is as follows:

k (Boltsman Constant)	-228.6 (dBW)
300K	24.8 (dB)
	-203.8 (dBW)
4 kHz	36.0 (dB)
	-167.8 dBW/4 kHz

Obviously, -167.8 corresponds to the noise level of the receiver and communication systems generally are designed to operate far above these noise levels considering multipath and atmospheric effects. The GM computer program, originally, was used for calculating the pfd limits for protecting terrestrial line-of-sight radio-relay systems. These systems generally use antennas pointed in the direction of the horizontal plane. As a result, the computer model does not take into account an inclination angle of antennas in the vertical plane which could be used by transhorizon systems. In addition, the pointing angles and the direction of trendlines are calculated statistically by the computer model. The use of the computer model in calculating power flux limit for systems using transhorizon transmission will yield an approximate result. Modification to the computer program should be made after a review of the characteristics of trendlines using trans-horizon transmission. A more detailed analysis, however, must await the determination of interference noise limit by the CCIR for satellites to protect the systems using tropospheric transmission.

DIGITAL SYSTEMS

Both GM and NGM computer programs consider only the potential interference from satellites in geostationary and non-geostationary orbits, respectively, to the analog terrestrial systems in the Fixed Service. There are a large number of digital systems in the 2025-2300 MHz frequency range which are now in operation by both Government and non-Government users.

Relative to analog systems, digital radios are more recent and had to be designed to function properly in the analog environment. Historically, digital systems used in radio telephony have followed the design guidelines previously set by the CCIR for analog radios. For example, the Hypothetical Reference Circuit for analog FDM/FM radios is identical to the Hypothetical Reference Digital Circuit established by the CCITT for digital radio-relay systems. This historical observation is not surprising, since the facts are that the digital radio should interface with their analog counterparts and that the environment once established by and for the analog radios could not be rearranged to accommodate any new systems with characteristics requiring a different environment. The pfd limits set by the CCIR are among the elements in the electromagnetic environment which were in place to protect the analog systems in the Fixed Service.

Efforts have been made by the CCIR to provide some design guidelines specially suited for the digital systems. For example, Recommendation 557 states "... that the concept of unavailability of a Hypothetical Reference Digital Path should be as follows: in at least one direction of transmission, one or both of the two following conditions occur for at least 10 consecutive seconds...: 1. The digital signal is interrupted (i.e. alignment or timing is lost). 2. The error rate is greater than 10^{-3}." More recent attempts were made by the CCIR to establish more definite guidelines for the bit-error-rate in digital systems, but no unanimous agreement has been achieved through the CCIR and, in addition, there exists no criteria for interference noise from satellites to the digital systems. Despite the ruggedness which had been used in the design of the digital system in this frequency range, it was found advantageous to conduct a cursory analysis to assess, approximately, the degree of protection that the digital systems in the 2025-2300 MHz frequency now have.

In the analysis given here, let us assume that the bit-error-rate (ber) has to be less than 10^{-3} and that this is the limiting value. The characteristics of the digital systems vary with the modulation schemes used and the performance of these systems are sensitive to these characteristics. Variations in modulation schemes are often to accommodate marketing features which appeal to system users. For example, one system uses quadrature amplitude modulation (a form of amplitude shift keying) and another system uses quadrature phase shift keying modulation. Despite apparent variation of modulation schemes used by different manufacturers, every system must be designed with sufficient flexibility; and, in general, it may be stated that all the modulation schemes used in the digital equipment may be described by the three basic forms of modulation, i.e. Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Frequency Shift Keying (FSK). Coherent detection has been assumed in the analysis. As far as signal-to-noise ratio and its relation to ber are concerned, it may be possible to consider a system to be in one of the three categories of modulation mentioned above. The relationship between ber and signal-to-noise ratio may be used to estimate the degree of protection afforded for the digital systems in the 2025-2300 MHz frequency range.

It has been shown (Newhouse, 1981) that with continuous interference signals, noise and CW generally produce the two extremes, i.e., noise causes the worst and CW interference causes the least degradation in performance of a digital radio reciever. Hence, Gaussian noise being the worse case interference may be used to calculate the ber which a system may have to endure under severe interference. Therefore, if the signal-to-noise ratio for a system is such that it can function in the presence of Gaussian noise, then the system may be assumed to be compatible with other interference sources whose effects on the system are always less than that caused by the Gaussian noise.

Three computer programs were prepared in order to calculate the signal-to-noise ratio as a function of ber for the three modulation techniques (ASK, PSK, and FSK) used by digital systems. The results of the calculations are shown in Figures 20, 21, and 22. The curves in these figures are for M = 2, 4, 6, and 8. Generally, signal-to-noise ratio of a radio-relay receiver is greater than approximately 33 dB under faded condition in a channel. (The acceptable criteria for signal-to-noise ratio set by the Bell Systems is 33 dB). Using 26-43.5 dB signal-to-noise ratio at the input to receiver demodulator as an operational parameter, the data in Figures 20, 21, and 22 indicate that ber for all types of modulation techniques used for digital systems will be less than 10^{-3}.

The cursory analysis given above indicates that if digital systems in the 2025-2300 MHz frequency range were designed to operate in the analog environment, they can function properly under the guidelines set by the CCIR. At this time when no criteria for interference from satellites to digital systems are available, the discussions on ber and the fact that digital systems have been designed to operate in the analog environment may be sufficient to state that the digital systems are protected against interference from satellites if the pfd limits from these satellites provide protection of the analog systems in the 2025-2300 MHz frequency range.

Receiver Transfer Function

In Part 1 of this report, a qualitative analysis was conducted which gave an estimate of the approximation in the receiver transfer function (May and Pagones, 1973)

$$\frac{i_c}{n_c} = \frac{i_4}{n_4} \tag{2}$$

where i_c and n_c are interference and free space noise power in a channel, respectively, and i_4 and n_4 are the interference and noise power, respectively, in a 4 kHz bandwidth at receiver input. For the analysis given here N is equal to 25 pW as indicated in CCIR Report 387-1. Equation (2) was used in both GM and NGM computer programs. A quantitative analysis was conducted here using a convolution technique in order to determine the inaccuracy involved in using Equation (2) for the determination of pfd limits in the 2025-2300 MHz frequency range.

A more exact form of Equation (2) may be written

$$\frac{i_c}{n_c} = k(\Delta f,m)\,\frac{i_4}{n_4} \tag{3}$$

where k is a function of frequency separation, Δf, and modulation index, m, of the desired signal. In addition, function k can vary from one channel to

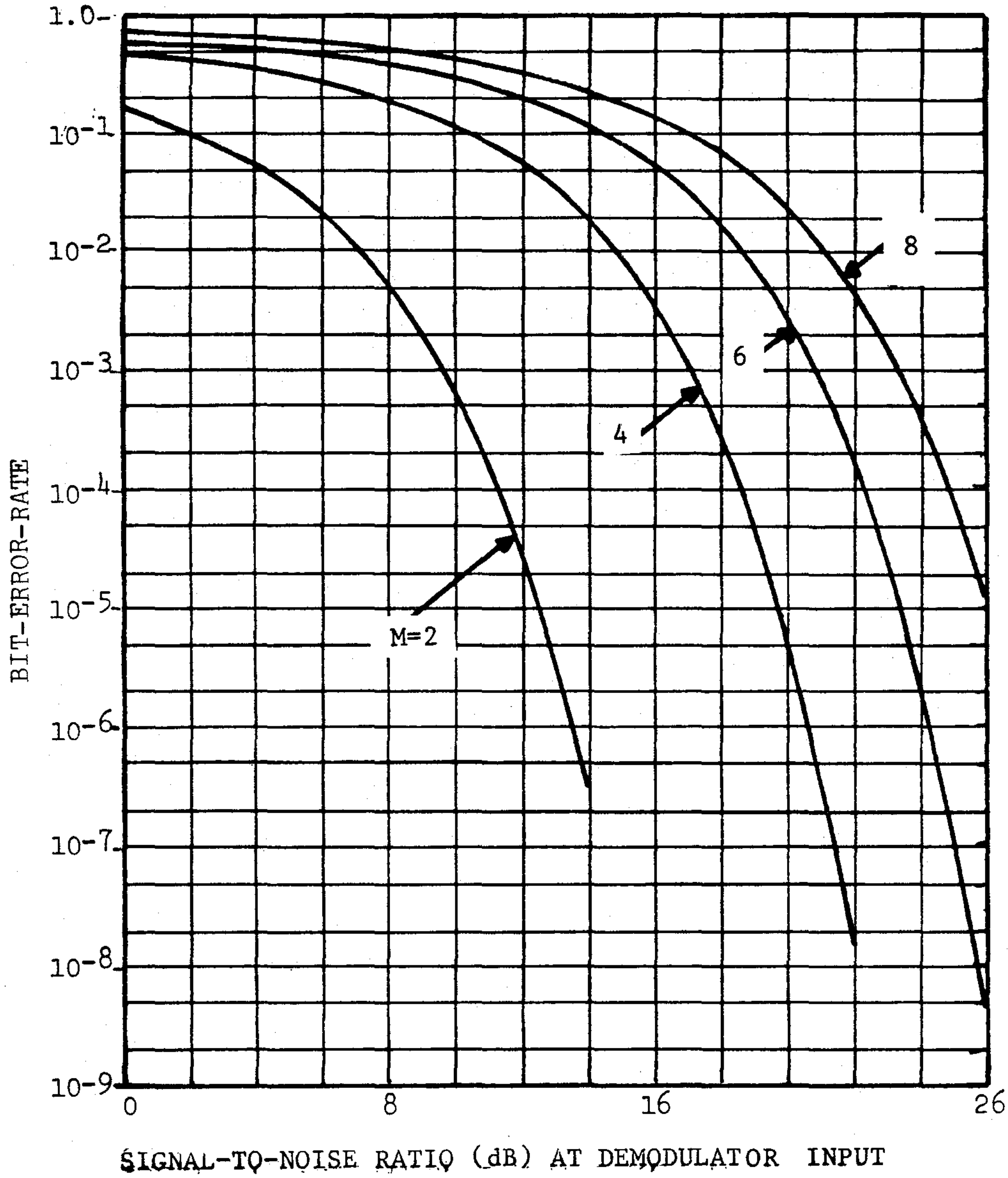


Figure 20. Probability of Bit-Error-Rate vs. Signal-to-Noise Ratio for ASK Modulation

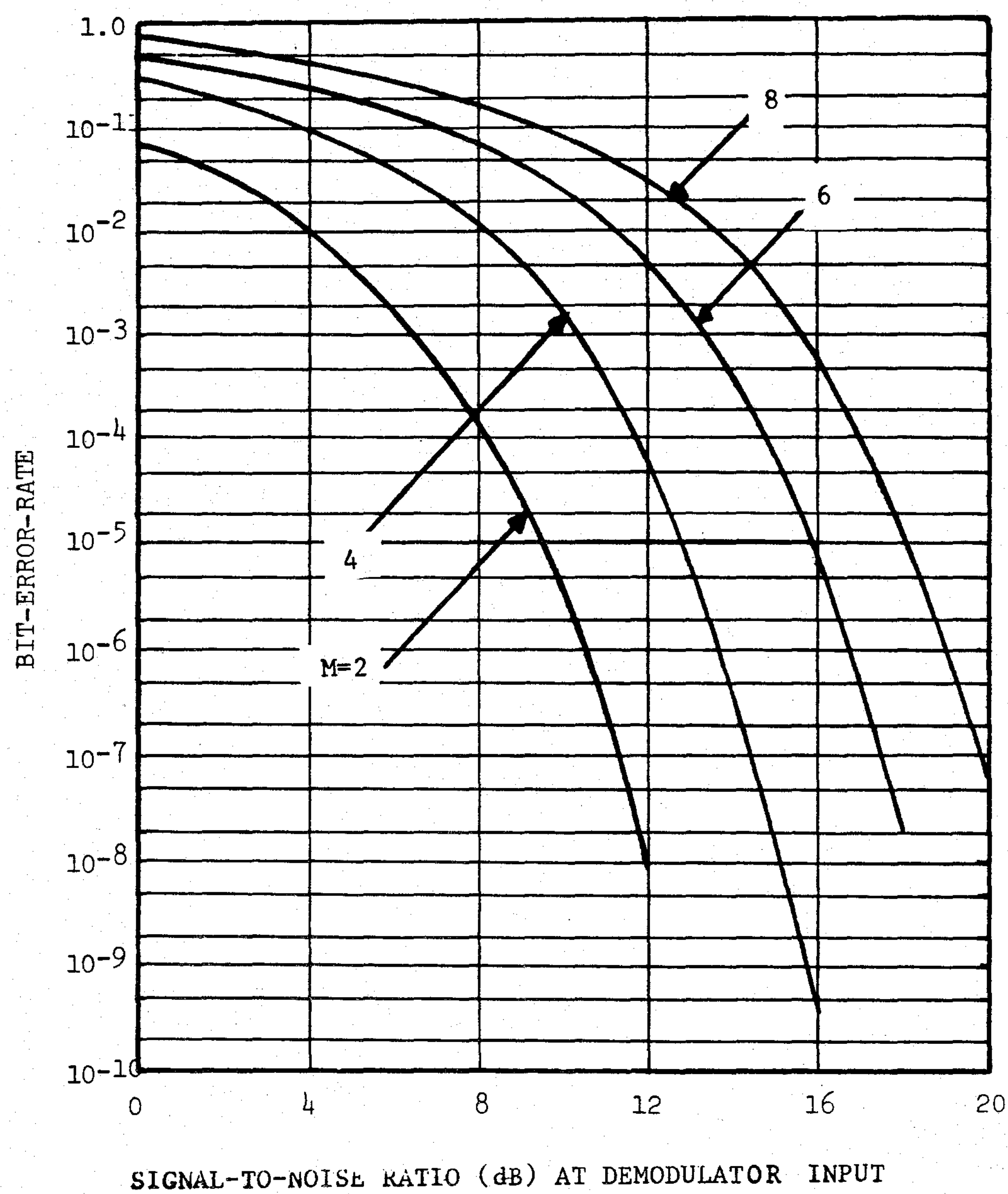


Figure 21. Probability of Bit-Error-Rate vs. Signal-to-Noise Ratio for PSK Modulation.

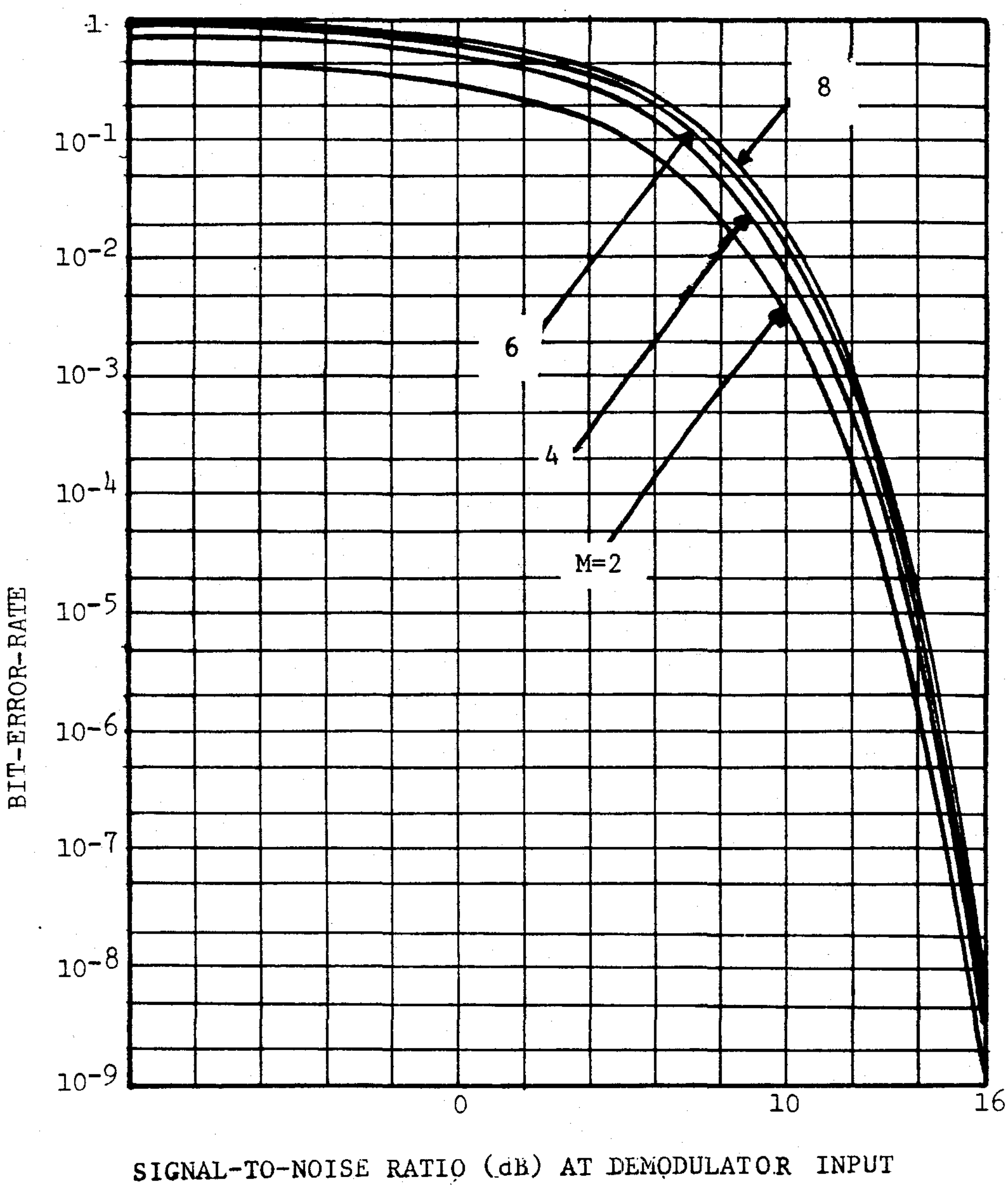


Figure 22. **Probability of Bit-Error-Rate vs. Signal-to-Noise Ratio for FSK Modulation.**

another in a receiver. The parameters i_c, n_c, i_4, and n_4, are defined above. Evaluation of function k is desired. Comparison of Equations (3) and (2) indicates that function k in Equation (2) was set equal to unity. This is a conservative approach and the underlying assumption is that interference spectrum is flat and noiselike. For the modulation indices used by the systems in the Fixed Service operating in the 2025-2300 MHz frequency range the value of k = 1 constitutes an upper bound.

For large modulation indices, $m > 1.5$, an FDM/FM spectrum assumes a Gaussian shape. For low modulation indices, $m < .1$, the spectrum becomes discontinuous with a predominant residual carrier. For these two extreme cases, function k may be evaluated using closed form expressions. However, signals with intermediate modulation indicies the problem is more difficult and the function k should be determined using convolution of the desired and undesired emission spectrums. The construction of the solution is as follows:

We begin by invoking the concept of noise-power ratio (npr). In this report NPR = 10 log (npr). In the absence of interference npr for a receiver loaded with a particular level of noise test signal, may be defined as the ratio of the noise power in an arbitrarily small bandwidth of the passband to the noise power in the same bandwidth within a stop-band. A mathematical expression for npr may be derived as follows; npr resulting from interference is, among other factors, directly proportional to the carrier-to-interference ratio. Mathematically npr as related to signal-to-interference ratio in a channel and carrier-to-interference (c/i) ratio at the input to the IF may be expressed by the relationship derived in Bulletin No. 10-C (Electronics Industries Association, 1976).

$$(c/i)\mathrm{dB} = \mathrm{NLR/CH} - 10\log i_c + 87.5 - \mathrm{NPR} \quad (4)$$

where i_c was defined earlier. The desired signal level in Equation (4) was offset relative to the zero reference level by an amount given by the noise loading ratio per channel (NLR/CH). Derived from the FCC loading equation, the NLR/CH in dBm0 is given by:

$$\mathrm{NLR/CH} = \begin{cases} -15 & N > 240 \\ -1-6\log N & 60 < N<240 \\ 2.6-8\log N & 12 < N<60 \end{cases}$$

where N is the number of voice channels. In Equation (4) signal is a test tone with zero dBm level and constant 87.5 is psophometrically weighted noise reference (-90 + 2.5 = -87.5) in a channel. A different form of Equation (4) is given in CCIR Report 388-3. The interference power i_c is obtained using expression:

$$10\log i_c = 87.5 - B - (c/i)_{\mathrm{dB}} \quad (5)$$

An interesting feature of Equation (5) is the term B which is given by CCIR Report 388-3.

$$B = 10\log\left[(s/i_c)/(c/i)\right] \qquad (5a)$$

where

- s : test signal power in a telephone channel = 1 mW,
- i_c : interference power in a telephone channel (bandwidth 3.1 kHz),
- c : power of the wanted signal carrier (W),
- i : power of the interfering signal carrier (W).

Using Equations (4) and (5) relationship between B and NPR may be found:

$$B = NPR - NLR/CH \qquad (6)$$

Equation (6) states that B is different from NPR by a constant (NLR/CH). NLR/CH is a constant for given number of channels for a receiver. Another word B may be evaluated after NPR has been determined. Before discussing the evaluation of NPR let us write NPR in the following forms using Equations (5a) and (6):

$$(npr)_i \sim (s/i)_o/(c/i)_{in} \qquad (7)$$

when interference is present and when noise is the source of impairment in the receiver:

$$(npr)_n \sim (s/i)_o/(c/n)_{in} \qquad (8)$$

Subscripts i and n in Equations (7) and (8) refer to interference and noise, respectively, and subscripts o and i_n indicate output and input, respectively. The reason for the symbol $\sim$ used in Equations (7) and (8) is that we have neglected the term NLR/CH in these equations. Dividing Equation (8) by Equation (7) we obtain

$$\frac{(npr)_n}{(npr)_i} = \frac{i_c}{n_c} \cdot \frac{n_{in}}{i_{in}} \qquad (9)$$

Note that Equation (9) resembles Equation (3) except that the ratio of i_4/n_4 in Equation (3) is replaced by i_{in}/n_{in} in Equation (9). A method of converting i_{in}/n_{in} to i_4/n_4 is as follows. Assuming the noise at the input to the receiver be flat a linear realtionship between n_{in} and n_4 may be obtained.

$$n_{in} = n_4\, BW_n/4000 \qquad (10)$$

when BW_n is the noise bandwidth of the receiver. The interference signal is never flat and i_{in} may be concentrated in certain sections of the interference spectrum density. Sections of spectrum where concentration of power is higher contribute most to evaluation of npr and the impairment of radio channels.

Consider the schematic view of a spectrum density for the interfering signal shown in Figure 23. The schematic in Figure 23 is a simplified version of some of the oscillograms in Section 4. This simplification is for explaining the analysis procedure and it will have no effect on the accuracy of the results. The curve in Figure 23 shows only three peaks of a spectrum. In practice there are more. BW_n in Figure 23 represents bandwidth for the i_{in} peak of the spectrum. The hypothetical spectrum shown in Figure 23 is a good approximation, since it is possible to define BW_n for a section i_{in} of the spectrum over which the power density is approximately linear (4 kHz was assumed to be the smallest subdivision) that there is not restriction on size of BWi.

The interference power under the curve shown in Figure 23 may now be represented by the relation.

$$i_{in} = i_{41} \frac{BW_1}{4000} + i_{42} \frac{BW_2}{4000} + \ldots + i_{4m} \frac{BW_m}{4000}$$

or simply

$$i_{in} = \frac{1}{4000} \sum_{i=1}^{m} i_{4i} \, BW_i \tag{11}$$

Now substitute Equations (11) and (10) into Equation (9):

$$\sum_{i=1}^{m} \frac{i_{4i} BW_i}{n_4 BW_n} \cdot \frac{(npr)_n}{(npr)_i} = \frac{i_c}{n_c} \tag{12}$$

Let i_{4m} represent maximum level of interfering signal and write Equation (12) in the form:

$$\frac{i_{4m}}{n_4} \frac{\sum_{i=1}^{m} i_{4in} BW_i}{BW_n} \cdot \frac{(npr)_n}{(npr)_i} = \frac{i_c}{n_c} \tag{13}$$

where i_{4in} are now the normalized levels of interfering signal. A term-by-term comparison of Equation (13) with Equation (3) indicates:

$$k(\Delta f, m) = \sum_{i=1}^{m} \frac{i_{4in} BW_i}{BW_n} \cdot \frac{(npr)_n}{(npr)_i} \tag{14}$$

The summation term in Equation (14) is smaller than unity. A conservative analysis will result if we let:

$$k = (npr)_n/(npr)_i \tag{15}$$

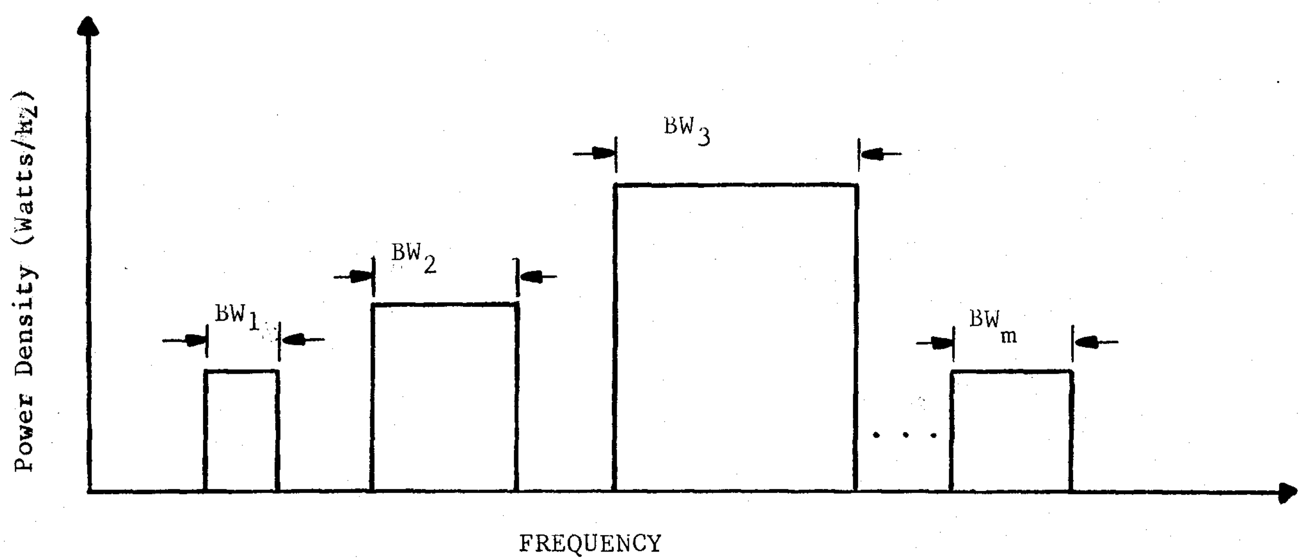


Figure 23: Typical spectrum density for interfering signal.

Substituting Equation (15) into Equation (3) we obtain:

$$\frac{i_4}{n_4} \cdot \frac{(npr)_n}{(npr)_i} \geq \frac{i_c}{n_4} \qquad (16)$$

Therefore

$$k(\Delta f, m) = \alpha_{dB} + (NPR)_n - (NPR)_i \qquad (17)$$

where

$$= \sum_{i=1}^{m} i_{4in} \; BW_i / BW_n$$

The function k for a receiver varies for every channel. For a conservative analysis k was evaluated for a receiver channel which endures the greatest impairment. Evaluation of npr is a key factor in the evaluation of function k which is the desired result.

As was mentioned above npr may be evaluated using closed form expressions for signals using very high or very low modulation indices. For signals with intermediate modulation indices the evaluation of npr should be carried out using the general formula given in Bulletin No. 10-C (Industrial Electronics Ass.):

$$(npr) \sim \frac{2(\delta F)^2 H^2(fr)}{fr^2 (f_n - f_1) I} \qquad (18)$$

δF = total multichannel rms deviation
f_r = baseband frequency
f_n = maximum baseband frequency
f_1 = minimum baseband frequency

$$I = \int_{-\infty}^{\infty} [P_1(f+a)P_2(f-a) + P_1(f+b)P_2(f-b)] \, df$$

P_2 (f) = interfering signal power spectra
P_1 (f) = desired signal power spectra

$a = 1/2 \; (f_s + f_r)$
$b = 1/2 \; (f_s - f_r)$
f_s = frequency separation of desired and interfering signal
$H(f_r)$ = desired signal emphasis function
$= 0.634 \; [1 + 1.505 \; (f_r/f_n) \;]$
$H(f_r)$ = 1.0 for unemphasized systems

The approximation given by Equation (18) becomes very good for C/I > 10 dB. A computer program developed by Sharp (1975) for the evaluation of Equation (18) was used to determine $(npr)_i$ and $(npr)_n$. A discussion of the algorithm and the input parameters for the program is given in Sharp's report. This computer model was incorporated in the NTIA computer file. The basic input data consists of emission spectrums (watts/Hz) for the desired and undesired signals and the appropriate parameters associated with these spectrums such as modulation index and bandwidth. For convenience, the computer file has a list of some of the generally used spectrum. This list is called MENUE and the user has the option of selecting a spectrum from this list.

For evaluation of $(NPR)_n$ flat noise was used for function n and in evaluation of $(NPR)_i$ input interference was assumed to be $(\sin x/x)^2$ which is similar to the signal from TDRSS and for a non-TRDSS type signal the interference signal was assumed to be similar to the signal used by Landsat-4 and satellites in SGLS. The calculation was carried out for 48 and 600 channel FDM/FM receivers for f_1 = 12kHz.

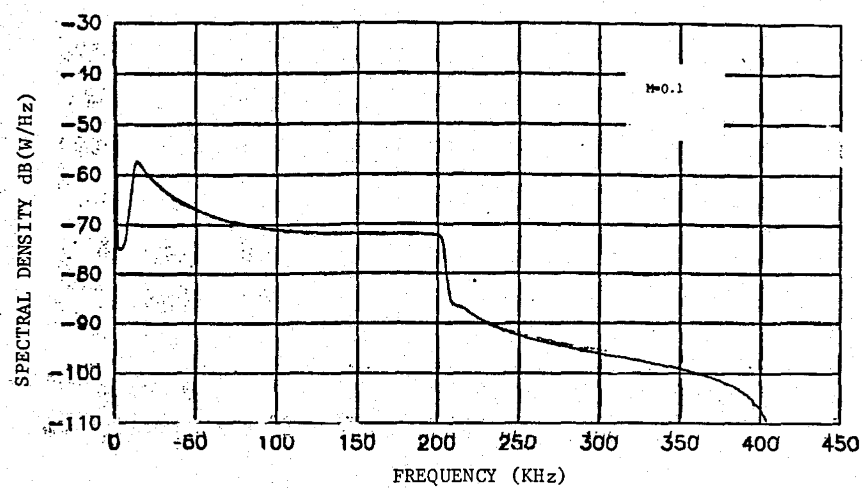
The bandwidth for the interference signal (TDRSS signal) was assumed to vary from 2 to 6 MHz. The noise bandwidths were 1 and 20 MHz in the calculation. The modulation indices for the desired signal in the calculations were from 0.1 to 0.5. The simulated FDM/FM signal for these different modulation indices used in the calculations are shown in Figure 24.

Results of the evaluation of function k are given in Figures 25-28. The curves in Figures 25 and 26 show the variation of the function k for different modulation index of the desired signal and when the interference signal is described by $(\sin x/x)^2$. Note that k varies from -0.1 dB for the worst combination to -39 dB depending on the channel number, noise bandwidth, and the bandwidth of the undesired signal. Function k was also evaluated for signals similar to that used by Landsat-4 and the satellites associated with SGLS. This type of signal was referred to as non-TDRSS type signal in Section 4. Figures 27 and 28 show the results of such evaluation when the satellite signal is 256 kbps or 32 kbps, respectively. Note that for these signals values of function k vary from -6 dB to -63 dB.

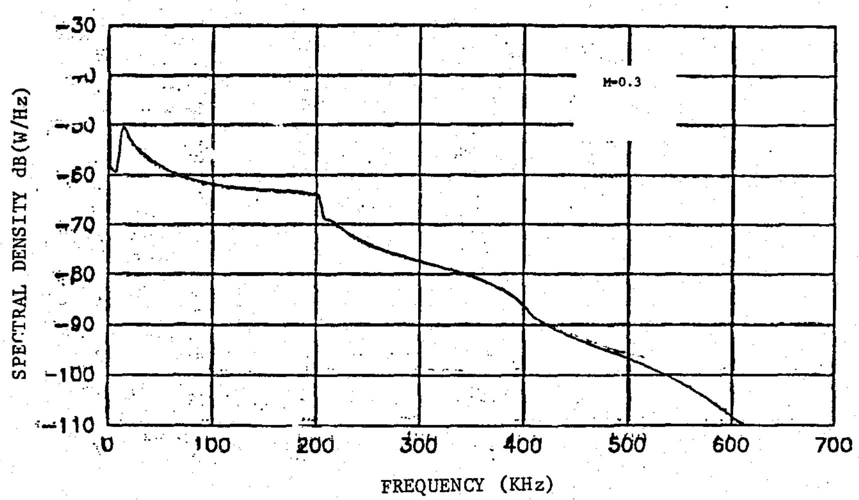
Interviews with major U.S. manufacturers indicated that terrestrial radio receivers in the 2200-2300 MHz band have generally less than 100 channels and for these receivers the IF bandwidth is approximately 5 MHz. As was discussed earlier, a bandwidth of 2-4 MHz is representative for signals from satellites in the 2025-2300 MHz frequency range. Assuming 5 MHz noise bandwidth for a radio receiver and 4 MHz bandwidth for interfering signal, interpolation of the data shown in Figures 25-28 shows that, for the worst channel k function is approximately equal to -3 dB. For most systems in the 2200-2300 MHz band the value of -3dB is conservative.

ANALYSIS RESULTS

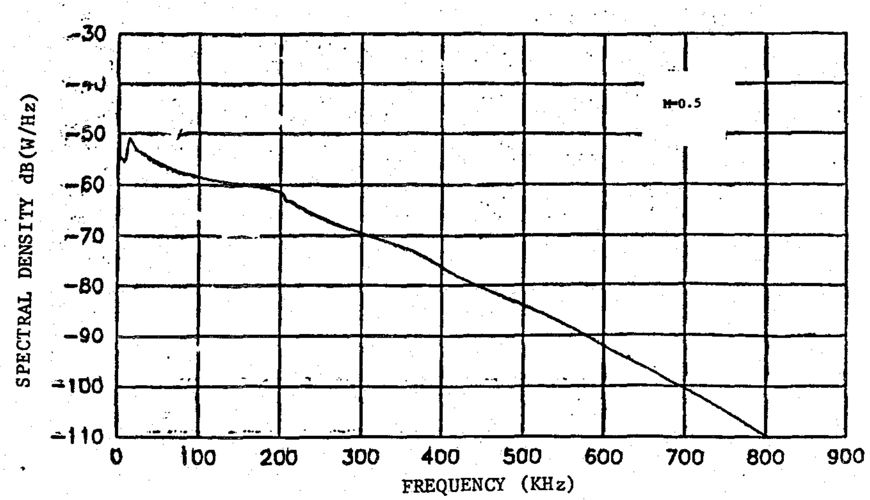
The results of modifications to the GM and NGM programs will now be summarized. Using these results pfd limits for the 2025-2300 MHz frequency range will then be determined. In this frequency range, satellites operate in either geostationary or non-geostationary orbits. The limits for the satellites in the geostationary orbit are different from those in non-geostationary orbit and will be discussed separately. PFD limits given here are applicable to the United States. Assumptions used in their derivation should be reviewed prior to their use by other administrations.



(a)



(b)



(c)

Figure 24. Simulation of FDM/FM signal for 48 channels.
(a) modulation index = 0.1. (b) modulation index = 0.3.
(c) modulation index = 0.5.

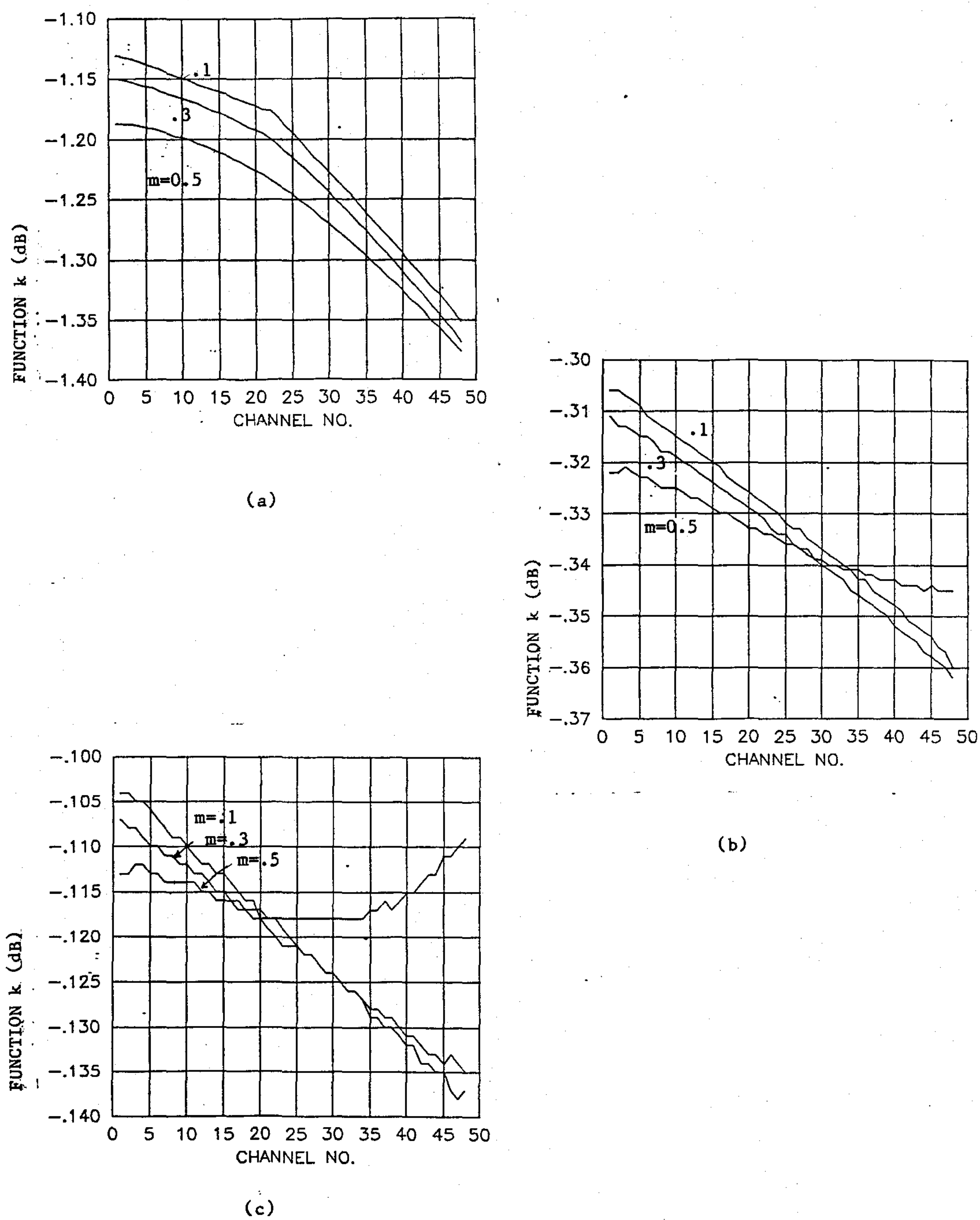


FIGURE 25: A plot of function k vs channel number for TDRSS type-signal and 1 MHz noise bandwidth of receiver: (a) interfering signal bandwidth = 2 MHz, (b) interfering signal bandwidth = 4 MHz; (c) interfering siganl banwidth = 6 MHz.

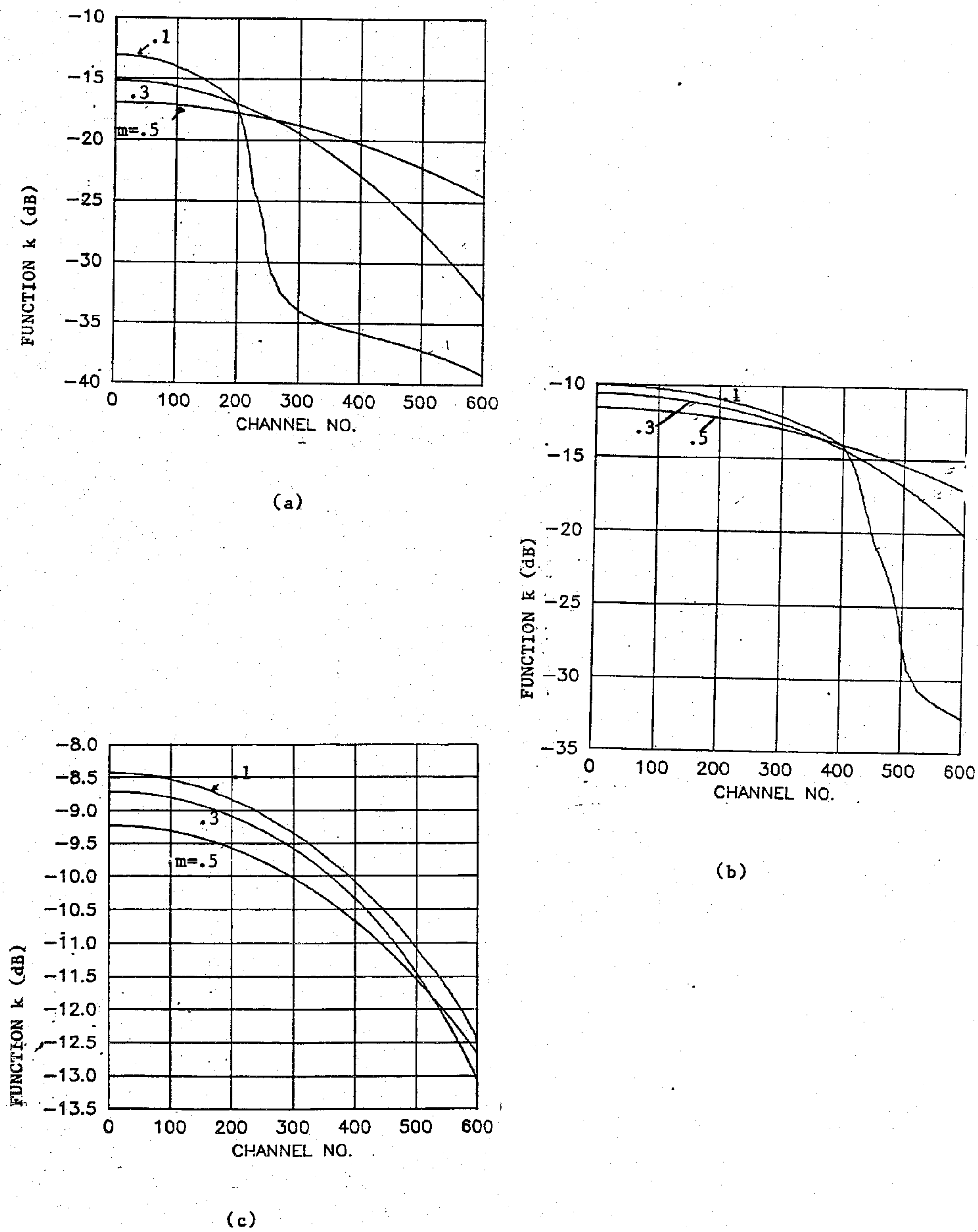
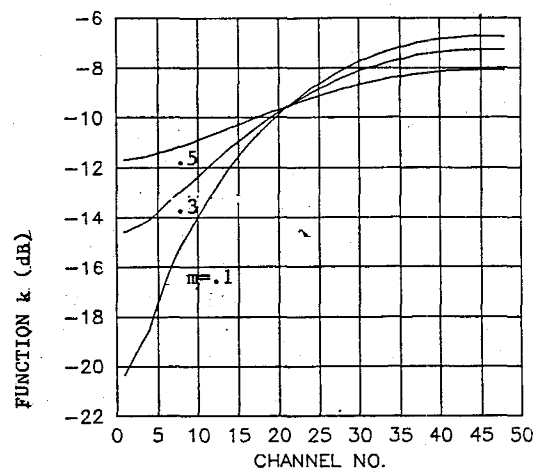
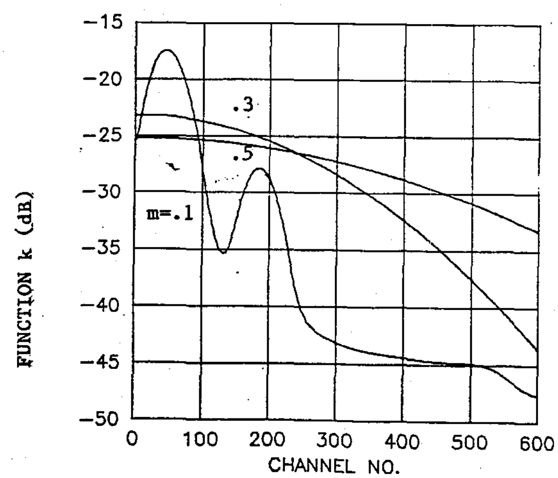


FIGURE 26: A plot of function k vs channel number for TDRSS—type signal and 20 MHz noise bandwidth of receiver: (a) interfering signal bandwidth = 2 MHz, (b) interfering signal bandwidth = 4 MHz; (c) interfering signal bandwidth = 6 MHz.

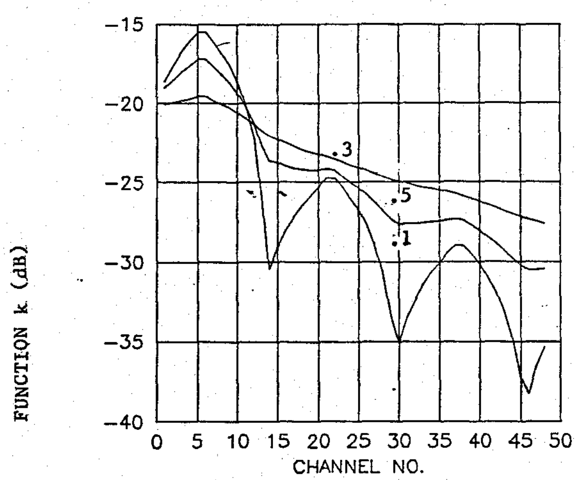


(a)

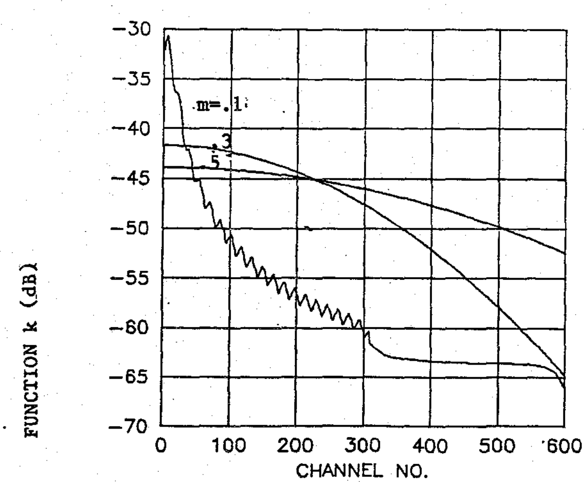


(b)

FIGURE 27: A plot of function k vs channel number for Landsat-type signal (256 kbps): (a) receiver noise bandwidth equal to 1 MHz, (b) receiver noise bandwidth equal to 20 MHz.



(a)



(b)

FIGURE 28: A plot of function k vs channel number for Landsat-type signal (32 kbps): (a) receiver noise bandwidth equal to 1 MHz, (b) receiver noise bandwidth equal to 20 MHz.

Modifications to GM and NGM Computer Models

Modifications to the GM and NGM computer models were discussed above and the effects of each modification on pfd limits were separately calculated. The modifications which proved to have significant impact on the pfd limits for the geostationary orbit were those due to the frequency engineering of trendline and receiver transfer function. The multiple-orbit effects and latter two modifications also showed a sizeable effect on the pfd limits for the satellites in the non-geostationary orbits. Fading statistics based on the data obtained in several regions in the United States indicated a negligible change in the pfd limits compared with originally calculated limits using the data obtained in Europe and given in CCIR Report 338-3. Similarly the inclusion of the fading statistics in the GM computer model, although improving the consistency of the approach used in the two models, did not change the value of the pfd limits which were evaluated without fading statistics.

pfd Limits for Satellites in Geostationary Orbit

Considering the modifications due to the frequency engineering of a trendline and the data representative of the characteristics of the systems in terrestrial services given in Section 4, the calculated pfd limit for the satellites in geostationary orbit may be summarized as shown in Table 9. The data in Table 9 does not include 3 dB correction due to the receiver transfer function.

The results corresponding to a 15 degree satellite spacing and double frequency engineering of a trendline shown in Table 9 are realistic for the satellite operations in the 2025-2300 MHz frequency range. Fifteen-degree separation corresponds to approximately 13 satellites in the geostationary orbit. According to the data in Section 4, there are approximately 13 satellites presently in operation in the geostationary orbit. This is highly conservative, since it is difficult to envision that all 13 satellites will operate co-channel with the terrestrial receivers in a trendline. In addition, double frequency engineering is a technique rarely used in a long-haul communication. A four-frequency plan is favored more by commercial communication industries. However, this conservative choice of parameters should compensate for any future growth in the number of satellites and will protect the rare occasions where terrestrial radio users use two frequency plans. The United States are bounded by 20 to 50 degree latitudes. The relaxation in the present pfd indicated by the entries in Table 9 ranges from 6.5 to 11.9 dB for double frequency plan and spacing between satellites in the range of 10 to 20 degrees. Adding 3dB correction factor due to the receiver transfer function the calculated values for relation of pfd vary from 9.5 to 14.9. A 10 dB relaxation in the present pfd limits was found to be reasonable. Therefore, the minimum value for pfd limit in the 2025-2300 MHz frequency range may be determined to be -144 dB (W/m^2) in any 4 kHz frequency band based on the results given in Table 9. This new limit indicates approximately 10dB increase, including 3 dB correction for the receiver transfunction discussed before, from the existing limits. This pfd limit was calculated using the information on the spectrum usage in the United States.

TABLE 9

CHANGE IN pfd LIMITS, dB (W/m^2) IN ANY 4 kHz, FOR SATELLITES IN GEOSTATIONARY ORBIT

FREQUENCY PLAN	LATITUDE (deg)	SATELLITE SPACING (deg)			
		3	10	15	20
Single	20	0.0	4.5	8.8	8.9
Single	30	0.0	3.6	8.6	8.7
Single	40	0.0	3.4	8.0	8.3
Single	50	0.0	3.3	6.5	8.1
Double	20	1.5	8.4	11.7	11.9
Double	30	1.2	8.0	11.7	11.8
Double	40	1.0	7.4	11.0	11.2
Double	50	0.0	6.5	9.2	11.5
Four	20	4.5	11.9	14.4	14.5
Four	30	3.8	8.8	14.3	14.4
Four	40	3.7	8.5	14.1	14.3
Four	50	2.2	8.2	12.8	14.2

pfd Limits for Satellites in Non-Geostationary Orbits

It was shown earlier that the effects of interference from satellites in non-geostationary orbits are independent of those from satellites in geostationary orbit. Hence, the modified NGM computer model was used to evaluate the pfd limits for satellites in non-geostationary orbits. The effects on the pfd limits after a number of modifications to the NGM program were discussed previously in this section. Of these modifications frequency engineering of a trendline, receiver transfer function, and multi-orbit effects have significant impact on pfd limits in the 2025-2300 MHz frequency range.

The data in Section 4 were used in conjunction with the modified NGM simulation model to calculate the pfd limits for low-orbit satellites in the 2025-2300 MHz frequency range. The results of the calculations for single, double, and four-frequency plan of radio-relay trendlines are given in Figures 29, 30, and 31 respectively. The data in Figures 29-31 show the cumulative interference power level as a function of time at the input to receivers in a typical trendline in the 2025-2300 MHz frequency range. Curve E in Figures 29-30 show the criteria for noise due to interference in the hypothetical reference circuit established by the CCIR Recommendation 357-3 (1978). Note that the interference Curve B in Figures 29-31 differs from the criteria Curve E by 10, 13, and 16 dB for single, double, and four-frequency plan, respectively. The interference curves in these figures do not include the 3 dB correction due to the receiver transfer function discussed earlier. The case of double-frequency plan is of interest. A 13 dB increase to the interference in curve on Figure 30 will allow the noise due to interference to reach the noise criteria level accepted by the CCIR. Therefore, the pfd limit for the satellites in non-geostationary orbits may be increased by 16 dB without exceeding the noise criteria level set by the CCIR in the frequency range 2025-2300 MHz. The minimum pfd limits for non-geostationary satellites may then be increased to -138 dBW/m^2 in any 4 kHz bandwidth. The calculated pfd limits using modified NGM computer model are given in Figure 32.

Note that the shape of the curve in Figure 32 is not different from that originally recommended by the ITU Radio Regulations. The data in Figure 32 were obtained using spectrum usage data in the United States.

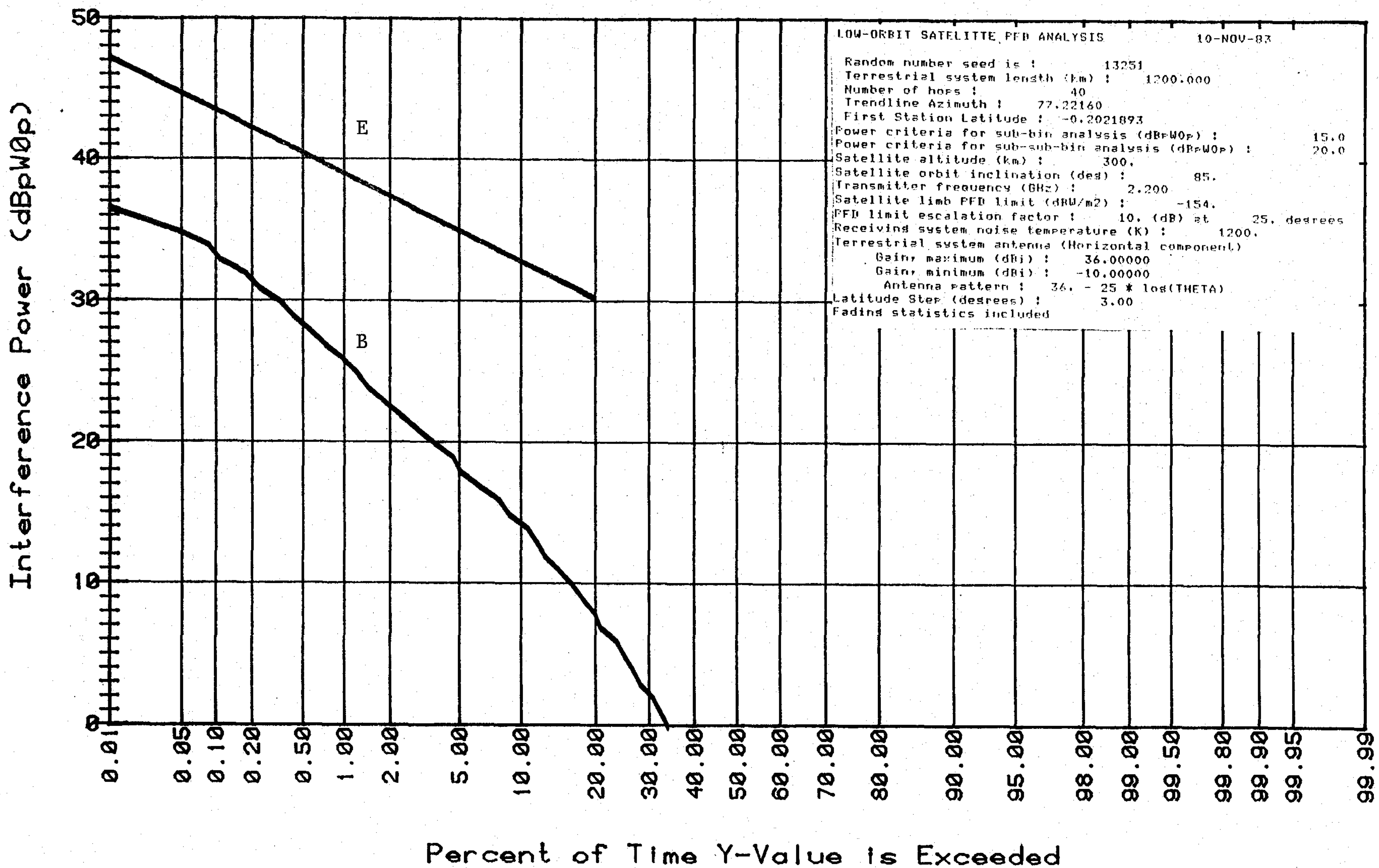


Figure 29 Interference Power From Eight Satellites in Non-Geostationary Orbits to Radio-Relay Receivers in a Trendline Using Double Frequency Plan.

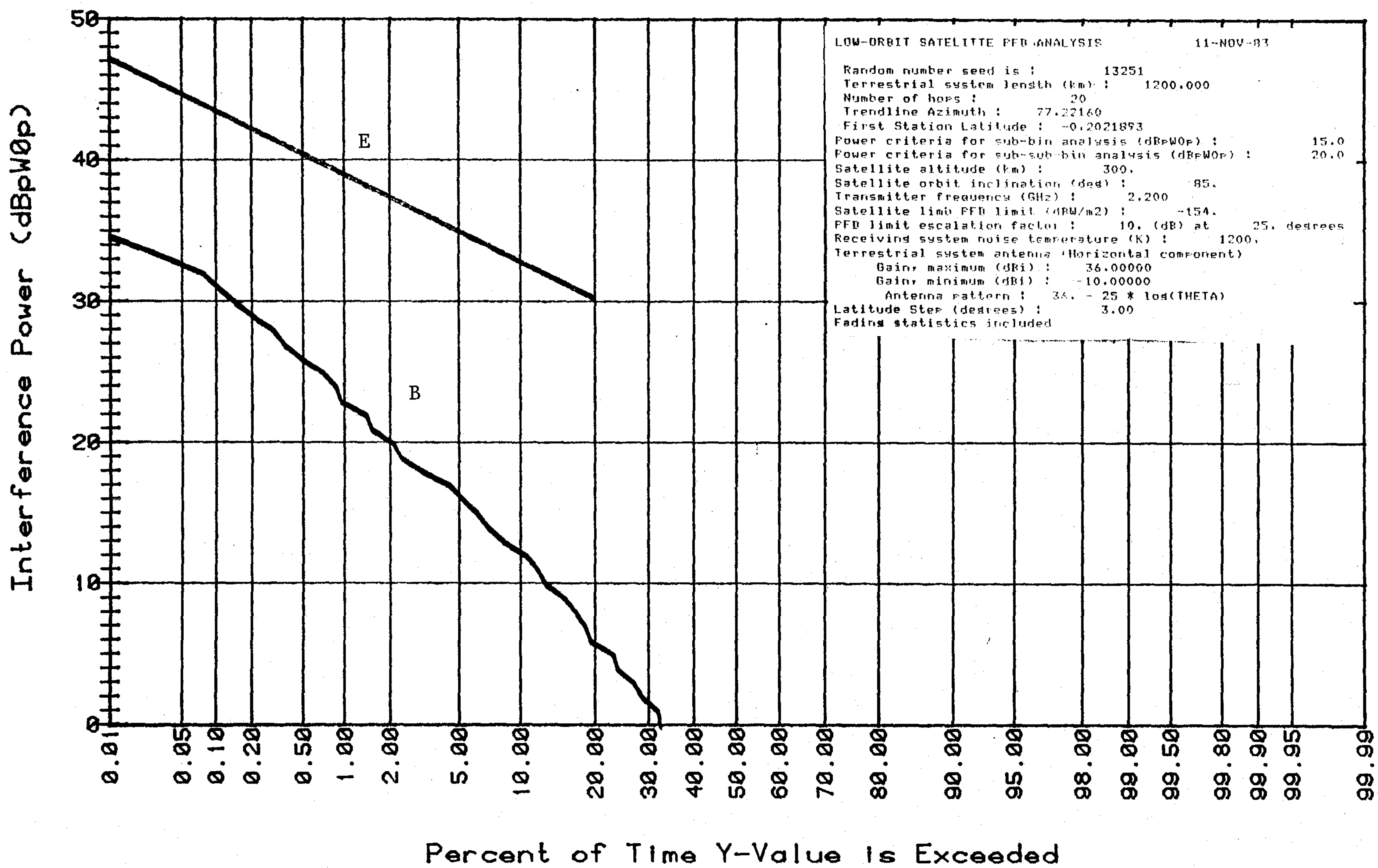


Figure 30 Interference Power From Eight Satelllites in Non-Geostationary Orbits to Radio-Relay Receivers in a Trendline Using Single Frequency Plan

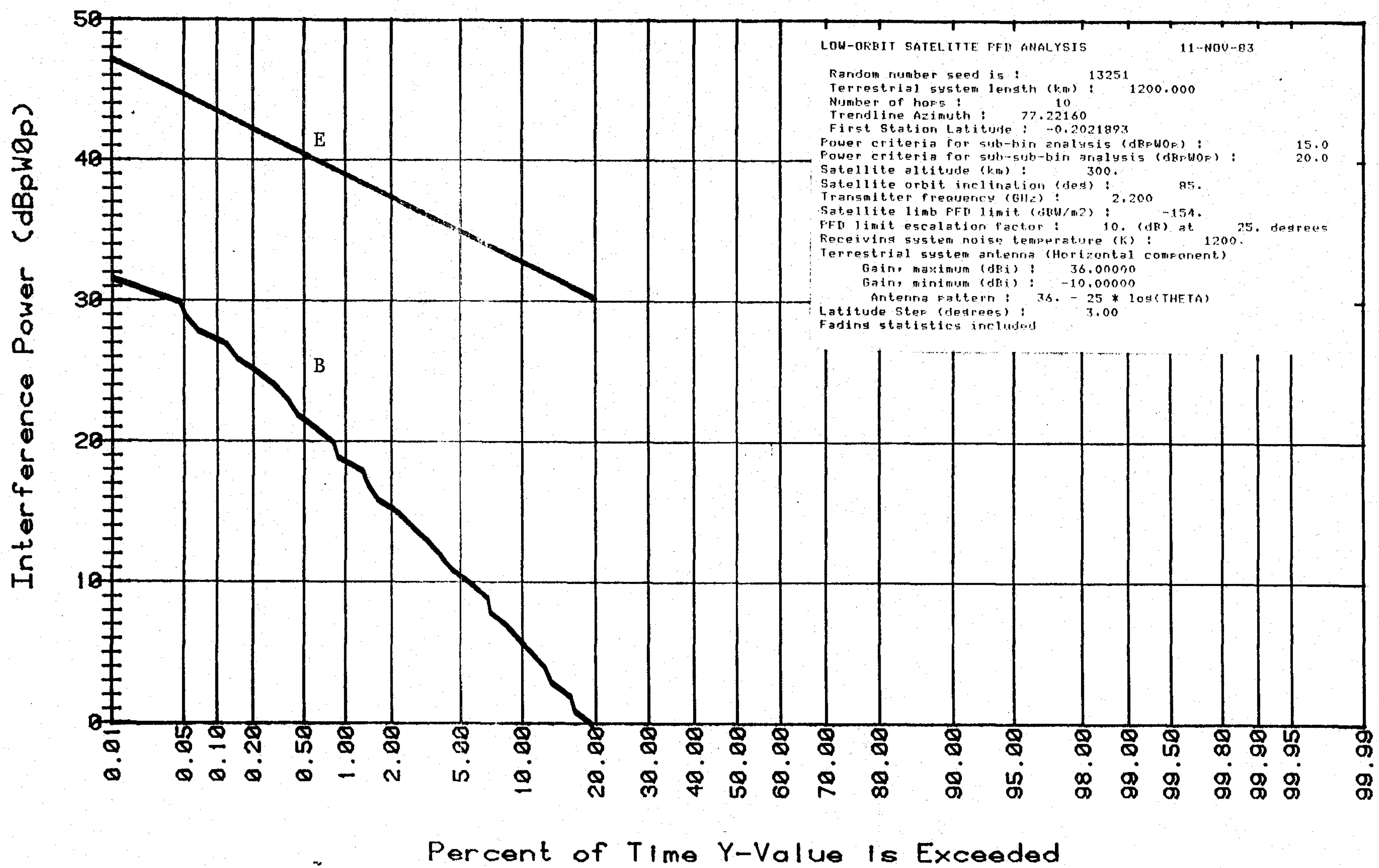


Figure 31 Interference Power from Eight Satellites in Non-Geostationary Orbits to Radio-Relay Receivers in a Trendline Uisng Frou Frequency Plan.

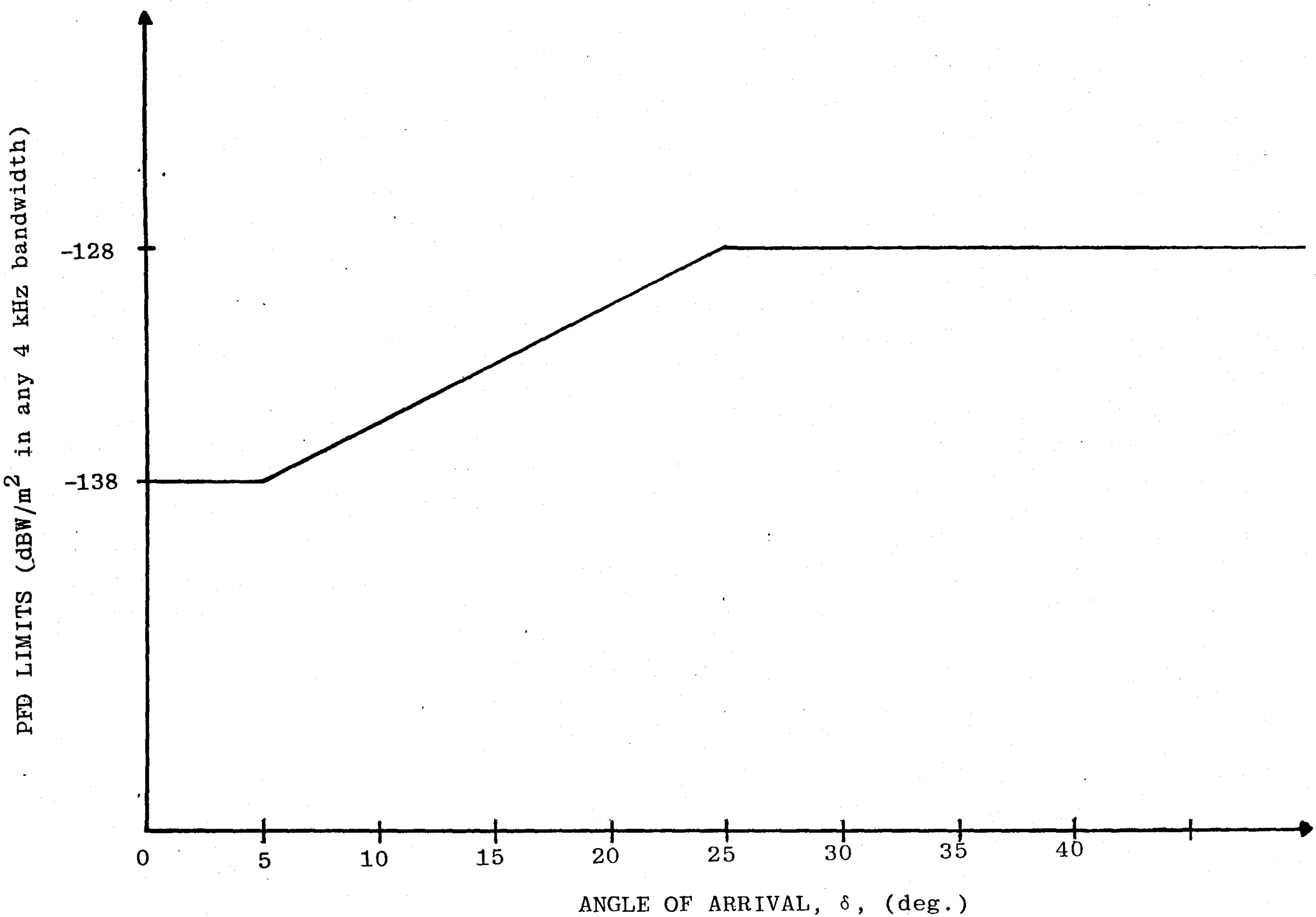


Figure 32 pfd Limits for Satellites in Non-Geostationary Orbits

SECTION 6

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(4-80)

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NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

	1. PUBLICATION NO.	2. Gov't Accession No.	3. Recipient's Accession No.
	NTIA REPORT 84-152		

4. TITLE AND SUBTITLE
ASSESSMENT OF SATELLITE POWER FLUX-DENSITY LIMITS IN THE 2025-2300 MHz FREQUENCY RANGE PART II

5. Publication Date
July, 1984

6. Performing Organization Code

7. AUTHOR(S)
Andrew Farrar

8. PERFORMING ORGANIZATION NAME AND ADDRESS
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
179 ADMIRAL COCHRANE DRIVE
ANNAPOLIS, MD 21041

9. Project/Task/Work Unit No.
9014103

10. Contract/Grant No.

11. Sponsoring Organization Name and Address
U.S. DEPARTMENT OF COMMNERCE/NTIA
179 ADMIRAL COCHRANE DRIVE
ANNAPOLIS, MD 21401

12. Type of Report and Period Covered
Technical

13.

14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The power flux-density (pfd) limits for satellites operating in the 2025-2300 MHz frequency range were calculated. Two computer models, one developed by the Bell Telephone Laboratories (BTL) and the other by the Systematics General Corporation (SGC), were used in the analysis. Modifications to these models were made in order to enhance their accuracy in the evaluation of the pfd limits in this and other bands. Distinctions were made between the satellites in geostationary satellite orbit and those in non-geostationary orbits. Two different sets of limits were calculated, one for the satellites in the geostationary satellite orbit and the other for the satellites in ono-geostationary orbits. These limits were calculated using the technical characteristics of equipment in the 2025-2300 MHz frequency range and the criteria of noise due to interference from satellites set by the CCIR Recommendation 357-3. The pfd limits calculated here for the 2025-2300 MHz frequency range are applicable in the portions of this frequency range authorized for use by space services. These limits were compared with the existing limits in the NTIA Manual and the analysis indicated that the pfd limits for satellites could be relaxed.

16. Key Words (Alphabetical order, separated by semicolons)

Computer Models; Determination of Power Flux Density Limits; Electromagnetic Compatibility; Power Flux Density; Systems in Space and Fixed Service Sharing; 2025-2300 MHz

17. AVAILABILITY STATEMENT	18. Security Class. *(This report)*	20. Number of pages
☒ UNLIMITED.	Unclassified	85
	19. Security Class. *(This page)*	21. Price:
☐ FOR OFFICIAL DISTRIBUTION.	Unclassified	

☆ U.S. Government Printing Office: 1980—678-495/529