NTIA REPORT 83 -135

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

PART I

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PART I

ANDREW FARRAR

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

David J. Markey, Assistant Secretary
for Communications and Information

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ABSTRACT

An assessment of the line-of-sight (LOS) power flux-density (pfd) limits for satellites operating in the 2025-2300 MHz frequency range was conducted. 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 suggested in order to enhance their accuracy in the evaluation of the pfd limits in this and other shared bands. Distinctions were made between the satellites in geostationary satellite orbit and those in nongeostationary orbits. Two different sets of limits were calculated, one for the satellites in the geostationary satellite orbit and the other for the satellites in nongeostationary satellite orbits. These limits were calculated using the technical characteristics of equipment in the 2025-2300 MHz frequency range. The preliminary calculations using the existing computer models indicate that the pfd limits for the satellites operating in this frequency range may 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

SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the radio spectrum allocated to the U.S. Federal Government. Part of NTIA's responsibility is to "...manage a program to identify potential sharing problems within specific frequency bands allocated to the Federal Government" (NTIA, 1982). The objectives of the program include the identification of potential band sharing problems which may impact the efficient use of the spectrum. The power flux-density (pfd) limits from the satellites on the surface of the Earth were identified as key factors affecting the compatible operation of the systems in the frequency ranges 2025-2300 MHz, 13.4-14.0 GHz and 14.5-15.35 GHz. This report treats the problem of establishing new pfd limits that continue to provide compatible operation between the space and terrestrial services in the 2025-2300 MHz frequency range. The pfd limits for the frequency ranges 13.4-14.05 and 14.5-15.35 GHz will be treated at a later date.

ORIGIN OF PFD LIMITS

The series of events leading to the present pfd limits in the ITU Radio Regulations was initiated during the 1959 World Administrative Radio Conference (WARC). A review of these events aid development of insight for the problem of determining pfd limits which provide compatible operation between satellite transmitters and terrestrial receivers in the 2025-2300 MHz frequency range. The space activities during the second half of the 1950's alerted the member administrations in the ITU to a new and different demand on the frequency spectrum. Thus far the spectrum management problems encountered among the ground-based emitters and/or airborne transmitters had been more regionally oriented and had not had large simultaneous global impacts as the spectrum sharing difficulties which were then surfacing between the spaceborne satellites and the systems in the Fixed and Mobile Services. Hence the need for new provisions to control spacecraft emission was evident.

Recommendation 36, prepared by the 1959 WARC, stated that an Extraordinary Administrative Radio Conference be convened during the latter part of 1963 with an agenda that was to include the following original item:

> . . . to adopt, if such action is considered desirable, new provisions revising the radio regulations to provide for the identification and control of radio emissions from space vehicles, taking into account possible recommendations of the CCIR (International Radio Consultative Committee).

Resolution No. 7 which was also adopted by the 1959 WARC identified two problem areas associated with the radio emissions from artificial satellites and other space vehicles and invited the CCIR and the members of the ITU involved in launching satellites to study the problems and to present the results of their studies to the CCIR.

Since the 1959 WARC, numerous reports and recommendations on the subject matter of pfd limits have appeared in the CCIR publications. A comprehensive compilation of basic derivation of all pfd limits in the ITU Radio Regulations was prepared by E.L. McHugh and R. Watson (1975). In addition, the report includes an extensive list of the published articles on the subject of the pfd limits.

Originally the pfd limit adopted by the ITU in each specific shared band was constant and did not vary with the angle of arrival of emission from satellites. The various studies made later (May and Pagones, 1971) showed that a relation between permissible pfd and angle of arrival was acceptable as far as the protection of radio-relay systems was concerned. The results of such studies were included later in CCIR Report No. 387-3 (1978).

Report 387 (1966) first published by CCIR Study Group 9 in 1966 and successively revised by 387-1 (1970), 387-2 (1974), and 387-3 (1978) has had significant impact on the pfd limits adopted by the ITU. Included in Report 387-3 are the pfd limits calculated for the 2500 MHz frequency. These limits were adopted by the ITU and the U.S. Government and were included in the NTIA Manual without any modification.

It should be pointed out that the present pfd limits in the shared bands were developed taking into account mainly the characteristics of satellites in the geostationary orbit in the 3.7-4.2 GHz and 5.925-6.425 GHz (4/6 GHz band) frequency ranges. This band had been fully developed and was of great interest to the non-Government users. The assumptions used in the analysis which led to the pfd limits presently in the ITU Radio Regulations are not entirely applicable to the systems presently operational in the 2025-2300 MHz frequency range.

In addition, pfd limits for low-orbit satellites have not been addressed separately in the ITU Radio Regulations or the NTIA Manual. These satellites often have distinctly different operational characteristics from those satellites in the geostationary orbit. Hence, it would often be unrealistic to impose pfd limits on the low-orbit satellites similar to those derived for satellites in the geostationary orbit.

This report treats the assessment of pfd limits in the 2025-2300 MHz frequency range. A review of the existing limits and the rationale as well as the assumptions used for their derivation are included. An assessment of the pfd limits for this frequency range is given using the same computer model developed earlier and used in the derivation of the pfd limits presently included in the ITU Radio Regulations. This computer model was developed by the Bell Telephone Laboratories (BTL) and will be referred to as the Geostationary Model (GM) in this report. The assessment given in this report was based on the technical characteristics of the operational and/or planned systems in the frequency range 2025-2300 MHz. A different computer model was developed for nongeostationary spacecraft by the Systematics General Corporation (SGC) under a contract with National Aeronautics and Space Administration (NASA). This Nongeostationary Model (NGM) was used to assess the pfd limits for low orbit satellites in this frequency range. As we shall see later, the NGM was designed for satellites in circular orbits at constant altitudes. Modifications to these computer models are suggested in order to provide the capability for more accurate determination of the pfd limits in this frequency range.

OBJECTIVES

The overall objective of this task was to assess the power flux-density limits required on the surface of the Earth from satellites in the 2025-2300 MHz frequency range. The following objectives were identified for this effort.

1. Identify the analysis approach used previously in the development of the present pfd limits given in the ITU Radio Regulations and the NTIA Manual.

2. Determine if the existing pfd limits for the LOS systems may be modified without jeopardizing the compatibility between the satellites and systems in the Fixed and Mobile Services that operate in the 2025-2300 MHz frequency range.

3. Identify and outline specific problem areas requiring additional analysis which will aid the determination of more appropriate pfd limits.

APPROACH:

The objectives require a comprehensive study to determine the impact of the potential interference from multiple satellites in the geostationary and lower orbits to a multihop LOS microwave radio-relay system in the 2025-2300 MHz frequency range. The potential co-channel interference from the satellites is complicated by the fact that such interference is often times dependent because of the fading of radiowave propagation in the Earth's atmosphere. In addition, the potential interference from nongeosynchronous or nongeostationary satellites to any one radio-relay system consisting of a number of repeater stations is intermittent because of the relative motion of the satellite with respect to the Earth. Based on the continuity of exposure, the impact of potential interference to systems in the Fixed and Mobile Services from a satellite in the geostationary orbit is different from satellites in other orbits. Hence, two different computer models were used to assess the pfd limits that can be tolerated by systems in the Fixed and Mobile Services in the frequency range noted above. These models consider the potential interference from satellites to systems in the Fixed Service. Generally, the systems in the Fixed Service are more susceptible than systems in the Mobile Service to the emissions from satellites in the orbits. The operational and technical characteristics of the systems in the Fixed Service were used in the assessment of the pfd limits for this frequency range. The assumptions made in the development of each computer model were identified, and the applicability of these assumptions to the systems presently in operation in the frequency range was assessed.

ITU and CCIR documents from 1959 were reviewed in order to develop an insight and to determine the approach used in the analysis which led to the existing pfd limits in the ITU Radio Regulations.

The technical characteristics appropriate to the systems in the 2025-2300 MHz frequency range were determined using the data obtained from the Federal Communications Commission (FCC), the manufacturers, Government Master File (GMF), NTIA System Review Files and NASA. The input data for the computer models were prepared using the characteristics for the systems in the frequency range. The calculated pfd limits were compared with the existing pfd limits in the CCIR. Several modifications to these programs were suggested for more in-depth analysis and determination of the pfd limits in this and other shared frequency ranges. A preliminary assessment of the effects of these modifications on the pfd limits for this frequency range was conducted using the available information in the literature.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

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

The present pfd limits protecting the Fixed Service using line-of-sight techniques in this 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 a 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 for angles of arrival between 0 and 5 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 and 25 above the horizontal plane;

-144 dB(W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 above the horizontal plane."

The symbol δ used here represents the angle of arrival. These limits relate to the pfd which would be obtained under assumed free-space propagation conditions. These same limits are contained in the NTIA Manual for systems in line-of-sight operation.

Two computer models, Geostationary Model (GM) and Nongeostationary Model (NGM) developed earlier for the determination of the pfd limits in the frequency bands shared between the systems in the Fixed Service and the satellites, were reviewed and found to be applicable for this assessment. Modifications to these programs, as described in this report and outlined in this section, are necessary before a final recommendation can be made on the pfd limits for the frequency range 2025-2300 MHz.

In the development of pfd limits, a distinction must be made between the satellites that operate in the geostationary orbit and those which operate in nongeostationary or low orbits. Terrestrial systems in the Fixed Service potentially receive constant emissions from satellites in the geostationary orbit whereas they receive intermittent emissions from satellites in low orbits.

GENERAL CONCLUSIONS

Modifications to the GM and NGM programs are necessary for the determination of the pfd limits in the 2025-2300 MHz frequency range. The following is a summary of these modifications described in the analysis section of this report.

1. The receiver transfer function used in both GM and NGM programs should be modified to include the effect of an interference reduction factor. A qualitative analysis indicated that the value of this reduction factor varies from approximately 4 to 19 dB depending on the modulation indices for the desired and undesired signals in the 2025-2300 MHz frequency range.

2. Fading effects should be incorporated in the GM computer algorithm to determine the time statistics of interference noise power into a radio-relay trendline. (a)

3. The effect of potential interference to radio relay receivers from nongeostationary 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 the fading data measured in Germany).

5. The computer models identified and investigated here are valid for calculating the pfd limits for analog systems in the Fixed Service using line-of-sight techniques. Digital systems in the band should be treated at a later date.

6. Systems in Mobile Service were assumed to be less susceptible to interference from satellites than the systems in the Fixed Service. However, systems in Aeronautical Telemetry Mobile Station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof will be considered in the follow-up analysis.

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 plane to approximately 50 degree latitude. The potential interference to terrestrial systems then decreases to 80 degree latitude, and beyond this only negligible interference may be experienced by the terrestrial systems. The worst interference occurs when the trendline for a terrestrial system is pointed toward the geostationary orbit. For example, this happens when the antennas of a trendline system in North America are pointed in a southerly direction.

2. In the northern hemisphere, a spacecraft in or near a polar orbit, operating in the 2025-2300 MHz frequency range, will illuminate a northerly directed radio relay trendline (The orbits traversed by the spacecraft are more concentrated in the polar region than in the equatorial zone). Therefore, the potential interference from spacecraft to a radio relay trendline in this frequency range is not always the sum total of maximum interference from the satellites in the geostationary and low orbits.

Note a. Communication link between two points with a number of repeaters constitute a trendline.

3. In the calculation of the pfd limits, the potential interference from a satellite to the systems in a radio relay trendline should include the interference from satellites in geostationary and nongeostationary orbits when the inclination angles for the non-geostationary orbit are not polar (less than approximately 60 degrees).

4. In the United States, the Government allocation in the subband 2200-2290 MHz is only for line-of-sight transmissions. Internationally, the band may be used by systems designed for tropospheric scatter transmission. The noise power criteria established by the CCIR for tropo systems are higher (i.e., less restrictive) than those for line-of-sight transmission, despite the fact that the systems using tropospheric transmission are more tolerant of noise power. The pfd limit from satellites to tropo systems should be investigated.

5. Operational and technical characteristics of the satellites and the terrestrial equipment in the 2025-2300 MHz frequency range considered in the analysis given in this report indicate that there is a potential for an increase in the pfd limits presently given in the NTIA Manual. The value of these new limits should be determined after the modifications have been made to the noted computer programs.

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 computer models described in this report be modified in accordance with the list of modifications given in the analysis section.

2. The task be continued to determine the appropriate pfd limits for geostationary and nongeostationary satellites in the 2025-2300 MHz frequency range.

SECTION 3

ALLOCATIONS AND PFD CRITERA

ALLOCATIONS

A summary of the current International Allocations for the 2025-2300 MHz frequency range is given in Table 1. Footnotes for Table 1 are given in Appendix A. In Region 2, which includes the United States, the entire frequency range is allocated on a primary basis to the Fixed and Mobile Services. The Space Research Service has a primary allocation in the subband 2290-2300 MHz. Earth-to-space, space-to-space, and space-to-Earth transmissions in the Region may be used on a primary basis in the various portions of the 2025-2290 MHz frequency range as indicated in footnotes 747, 748, 749, and 750 given in Appendix A. The spectrum use support by these footnotes is subject to obtaining international agreement as described in Article 14 of the ITU Radio Regulations. Also systems using space-to-space transmissions shall not cause harmful interference to the other space services and their received power at the surface of the Earth shall not exceed the power flux-density limits set forth in ITU Radio Regulations Nos. 2557 to 2560.

Nationally, the various portions of the 2025-2300 MHz frequency range are allocated to the Fixed, Mobile, Space Research and Space Operation Services. Table 2 shows that the non-Government Fixed and Mobile Services have primary allocation in the 2025 to 2110 MHz range and non-Government Fixed Service has primary allocations in the 2110-2200 MHz subband.

Four footnotes (US90, US111, US219, US222), given in Appendix A, provide for the Government Space Services which may be authorized in the frequency range 2025-2200 MHz. The 2200-2290 MHz subband is strictly for the Government use while the 2290-2300 MHz subband is shared between the Government and non-Government users. In the 2200-2290 MHz subband the primary allocation for Fixed and Mobile Services are restricted to stations using the line-of-sight (LOS) mode of operation. Note that this restriction applies only to the U.S. Table of Allocation.

Since WARC-79 the Table of Allocations in the frequency range 2025-2300 MHz has been under review by the Interdepartment Radio Advisory Committee (IRAC). The significant modifications made in the table are stated in footnotes US90, G101 as well as US252 which is a new addition. These footnotes are also given in Appendix A. These changes indicated in Table 2 brought closer agreement between the United States and the International Tables of Allocations. In this frequency range 2025-2110 MHz, the Space Research and Earth Exploration Services are permitted subject to the provisions of power flux-density limits delineated in the modified footnote US90.

PFD CRITERIA

The ITU Radio Regulations make a distinction between the LOS and the troposcatter transmissions. This distinction was due to the fact that noise power requirements recommended by the CCIR for the two methods of transmission were different. As a result, the pfd criteria for LOS transmission are different from those specified for the systems using troposcatter techniques. These criteria are discussed here.

TABLE 1

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

MHz
1710-2300

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)**	

For footnotes see Appendix A:

TABLE 2

EXCERPTS FROM THE PROPOSED U.S.
TABLE OF ALLOCATIONS (1990-2300 MHz) [a]

UNITED STATES				
Band MHz 1	National Provisions 2	Government Allocation 3	Non-Government Allocation 4	Remarks 5
1990-2110	US90 US111 US219 US222		FIXED MOBILE NG23 NG118	
2110-2200	US111 US219 US222 US252		FIXED NG23	
2200-2290		FIXED (LOS*only) MOBILE (LOS only including aeronautical telemetering, but excluding flight testing of manned aircraft) SPACE RESEARCH (Space-to-Earth) (Space-to-space) G101		*Line of sight
2290-2300		SPACE RESEARCH (Space-to-Earth) (Deep Space Only) FIXED MOBILE except aeronautical mobile	SPACE RESEARCH (Space-to-Earth) (Deep Space Only)	

a Footnotes in this Table are given in Appendix A. Footnotes US90 and G101 in this Table are modified. The modified US90 and US101 are given in Appendix A.

Line-of-Sight Systems

The pfd limits in the ITU Radio Regulations were derived using the recommended CCIR interference power levels in a hypothetical reference circuit for analog radio-relay systems. The maximum allowable values of interference in a telephone channel of an analog angle-modulated radio-relay system sharing the same frequency bands with the systems in the Fixed Satellite Service are given in CCIR Recommendation 357-3. This recommendation was unanimously approved in 1978 and stated that:

"...systems in the Fixed Satellite Service and line-of-sight analog 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, analog 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 transmitters, should not exceed:

1.1 1,000 pWOp psophometrically-weighted one-minute mean power for more than 20% of any month;

1.2 50,000 pWOp psophometrically-weighted one-minute mean power for more than 0.01% of any month."

This recommendation further specified that the way in which the above interference noise power levels are to be taken into account in the general noise objective for radio-relay systems is defined in CCIR Recommendation 393-3. The data in this latter recommendation take into account the effects of fading.

The pfd limits which were adopted by the CCIR and derived using the allowable noise power levels given above are included in Section IV, Article 28 of the ITU Radio Regulations, Edition 1982. Of particular interest, are the provisions in Nos. 2556-2559 which are applicable to line-of-sight systems in the 2025-2300 MHz frequency range and are reproduced here for easy reference.

"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(δ-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 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 No. 2557 are applicable to space services in the 2025-2110 MHz and 2200-2290 MHz frequency ranges by footnotes 747 and 748 of the International Table of Allocations. All of the pfd limits mentioned above have been adopted by the United States and are now in Chapter 8 of the NTIA Manual.

As was mentioned above, the pfd limits presently adopted by the ITU are applicable to analog systems. Digital systems in the Fixed and Mobile Services were assumed to be capable of functioning properly if the established pfd limits in the ITU Radio Regulations are not exceeded. A number of papers in the CCIR treat the problem of probability of bit error rate for digital systems as a function of signal-to-noise and/or signal-to-interference ratios. For the protection of high-capacity terrestrial radio relay systems employing digital modulation techniques, the following recommendations were submitted (CCIR Doc. 4/347-E, 1981):

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

"the % of any month for which a bit error rate of 1×10^{-3} 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 modulation.

The above limits for the digital modulation are based on the currently available information and are subject to review in the future by the CCIR. These limits appeared in a number of CCIR papers which treated specific radio-relay systems. The question remains unanswered as to whether or not the error rates mentioned above will be satisfied when digital systems are exposed to signals at levels equal to the pfd limits developed by the CCIR for analog systems.

Troposcatter Systems

The allowed interference power levels specified in CCIR Recommendation 357-3 are for the analog radio-relay circuits used for the line-of-sight (LOS) transmission. Troposcatter radio-relay (sometimes referred to as transhorizon radio-relay) systems are also required to operate within specific allowed noise power levels. 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 excessive 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.

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.

According to Recommendations 397-3 and 393-3, all the values given in Table 3 include the intermodulation noise in the radio part of the system. On the other hand, noise within the frequency-division multiplex equipment is excluded. On a hypothetical reference circuit 2500 km long, the CCITT authorizes a mean value of 2500 pW for this latter noise.

Provisions in No. 2560 of ITU Radio Regulations are for systems which are designed to operate using tropospheric scatter. Although these systems do not have allocations in the 2200-2290 MHz subband in the United States, internationally these systems may operate in the 2025-2300 MHz frequency range and are protected against potential interference from a spacecraft under the provisions of No. 2560 which are as follows:

> "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."

SECTION 4

EQUIPMENT CHARACTERISTICS IN THE 2025-2300 MHz FREQUENCY RANGE

INTRODUCTION

This section discusses the technical characteristics of the operational and planned equipment in the 2025-2300 MHz frequency range. Typical data obtained from these characteristics were used in the analysis given later to assess the pfd limits for this frequency range. For this assessment the equipment in the frequency range were categorized according to the allocated services. As was mentioned before, there are five services which have allocations in various portions of this frequency range. These services are: Fixed, Mobile, Space Research, Space Operation and Earth Exploration Satellite. Fixed and mobile equipment were divided into Government and non-Government categories. In the analysis the technical characteristics of the equipment in the Fixed Service and the operational parameters of the satellites in this frequency range were used.

SYSTEMS IN FIXED SERVICE

The majority of the equipment operating in the non-Government portion of the frequency range is manufactured by less than a dozen U.S. companies and is used for commercial communication (audio and video) purposes. A partial list of the typical characteristics of the commercial equipment designed to operate in this frequency range is given in Table 4. The data in this table were obtained from the FCC and through private communications with the appropriate U.S. manufacturers. For the analysis given here, parameters, such as receiver noise temperature, number of stations in a trendline, separation between stations in a trendline, modulation type and modulation indices, were needed. The term "trendline" used here implies a radio-relay circuit designed to establish communication between two locations with a number of relay stations (hops). Non-Government radio communication systems in the Fixed Service are not expected to have more than 40 hops in a trendline with separation distances between stations not exceeding 30 km. Communication systems for video transmission are often used by the news media for neighborhood television news coverage. These systems are transportable and their communication links are shorter in length than the links used by the systems in Fixed Service.

The performance of equipment manufactured and marketed in the United States is similar for all commercial communication products in the 2025-2200 MHz frequency range. Therefore, it is possible to define typical data which are representative of the technical characteristics and operations of commercial communication equipment in this frequency range.

In contrast to the 2025 to 2200 MHz range, the remaining part of the frequency range (2200-2300 MHz) is for Government use with the exception of non-Government allocation to space-to-Earth (deep space only) transmission in the subband 2290-2300 MHz. It should be pointed out that the Government Fixed and Mobile Services in the subband 2200-2290 MHz are for the line-of-sight (LOS) operation only. The key parameters related to the analysis given here for the terrestrial systems operating in the Fixed Service are given in Table 5. The systems in the Fixed Service are generally characterized by the station class FX, FXR, FXD, FXDR, FXE, and FXER. The average transmitter power for these systems is less than 20 watts and their directional antennas provide a

TABLE 4

TYPICAL CHARACTERISTICS OF NON-GOVERNMENT TERRESTRIAL EQUIPMENT IN THE 2025-2300 MHz FREQUENCY RANGE

TUNING RANGE (MHz)	EMISSION DESIGNATOR	IF BW (MHz)	NO. OF CHANNELS	RMS DEV/CH (kHz)	RX THRESHOLD (-dBM)	DESIGN SIGNAL LEVEL (-dBM)	NOISE TEMP (K°)	TX POWER (Watts)	NOISE FIGURE (dB)	MOD IND	APPLICATION	ANTENNA GAIN (dBi)
2130 - 2150 2180 - 2200	800F9	1-3	24 36 48	41.8 33 26	98.6 88.3 83.9	30 45 40	880	1.2 to 4.8	6	.1 to .5	VOICE COMMUNICATION (MICROWAVE RADIO)	
	1600F9	2.5	48 72 96	79.8 63 46.9	93.0 88.2 83.0	50 45 40						
2110 - 2130 2160 - 2180	3500F9	5.6	132 252	134 65	90.3 81.0	45 35						
2130 - 2300	800F9 1600F9	2.5 6.0	24 48 72	200		33 45	1540	1 to 5	8			
2150 - 2300	800F9 1600F9		12 24 72 to 300	35 30 60	86 88	36 47	2000	1 to 15	9			26 to 35
2100 - 2300	800F9 1600F9	2.5	24 48 96		98 88.5 87.5	33	620		5			
1990 - 2110		30 8 16		1,7,21 75			440	2 to 12	8 4		TELEVISION AUDIO AND VIDEO TRANSMISSION	16 to 24

TABLE 5

TYPICAL CHARACTERISTICS OF GOVERNMENT FIXED SERVICE EQUIPMENT IN THE 2025-2300 MHz FREQUENCY RANGE

EMISSION DESIGNATOR	IF BW (MHz)	STATION CLASS	# OF ASSIGN-MENTS	AGENCY	RX SENSITIVITY (-dBm)	TX POWER WATTS	NOISE FIGURE (dB)	FUNCTION	ANTENNA GAIN	
									TX (dBi)	RX (dBi)
135KFA-30MFZ	1-30	FX	87	AR, CIA, CG, N, AF, DOE, FAA, TRAN	78 to 105	1-20	8-16	Pt-to-Pt TELEMETRY TELECOMMAND	6-40	12-40
200KFA-1MFA	12	FXD	2	N, DOE		5-10	8	TELECOMMAND	21-30	21-30
500KFA-3MFA	.5-30	FXE	51	AF, DOC		0.1-20	8-11	TELEMETRY	3-30	3-42

maximum gain less than 40 dBi. Examination of the data given in Tables 4 and 5 shows that the typical data listed below are reasonable estimates for the parameters needed in the analysis for both Government and non-Government equipment given in these tables.

Fixed Service Typical Characteristics

The typical data required for the pfd analysis in the frequency range 2025-2300 MHz were extracted from the information given in the last sub-section. The data were used to prepare input parameters for the computer models used in the analysis. The input parameters for the computer models are given in Appendix B.

The analysis data for the Government and non-Government equipment are as follows:

Receiver Noise Temperature	1200 K
Number of Stations in a Trendline	40
Separation between Stations	30 km
Maximum Antenna Gain	36 dBi
Receiver Interference Threshold	14 dBrnco
Feeder Loss	3 dB
Branching Loss	0 dB
Antenna Pattern	CCIR Pattern (Report 614-2)

The rationale for the selected values given above will now be discussed. The receiver noise temperature and maximum antenna gain given above were extracted from the information in Table 5. 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 kelvins 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 sensitivity type receiver operating at 2500 MHz. The noise temperatures for the system discussed in Table 4 vary 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 2025-2200 MHz frequency range is representative for the systems in this frequency range.

The receiver interference threshold level equal to 14 dBrnco corresponds to 25pw 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 maximum for this frequency range. The assumption of 40 hops in a trendline is conservative. Nationally, the assumption is applicable to non-Goverment radio-relay communication systems which have received spectrum support in the 2110-2200 MHz frequency range. 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). However, internationally the band usage is different and the assumption of 40 hops in a trendline is not out of line with the 50 hops given in the CCIR hypothetical reference circuit. Three dB feeder loss listed above includes the loss for 33 feet of rigid waveguide and 0.5 dB connector loss. Branching loss was assumed to be equal to zero and space diversity used in at least some of the sites in a trendline was not considered in the analysis.

SYSTEMS IN SPACE SERVICES

The spectrum allocation rules and regulations in the United States have authorized spectrum supprt to a variety of satellites in the 2025-2300 MHz frequency range. The use of this frequency range for Space Research and Space Operation Services is by systems primarily operated by the U.S. Air Force and NASA. The space systems and their operational orbits currently in use are given in Table 6. With the exception of five satellites which are in highly elliptical orbits, all the satellites in this frequency range were assumed to be in circular orbits. Low orbit satellites are used for different operations, such as, earth exploration, deep-space-research and space operations. A more careful description and missions of the satellites in this frequency range are covered in the NTIA Report No. 80-48 (Flynn, 1980). Examination of the data in Table 6 indicates that not all the satellites in this frequency range are currently in operation. The dates which the planned systems are expected to become operational are subject to change and are not given. Table 6 includes only the U.S. satellites. A list of the satellites in operation or planned by administrations other than the United States is given in Table 7. The number of satellites in this frequency range registered by other administrations is not large relative to those in Table 6. However, in the analysis the number of satellites chosen was such that it simulates the effect of the satellites currently used by administrations other than the United States.

Typical Characteristics of Satellites

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

Satellite Orbit Altitude (km)	400-1200
Number of Satellites in the 1100 km Orbit visible at any one time	8
Number of Satellites in the Geostationary Orbit	15
Satellite Inclination Angles (deg.)	90-99
Modulation Index for Low Orbiting Satellites	0.8 to 1.6
Modulation Index for Satellites in the Geostationary Orbit	0.3 to 2
Separation Between Satellites (deg.)	10 to 20

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. The input data for the computer programs are given in Appendix B. The rationale for the satellite parameters used in the analysis is as follows.

TABLE 6

U.S. SATELLITES IN 2025-2300 MHz FREQUENCY RANGE

ORBIT	SPACE SYSTEMS	NATIONAL STATUS	IFRB STATUS	OPERATIONAL STATUS
ON MOON	ALSEP 1-5			INACTIVE
HE	AMPTE	SR(3)	AP(prep)	PLANNED
LO	COBE(TDRSS)			PLANNED
HE	DE-A	SR(3)	AP	ACTIVE
HE	DE-B	SR(3)	AP	ACTIVE
LO	ERBS(TDRSS)	SR(prep)	AP(prep)	PLANNED
LO	EUVE(TDRSS)			PLANNED
DS	GALILEO	SR(3)	AP(prep)	PLANNED
G	GOES-3			ACTIVE
G	GOES-4 (D)			ACTIVE
G	GOES E, F			PLANNED
LO	GRO(TDRSS)	SR(3)	AP(prep)	PLANNED
LO	IRAS	SR(3)	AP	PLANNED
HE	ISEE-1 (A)	SR(3)	AP	ACTIVE
HALO	ISEE-3 (C)	SR(3)		ACTIVE
HE	IUE		AP	ACTIVE
LO	LANDSAT		REG	ACTIVE
LO	LANDSAT-3 (C)			ACTIVE
LO	LANDSAT-D(TDRSS)	SR(3)	AP	ACTIVE
LO	NIMBUS-6 (F)			ACTIVE
LO	NIMBUS-7 (G)		AP(prep)	ACTIVE
DS	OPEN			PLANNED
DS	PIONEER 6-11		REG	ACTIVE
LO	SME(TDRSS)	SR	AP	PLANNED
LO	SMM(TDRSS)	SR(3)	AP REG(prep)	ACTIVE
LO	ST	SR	AP	PLANNED
LO	STS(TDRSS)	SR(2)	AP(prep)	PLANNED
G	TDRSS-E,W,C	SR(3)	AP, REG(prep)	PLANNED
LO	UARS-A&B			PLANNED
DS	VIKING 1 LAND	SR(4)	AP REG	ACTIVE
DS	VOYAGER 1	SR(3)	REG	ACTIVE
DS	VOYAGER 2	SR(3)	REG	ACTIVE

(Continued)

TABLE 6 (cont)

U.S. SATELLITES IN 2025-2300 MHz FREQUENCY RANGE

ORBIT	SPACE SYSTEMS	NATIONAL STATUS	IFRB STATUS	OPERATIONAL STATUS
LO	Block 5D (DMSP)	SR(4)	AP	ACTIVE
G	GPS/NAVSTAR	SR(4)	AP REG	ACTIVE
G	IRV	SR(2)		UNKNOWN
G	LES 8.9	GMF		ACTIVE
LO	P78-1	SR(4)	AP COORD*REG*	ACTIVE
LO	P78-2	SR(4)	AP CORD REG	ACTIVE
LO	P80-1	SR(3)	AP CORD	PLANNED NOV 82
	SAMS026-70			UNKNOWN
G	DSCSII IND OCN			ACTIVE
G	DSCSII ATL			ACTIVE
G	DSCSII EPAC			ACTIVE
G	DSCSII WPAC			ACTIVE
G	DSCSIII IND OCN	SR(3)		PLANNED
G	DSCSIII ATL	SR(3)		PLANNED
G	DSCSIII EPAC	SR(3)		PLANNED
G	DSCSIII WPAC	SR(3)		PLANNED
G	FLTSATCOM IND OCN			ACTIVE
G	FLTSATCOM ATL			ACTIVE
G	FLTSATCOM EPAC			ACTIVE
G	FLTSATCOM WPAC			ACTIVE
G	FLTSATCOM IND OCN	SR(4)		PLANNED
G	FLTSATCOM ATL	SR(4)		PLANNED
G	FLTSATCOM EPAC	SR(4)		PLANNED
G	FLTSATCOM WPAC	SR(4)		PLANNED

SR = System review (stage of review)

GMF = Frequency Assignment in GMF

AP = Advanced Publication

COORD = Frequency assignment 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 been completed.

LO = Low orbiting

HE = Highly Elliptical

G = Geostationary

DS = Deep Space

TABLE 7

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

ORBIT[a]	SPACE SYSTEM	COUNTRY	IFRB STATUS	DATE OF USE
HE	EXOS	FRANCE	AP	DEC. 1981
G	LSAT	FRANCE	AP	1985
LO	SPOT	FRANCE	AP	JUNE 1984
LO	SPOT 2	FRANCE	AP	JUNE 1985
G	TDF-1	FRANCE	AP	1984
G	TELECOM 1A	FRANCE	COORD	JULY 1982
G	TELECOM 1B	FRANCE	COORD	JULY 1982
G	TELECOM 1C	FRANCE	AP	---------
HE	IC2	FRANCE	AP	1977
LO	ERS	FRANCE		PLANNED
G	TV-SAT	GERMANY	AP	1984
LO	ASTRO-A	JAPAN	AP	1981
LO	ASTRO-B	JAPAN	AP	1983
G	BS-2	JAPAN	COORD	FEB. 1984
G	CSE	JAPAN	AP	FEB. 1977
G	CS-2A	JAPAN	COORD	FEB. 1983
G	CS-2B	JAPAN	COORD	NOV. 1983
HE	ETS-IV	JAPAN	AP	1981
G	TELEX	SWEDEN	AP	1986
G	PROGNOZ 1	USSR	COORD	1982
G	PROGNOZ 2	USSR	COORD	1982
G	PROGNOZ 3	USSR	COORD	1982
G	PROGNOZ 4	USSR	COORD	1982

a. The abbreviations in this column are described in Table 6.

A breakdown for the majority of the satellites in Table 6 is given below:

ORBIT	NUMBER OF SATELLITES	ACTIVE	PLANNED
Low Orbit	21	10	11
Geostationary	19	13	6
Deep Space	6	4	2
Highly Elliptical	5	4	1

The above data indicate that 42 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 expected to be up to 10 years. The low orbit satellites in this frequency range operate at altitudes between 400 to 1200 km. The active low orbit satellites in the frequency range are launched in several orbits with a maximum of six U.S. satellites at higher altitudes of approximately 1100 km. The majority of the satellites are in the 800 to 900 km altitudes. The planned satellites may use higher altitudes. Since the satellites in the higher altitudes are more visible to the terrestrial systems, 1100 km altitude was used in the analysis. In the computation, the number of satellites in this orbit was increased from six to eight in order to account partially for the effects of the satellites in the 800 to 900 km orbits. The inclination angles for the majority of low orbit satellites range from 90 to 99 degrees. There are approximately six U.S. satellites in the frequency range 2025-2300 MHz which may have inclination angles as low as 30 degrees. In the analysis given here, the computation was carried out for the satellites in polar orbits. The computation of the pfd limits which takes into account the effects of satellites in low inclination angles (less than 60 degrees) remains to be carried out in a follow-up effort. The majority of satellites in the frequency range 2025-2300 MHz are digital systems each with the capability to operate with multiple modes. The equivalent modulation indices for the different modes of operation for the low orbiting satellite from 0.8 to 1.6 and for the geostationary satellites from 0.3 to 2.0. The modulation indices given here are directly applicable to those satellites not associated with TDRSS (Tracking Data Relay Satellite System) which have a spread spectrum modulation with suppressed carrier. These satellites use BPSK signal which is characterized by phase variation of $\pm \pi/2$. The maximum phase variation for this signal is π which defines the worst-case bandwidth requirement for the signal.

SECTION 5

ANALYSIS

GENERAL

A review of the CCIR documents indicates that since the emergence of the space services, efforts have been made to limit the radio frequency noise due to interference from spacecraft emission in the telephone channels of existing radio-relay systems to a fraction of the total noise in those systems. In addition, maximum allowable interference power in a telephone channel had to be specified in order to facilitate the determination of the maximum pfd from communication satellites that can be tolerated by the terrestrial systems at the surface of the Earth. The pfd limits currently in the ITU Radio Regulations were given earlier in this report. The noise power limits due to the potential interference from satellites to a terrestrial system in the Fixed Service mentioned earlier in the report (CCIR Recommendation 357-3) were internationally accepted in the shared frequency bands.

The pfd limits in the frequency range 2025-2300 MHz, a result of 15 years of development, have progressed from the original single limits of -154 dBW/m^2 in any 4 kHz band, applicable under all conditions, to a set of limits that varies with the angle of arrival of radio frequency energy from satellites. In the derivation of these limits, only the effect of geostationary satellite emissions upon the systems in the terrestrial Fixed Service was taken into account. The pfd limits in this frequency range are not time-dependent even though the interference noise power levels from satellites given in Recommendation 357-3 are a function of time.

As was mentioned earlier in Section 4, some of the systems in the space services are in the geostationary orbit and the remaining systems used for space research, meteorological and earth exploration purposes are in low orbits. To a system in the Fixed Service, a geostationary space station appears as an ever-present source of energy. Distinction must be made between transmitters in the geostationary orbit and those in low orbits. The emissions from spacecraft in low orbits are time-dependent because of the relative motion of the spacecraft with the Earth. The received power on the surface of the Earth from satellites in low orbits is also a function of spacecraft orbital parameters (height angle) and antenna patterns. An analysis of pfd limits in the 2025-2300 MHz frequency range should take into account the effects and the consequences of this distinction. Hence, the distinct features of operation of satellites in the low orbits may make it necessary to adopt a set of pfd limits for these satellites that may be different from those for satellites in the geostationary orbit.

The determination of the present pfd limits within the CCIR was based on a statistical approach incorporated in the Geostationary Model (GM), a computer simulation program prepared by the BTL. This model was used to calculate the pfd limits at 2.5 and 4 GHz. The results of the computation are given in CCIR Report No. 387-3. In the calculation given in Report No. 387-3, the following technical data were used to represent terrestrial and space systems at 2.5 GHz frequency:

Frequency..........................2500 MHz
Hop length (km)....................50
Number of hops.....................50
Maximum Antenna gain (dBi).........38
Feeder loss (dB)...................3
Receiver noise temp (k)............750
Channel thermal noise
  power per hop (pWop).............25
Satellite spacing (deg.)............3

The GM computer model as used in CCIR Report No. 387-3 made use of the following assumptions (the appropriateness of these assumptions for systems operating in the 2025-2300 MHz range are discussed later):

1. Satellites operating in the geostationary orbit produce maximum allowable pfd's on the surface of the Earth.

2. The entire geostationary orbit visible to the trendline is filled with satellites separated by three-degree spacing.

3. Short term effects of low orbiting satellites were not directly considered.

4. The azimuth angle of each radio relay system (trendline) was assumed to be a random variable. This random variable has a uniform distribution and varies between 0 and 2π.

5. The antenna direction for each radio-relay station in a trendline is a random variable with uniform distribution within $\pm$ 25 degrees of the trendline direction.

6. The radio-relay receiver transfer function is defined by the approximate relationship:

$$\frac{i_c}{n_c} = \frac{i_4}{n_4} \qquad (1)$$

where:

i_c = Baseband interference power
n_c = Baseband noise power
i_4 = Interference at the input to receiver
n_4 = Noise power at the input to receiver

Equation 1 has the underlying assumption that the emission spectrum from satellite transmitter is flat (noiselike) over the entire bandwidth of the radio-relay receiver.

7. The antenna pattern for the receivers in the radio-relay system was of the form:

$$G(\gamma) = \begin{cases} 38 & (\text{dBi}) \quad 0^{\circ} \leq \gamma \leq 48^{\circ} \\ 30 - 25 \log \gamma & (\text{dBi}) \quad .41^{\circ} \leq \gamma \leq 40^{\circ} \\ -10 & \qquad\qquad\qquad \leq 40^{\circ} \end{cases}$$

8. The terrestrial radio-relay systems use only analog receivers.

9. Fading effects which are time-dependent and vary with location of radio-relay receivers were not considered.

10. Space diversity, often used to avoid multipath effects, was considered to have negligible effects on the results.

11. The frequency of the satellite transmitters in the visible orbit remains on-tune with all the receivers in a radio-relay trendline.

12. The potential interference power from the spacecraft to each radio-relay station in a trendline is noiselike and hence is additive.

As was mentioned earlier, the present pfd limits for the 2025-2300 MHz frequency range given in the ITU Radio Regulations and the NTIA Manual are applied to satellites in both geostationary and low orbits even though these limits were derived using primarily the characteristics of the satellites in the geostationary orbit in the frequency range near 4 GHz. The distinguishing features which exist in the operation and the technical characteristics of satellites in the geostationary orbit as compared to those in the low orbits make it necessary to use a different set of pfd limits for satellites in the low orbit. In contrast with satellites in the geostationary orbit, satellites in low orbits are not constantly visible to terrestrial systems in the Fixed Service. These satellites do not remain in the same position because of their relative motion with respect to the Earth. In addition, they are often launched in a low and nearly circular orbit with the exception of a very few special satellites which follow a highly elliptical orbit. Satellites at low altitudes are less visible to the terrestrial systems in the Fixed Service than those in the orbits with greater altitudes. Generally, the design of the satellites in low orbits is such that their RF transmitters are turned off except for a short duration when they communicate with their associated ground stations. Hence, the interference noise from the low orbit satellites is time-dependent. This time-dependent interference is related to the visibility duration statistics of these satellites by the terrestrial systems in the Fixed Service. In addition, the level of this potential interference is a function of the angular separation between the pointing direction of the ground system receiving antenna and the spacecraft transmitter. This angular separation varies as a function of the relative motion of the spacecraft with respect to the Earth. Obviously, a statistical approach is well suited for determining the pfd limits for these satellites.

The above mentioned time-dependent statistics were incorporated in the computer program called NGM which is an extension of the GM program. The NGM program was used to determine the pfd limits for low orbit satellites. The results of a previous analysis for these satellites were presented to the CCIR Study Group 4 in Locke (1981). Several significant assumptions were made in the development of this model. These assumptions were as follows:

1. All victim radio-relays in a trendline operate on the same frequency used by the interfering satellites.

2. The noise level in the channel of a receiver is subject to the same fading effects experienced by the desired signal.

3. The spacing between the repeater stations in a trendline is constant.

4. The effects of the emission from satellites in the geostationary orbit operating on the same frequency as spacecraft in low orbits were not considered.

5. Satellite orbits are circular.

6. The fundamental relationship describing the transfer function characteristic of the radio-relay system in a trendline was of the form described by Equation 1.

The value of n_c , noise in a channel used in Equation 1, in the NGM model is computed by taking into account the effects of the fading statistics of the desired signal. The fading statistic for the desired signal was assumed to be identical to the results for 4 GHz reported in CCIR Report 338-3. The statistical fading depth data at 4 GHz used in this model were measured on an average rolling terrain in northwest Europe.

ANALYSIS APPROACH

The two computer models (GM and NGM) referred to above use a statistical approach to develop pfd limits for satellites in the geostationary and low orbits. The statistical approach used in the GM is different from that used in NGM. The parameters generated statistically by a random number generator in the GM program are the directions of trendlines and the pointing azimuth angles of the antennas in a trendline. In addition to these two parameters, the NGM program takes into account the fading statistics of the desired signal and the visibility statistics of the satellites in orbits. For the analysis given here, the input data for these models were determined using the data for typical equipment presently operational in the 2025-2300 MHz frequency range. In addition, an assessment was conducted to determine the impact of the assumptions used in the development of the models on the computed pfd limits for the frequency range. An assessment is given on those assumptions which could not be changed at this time without major modifications to the programs.

PFD LIMITS FOR GEOSTATIONARY SATELLITES

In Section 4 typical data which characterize the systems in the Fixed and Mobile Services were given. Examination of the data in Tables 4, 5, and 6 indicated that there is similarity in the functions and the characteristics of equipment presently operational and that the use of the typical data in Section 4 for analysis of pfd limits is reasonable. It should be pointed out that the intent of the analysis given here was to develop an appreciation of the presently accepted pfd limits and to determine if these limits can be relaxed for systems currently in operation in the 2025-2300 MHz frequency range. The typical data given in Section 4 were arrived at by considering the data for the systems in the Fixed Service. Mobile equipment usually have lower gain antennas. Generally, mobile systems in the band are characterized by parameters which either are similar to or less restrictive than those for the systems in the Fixed Service. Considering the operational and technical characteristics of systems in the Mobile Service, it was assumed that characteristics of systems in the Fixed Service were the limiting factor in the determination of pfd limits for the frequency range 2025-2300 MHz.

As was mentioned above, the GM computer program, originally used to develop the present pfd limits for the CCIR, was used here in the analysis to develop the pfd limits in the 2025-2300 MHz frequency range. The input parameters required by the program were derived in Section 4 and are repeated here:

Receiver noise temperature	1200 K
Number of stations in a trendline	40
Separation between stations	30 km
Maximum antenna gain	36 dBi
Receiver interference threshold	14 dBrnco
Feeder loss	3 dB
Branching loss	0 dB
Separation between satellites	10 to 20 deg.

The rationale for selecting the above values as the typical characteristics of the system in the 2025-2300 MHz frequency range was discussed before. Note that the data used here indicate that the geostationary orbit is not as heavily used as was assumed in the earlier analysis in the development of CCIR pfd limits and that the number of stations in a trendline was assumed to be less (40 as compared to 50 hops used by the CCIR).

The number of the U.S. satellites in the geostationary orbit in the frequency range 2025-2300 MHz is currently less than that in the 4-6 GHz bands. In addition, it is not expected that the orbit in this frequency range will be as crowded and filled to capacity as it is expected to be in the 4-6 GHz bands. The GM program was designed originally with the assumption that the orbit was filled with three-degree separation between the satellites. To show the effect of this assumption and to make the results more realistic for the 2025-2300 MHz frequency range, the separation angle between the satellites in the orbit was increased in steps of 5 degrees from 10 to 20 degrees. The effect of this change was to reduce the number of satellites as potential interferers to radio-relays in a trendline. At 20 degree latitude, for 10 degree spacing, approximately 16 satellites are visible to the terrestrial radio-relays and for 20-degree separation between the satellites in the orbit, approximately 8 satellites are considered in the computation. For the purpose of comparison, the pfd limits for three-degree separation were also calculated. In the 2025-2300 MHz frequency range, 8 to 16 satellites operating on the same frequency in the geostationary orbit are more representative of the band usage by the Space Services.

The maximum antenna gain selected for this analysis was 36 dBi in comparison with 38 and 40 dBi used in the earlier analysis. This was due to the fact that nearly 90 percent of the equipment in this frequency range use antennas with maximum gain in the upper 20 dBi range and 36 dBi was considered a reasonable estimate considering the fact that there is a small number of equipment in the desired frequency range with maximum antenna gains close to 40 dBi. The angle dependency of the antenna pattern for the terrestrial receivers in the band was assumed to be similar to that recommended by the CCIR (Rec. 624-2). This pattern is shown in Figure 1. Note that the pattern in Figure 1 assumes that the antenna is circularly symmetrical and that the secondary sidelobes are approximated by an envelope. Mathematically, the pattern in Figure 1 may be described as follows:

$$G(\gamma) = \begin{cases} 36 & \text{(dBi)} \quad 0^\circ \leq \gamma \leq 1^\circ \\ 36 - 25 \log \gamma & \text{(dBi)} \quad 1^\circ \leq \gamma \leq 69^\circ \\ 10 & \text{(dBi)} \quad 69^\circ \leq \gamma \leq 180^\circ \end{cases}$$

The antenna pattern shown in Figure 1 is a worst case model for the equipment presently operational in this frequency range and it tends to contribute to the enhancement of the interference signal level from a satellite. However, any alternative antenna pattern would be in conflict with the accepted CCIR pattern and would tend to specialize the results to selected systems.

The interference level from each satellite in the geostationary orbit was assumed to follow the shape described by the CCIR and is repeated here in Figure 2. The values of the current pfd limits shown in the ITU Radio Regulations corresponding to MIN and MAX in Figure 2 are:

$$\text{MIN} = -154 \text{ dB(W/m}^2\text{) in any 4 kHz}$$
$$\text{MAX} = \text{MIN} + 10 = -144 \text{ dB(W/m}^2\text{) in any 4 kHz}$$

The procedure for determining pfd limits in the GM program is as follows. Data input parameters such as those listed above as typical data are determined first. Assumed numbers for MIN and MAX corresponding to 0 and 25 degrees as shown in Figure 2 are then used as best estimates in the program. The results of the computation which show the total interference in picowatts are used to calculate the cumulative probability of this interference. The value of total interference at the 90 percent point on this cumulative distribution is then used to determine if the assumed values of pfd for MIN and MAX were in agreement with 1000 pW of noise power interference recommended by the CCIR. New estimates for MIN and MAX are used successively until this agreement is reached. The value of MIN and MAX which correspond to 1000 pW noise power will be declared as the required pfd limits by the model. The following example illustrates the algorithm. The results of the computation assuming three-degree separation as an input parameter to the computer model are shown in Figure 3. A careful understanding of the example in Figure 3 is important. The parameters used in the computation of the data in Figure 3 were for a hypothetical case and are listed in the figure. The values of MIN and MAX used in this computation were -154 and -144 dBW/m^2 in any 4 kHz bandwidth, respectively. By convention, adopted by the CCIR, the estimated values of MIN and MAX were considered acceptable if the curves such as the one shown in Figure 3 showed that the interference power was equal to 1000 pW at the 90

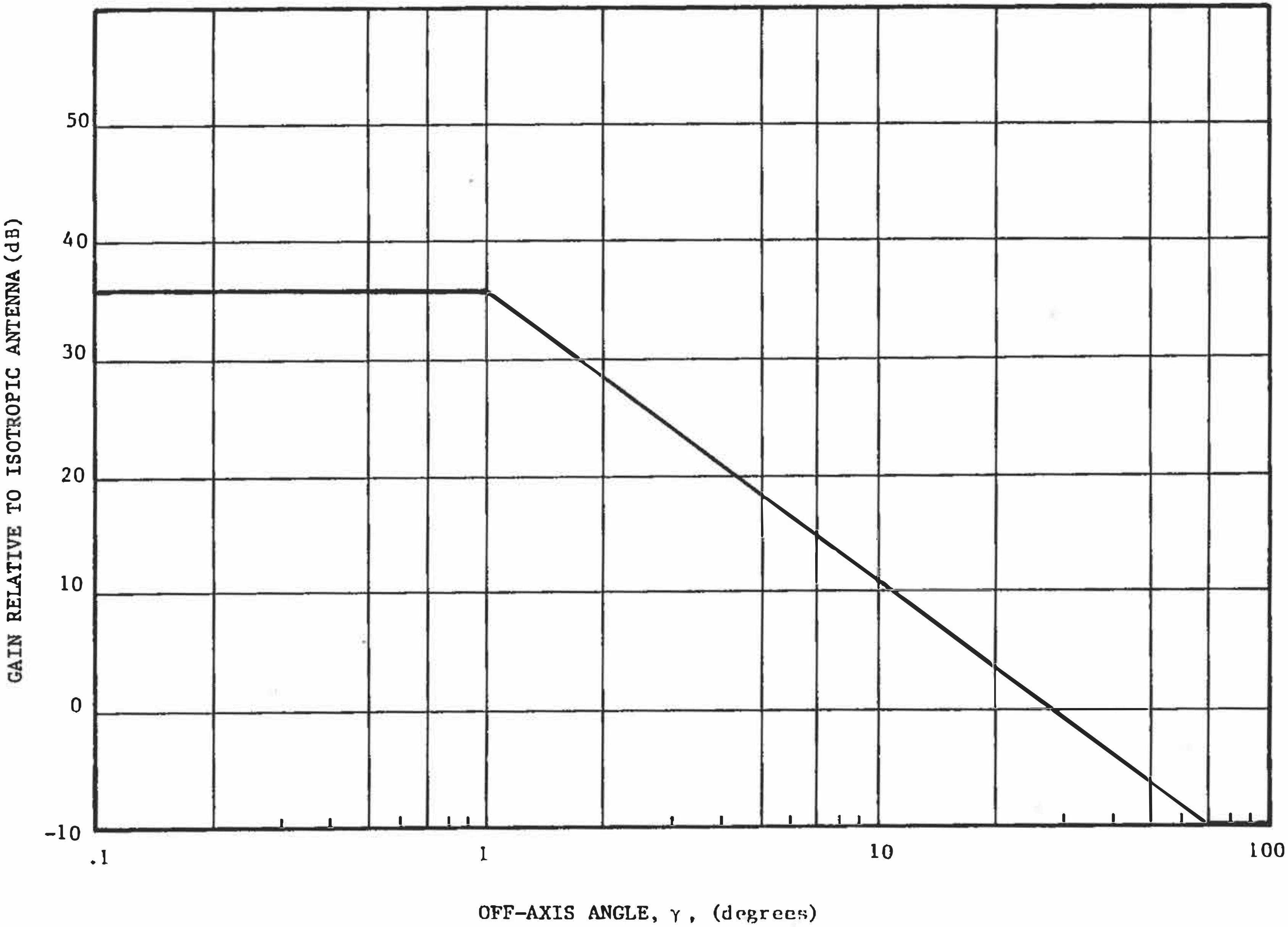

Figure 1. Typical Antenna Pattern for a Radio-Relay Station.

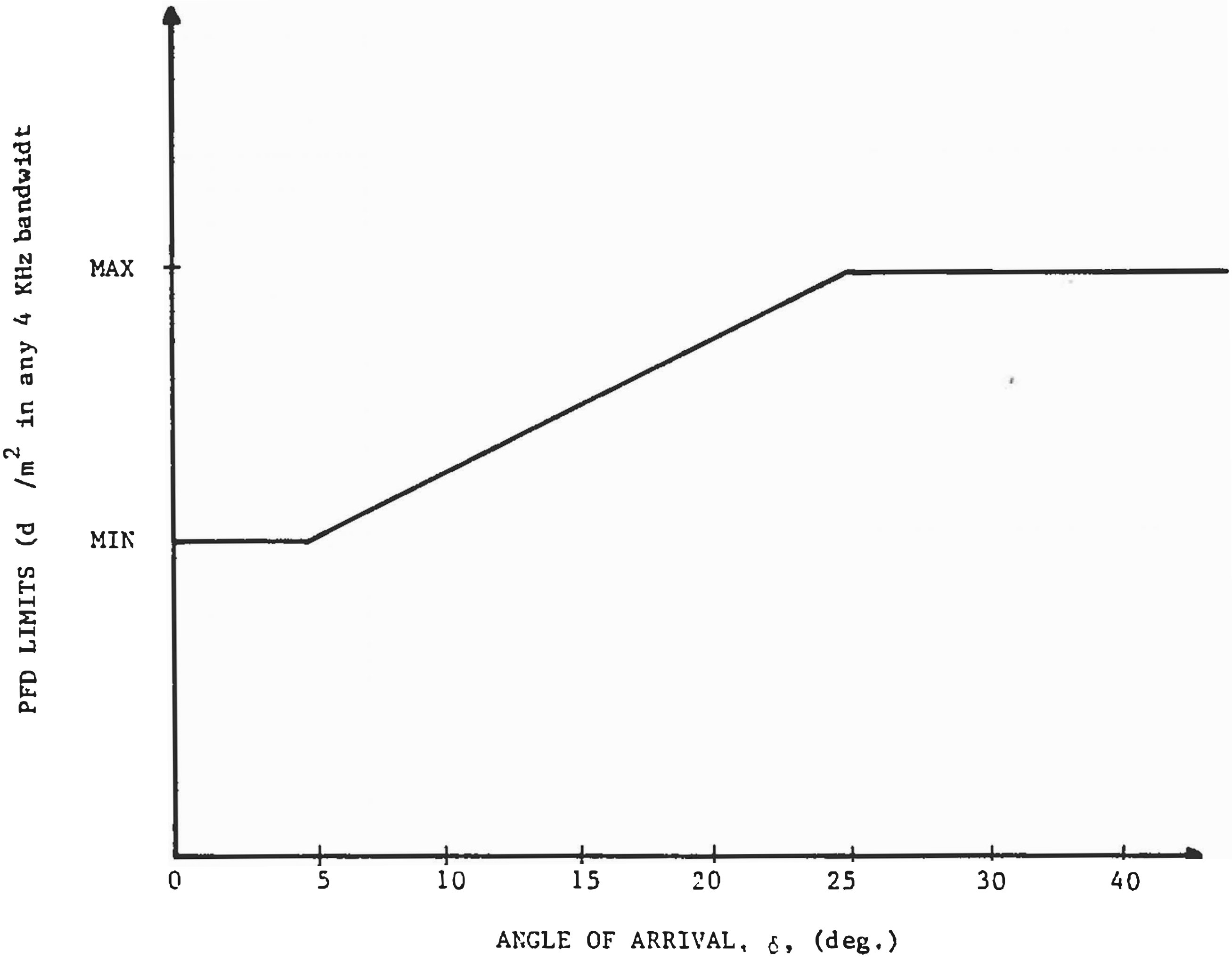

Figure 2: Shape of Power Flux-Density Limits Recommended by the CCIR and Used in the Computation of PFD Limits for the 2025-2300 MHz Frequency Range.

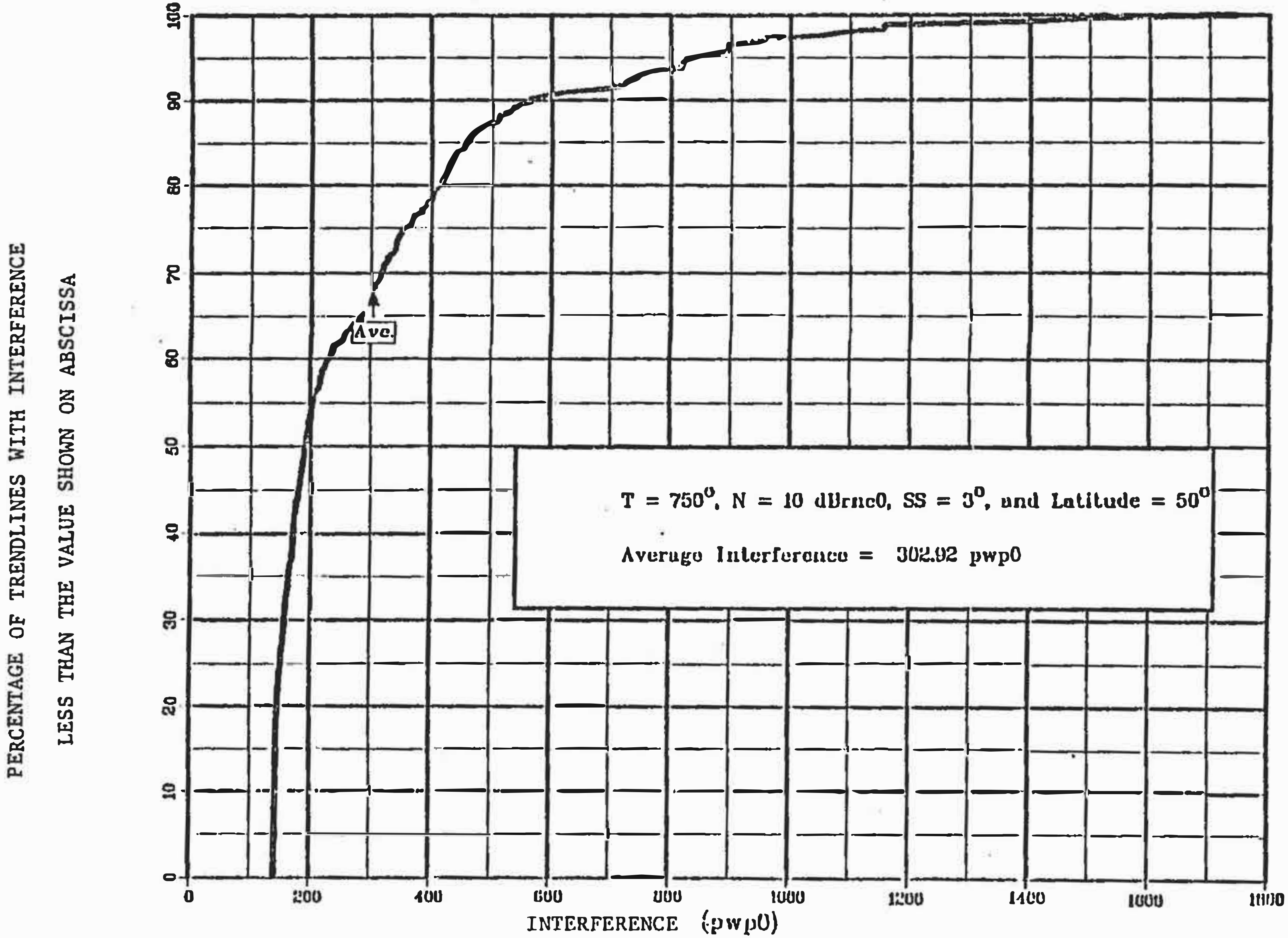

Figure 3. Example of the Distribution of Interference into CCIR Hypothetical Reference System.

percent point. Note that according to the results shown in Figure 3, the values of MIN and MAX in the example must be increased to just meet this criteria.

Obviously, the results of the computation also depend on the latitude location of the terrestrial radio-relay stations. Results of the calculations indicate that the potential interference from satellites in the geostationary orbit increases up to about 60 degree latitude beyond which the interference decreases until it becomes approximately zero at 90 degree latitude. The boundaries of the United States lie between approximately 20 to 50 degree latitudes.

Using the data described earlier, new pfd limits for the 2025-2300 MHz frequency range were calculated using the algorithm described above. The results of this computation (acceptable values for MIN) are summarized in Table 8. To find the corresponding values of MAX shown in Figure 2, add 10 dB to the entries in Table 8. The results corresponding to a 15 degree satellite spacing shown in Table 8 are realistic for the satellite operations in the Space Services 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 13 satellites presently in operation in the geostationary orbit. The results shown in Table 8 are higher than the values accepted by the ITU Radio Regulations and the NTIA Manual by approximately 3 dB for the worst case. Assuming 13 satellites for the computation of pfd limits in this frequency range may seem to be pessimistic, because not all of these satellites operate co-channel with the radio-relay stations in a trendline. However, in the computation, 13 satellites were assumed to be in the geostationary orbit in order to compensate for the fact that there are satellites in this orbit by the administrations other than the United States that were not included in Table 6. The results shown in Table 8 may be considered as preliminary criteria, since additional modifications in the models are required to more accurately simulate the interaction between the satellites and the radio-relay systems in the desired frequency range. A description of suggested modifications to the computer model used in the computation of pfd limits for satellites in the geostationary orbit will be discussed next.

COMMENTS ON GEOSTATIONARY MODEL (GM)

Certain simplifying assumptions, described above in the analysis section, were made originally in the development of the GM program. In the analysis given above, some of the assumptions were altered by preparing realistic input data for the model which were representative of the equipment in the 2025-2300 MHz frequency range. Yet, there remain some assumptions which impact the results and cannot be changed at this time. The qualitative effects of these assumptions on the calculated pfd limits are discussed here. Modifications to the computer program (GM), as described below, should be made at a future date for a careful determination of the pfd limits for this frequency range. Hence, one should consider the possible effects of these future modifications in the application of the calculated pfd limits to the systems in this frequency range.

TABLE 8

CALCULATED RESULTS FOR PARAMETER MIN
(dBW/m^2 in any 4 KHz bandwidth)

LATITUDES (deg)	SATELLITE SPACING (deg)			
	3	10	15	20
20	-153.4	-149.4	-144.9	-144.5
30	-153.8	-149.8	-148.1	-148.0
40	-154.0	-151.2	-149.2	-149.1
50	-154.3	-151.4	-150.1	-150.0

Receiver Transfer Function

The approximate relationship given in Equation 1 was used in the GM computer algorithm as the fundamental relationship between the input interference and the interference in a telephone channel.

The relationship in Equation 1 was derived (CCIR Report 388-3) for treating the interference from a high modulation index FDM/FM signal to a low modulation index FDM/FM signal. A large number of satellites in the 2025-2300 MHz frequency range fall in the category of medium modulation index. Therefore a more rigorous relationship describing the transfer function of the radio-relay receiver was felt necessary. A qualitative analysis given in Appendix C indicates that the approximation expressed by Equation 1 may cause the calculated pfd limits to be approximately 4 to 19 dB more stringent than necessary to protect terrestrial radio-relay systems in this frequency range. An in-depth investigation is necessary to determine a better approximation describing the transfer function of a radio-relay receiver. This transfer function should be used in the GM program for the computation of the pfd limits in this frequency range.

Fading Effects

The effects of fading were not considered in the GM computer model. The term "fading" used here implies the variation in signal level with time caused by changing atmospheric conditions. Fading comes about either by multipath effects or through bending of electromagnetic waves. An undesirable feature of fading is that it generally attenuates the desired signal in a radio communication path and hence it causes a degradation in signal-to-noise ratio. As a result of the work done by Bullington (1957), fading effects in microwave propagation have been treated as a random process often expressed by a Rayleigh distribution function. A typical family of curves proposed by Bullington are shown in Figure 4. The dashed-dot lines in Figure 8 represent the extrapolated portion of the curves. It is important to mention that the attenuation due to fading for 0.01 percent of time is less than approximately 30 dB for the 2025-2300 MHz frequency range. The data shown in Figure 4 are used as a guideline for estimating the loss due to fading in the design of long LOS microwave links. Figure 4 shows that the effects of fading at low frequency are less serious. In fact at 0.01 percent of time the fading at 2000 MHz is approximately 8 dB less than that for 4000 MHz. This fading effect may contribute to the difference in pfd limits specified for the 2025-2300 MHz frequency range and those limits for frequencies above this range.

The inclusion of the fading statistics in the BTL models requires a modification to the program and may be accomplished using various methods. The statistics for interference levels may then be plotted for comparison with the time dependent criteria set by the CCIR for noise due to interference in the Fixed Service by the Fixed Satellite Service (CCIR Rec. 357-3). One possible interpolation of the statistical criteria suggested by the CCIR is shown in Figure 5 (CCIR Rec. 357-3).

The noise power levels of 1000 and 50000 pWOp given in CCIR Rec. 357-3 are for 20 percent and 0.01 percent of any month, respectively, and it is not obvious what the noise levels for points between 20 percent and 0.01 percent of any month should be. The data in Figure 5, according to CCIR Recommendation 356-4, exemplify a distribution and allot to interference an appropriate

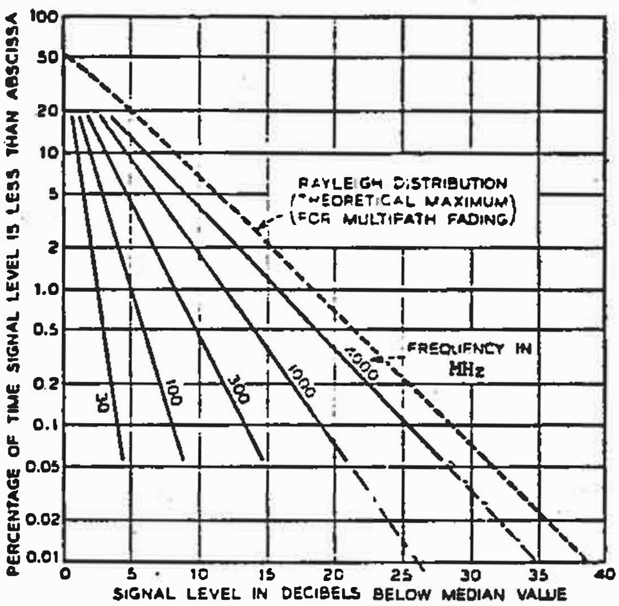

Figure 4. Typical Fading Characteristics in the Worst Month on 50 to 65 km Line-of-Sight Paths With 150 to 300 meters Clearance.

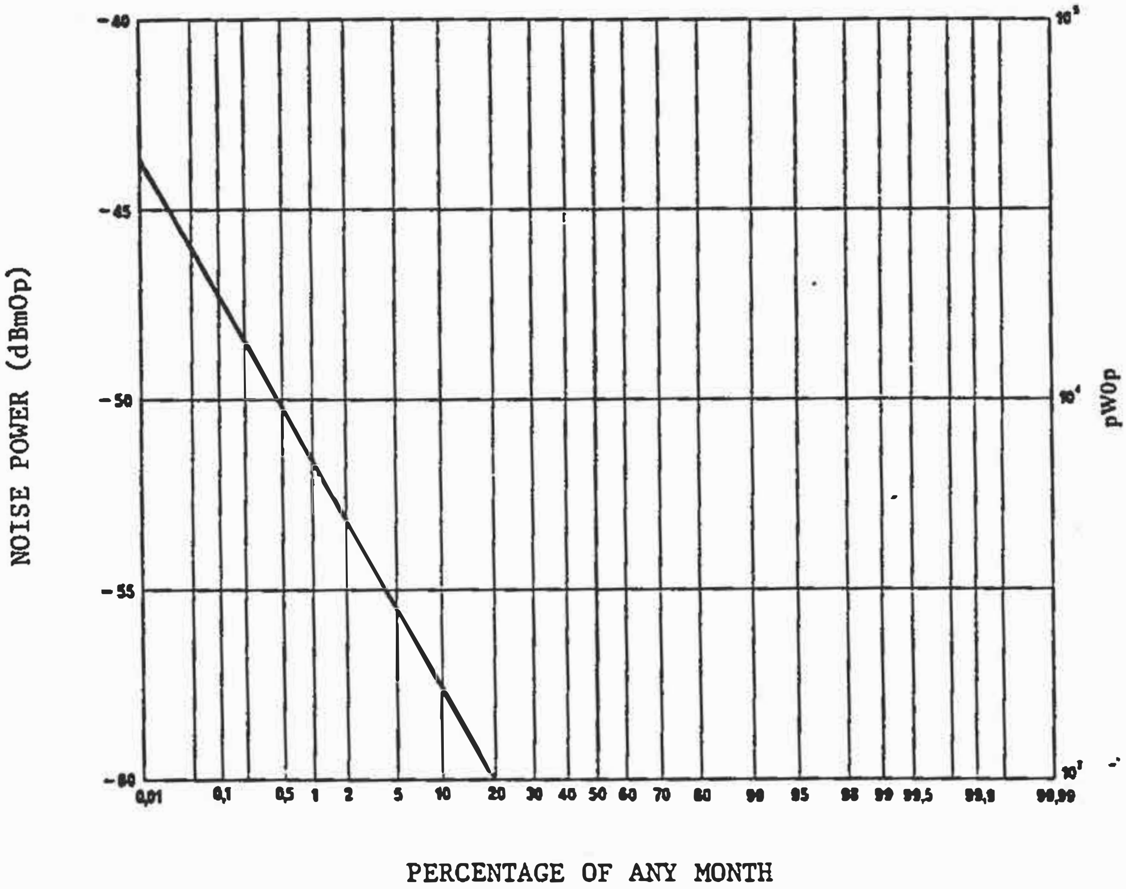

FIGURE 5. Example of Possible Interpolation

fraction of the total noise power permitted in the hypothetical CCIR reference circuit. Since the determination of the pfd limits depends on the allowed values of interference power specified by the CCIR, the interpolated percentile points of the interference levels for the percentile points between 20 percent and 0.01 percent have a marked effect on the results of analysis. In the analysis given later in the report addressing satellites in low orbits, the interpolation shown in Figure 5 was used.

The GM program treats the interference statistics from the Fixed Satellite Service and determines the allowable level of this interference through comparison with the long term criterion (20 percent point) shown in Figure 5. Since fading is a transient phenomenon, any interference calculation should consider the time-dependent criteria shown in Figure 5. The inclusion of the fading statistics in the computation of the pfd limits would assure an acceptable performance for the terrestrial systems and may allow higher levels for the pfd limits in the 2025-2300 MHz frequency range.

Digital Systems

There are a large number of digital systems which operate in the 2025-2300 MHz frequency range. The interference criteria for these systems have been treated by the CCIR as discussed in Section 3. The GM computer program treats only analog systems in the Fixed Service. The calculation of pfd limits for digital systems requires a different computer model than the one used to calculate the pfd limits for the analog systems.

A cursory calculation performed during this investigation shows that the pfd limits determined for the allowable interference to analog systems in the Fixed Service also meet the requirements for digital systems in this service. A digital system is generally more immune to interference than a comparable analog system with similar performance characteristics. However, despite these results, there is a need to develop a separate computer model for the calculation of pfd limits for the proper operations of digital systems in the 2025-2300 MHz frequency range. The problem which should be addressed is to determine if the pfd limits established for analog systems in the 2025-2300 MHz frequency range are sufficiently low to ensure the compatible operation of digital systems operating in this frequency range. This effort should be pursued during a follow-up task on the pfd investigation.

PFD LIMITS FOR SATELLITES IN NONGEOSTATIONARY ORBITS

As was mentioned earlier, the pfd limits which appear in the ITU Radio Regulations and were later adopted by the United States were based on the analysis of interference from geostationary satellites to systems in the Fixed Service. Hence, the low-orbit satellites have been subject to the same pfd limits originally developed for satellites in the geostationary orbits, despite the fact that the operational and technical characteristics of low orbit satellites are different from those for the satellites in the geostationary orbit.

The satellites in the low orbits are only intermittently visible to the terrestrial systems in the Fixed Service. For the analysis of pfd limits for low orbit satellites, a computer model was developed having the capability of taking into account the short duration of the exposure of terrestrial systems to the potential interference from these satellites. Clearly, the time-dependency nature of the interference dictates the use of time-dependent criteria (short-term criteria) set by the CCIR and shown by the interpolated curve in Figure 5.

The NGM program developed by SGC for the computation of pfd limits was designed to include the visibility statistics of satellites in low orbits. This program has been described elsewhere (Locke and Rinker, 1978) and will not be discussed in detail. In addition to the sampling method used in the GM program, the NGM has the capability of treating the effects of the visibility statistics of the electromagnetic wave received by the terrestrial systems. As was mentioned earlier, the fundamental transfer function equation in the SGC model is exactly the same as that used in the GM program.

The visibility statistics of low-orbiting satellites have been treated by Locke (CCIR Report No. 684). A bounding equation was derived which related the long-term visibility of a circular-orbit satellite to the orbital inclination angle and the latitude and longitude bounds of a region on the orbital sphere of a satellite. The percentage of time that a low-orbiting spacecraft will remain in a certain region visible to a ground station over a long period of time is given by:

$$T\ (^{o}/_{o}) = \frac{\delta\lambda}{2\pi^2} \left\{ \sin^{-1}\left[\frac{\sin^{-1}(L_1)}{\sin i}\right] - \sin^{-1}\left[\frac{\sin^{-1}(L_2)}{\sin i}\right] \right\} \quad X\ 100 \qquad (2)$$

where:

$\delta\lambda$ = the longitudinal region on the orbital shell, between the latitude limits of L_1 and L_2

i = the inclination angle of the satellite orbit

L_1, L_2 = upper and lower latitudes of visibility regions

Hence, the computation of the visibility statistics mentioned above is facilitated by calculating first L_1 and L_2 for every segment of the visible segment of the spacecraft orbital sphere.

Briefly, the NGM algorithm uses the expression in Equation 2 to calculate the percentage of visibility for every segment of the visible orbit. The interference power received by stations in a trendline is then calculated for each portion for which the visibility percentage was calculated.

The cumulative plot of interference power, calculated in a manner similar to that described for the GM program as a function of the percentage of duration of interference over a long period of time (say one month), is the desired result.

The pertinent characteristics required as input for the NGM computer program were discussed earlier in Section 4. The input parameters used in the program are given in Appendix B. The parameters for the terrestrial radio-relays used in the NGM program were identical to those used in the GM program. A limited number of satellites in the 2025-2300 MHz frequency range are in elliptical or highly elliptical orbits. The NGM program treats only the satellites in circular orbits.

The inclination angles given in Section 4 are with respect to the equatorial plane. The high inclination angles for the low orbits in the 2025-2300 MHz freqency range make it possible to treat the calculations of pfd limits for the satellites in low orbits independently from satellites in geostationary orbit. For example, for a satellite in the geostationary orbit the worst sharing geometry is when the antennas of radio-relay stations are pointed towards the geostationary orbit. This means that interference from the geostationary orbit to the systems in the northern hemisphere is highest when their trendlines are southerly-directed. Conversely, CCIR Report No. 684 indicated that a low orbit spacecraft will appear with greater frequency to a northerly directed trendline in the northern hemisphere. The reason for this is the fact that the concentration of the orbits transversed by a spacecraft is higher in the polar region than the areas close to the equator. Hence, in the computation of the pfd limits one should not simply add the maximum allowed values of interference from the satellites in geostationary and low orbits. The potential interference from satellites in the geostationary orbit is complementary to that from satellites in low orbits. In other words, for satellites in the 2025-2300 MHz frequency range, the potential interference to a terrestrial system is minimum when the potential interference from satellites in polar orbits is the highest.

The data given in Section 4 were used in conjunction with the NGM simulation model to calculate the pfd limits for the low-orbit satellites in the 2025-2300 MHz frequency range. The results of the calculations are given in Figure 6. The data in Figure 6 show the cumulative interference power level at the input to a typical terrestrial receiver in the Fixed Service in the 2025-2300 MHz frequency range. The curves in Figure 6 show the level of interference that is exceeded for various percentages of time. The CCIR criteria for noise due to interference in a radio-relay are shown in the figure. It can be seen that the total interference power from eight satellites falls well below (approximately 10 dB) the maximum permissible level of interference for systems in the Fixed Service given in CCIR Recommendation 357-3. For comparison, the curves showing the level of the potential interference curves for 1 and 20 satellites in the orbit are also given in the figure. Note that the results in Figure 6 show that even the interference curve for the worst case scenario of 20 satellites in the orbit still remains below the CCIR permissible criteria. As was mentioned earlier, the data in Figure 6 were calculated using the present values of pfd limits (-154 dBw/m^2 in a 4 kHz bandwidth). The computed interference level may reach the permissible level if pfd limits are increased by approximately 10 dB. The calculations show that an increase of 10 dB in the present pfd limits for the 2025-2300 MHz frequency range will not cause interference noise power to the systems in the Fixed Service in excess of the permissible levels approved by the CCIR. An increase of 10 dB in the pfd limits will cause the calculated interference to reach the interference curve recommended by the CCIR and will not alter the shape of the calculated curves in Figure 6.

The calculations given here assume that the effects of interference from satellites in non-geostationary orbits are independent from those in geostationary orbits. Modifications to the NGM program as discussed below are necessary in order to determine the PFD limits from non-geostationary satellites in the 2025-2300 MHz frequency range.

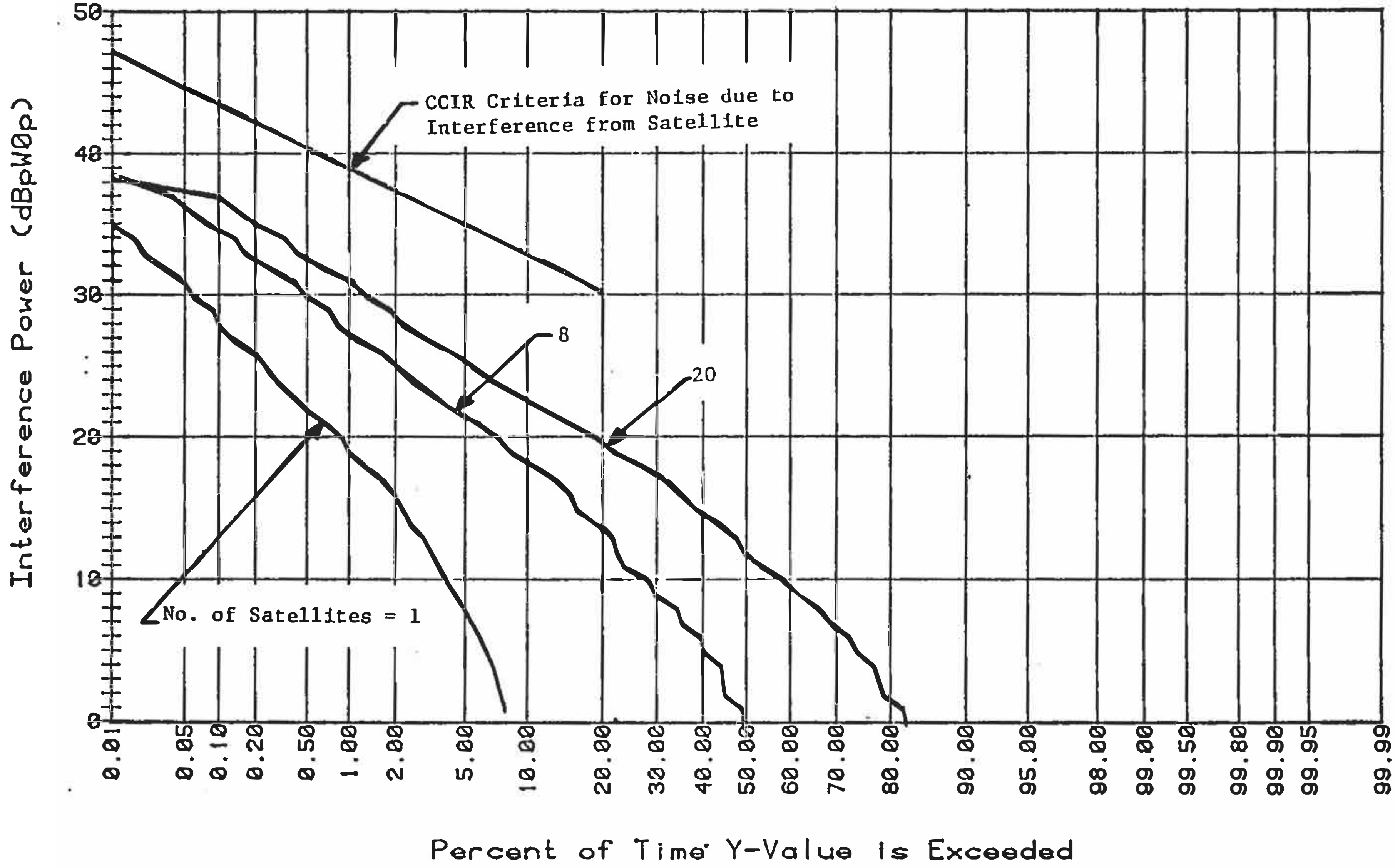

Figure 6. Calculated Interference for Different Number of Satellites in the 1100 km Orbit.

COMMENTS ON NONGEOSTATIONARY MODEL (NGM)

Receiver Transfer Function

The fundamental relationship for the computation of interference used by the NGM program was identical to that used by the GM program. This relationship is given by Equation 1. As was discussed earlier, this relationship is an approximation and is not applicable to the technical characteristics of the equipment in the 2025-2300 MHz frequency range. The discussion in Appendix C indicates that the relationship in Equation 1 may overestimate the interference by as much as 4 to 19 dB. This in turn may cause the calculated pfd limits by the two models to be higher by 4 to 19 dB (i.e., less stringent). Hence, the modification of this relationship may have a significant effect on the pfd limits calculated by these models and should be seriously pursued in future efforts.

Digital Systems

The SGC model considers only the potential interference from satellites in the low orbits to the analog terrestrial systems in the Fixed Service. There are a considerable number of digital systems in the 2025-2300 MHz frequency range. A model similar to that described earlier is needed to calculate the effect of interference from the low-orbit spacecrafts into the digital radio-relay systems in this frequency range.

Multiple Orbit Effects

The NGM computer program was designed to assess the pfd limits for a finite number of satellites in a given orbit. An orbit is identified by its inclination angle and altitude. The total effects due to satellites in different orbits were not considered in the computation. The computer program should be modified to iterate the computation over a number of different orbits in a range of altitudes and inclination angles. The multiple-orbit effects in the computation of the pfd limits may not be negligible.

Fading

The computer program (NGM) takes into account the effects of fading of the desired signal. The assumption in the model is that all the stations in a trendline undergo fading. This assumption is not realistic since all the stations will not simultaneously experience similar fading. Fading is a random process and some stations in a trendline may not experience fading as often or at the same time as the others in the same trendline. An assessment should be conducted to determine the influence of this assumption on the results computed by the program. The fading statistics used in the computer algorithm were those given in the CCIR Report No. 338-3. The empirical equation in this report was based on the data taken in Europe. The data for fading measured in the United States are available. A comparison depicted in Figure 8 indicates that the measured data for the United States (dashed lines) are different from those calculated by the empirical equation given in the CCIR report (solid line) by approximately 10 dB at 99.99 percent of time. A perturbation method was used in conjunction with the NGM program to assess the effect of fading statistics on the computation of the pfd limits. The results of such calculations showed that if the fading statistic is raised by 10 dB according to the data shown by the dotted lines in Figure 7, the pfd limits will be lowered by approximately 1 dB. Therefore the use of more accurate data for fading in the modified NGM program is desirable to improve the capability of the model.

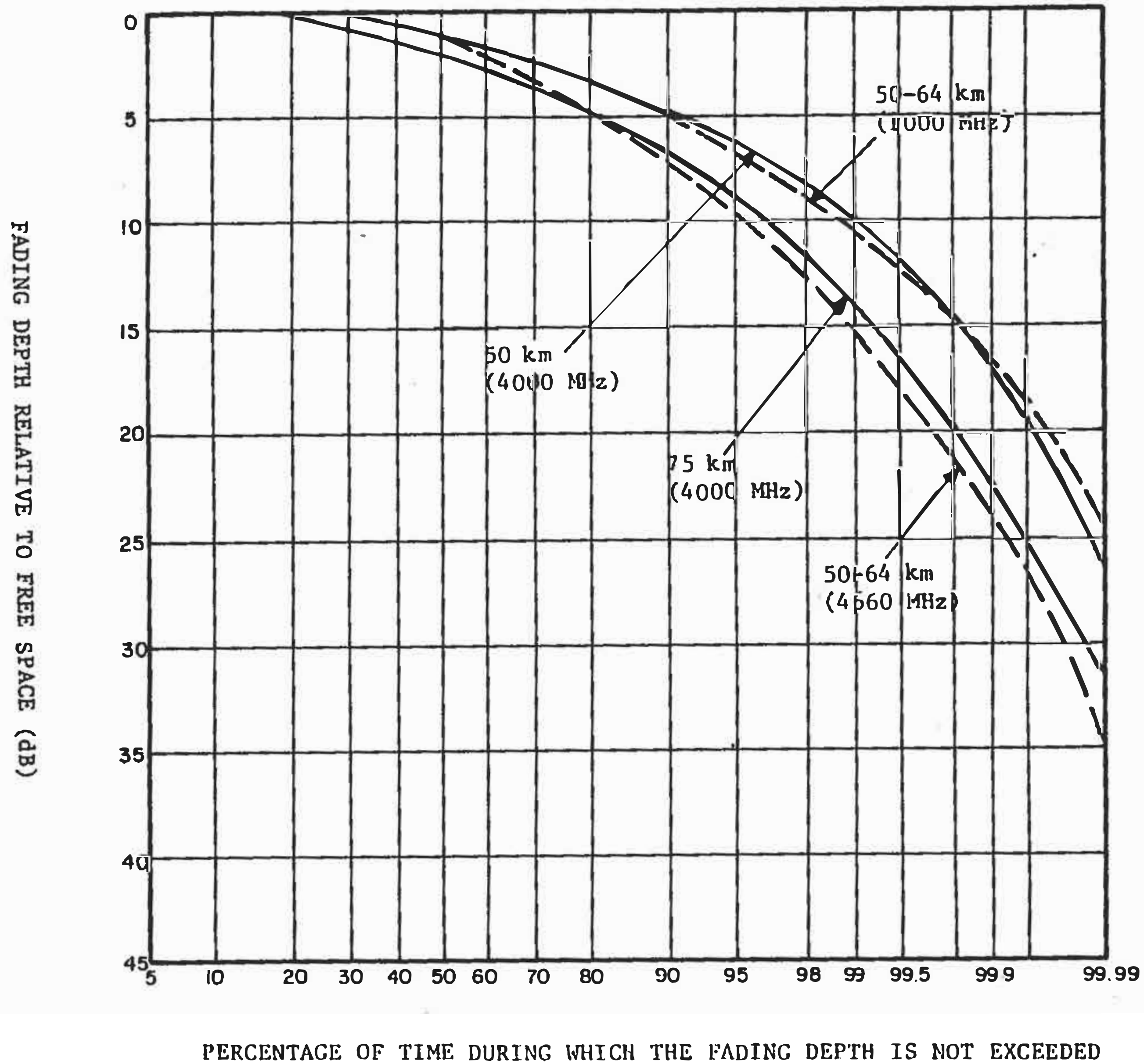

Figure 7. Typical Fading Characteristics in the Worst Month.
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SECTION 6

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APPENDIX A

FOOTNOTES IN TABLES 1 AND 2

The following footnotes which are applicable to the Space Services in the frequency range 2025-2300 MHz shown in Tables 1 and 2. The footnotes G101 and US90 were modified and footnote US252 was added.

G101a In the band 2200-2300 MHz, telemetering, tracking, ranging, analog/digital data and/or voice from operational space stations may be accommodated on a co-equal basis with fixed, mobile and space research service.

G101b 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.

US90a In the band 2025-2120 MHz earth-to-space transmissions in the space research and earth exploration-satellite services by the Government and non-Governmment stations at specific locations may be authorized subject to such conditions as may be applied on a case-by-case basis.

US90b 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 by Government and non-Government stations at specific locations may be authorized subject to such conditions as may be applied on a case-by-case basis. Such transmissions shall not cause harmful interference in non-Government stations operating in accordance with the Table of Frequency Allocations. All space-to-space transmissions reaching the earth's surface shall adhere to a power flux density of between -144 and -154 $dBW/m^2/4$ kHz depending on angle of arrival in accordance with ITU Radio Regulations, 2557 NE through 2560 NGA and shall not cause harmful interferece to the other space services.

In the band 1990-2120 MHz, Government space research earth stations may be authorized to use specific frequencies at specific locations for earth-to-space transmissions. Such authorizations shall be secondary to non-Government use of this band and subject to such other conditions as may be applied on a case-by-case basis.

Corpus Christi, Tex., 27° 39' N 097° 23' W.
Fairbanks, Alaska, 64° 59' N 147° 53' W.
Goldstone, Calif., 35° 18' N 116° 54' W.
Greenbelt, MD., 39° 00' N 076° 50' W.
Guam, Mariana IS., 13° 19' N 144° 44' E.
Kauai, Hawaii, 22° 08' N 159° 40' W.
Merritt Is., Fla., 28° 29' N 080° 35' W.
Rosman, N.C., 35° 12' N 082° 52' W.
Wallops Is., 37° 57' N 075° 28' W.

US219 In the band 2025-2120 MHz Government Earth Resources Satellite Earth Stations in the Earth Exploration-Satellite Service may be authorized to use the frequency 2106.4 MHz for earth-to-space transmissions for tracking, telemetry, and telecommand at the sites listed below. Such transmissions shall not cause harmful interference to non-Government operations:

Sioux Falls, S.D., 43° 32' 03.1" N 96° 45' 42.8" W.
Fairbanks, Alaska, 64° 58' 36.6" N 147° 30' 54.2" W.

US222 In the band 2025-2120 MHz Geostationary Operational Environmental Satellite Earth stations in the Space Research and Earth Exploration-Satellite Services may be authorized on a coequal basis to use the frequency band 2025-2035 MHz for earth-to-space transmissions for tracking, telemetry, and telecommand at the sites listed below:

Wallops Is., VA., 37° 50' 48" N 75° 27' 33" W.
Seattle, Wa., 47° 34' 15" N 122° 33' 10" W.
Honolulu, Ha., 21° 21' 12" N 157° 52' 36" W.

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

747 Subject to agreement obtained under the procedure set forth in Article 14, the band 2025-2110 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 2110-2120 MHz may also be used for Earth-to-space transmissions in the space research (deep space) service.

749 Subject to agreement obtained under the procedure set forth in Article 14, the band 2110-2120 MHz may also be used in Japan for the space research (Earth-to-space) and space operation (Earth-to-space) services until 31 December 1990.

750 Subject to agreement obtained under the procedure set forth in Article 14, the band 2200-2290 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.

NG118 Television translator relay stations may be authorized to use frequencies in this band on a secondary basis to stations operating in accordance with the table of frequency allocations.

NG10 Frequencies in this band will be selected for assignment in such a manner that, on an engineering basis, the highest frequency in the band is assigned which will not cause harmful interference to stations in that area already assigned frequencies in accordance with the Table of Frequency Allocations.

NG23 Frequencies in the band 2100-2200 MHz may also be assigned to stations in the international fixed public radio service located south of 25° 30' North latitude in the State of Florida and in U.S. Possessions in the Caribbean area, provided, however, no new assignments in the band 2150-2162 MHz will be made to such stations after February 25, 1974.

NG45 In the 2150-2160 MHz band, operational fixed stations are limited to omnidirectional operations only.

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a. Indicates footnotes before modification
b. Indicates footnotes after modification

APPENDIX B

INPUT DATA FOR THE COMPUTER PROGRAMS

The input data to the computer programs GM and NGM used in the computation of the PFD limits from the satellites are given in this appendix. The purpose of the data is to provide the reader who is familiar with the program with sufficient information in order to duplicate the calculated results given in this report. As was mentioned before, the data for the programs were prepared considering the operation and the characteristics of the systems in the 2025-2300 MHz range. As was mentioned in Section 4, some of the input data such as the antenna pattern for the terrestrial systems and the interference noise criteria were extracted from the appropriate CCIR Recommendations. The data used in the calculations are given below.

I. Input data for the GM

1. Radio relay system and satellite arrangement.

Number of stations per trendline 40
Number of trendlines...............................300
Latitude of the first station in the
first system (deg.)..............................20
Latitude of the first station in the
last system (deg.)...............................70
System latitude increment (deg.)...................10
Satellite spacing (deg.).....................10,15,20

2. Characteristics of a radio-relay station.

Noise per hop (dBrnco)..............................14
Feeder loss (dB)....................................3
Receiver noise temperature (deg. kelvin)..........1200
Frequency (GHz).....................................2.2
Antenna gain (dBi)..................................36

3. The CCIR antenna pattern used in the computation.

$$G(\gamma) = \begin{cases} 36 & \text{(dBi)} \quad 0^\circ \le \gamma \le 1^\circ \\ 36 - 25 \log & \text{(dBi)} \quad 1^\circ \le \gamma \le 69^\circ \\ -10 & \text{(dBi)} \quad 69^\circ \le \gamma < 180^\circ \end{cases}$$

4. Trial values of power flux density limits.

a) Initial value

$$F(\delta) = \begin{cases} -154 \ (\text{dBw/m}^2.4 \text{ kHz}) & 0^\circ < \delta < 5^\circ \\ -154 + 0.5(\delta - 5) & 5^\circ \le \delta \le 25^\circ \\ -144 & \delta \ge 25 \end{cases}$$

b) Final value

$$
F(\delta) = \begin{cases} -148 \quad (\mathrm{dBW/m^2.4\ kHz}) & 0^\circ \le \delta \le 5^\circ \\ -148 + 0.5\,(\delta - 5) & 5^\circ \le \delta \le 25^\circ \\ -138 & \delta \ge 25^\circ \end{cases}
$$

II. Input data for the NGM

The following data were used as the input to NGM for the calculation of pfd limits for satellites in nongeostationary orbits.

Random number seed	15693
Terrestrial system length (km)	1100
Number of hops	40
Trendline azimuth	16.63511
First station latitude (deg.)	51.05767
Power criteria for sub-bin analysis (dBpWOp)	15
Power criteria for sub-bin analysis (dBpWOp)	20
Satellite altitude (km)	1200
Satellite orbit inclination (deg.)	95
Frequency (GHz)	2.2
Satellite PFD limit (dBW/m .4kHz)	-154
PFD limit escalation factor (dB)	10
Receiver noise temperature (K)	1200
Terrestrial system antenna (see input data for GM)	

APPENDIX C

RADIO-RELAY RECEIVER TRANSFER FUNCTION

The qualitative analysis described here gives an estimate of the impact on the pfd computations caused by the approximation expressed by Equation 1. This approximation describes the transfer function of a radio-relay receiver and is repeated here for easy reference.

$$\frac{i_c}{n_c} = \frac{i_4}{n_4} \qquad \text{(C-1)}$$

where i_c and n_c are interference and noise power in a channel, respectively, and i_4 and n_4 are the interference and noise power, respectively, in a 4 kHz band at the receiver input. CCIR Report 388-3 is in agreement with the relationship given in Equation (1) for the case in which the interference is produced by an FDM/FM source with large modulation index to a victim receiver with small modulation index. Large and small modulation indices were not defined in the report, but Hamer (1961) in his analysis refers to low and high modulation indices when the value of these indices are less than .2 and greater than 1.6, respectively.

In the 2025-2300 MHz frequency range the modulation index for the majority of systems in the Fixed Service is in the range of .1 to .4 and the modulation index for the system in the Space Services is in the range of 0.8 to 1.6. These values of modulation index are in the intermediate range. Hence, the approximation given by Equation 1 should be modified for the computation of the pfd limit in the 2025-2300 MHz frequency range. The following qualitative analysis, based on available information, gives an estimate of the change in pfd limits for this frequency ragne produced by the use of the approximation expressed by Equation (C-1).

A more exact form of Equation (C-1) may be written

$$\frac{i_c}{n_c} = k\,\frac{i_4}{n_4} \qquad \text{(C-2)}$$

where k is a constant of proportionality and it depends on the characteristics of the desired and undesired signals and receiver processing. Evaluation of k is desired. The relationship between the signal-to-noise ratio in a channel and carrier-to-noise ratio at the input to a radio receiver has been derived (CCIR Report 211-2) and is given below:

$$S/n_c = (C/N) \times (B_n/2b) \times (F_d/f_m)^2 \qquad \text{(C-3)}$$

where:

C = carrier power at the FM demodulator input
N = noise power at the FM demodulator input
B = receiver noise bandwidth (IF)

b = voice channel noise bandwidth
F_d = rms test-tone deviation per channel (H2)
f_m = mid-frequency of the highest baseband channel (H2)

Psophometric weighting and pre-emphasis factors are not included in Equation (C-3).

Assuming that the noise at the input to the IF is uniformly distributed, it is possible to write:

$$B_n/b = N/n_4 \qquad \text{(C-4)}$$

Divide Equation (C-3) by Equation (C-2) and obtain:

$$S/i_c = (C/i_4) \times (F_d/f_m)^2/2k \qquad \text{(C-5)}$$

In the derivation of Equation (C-5) the assumption of uniformly distributed noise expressed in (C-4) was used.

Examination of the measured emission spectra of a number of satellites in the 2025-2300 MHz range indicated that approximately 99 percent of the interference power at a radio receiver input in this frequency range may be expressed by the relationship:

$$I = \alpha \, i_4 \qquad \text{(C-6)}$$

where

I = interference power at the input to radio receiver

α = constant

and i_4 was defined earlier. An empirical evaluation of α was carried out using several emission spectrum measured by the NASA during earlier compliance tests.

The emission spectrums for some operational transmitters measured by NASA indicated that the 20 dB points on the emission bandwidth contained approximately 99 percent of the interference power furnished by a satellite transmitter to a radio receiver. Assuming the interference power to be flat (uniform) across the 20 dB bandwidth at the input to the radio receiver, the value for α was calculated by taking the ratio of the 20 dB bandwidth of the satellite emission to 4 kHz. Measured data indicated that the ratio of this 20 dB bandwidth to 4 kHz was approximately 18 dB for a typical satellite in the

2025-2300 MHz frequency. For the qualitative analysis given here α was set equal to 18 dB. A quantitative analysis will require examination of additional data. Substituting Equation C-6 into Equation C-5 we obtain:

$$S/i_c = (C/I) \times (F_d/f_m)^2 \times (\alpha/2k) \qquad \text{(C-7)}$$

Equation (C-7) describes a relationship between baseband interference power in a telephone channel and the input carrier-to-interference ratio (CCIR Report 388-3). A different form of Equation (C-7) is given in CCIR report No. 388-3.

$$S/i_c = (C/I)B \qquad \text{(C-8)}$$

A comparison of Equations (C-7) and (C-8) shows that:

$$B = (F_d/f_m)^2 \alpha/2k \qquad \text{(C-9)}$$

Our objective now is to determine the values of B, the interference reduction factor, for the range of modulation indices given in section 4. The data in the CCIR report was used to evaluate B.

For the intermediate range of modulation indices of FDM/FM signals, a generalized set of curves have been evaluated (CCIR Report 388-3). These curves are shown in Figure (C-1).

The curves in Figure C-1 give the value of a factor K (K is related to noise power ratio and signal strength in a channel) normalized to the square of the r.m.s. modulation index of the desired signal as a function of a normalized carrier frequency separation. The difference between K and B is that K is based on a signal power equal to the level of a white noise test signal rather than a 1mW test tone. K and B are related by the expression:

$$B - K = \begin{cases} 16.1 \ \text{(dB)} & n > 240 \text{ channels} \\ 2.1 + 6. \ \log n & 12 \leq n < \text{ channels} \end{cases}$$

The interference is computed at the worst channel, for those cases where such generalized curves can be given. Moreover, the assumptions that the receiver baseband is either wide enough to accept both the desired and interfering signals without distortion, or that it is just wide enough to accept the desired signal without distortion, lead to similar results. The pre-emphasis improvement is included in the curves shown in Figure C-1. For a broad range of modulation indices, the curves provide a good estimate of interference when the baseband of the interfering signal is smaller than, or identical with, that of the signal suffering interference. The parameter m in Figure C-1 is defined by the relation:

$$m = \left(m_1^2 + (m'_2)^2 \right)^{1/2} \qquad \text{(C-10)}$$

where:

- m_1, m_2: rms modulation indices of desired and interfering signals, respectively
- m' : $m_2 \times f_{m2}/f_{m1}$
- f_{m1}, f_{m2} = Mid-frequencies of the top baseband channel of the desired and interfering signals, respectively

The symbol, f_o , shown on the abscissa of Figure C-1 is the carrier frequency separation between interfering and desired signal.

For on-tune operation (f_o =0), the following data were obtained from the curves in Figure C-1.

m	K-20 log m_1 (dB)	B-20log m_1 (dB)
.8	9.0	21.2
1.0	9.1	21.3
1.2	10.0	22.2
1.4	11.0	23.2
1.6	11.5	23.7
1.8	11.7	23.9
2.0	12.0	24.2

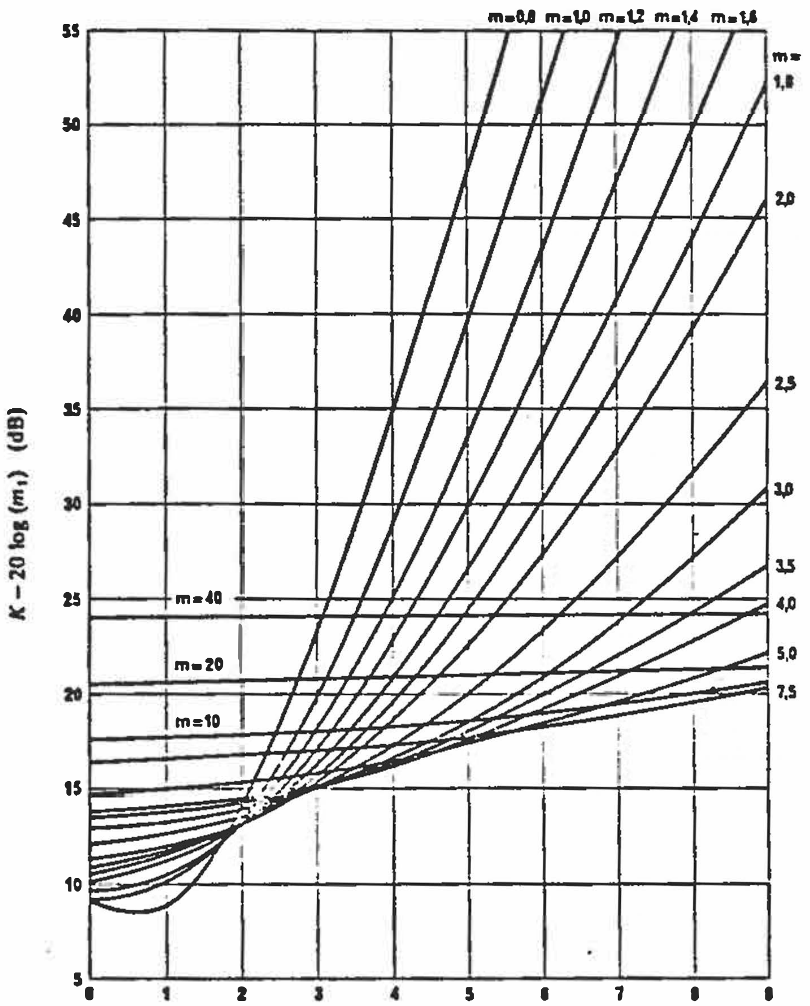
The data in the right column were derived for n=48 channels. A plot of m vs B-20 logm is given in Figure C-2. Using the information in Figure 6, the interference reduction factor B was calculated for different values of modulation indices of interfering and desired signals. The results of such calculations are shown in Figure C-3. The curves in Figure C-3 obtained for different modulation indices indicate that the interference reduction factor B varies from 1 to 16 dB for the characteristics of the equipment in the 2025-2300 MHz frequency range. Parameter B known as processing gain (interference suppression factor) and given in Figure C-3 could have been obtained directly using the expression (Mayher and Parlow, 1973),

$$B = \frac{2\pi \; f_d^2 \; f_s \; \exp\left(f_m^2/2f_s^2\right)}{f_m^3} \qquad \text{(C-11)}$$

where

- Δf_d = Total RMS deviation of desired signal
- Δf_u = Total RMS deviation of undesired signal
- f_s = $\left(\Delta f_d^2 + \Delta f_u^2 \right)^{1/2}$

Similar analysis conducted earlier for a related problem using Equation (C-11) showed that B varied from 12 to 25 dB for a 48 channel FM system. Therefore, it can be concluded that the processing gain has a significant effect on the transfer function of a radio-relay receiver. Obviously, values of B directly effect the computation of the pfd limits on the surface of the earth. From Equation (C-9) the factor B in dB may be written:



NORMALIZED CARRIER FREQUENCY SEPARATION f_o/f_{m1}

FIGURE C-1. Generalized Interference Curves for FDM/FM Signals

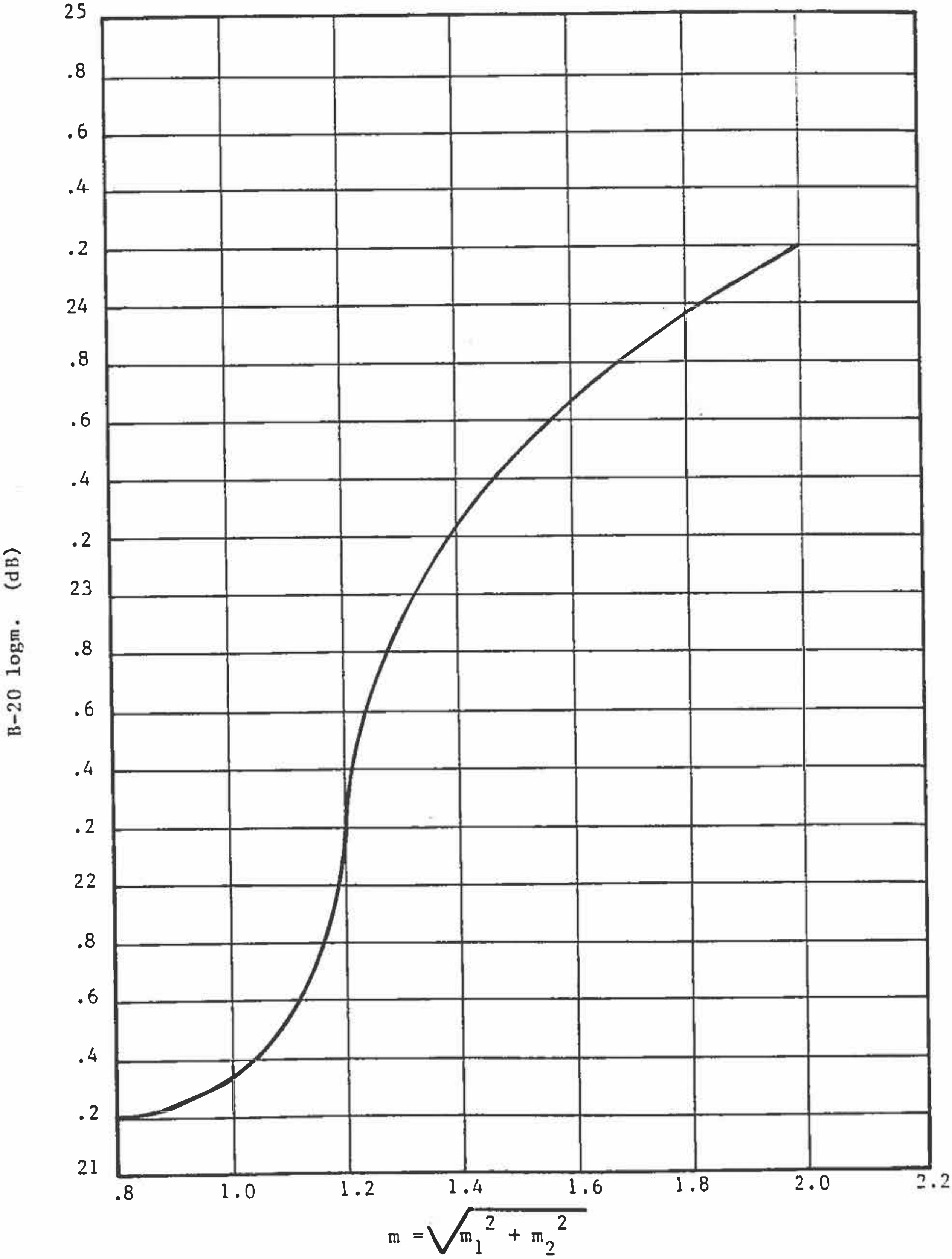


FIGURE C-2. Co-Channel Interference Between FDM/FM Signals.

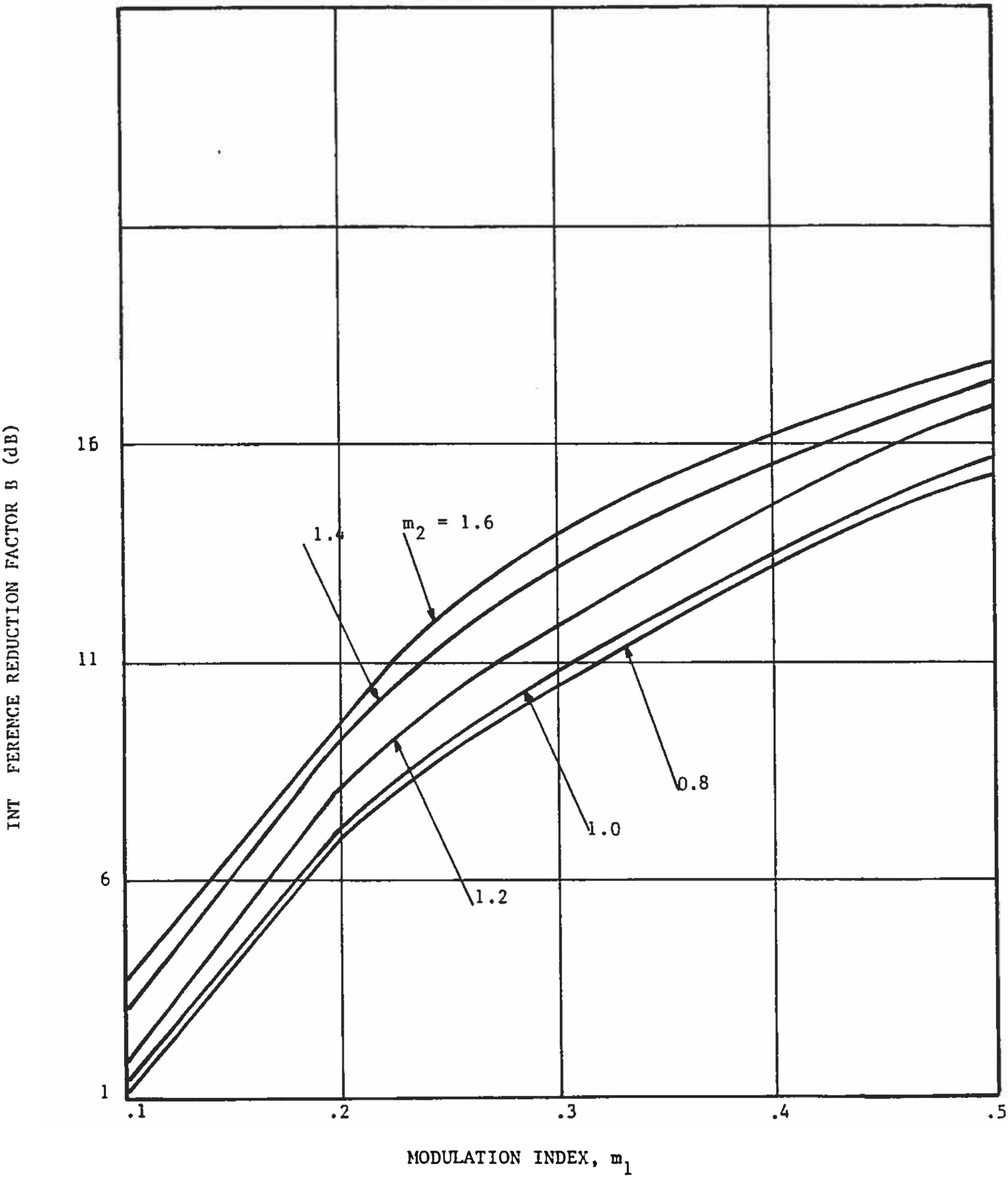


FIGURE C-3. Interference Reduction Factor, B, for Different Values of Modulation Index.

$$B = \alpha + (F_d/f_m)^2 - 2k \qquad \text{(C-12)}$$

For a 48 channel commercial communication system in this frequency range, the value of the bracketed term in Equation (C-11) is approximately -21 dB. The -21 dB was calculated from the data obtained for the operational equipment in this frequency range. Substituting -21 dB for the bracketed term in Equation (C-11) we obtain:

$$-19 < k < -4 \qquad \text{(C-13)}$$

These results indicate that the calculated values for the PFD limits in the 2 to 2.3 GHz may be too stringent by as much as 4 to 19 dB. It should be pointed out that the range of values calculated here for parameter k as given in Equation (C-12) is an approximation based on the above noted assumptions. The point to be made is the fact that k is not always equal to unity. This is contrary to the expression used in both GM and NGM programs where k was assumed to be equal to unity. Hence, Equation (C-1) used in these programs as a relationship for a receiver transfer function may have to be modified in the models at a future date in order to determine the PFD limits for the 2025-2300 MHz frequency range. The above analysis is applicable when the RF interference level is near the noise power level of the system and care should be exercised in the indiscriminate use of the calculated results given here.

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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.)

An assessment of the line-of-sight (LOS) power flux-density (pfd) limits for satellites operating in the 2025-2300 MHz frequency range was conducted. 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 suggested in order to enhance their accuracy in the evaluation of the pfd limits in this and other shared bands. Distinctions were made between the satellites in geostationary satellite orbit and those in nongeostationary 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 satellite orbits. These limits were calculated using the technical characteristics of equipment in the 2025-2300 MHz frequency range. The preliminary calculations using the existing computer models indicate that the pfd limits for the satellites operating in this frequency range may be relaxed.

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

1) Computer Models
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3) Electromagnetic Compatibility
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5) Systems in Space and Fixed Service Sharing
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