SECTION 5

ANALYSIS

PROBLEM DEFINITION

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

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

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

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

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

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

NG: Denotes Non-Government
G: Denotes Government

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

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

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

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

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

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

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

GENERAL DISCUSSIONS

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

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

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

FREQUENCY ENGINEERING OF RADIO-RELAY SYSTEMS

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

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

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

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

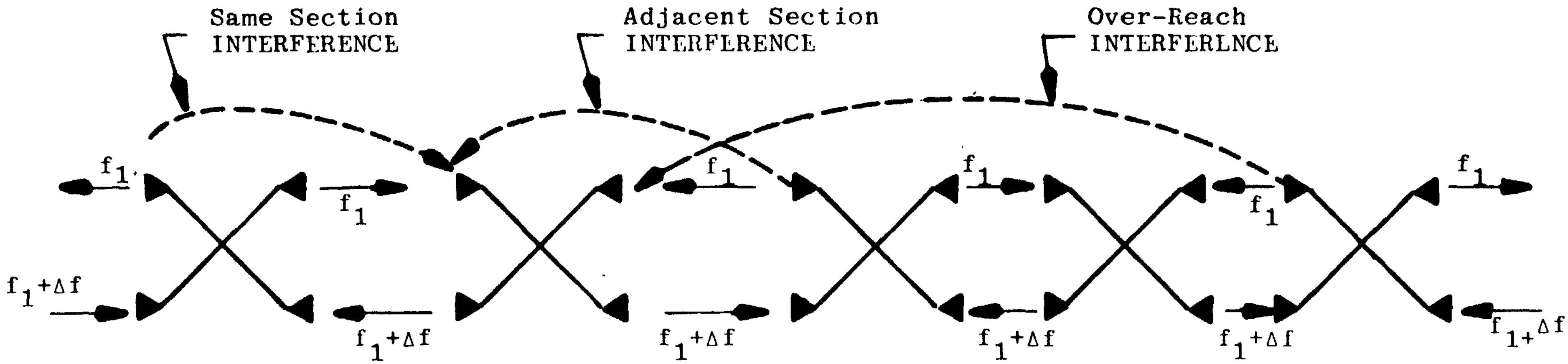

FIGURE 7. Types of Interference in a Microwave Radio-relay Communication System

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

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

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

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

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

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

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

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

FADING AND DIVERSITY CONSIDERATIONS

General

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

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

Design Margin

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

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

where;

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

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

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

where;

c = 4 over water and Gulf coast
1 average terrain and climate
¼ mountains and dry climate

f = frequency in GHz

D = path length in miles

L = ratio of faded to unfaded signal

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

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

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

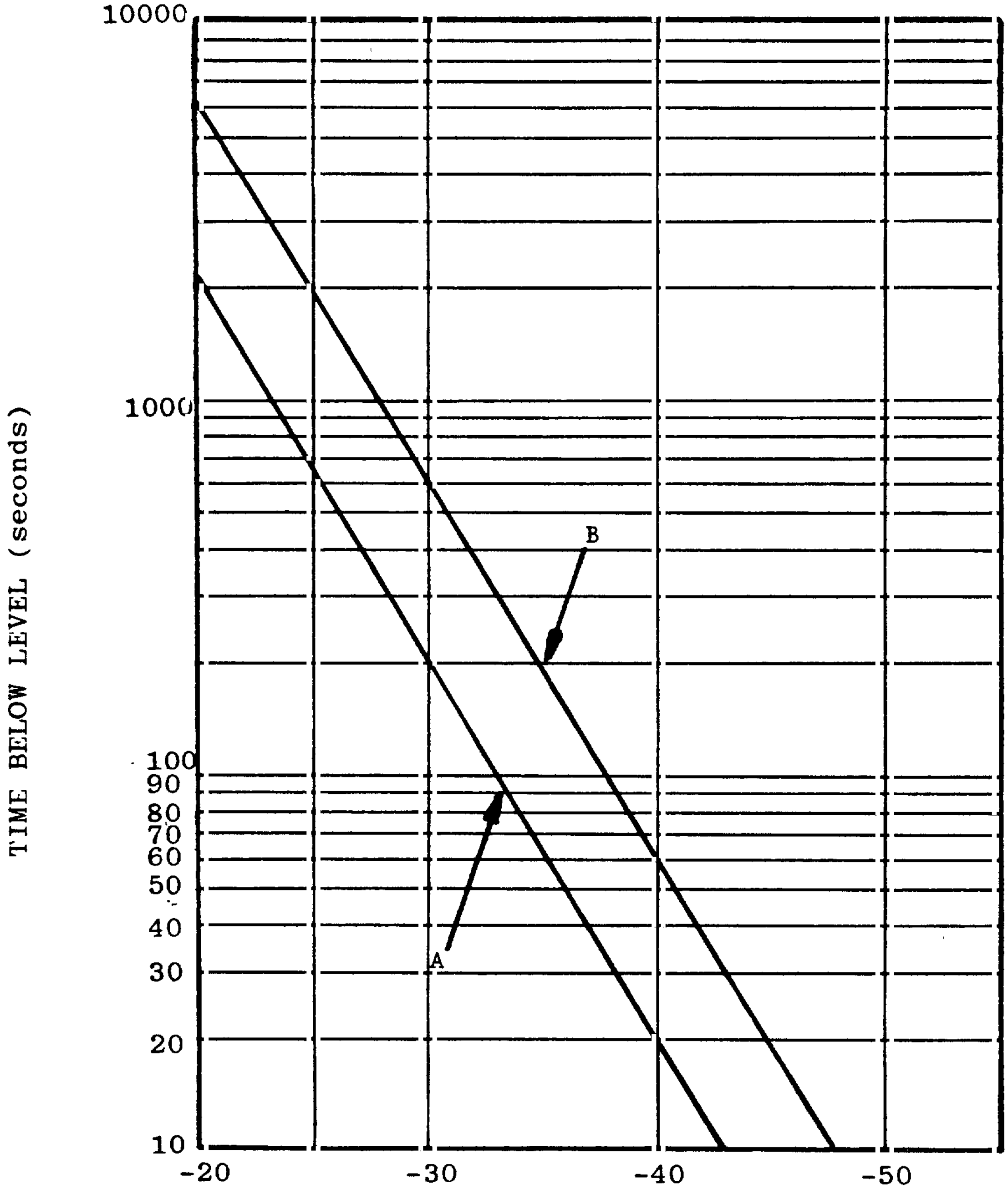

Figure 8 Time Below Level: A) Heavy Fading Month, B) Annual Fading (D=40 km, C=1, T_o=31 days= 2.68×10^6 seconds).

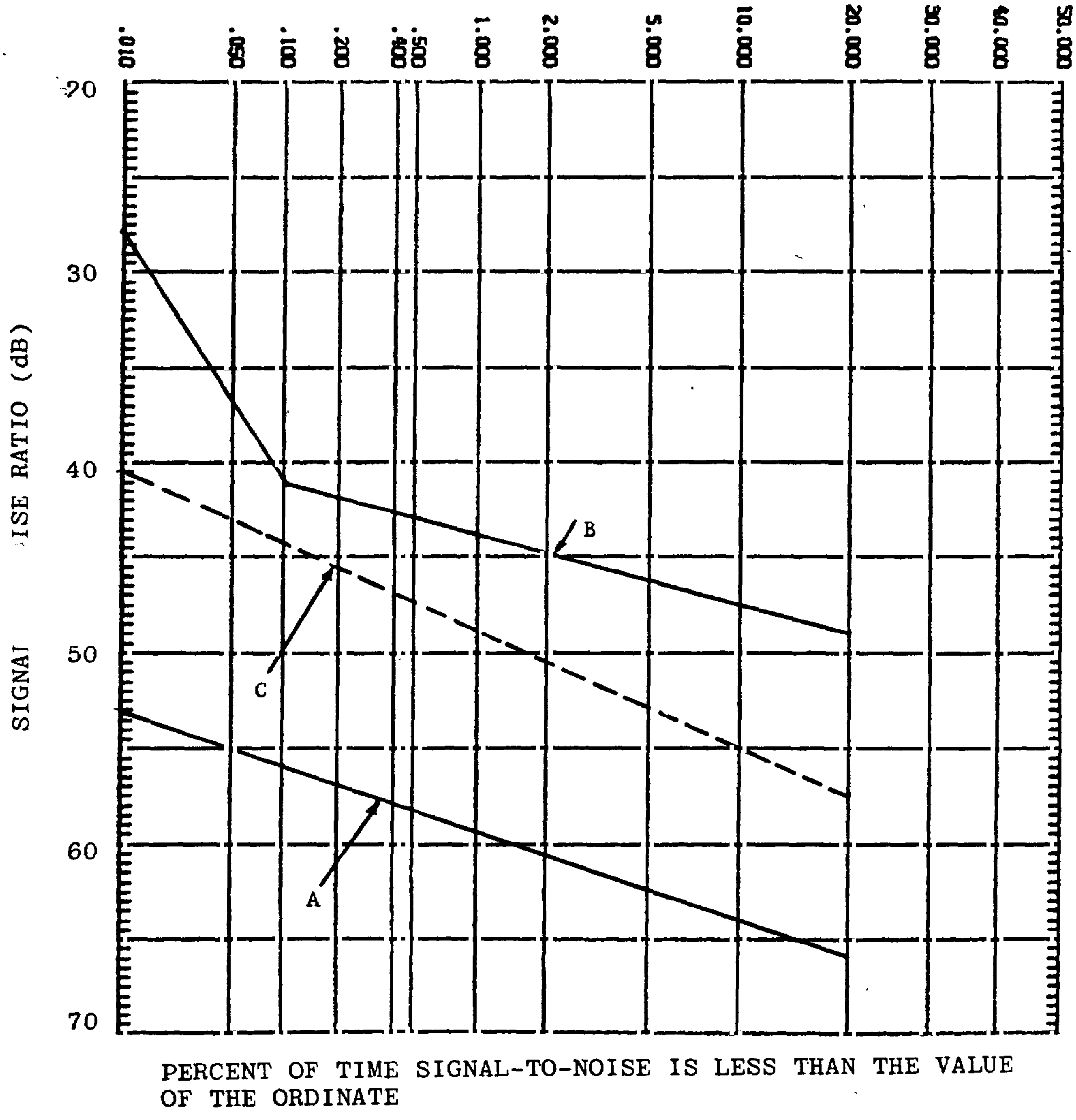

FIGURE 9 — SIGNAL-TO-NOISE RATIO - For a 250 Mile (400 km) Microwave Multihop System Fixed Service Using the Fading Data for 2025-2300 MHz Frequency Range.

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

Impact of Fading on pfd limits

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

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

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

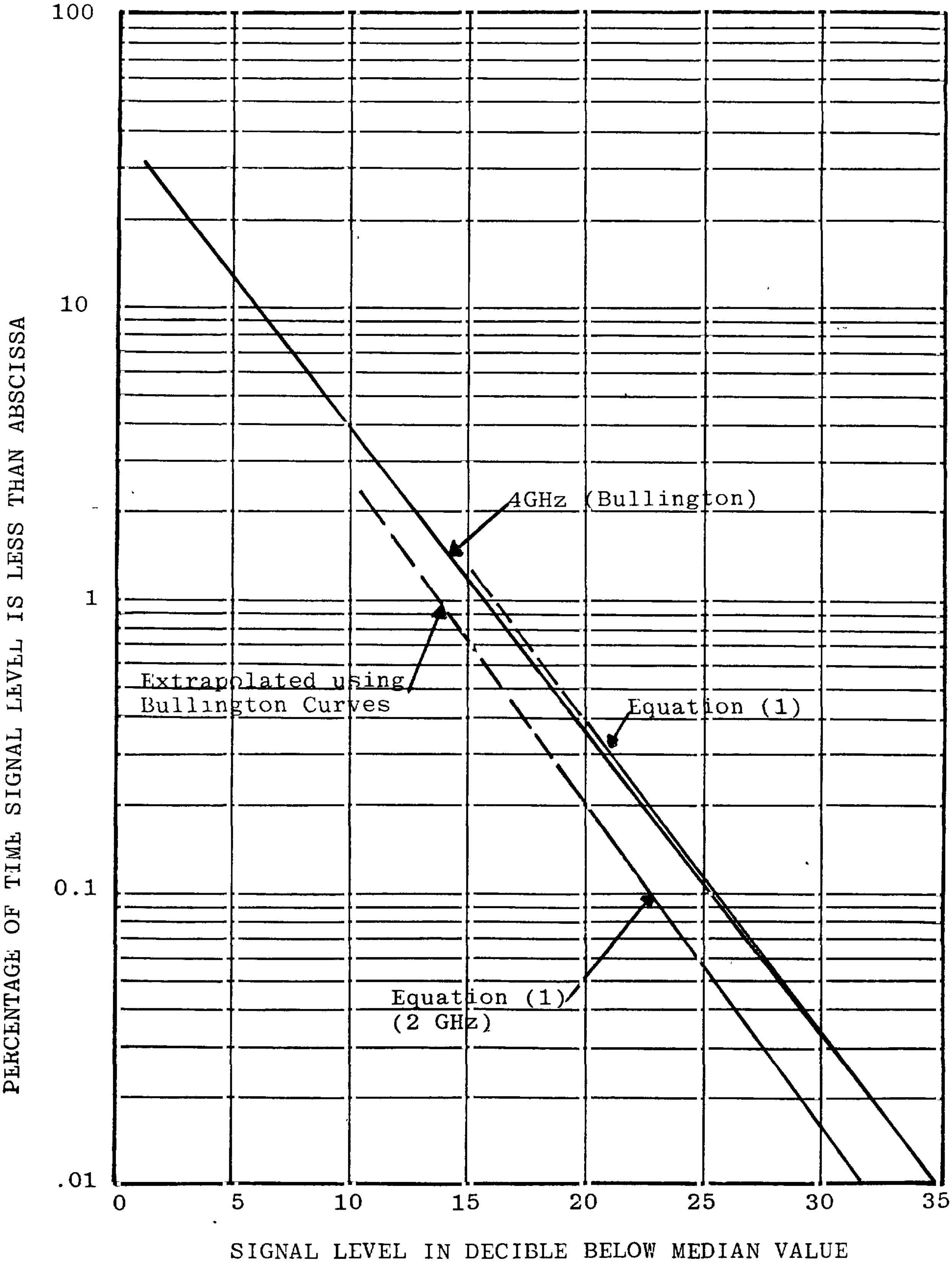

FIGURE 10: Comparison of Bullington results with data given by Equation (1)

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

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

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

MULTIPLE-ORBIT AND INCLINATION ANGLE EFFECTS

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

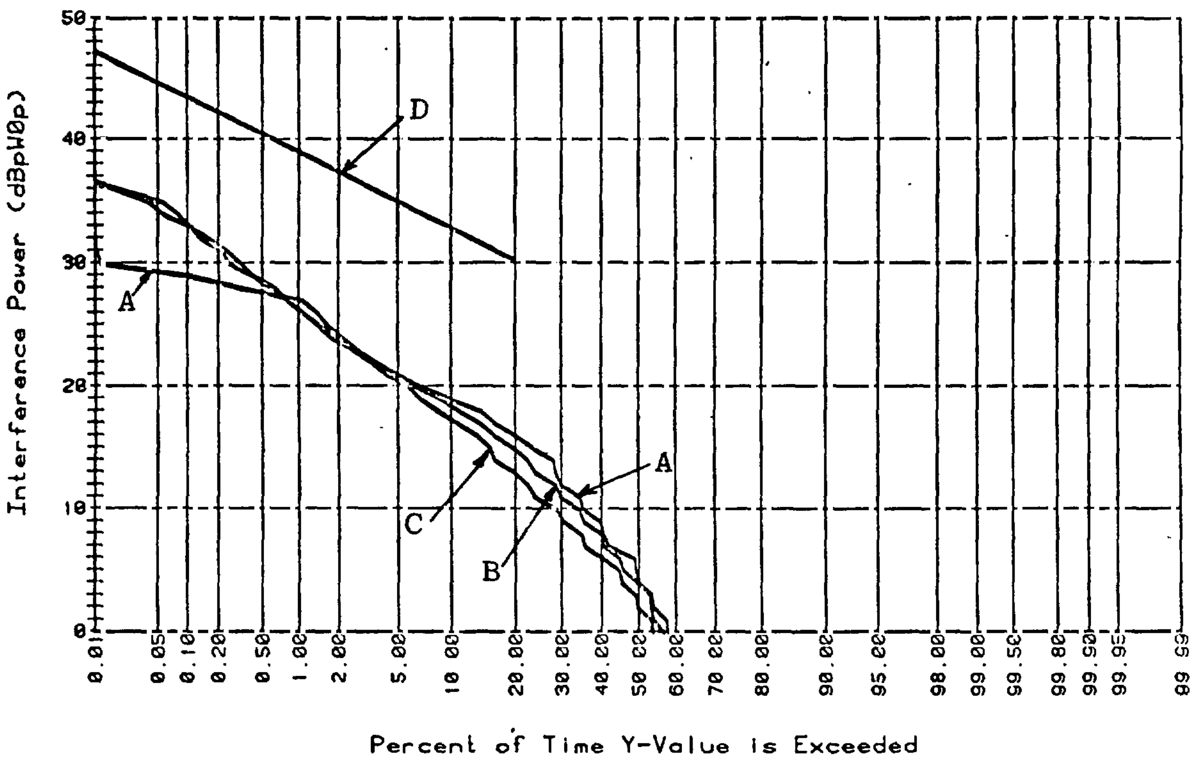

Figure 11. Inclusion of Fade Statistics in the Computation of pfd Limits for Satellites in non-geostationary Model. A) No fading statistics, B) Fading Data from Europe, C) Fading Data reported by Bullington, D) CCIR Noise Criteria Rec. 357-3.

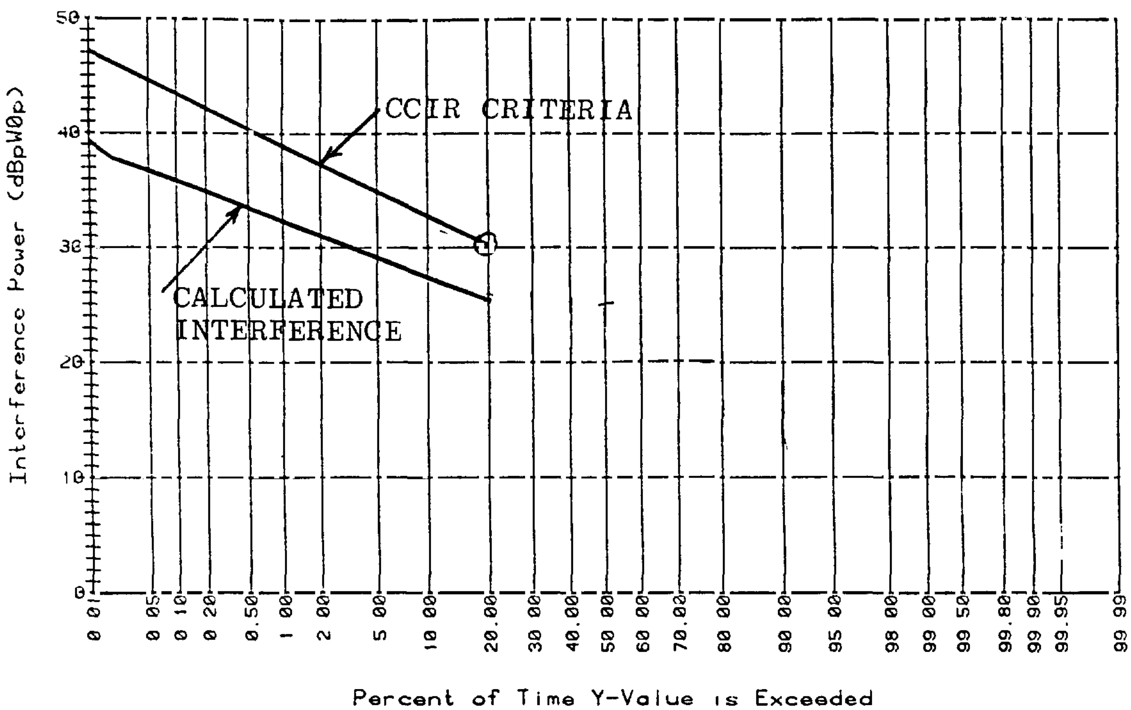

Figure 12. Inclusion of Fade Statistics in the Computation of pfd Limits for Satellites in Geostationary Orbit.