NTIA REPORT 86-199

CALCULATION OF POWER-FLUX DENSITY LEVELS IN THE 2 GHz BAND, PHASE THREE

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ABSTRACT

The analysis technique developed and discussed in two earlier NTIA reports [Farrar, 1984; Farrar, 1983] was used in conjunction with the data obtained from a number of different countries to calculate the power-flux-density (pfd) levels in the 2 GHz band. The data included the characteristics of satellites in the space services and fixed service systems in the band. Sharing criteria with other services, such as mobile, are not addressed.

KEY WORDS

Pfd Computer Models
Power-Flux-Density Limits
Satellite Services in 2 GHz
Sharing Criteria Near 2 GHz

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SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio frequency spectrum. Part of NTIA's responsibility is to "establish policies concerning spectrum assignment, allocation and use, and provide the various departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies" [NTIA, 1985]. In support of these requirements, NTIA has undertaken a number of studies. The objectives of these studies are to assess spectrum utilization, identify existing and/or potential compatibility problems between systems of various departments and agencies, provide recommendations for resolving any compatibility conflicts, recommend changes to promote efficient use of the radio spectrum, and improve spectrum management procedures.

In carrying out its mission, NTIA has undertaken the task of determining the power-flux-density (pfd) levels that may be recommended to International Radio Consultative Committee (CCIR) Study Group 2 for the space services in the 2025-2110 and 2200-2300 MHz frequency ranges. These frequency ranges will be referred to collectively as the 2 GHz band in this report, which is Phase III of the pfd studies. The analytical techniques for this Phase III task were developed earlier and are discussed in two NTIA reports [Farrar, 1984; Farrar, 1983]. The analysis results discussed in those reports are applicable to US satellites and radio-relay systems in the fixed service. This report contains a similar analysis, using the data on microwave radio-relay and space systems characteristics received from a number of countries for the purpose of preparing a CCIR report for Study Group 2. Sharing criteria between satellites and systems in other services, such as mobile, are not addressed in this report.

OBJECTIVES

The objectives of this effort were to:

1. collect and document the appropriate technical characteristics of spacecraft and fixed service stations in the 2 GHz band used by the United States and a number of other countries

2. calculate appropriate pfd levels for satellites in geostationary and nongeostationary orbits and present them in a report to CCIR Study Group 2.

APPROACH

To calculate the pfd levels for satellites in the 2 GHz band, it is necessary to determine the representative characteristics of space and terrestrial line-of-sight (LOS) radio-relay systems. Data for fixed service stations in India, Japan, Australia, England, Germany, and Canada were obtained and reviewed to determine the characteristics of a representative radio-relay circuit. This data was used in conjunction with the properties of the CCIR hypothetical reference circuit (HRC) [CCIR Recommendation 391, 1982], to determine the appropriate radio-relay characteristics.

Characteristics of space stations in both geostationary and nongeostationary orbits were also determined using the data in the International Frequency Registration Board (IFRB) file, data received from National Aeronautics and Space Administration (NASA) and information in NTIA files. The data for the fixed and space systems models were then used by the computer models discussed in the Phase I and Phase II NTIA reports [Farrar, 1983; 1984] to calculate the pfd limits applicable to space systems in the 2 GHz band. For easy reference, a brief description of these computer models is included in APPENDIX A.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Appropriate data, described in Section 3, for fixed service systems in the United States and a number of other countries, were used for this analysis. Band use varied from one administration to another, and the combination of the data and characteristics of the CCIR hypothetical reference circuit (HRC) provided an appropriate basis for developing model parameters representative of radio-relay circuits. The United States has a number of major systems that incorporate state-of-the-art technology and operate in the space services allocated in the 2 GHz band. The emission and operational characteristics of non-US satellites are not expected to be significantly different than those of the US satellites and, therefore, the characteristics of US satellites were used in the analysis.

The analysis results provide pfd levels to protect typical worldwide line-of-sight (LOS) fixed service systems, operating in the 2 GHz band, from potential interference caused by satellites in both geostationary and nongeostationary orbits. A report summarizing the results of the analysis was prepared and was approved by CCIR Study Group 2 at its meeting in September 1985 in Geneva, Switzerland. Sharing with fixed service systems using troposcatter or mobile service systems was not addressed. Based on an earlier analysis [Farrar, 1984], IRAC Ad Hoc group 199 was formed to determine the coordination procedures, using the calculated pfd levels given in Figure 2-1, required for sharing between satellites and aeronautical telemetry systems operating in the mobile service.

CONCLUSIONS

1. The calculated results, based on the analysis of satellite transmitter and typical worldwide fixed service systems characteristics, indicate that in the 2 GHz band, sharing is

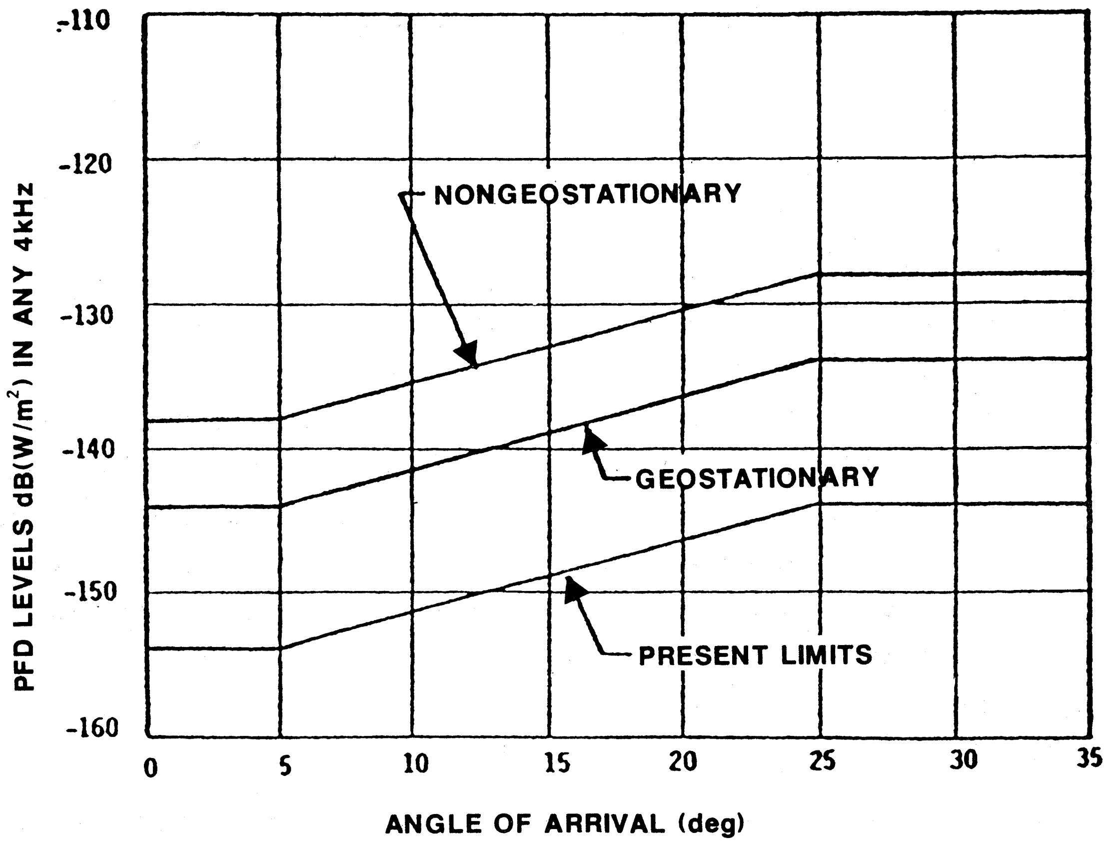


Figure 2-1. Calculated pfd levels for geostationary and nongeostationary satellites.

possible between space services and fixed service systems with relaxed pfd limits.

2. The data on radio-relay systems received from different countries were found to be similar and appropriate for use in determining typical radio-relay model parameters (a representative system).

3. The analysis results indicate that satellite emissions received by LOS radio-relay circuits will be below the interference criteria given in CCIR Recommendation 357-3 [CCIR Recommendation, 1982], using the calculated pfd levels given in Figure 2-1. Figure 2-1 also shows the pfd limits given in the International Telecommunication Union's (ITU) Rules and Regulations (No. 2557)[ITU, 1984].

4. Analysis procedures, similar to those used to determine the pfd levels for the 2 GHz band, could also be used to calculate the levels applicable to other shared bands.

5. Additional studies may be required to determine the applicability of the results shown in Figure 2-1 to sharing with fixed systems using tropospheric transmission.

RECOMMENDATIONS

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

1. continue to complete the task assigned to Ad Hoc working group 199

2. develop a coordinated Federal Government position relative, to the adoption of relaxed pfd levels, based on the analysis results from Ad Hoc working group 199 and NTIA Report 84-152

3. develop, in conjunction with FCC, a national position relative to the relaxation of present pfd limits in the 2 GHz band

4. develop input material, as appropriate, for sumbission to relevant CCIR study groups to gain acceptance of the US position by other administrations.

SECTION 3

COMPUTATION AND DATA BASE

GENERAL

The determination of representative characteristics of fixed service radio-relay and space services systems is required as input data to the pfd analysis models. In this section, data base information leading to the determination of representative characteristics for both the terrestrial LOS and space systems is discussed. The model input data are influenced by the services allocated in the 2 GHz band, parameters of operational and planned systems, and band use.

Internationally, the 2 GHz band is allocated to the fixed and mobile services in all three ITU Regions. The actual use (spectrum occupancy) and number of frequency assignments often vary considerably from one administration to another, even within any one region. The band use by an administration is a function of the administration's telecommunications needs and economy. Generally, telecommunications needs grow with the economy. Therefore, it is reasonable to prepare a data base on the basis of the needs of industrial nations, since developing nations will continue to acquire telecommunications facilities similar to those used and made available to them by the industrial nations. Hence, manufacturers' equipment specifications are extremely useful in preparing representative system characteristics.

DATA BASE

This subsection includes representative characteristics of radio relays operating in some of the countries considered for this analysis. Data obtained from some US manufacturers are also discussed. Data for space and terrestrial systems in the 2 GHz band were obtained from the NTIA files, NASA, IFRB, International Telephone and Telegraph (ITT) World Headquarters, and some members of the Space Frequency Coordinators Group (SFCG). SFCG is an international organization comprised of representatives from approximately 27 countries that have spacecraft operating in the 2 GHz band.

Radio-Relay Characteristics

The key radio-relay parameters for determining pfd levels are the length of a radio-relay circuit, number of hops in a circuit, receiver free-space noise associated with a hop length and radio noise, receiver noise temperature, and frequency reuse in a trendline.[a] TABLE 3-1 shows the appropriate radio-relay system characteristics for the systems in a number of different countries. For the purpose of comparison, representative data obtained from some US manufacturers are also included in the table.

The data in TABLE 3-1 were used to determine the model parameters for a typical terrestrial LOS radio-relay circuit. It indicates that the HRC parameters used in CCIR Report 387-4 [CCIR Report, 1982] to evaluate pfd levels result in a worst-case analysis. The HRC defined in CCIR Recommendation 391 [CCIR Recommendation, 1982] and discussed by Panter [1972] is 2500 km long, consisting of nearly 50 hops, each separated by approximately 50 km. The purpose of establishing an HRC for radio-relay systems is to provide guidance to designers of equipment and systems that are used in international telecommunications networks.

For the majority of the administrations, the data in TABLE 3-1 indicate that the hop length for their systems is less than 50 km and the number of hops for operational circuits is generally less than 40. Less space between stations and fewer hops in a trendline imply less exposure of radio-relay receivers in the circuit to interference from satellites, resulting in more relaxed pfd limits. However, in determining pfd limits for this analysis, parameters for radio-relay circuits were carefully selected to allow for future growth, as well as advancement in technology. In this sense, the HRC

a. Trendline is defined as a communications link between two points, with a number of repeaters [May and Pagones, 1971].

TABLE 3-1

SOME REPRESENTATIVE CHARACTERISTICS OF RADIO-RELAY SYSTEMS IN THE 2 GHz BAND

ITEMS	ENGLAND	GERMANY	INDIA	JAPAN	AUSTRALIA	USA	CANADA
Receiver Temperature (K)	300-1160	360-870	2600	1150-6000	-	290-891	290-1163
Noise Figure (dB)	3.1-7	3.5-6	10	7-13.5	-	3-6.1	3-7
System Use	Private & Industrial	Military	-	-	Government & Industrial	-	Industrial
Frequency Reuse	Two	CCIR[(a)]	CCIR[(a)]	CCIR[(a)]	CCIR[(a)]	Two/Four/Six	Two/Four
Diversity	None	-	-	-	Space	Space	-
Antenna Gain (dBi)	35-40	35-40	30-34	25-36	35-40	20-40	20-40
No. of Hops in a System	$\leq$ 40	-	-	$\leq$ 20	-	$\leq$ 40	$\leq$ 40
Spacing Between Hops (km)	$\leq$ 50	20-40	$\leq$ 50	$\leq$ 50	$\leq$ 50	$\leq$ 40	$\leq$ 50
No. of Systems	-	200	-	$\leq$ 20	-(b)	-	Unknown
Modulation	Analog, Digital	Analog, Digital	Analog, Digital	Analog, Digital	Analog, Digital	Analog, Digital	Analog, Digital

(a) Use CCIR Recommendations.

may be considered a yardstick for equipment and systems designers and, hence, useful in determining pfd limits.

Model Parameters for a Terrestrial Line-of-Sight Radio-Relay System

Technical characteristics of current radio-relay circuits were used to develop model input parameters for those types of systems used in the calculations of pfd limits. Expansion and future development of both space and terrestrial systems were considered, using a conservative approach to select model parameters.

The model parameters for LOS radio-relay systems used in both the geostationary model (GM) and the nongeostationary model (NGM) are listed in TABLE 3-2. For this report, the word nongeostationary implies the orbit is below that of a geostationary satellite. Both the GM and NGM are discussed in an earlier NTIA report [Farrar, 1984]. The GM was used to calculate pfd limits for the geostationary satellites and the NGM was used to calculate pfd limits for nongeostationary satellites.

The 50 km hop length in TABLE 3-2 corresponds to the CCIR definition of an HRC [CCIR Recommendation 391, 1982].

Space System Characteristics

There are three space services allocated in the 2025-2300 MHz frequency range. They are space research, space operations, and earth exploration satellite. Despite definitions and attempts by the CCIR to characterize these services, it is difficult to relate the functions of satellites to these services. It is more meaningful to consider the characteristics of the operational satellites, regardless of the services in which they operate. Typical characteristics for the satellites were derived using the information given in TABLE 3-3. TABLE 3-3 describes the appropriate parameters for US satellites and TABLE 3-4 lists the parameters for non-US satellites. Note that there are 42 satellites in TABLE 3-3, compared to the 23 satellites in TABLE 3-4. It should be pointed out that TABLES 3-3 and 3-4 contain existing and planned satellites. The characteristics of the satellites given in TABLES

TABLE 3-2

GM AND NGM RADIO-RELAY CIRCUIT PARAMETERS	
Hop Length	50 km
Number of Hops	50
Antenna Mainbeam Gain	36 dBi
Feeder Loss	3 dB
Receiver Free-Space Noise Temperature[a]	750 K
Channel Thermal Noise Power [b]	25 pWOp

a. The overall receiver noise temperature used in this analysis was 750 K, which corresponds to a noise figure of 5.5 dB. This is practical and accommodates future growth in the design of radio-relay receivers in the 2 GHz band. The typical noise figure may be as high as 10 to 12 dB. Higher values result in a more relaxed pfd limit.

b. The value of the thermal noise power in a receiver, calculated on the basis of noise criteria discussed in CCIR Recommendation 393-4 [1982], varies from 8 to 25 pWOp. Higher values of free-space thermal-noise power result in lower pfd limits according to the models used for this report. The calculated results substantiate this. In the calculations of the current pfd limits in CCIR Report 387-4 [1982], the mean thermal noise power was assumed to be 25 pWOp.

3-3 and 3-4 were used to prepare the model parameters for the space sevices employed in this calculation.

The key parameters in determining pfd limits in the 2 GHz band are the number of satellites that may operate cochannel with a radio-relay circuit, the typical bandwidth of satellite emissions, and the spacing between geostationary satellites. Satellite spacing and the number of satellites are a function of the demands by various administrations on space services and the economy. As such, the assessment of these parameters should be based on past growth, keeping the future in mind. A satellite's emission bandwidth, however, depends on the allocated services and the mission the satellete is

TABLE 3-3

U.S. SATELLITES PLANNED OR OPERATIONAL IN THE 2025-2300 MHz FREQUENCY RANGE
(Page 1 of 3)

ORBIT	SPACE SYSTEM	NATIONAL STATUS	IFRB STATUS	OPERATIONAL STATUS	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	SPECTRUM TYPE
HE	AMPTE	SR(3)	AP(Prep)	Planned	Elliptical	28.5	2271.	1
LO	COBE (TDRSS)			Planned	900 x 900	99	2287.5	3
HE	DE-A	SR(3)	AP	Active	Elliptical	89.7	2214.	1
LO	ERBS(TDRSS)	SR(Prep)	AP(Prep	Planned	610 x 610	46	2287.5	3
LO	EUVE(TDRSS)			Planned	550 x 550	28.5	2287.5	3
DS	Galileo	SR(3)	AP(Prep)	Planned	Deep Space		2295,2296.4815	1
G	GOES-3			Active	Synch	0.0	2031.1, 2034.2	1
G	GOES-4 (D)			Active	Synch	0.0	2034.9, 2209.086	1
G	GOES E,F			Planned	Synch	0.0	2214,2033	3
LO	GRO(TDRSS)	SR(3)	AP(Prep)	Planned	400 x 400	28.5	2287.5	1
LO	IRAS	SR(3)	AP(Prep)	Planned	900 x 900	99	2253	1
HE	ISEE-1 (A)	SR(3)	AP	Active	Elliptical	27.5		1
HALO	ISEE-3(C)	SR(3)		Active	Elliptical	24.3	2215.5, 2264.8	
RE	IUE		AP	Active	Elliptical	28.7	2249.8	1
LO	LANDSAT-D(TDRSS)	SR(3)	AP	Active	705 x 705	98.2	2287.5, 2265.5	3
LO	NIMBUS-7 (G)		AP(Prep)	Active	960 x 945	99	2211,2273.5	1
DS	OPEN			Planned				1
DS	PIONEER 6-11		REG	Active	Deep Space		2294.26, 2293.89	3
LO	SME(TDRSS)	SR	AP	Planned	530 x 530	97.5	2287.5	3
LO	SMM(TDRSS)	SR(3)	AP REG(Prep)	Active	574 x 574	33	2287.5	3
LO	ST	SR	AP	Planned			2255.5, 2287.5	3
LO	STS(TDRSS)	SR(2)	AP(Prep)	Planned	Variable		2217.5,2250,2287.5	3
G	TDRSS-E,W,C	SR(3)	AP,REG(Prep)	Planned	Synch		2211,2106.4	3
LO	UARS-A+B			Planned	600 x 600	57		3
DS	Viking 1 Land	SR(4)	AP(REG)	Active	Deep Space		2293.15,2294.63	
DS	Voyager 1	SR(3)	REG	Active	Deepspace		2295, 2296.48	
DS	Voyager 2	SR(3)	REG	Active	Deepspace		2113.31, 2295	
G	GSP/NAVSTAR	SR(4)	AP REG	Active	Synch	0.0	2227.5	1
G	IRV	SR(2)		UNKNOWN	Synch	0.0		1

TABLE 3-3

U.S. SATELLITES PLANNED OR OPERATIONAL IN THE 2025-2300 MHz FREQUENCY RANGE
(Page 2 of 3)

ORBIT	SPACE SYSTEM	NATIONAL STATUS	IFRB STATUS	OPERATIONAL STATUS	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	SPECTRUM TYPE
G	LES 8	CMF		Active	Synch	0.0		1
LO	P78-1	SR(4)	AP COORD*REG*	Active	593 x 593	97.7	2247.5, 2252.5	1
LO	P78-2	SR(4)	AP COORD REG	Active	43 x 28	8.3	2222.5	1
LO	P80-1	SR(3)	AP COORD	Planned 11/82	740 x 740	72.5	2212.5-2207.5	1
	SAMS026-70			UNKNOWN				1
G	DSCS II IND OCN			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II ATL			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II EPAC			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS II WPAC			Active	Synch	0.0	2272.5, 2277.5	1
G	DSCS III INDOCN	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCSIII ATL/MID	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCS III EPAC	SR(4)		Planned	Synch	0.0	2257.5, 2277.5	1
G	DSCSIII WPAC	SR(4)		Planned	Synch.	0.0	2257.5, 2277.5	1
G	FLTSATCOM INDOCN			Active	Synch	0.0		
G	FLTSATCOM ATL			Active	Synch	0.0		
G	FLTSATCOM EPAC			Active	Synch	0.0		
G	FLTSATCOM WPAC			Active	Synch	0.0		
G	FLTSATCOM INDOCN	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM ATL	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM EPAC	SR(4)		Planned	Synch	0.0		
G	FLTSATCOM WPAC	SR(4)		Planned	Synch	0.0		
LO	BLOCK-5D(DMSP)	SR(4)	AP	Active	732 x 724	98	2207.5, 2252.5 2237.5, 2267.5	1

TABLE 3-3

U.S. SATELLITES PLANNED OR OPERATIONAL IN THE 2025-2300 MHz FREQUENCY RANGE
(Page 3 of 3)

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

SR()	=	System Review (stage of review)
GMF	=	Government Master File
AP	=	Advanced Publication
COORD	=	Frequency Assignments Coordinated with Other Administrations
REG	=	Frequency Assignments in the Master Register of IFRB
(Prep)	=	Documents in Question, Prepared But Not Submitted or Action Not Completed
*	=	Only Some of the Necessary Actions with the IFRB Have Been Completed
LO	=	Low Orbiting
HE	=	Highly Elliptical
G	=	Geostationary
DS	=	Deep Space

NOTE 2: TDRSS and LANDSAT represent two types of emission spectrum used in this frequency range. Type 1 in TABLE 3-3 represents aspectrum similar to that used by LANDSAT and Type 3 represents a satellite transmitter that is capable of producing LANDSAT and TDRSS type signals.

NOTE 3: Frequencies shown in TABLE 3-3 are satellite transmit and receive frequencies. All the frequencies in the 2025-2120 MHz frequency range are satellite receive frequencies, with the exception of those for TDRSS that may transmit on any frequency in the 2025-2120 MHz frequency range.

TABLE 3-4

SOME OF THE NON-US SATELLITES IN THE 2 GHz BAND
(Page 1 of 2)

ORBIT	SPACE SYSTEM	COUNTRY	IFRB STATUS	DATE OF USE	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	
							UPLINK	DOWNLINK
HE	EXOSAT	FRANCE	AP	DEC, 1981		72	2081.82	2260.8
G	L-SAT	FRANCE	AP	1985			2026.7542	2201
LO	SPOT-1	FRANCE	AP	JUNE, 1984	822 x 822	98.7	2031.294	2205.93
LO	SPOT-2	FRANCE	AP	JUNE, 1985	829 x 813	98.7	2031.846	2206.53
G	TDF-1	FRANCE	AP	1984			2033.45	2208.2715
G	TELECOM-1C	FRANCE	AP					2203.5-2208.5
G	TV-SAT	GERMANY	AP	1984			2026.054	2200.24
LO	ASTRO-A	JAPAN	AP	1981	640 x 480	31		2280.5
LO	ASTRO-B	JAPAN	AP	1983	650 x 550	31		2280.5
G	BS-2	JAPAN	COORD	FEB, 1984			2096-2101	2276.99,2280.7
G	CSE	JAPAN	AP	FEB, 1977			2110.8	2286.5
G	CS-2A	JAPAN	COORD	FEB, 1983			2110.8	2286.5
G	CS-2B	JAPAN	COORD	NOV, 1983			2110.8	2286.5
HE(1)	ETS-IV	JAPAN	AP	1981			2116.6	1705
G	TELE-X	SWEDEN	AP	1986			2027-2035	2202-2210
G(2)	PROGNOZ-1	USSR	COORD	1982				
G(2)	PROGNOZ-2	USSR	COORD	1982				
G(2)	PROGNOZ-3	USSR	COORD	1982				
G(2)	PROGNOZ-4	USSR	COORD	1982				

TABLE 3-4

SOME OF THE NON-US SATELLITES IN THE 2 GHz BAND
(Page 2 of 2)

ORBIT	SPACE SYSTEM	COUNTRY	IFRB STATUS	DATE OF USE	ORBIT ALTITUDE (KM)	INCLINATION ANGLE (DEG.)	FREQUENCY (MHz)	
							UPLINK	DOWNLINK
HE	VIKING	SWEDEN	AP	2nd half 1984	822 x 15,000	98.7	2033.35	2208.1629
G	MSAT	CANADA	AP	1987			2090.15	2269.85
G	DFS-1	FRG	AP	1987			2028	2202.35
G	DFS-2	FRG	AP	1988			2028	2202.35
HE	AMPTE-UKS	BRITIAN	AP	AUG, 1984	547 x 112,891	28.5	2093.75	2273.76
HE	AMPTE-IRM	FRG	AP	AUG, 1984	500 x 121,000	85	2103.6	2284.5
G	APEX	FRANCE	AP	1986			2029-2033.6	2203.5-2208.5
G	F-SAT-1	FRANCE	AP	1987			2025-2110	2200-2290
G	F-SAT-2	FRANCE	AP	1986			2025-2110	2200-2290
(3)	GIOTTO	FRANCE	AP	JULY, 1985			2116.723	2298.704
G	HIPPARCOS	FRANCE	AP	1988			2063.59	2241.00
(4)	ISPM	FRANCE	AP	MAY, 1986			2111.607	2293.148
G	VIDEOSAT-1	FRANCE	AP	1987			2025-2110	2200-2290
G	VIDEOSAT-2	FRANCE	AP	1987			2025-2110	2200-2290
LO	EXOS-C	JAPAN	COORD	FEB, 1984	320 x 1,000	73	2108.557	2280.5
G	CMS-3	JAPAN	AP	AUG, 1984			2025-2110	2200-2290
(5)	MS-T5	JAPAN	AP	JAN, 1985			2111.607	2293.148
(3)	PLANET-A	JAPAN	AP	AUG, 1985			2112.289	2293.8889
G	HELVESAT-1	SWITZERLAND	AP	1986			2025-2110	NONE
G	UNISAT-1	BRITIAN	AP	1986			2025-2110	2200-2290

1 - Earth-to-Space -- 2116.6 MHz, Space-to-Earth -- 1705 MHz

2 - All PROGNOZ Type Satellite Operation on These Bands: 2131, 2151, 2191, 2211, 2231, 2251 MHz, (all ± 10 MHz) 2277, 2289 MHz (both ± 6 MHz).

3 - Will observe Halley's Comet.

4 - Earth-to-Jupiter mission

5 - Interplanetary mission

used for in such services. An appreciation of bandwidth is important to the analysis of pfd limits.

In a strict sense, the signal structure and emission spectral density of any satellite system are generally unique. However, for a tractable analysis, it is desirable to categorize the spectral densities of satellites in the 2 GHz band. The analysis results, as shown later, are not sensitive to the detailed signal structure of satellites. The envelope of a signal emission spectral density, to a greater extent, and the positions of nulls near the main peaks of the spectrum, to a lesser extent, are all that are necessary for this analysis.

In general, the communications systems used to support the satellites of other countries are similar to those used in the US and consequently, the satellites spectra are similar to those characterized in this report as LANDSAT-4 for non-TDRSS type; that is, the signals are most commonly a PCM/PSK/PM modulation. The basic digital pulse code modulation (PCM) data is used to phase shift key (PSK) a subcarrier that in turn is used to phase modulate (PM) the carrier. The subcarrier must be sufficiently removed from the carrier so that a spectrally pure carrier component remains, as is required by the ground based receiver. Tone ranging is also used. (Discrete frequency tones are phase modulated (PM) on the uplink and coherently returned on the downlink.)

Many international spacecraft placed in geosynchronous orbit use the 2 GHz band only for minimal tracking, telemetry, and command (TT&C) during launch and back-up purposes. Service areas for both geosynchronous and nongeosynchronous orbits are limited usually to the country of origin, and the nongeostationary spacecraft transmitters are typically on only when they are being read out. Different orbits are used for low-earth orbiting satellites, depending on mission requirements, but as in the US, the polar orbit and the orbits around 28.5 degree inclination angles are most common.

In the US, the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and Department of Defense (DOD) are the primary users of satellite services using frequencies in the 2 GHz band. The use of these services is by no means restricted to the US, however, as a number of other administrations are active in space flight activities using these types of 2 GHz services. Included in this growing list of countries are Japan, Canada, India, France, United Kingdom, Germany (FRG), Sweden, Italy, and USSR. In addition, a number of European countries are active in space through the European Space Agency (ESA).

A rather coarse categorization of satellite emission spectral density may be achieved by considering two types of spectrum used by satellites. These two types of spectrum are designated by TDRSS and LANDSAT-4. Sometimes a satellite may be capable of transmitting both types. Examination of these two types of signal structure and their respective power density spectrum are as follows.

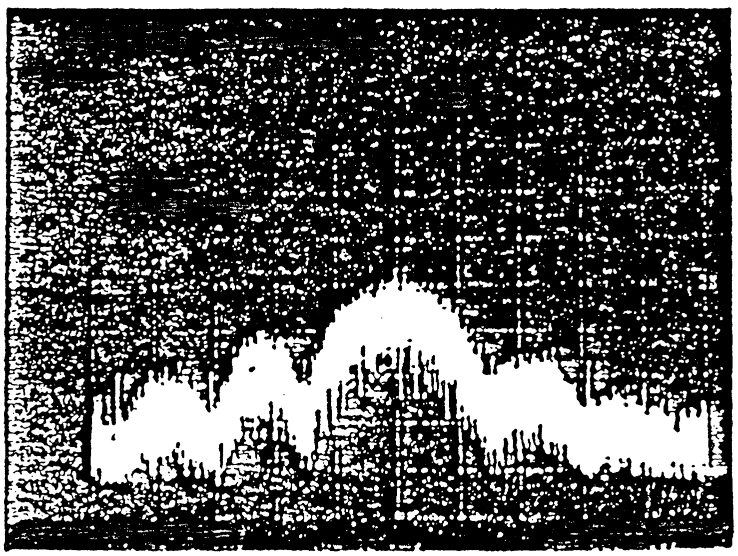
LANDSAT-4 Type Power Spectrum Density. This type of spectrum was originally used in the design of unified S-band (USB) systems used by the Navy. The downlink signal structure for the USB systems (as designed for Apollo) used subcarriers and a pseudonoise (PN) signal. The USB signal for this system was later modified to distribute the power more evenly over a wider band for use in the TDRSS design. The USB signal consisted of a carrier and standard subcarriers that were 1.024 and 1.25 MHz (used for telemetry and voice) away from the carrier frequency. This, of course, resulted in energy concentrations in certain segments of the spectrum, depending upon the number of subcarriers used. The USB used today operates in very much the same way as it did for Apollo.

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

Mode	Modulation	Data Rate (kb/s)	Modulation Index (rad)
1	PCM/PSK/PM	8	1.6
2	PCM/PSK+	8	0.8
	PCM/PM	32	1.0
3	PCM/PSK+	8	0.8
	PCM/PM	256	1.0
4	PCM/PSK+	8	0.8
	Tone PM	-	0.39

These modes all use a single 5-watt transmitter, and the subcarriers are separated by 1.024 MHz from the carrier. Note that the relatively low modulation indices imply most of the energy is contained in the first few sidebands. These modes are examined in detail in an earlier NTIA report [Farrar, 1984].

TDRSS-Type Power Spectrum Density. A photograph of the emission spectrum for LANDSAT-4 operating in the TDRSS mode is shown in Figure 3-1. The signal structure in Figure 3-1 is typical of both the TDRSS forward link transmit signal (to the user) and the return link signal transmitted from the user to TDRSS. TDRSS is a product of the latest technology developed by NASA. Briefly, TDRSS, as envisioned by NASA, is a consolidated system that provides, at once, communications requirements for the near-earth unmanned systems (previously performed at VHF frequencies) and for the USB system that operates at S-band. The USB was used for Apollo and other manned spacecraft; hence, TDRSS is a satellite network that provides communications functions for both manned and unmanned space programs. The data in Figure 3-1 shows a direct sequence spread spectrum signal in which the spreading chip rate is about three Mb/s.



H 2 MHz/div
V 10 dB/div
BW 10 kHz
SWP 600 ms
CP 2287.5 MHz

Figure 3-1. Emission spectrum of TDRSS down path transmission $(\sin x/x)^2$.

Note that the power density spectrum shown in Figure 3-1 is $(\sin x/x)^2$, with nulls above and below the center frequency and with a null-to-null bandwidth of about 6 MHz. It is estimated that about 80% of the power is in the region defined by $\pm$ 1.6 MHz. Considering the emission spectrum shown in Figure 3-1, a bandwidth of $\pm$ 1.6 MHz is close to 8 dB points on the spectrum and the first nulls occur approximately at $\pm$ 3 MHz where the spectrum is 20 dB below the peak.

As noted, the spectrum in Figure 3-1 is typical of TDRSS and for most spacecraft associated with TDRSS. The spreading signal is a PN code and can also be used for ranging and/or data transmission purposes. In the past, the satellite technology used by NASA was such that the spectrum for every satellite was generally custom designed based on the mission of the satellite. This mode of operation also required a number of earth stations to be maintained by NASA overseas. However, it should be pointed out that with the advent of TDRSS, the future user satellites should be designed in conformity with the spectrum designed for TDRSS. Most of the earth stations overseas are being phased out and data transmission and collections by the satellites will be carried out through TDRSS. The transfer should take place when TDRSS is fully operational. LANDSAT-4 has a transmitter with a spectrum compatible to TDRSS, which may be activated by ground control.

This discussion on TDRSS pertains to plans envisioned by NASA, a major user of the spectrum for space services in the 2025-2300 MHz frequency range. Other US agencies, such as the Department of Defense, may continue to design satellites with a spectrum similar to those used by LANDSAT-4 or a variety of other types. However, for the purpose of this pfd analysis, it is more desirable to use a typical spectrum rather than a variety, or even the worst case one, so that the analysis results will be more applicable to existing and planned systems.

A review of the available emission spectra used often by spacecraft in the 2 GHz band indicates that the systems for the allocated space services in this band are relatively narrowband, and that a bandwidth variation of 0.5 to 4 MHz is a reasonable range for the analysis. A bandwidth of 4 MHz accounts for nearly 90 percent of the power emitted from a wideband satellite in this frequency range. A bandwidth of 2 MHz was considered typical for emissions from spacecraft in this band.

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

TYPICAL CHARACTERISTICS OF SATELLITES

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

1. Geostationary Orbit

   Separation between satellites (deg.)....................10-20
   Emission bandwidth (MHz)................................4

2. Nongeostationary Orbit

   Satellite orbit altitude (km)...........................300-1200
   Number of satellites visible to receivers...............8
   Satellite inclination angles (deg)......................10-99
   Emission bandwidth (MHz)................................4

The above parameters were considered typical based on the information obtained from NASA, the GMF, IFRB, 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 data in TABLES 3-3 and 3-4 indicate that nearly 50 percent of the satellites in the 2025-2300 MHz frequency range are not yet active. The life expectancy of any of the active satellites is less than 10 years. The nongeostationary satellites in this frequency range operate at altitudes between 300 to 1200 km. The active nongeostationary satellites are in several orbits. In the computation, eight satellites were assumed to operate cochannel with radio relays in a trendline and the satellites were distributed evenly in 300, 500, 800 and 1200 km orbits. The inclination angles for approximately 50% of the nongeostationary satellites range from 90 to 99 degrees. There are approximately eight US satellites in the 2025-2300 MHz frequency range which may have inclination angles as low as 28 degrees. The majority of satellites in the 2025-2300 MHz frequency range use digital modulation, each with the capability to operate in multiple modes.

PFD CALCULATIONS

The two computer models (GM & NGM) discussed in an earlier NTIA report [Farrar, 1984] were used to evaluate the pfd limits in the 2 GHz band. The input data for the GM, as used in the calculation of the pfd limits, are given in APPENDIX B. The calculation of the results is discussed below.

Pfd limits for Geostationary Satellites

The data for radio-relay circuits given in APPENDIX B were used as input to the GM, and the pfd limits were calculated for 10, 15, and 20 degrees angular satellite separation. The results of the calculations are given in TABLE 3-5.

TABLE 3-5

CALCULATED GEOSTATIONARY SATELLITES' PFD LEVELS
THAT PERMIT SHARING WITH LOS RADIO-RELAY SYSTEMS[a]

Radio-Relay System Frequency Plan	Radio-Relay System Latitude (Deg)	PFD Levels ($dBW/m^2/4$ kHz) Satellite Spacing (Deg)		
		10	15	20
Single	20	-147.7	-145.6	-142.8
Single	30	-147.0	-145.5	143.2
Single	40	-147.2	-148.0	-147.4
Single	50	-149.0	-146.9	-146.2
Double	20	-143.6	-142.2	-139.7
Double	30	-144.0	-142.6	-140.1
Double	40	-143.8	-144.3	-140.0
Double	50	-146.0	-143.1	-142.3
Four	20	-141.1	-139.7	-137.0
Four	30	-140.9	-139.0	-138.1
Four	40	-140.9	-142.0	-137.7
Four	50	-142.2	-144.0	-138.4

a. For angles of arrival between 0 and 5 degrees.

The entries in TABLE 3-5 represent the pfd levels for an angle of arrival between 0 and 5 degrees. These new values still preclude satellite emissions from exceeding the criteria given in CCIR Recommendation 357-3 [1982]. The results in TABLE 3-5, which correspond to a 15-degree satellite spacing and double frequency plan of a radio-relay circuit, give an appropriate basis for the determination of pfd limits in the 2 GHz band. A 15-degree separation implies the emissions from approximately 13 satellites were assumed to continuously enter the receivers in an HRC. This conservative view is necessary to provide freedom in the technological development of the fixed systems. The results indicate that the calculated pfd levels for geostationary satellites in the 2 GHz band may be relaxed by 10 dB without degrading the operation of LOS radio-relay systems.

Pfd Limits for Nongeostationary Satellites

Representative characteristics pertinent to the computation of pfd limits for 2 GHz satellites in nongeostationary orbits were discussed earlier. The input parameters for the NGM are given in APPENDIX B.

A plot of the results obtained from the program is given in Figure 3-2. Curve B represents the noise criteria set by the CCIR Recommendation 357-3 and Curve A represents the total interference to an HRC from eight satellites inserted in orbits at altitudes ranging from 300 to 1200 km. This curve corresponds to a free-space thermal noise level of 25 pWOp in a radio-relay circuit. The difference in dB between Curve A and Curve B is the value that may be added to the existing pfd limits in the ITU Radio Regulations for nongeostationary satellites. For a conservative analysis, in the calculation of the data shown in Figure 3-2, n_c = 25 pW was used. This is consistent with the pfd analysis for geostationary satellites. Note that the total interference plotted is below the Curve B criteria by approximately 16 dB for .05 percent of the time. Therefore, the calculated results show that the minimum pfd limits for nongeostationary satellites may be increased to -138 dB (W/m^2) in any 4 kHz bandwidth. The calculated pfd limits, using

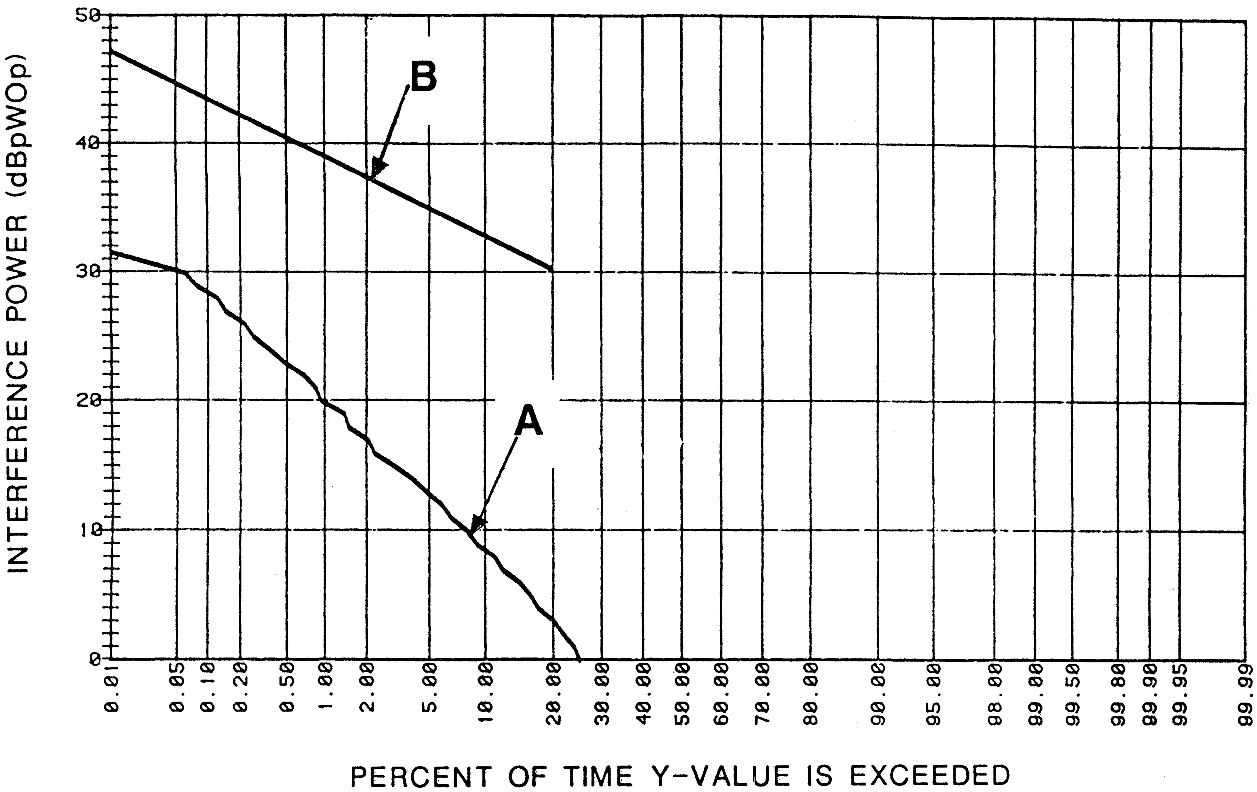


Figure 3-2. Calculated interference to a hypothetical reference circuit from nongeostationary satellites. B represents CCIR criteria and A represents the calculated interference level.

the NGM, are shown in Figure 2-1. Note that the shape of the curve in Figure 2-1 is not different from that originally recommended by the ITU Radio Regulations (No. 2557).

APPENDIX A

A DESCRIPTION OF GEOSTATIONARY AND NONGEOSTATIONARY COMPUTER MODELS

GENERAL

This appendix contains a brief description of the geostationary (GM) and nongeostationary models (NGM) used in the calculation of pfd limits. The GM was originally developed by the Bell Telephone Laboratories and has been used to calculate the limits for satellites in the geostationary orbit. The Systematics General Corporation developed the NGM for calculation of the pfd limits for satellites in nongeostationary orbits (low orbits). These models have been modified [Farrar, 1984; 1985] to determine the pfd limits for systems in the 2 GHz band.

GEOSTATIONARY MODEL (GM)

The GM is a computer simulation program in Fortran IV. It is a statistical model for the calculation of interference into terrestrial radio-relay systems from geostationary satellites. The model incorporates radio-relay characteristics of satellite arrangements in the geostationary orbit and allowable satellite power-flux densities.

The pfd limits evaluated by the GM are a function of the parameters that describe radio relays and satellites. Input parameters for the GM and data used in the calculations of the pfd limits discussed in this report are given in APPENDIX B. The calculations include the effects of the angle of arrival. The GM output is the total interference as a function of percentage of trendlines specified in the calculations. The calculated interference is directly proportional to the assumed values of pfd input to the program. The original algorithm and the later modifications made to this algorithm are discussed extensively in two earlier NTIA reports [Farrar, 1984; 1985].

NONGEOSTATIONARY MODEL (NGM)

The NGM is an extension of the GM program and was used to calculate the pfd limits for satellites in nongeostationary orbits. The NGM calculates total interference from satellites in nongeostationary orbits as does the GM program; however, the interference calculated by the NGM is a function of the percentage of time that the radio receivers, specified in the calculations, receive that interference. In this calculation, the effects of the relative motion of satellites, with respect to the earth, are included in the analysis. This relative motion causes the received emissions to vary widely, both in magnitude and angle-of-arrival. The input parameters and the data used in the calculations of the pfd limits discussed in this report are given in APPENDIX B. A careful description of the original algorithm is given by Locke and Rinker [Locke, P.; Rinker, A., 1978]. Modifications to this model, made prior to the calculation of the pfd limits in the 2 GHz band, are discussed in an earlier NTIA report [Farrar, 1985].

APPENDIX B

GM AND NGM COMPUTER MODEL INPUT PARAMETERS AND DATA

INTRODUCTION

The GM and NGM computer models were used in the evaluation of pfd limits for satellites in geostationary and nongeostationary orbits, respectively. This appendix contains a description of the input parameters for these programs and the data used in the evaluation of these limits.

GEOSTATIONARY MODEL (GM)

The input parameters for the GM program and the data used in the evaluation of the pfd limits for the 2 GHz band are as follows. The entries in the "data" column indicate the values used in the calculation of the limits discussed in this report.

PARAMETER	DESCRIPTION	DATA
IX	Random number generator starter (integer)	9999
NF	Type of frequency plan (1,2,3,...)	2
VK	Value of k function (dB)	3
N	Number of stations in a trendline	50
NTR	Number of trendlines	300
XL	Latitude of the first station (deg)	20
DXLL	Latitude of the last station (deg)	10
XLI	Latitude increment (deg)	50
SS	Satellite spacing (deg)	15
DBRNCO	Allowed noise level in receiver (DBrnc0)	14
DBL	Feed loss (dB)	3
TS	Receiver noise temperature (kelvin)	750
FGHz	Frequency (GHz)	2
C	Maximum antenna gain (dBi)	36

The gain of the radio-relay antenna is expressed as:

$$G = A - B \log \theta$$

where A and B are constants, in dB, and θ is the angle in degrees away from the beam in the direction of incoming interference from a satellite. The values of A and B used in the calculation of the limits discussed in this report were 36 and 25 respectively. The minimum value of antenna gain is -10 dBi.

The power flux density (pfd) of the satellite on the surface of the earth is a function of the angle-of-arrival as is shown by the relationship:

$$F(\delta) = \begin{cases} FV1 & 0^\circ \leqq \delta \leqq EVA1 \\ FV1 + FV2\ (\delta - EVA1) & EVA1 \leqq \delta \leqq EVA2 \\ FV3 & \delta \geqq EVA2 \end{cases}$$

where the constants FV1, FV2, and FV3 are constants in dB and EVA1 and EVA2 are two constants in degrees. δ is the angle-of-arrival. In the calculation of the limits, the constants FV1, FV2, FV3, EVA1, and EVA2 were equal to -154, 0.5, -144, 0.5, and 25, respectively.

NONGEOSTATIONARY MODEL (NGM)

The NGM program requires 15 different input parameters. These parameters are described below and are entered interactively.

DESCRIPTION	DATA	INPUT
Random Number Seed	Random number generator	3000
Trendline System Length:	Length of the trendline in analysis (km):	2500
Number of Hops	Number of hops in a trendline (integer):	50

A. Power Criteria For Sub-Bin Analysis (dBpWop)	Total interference levels above which more detailed calculation is needed (picowatts):	10
B. Power Criteria For Sub-Bin Analysis (dBpWop)		5
Satellite Altitude	Satellite orbit altitude (km)	300 - 1200
Satellite Orbit inclination:	Satellite orbit inclination angle (deg):	30
Transmitter Frequency	Satellite transmitter frequency (GHz):	2
Receiver System Noise Temperture:	Radio-relay receiver noise temperature (k):	750
1. CCIR 2. BSS 3. FSS	Type of antenna pattern used by radio-relay:	CCIR
Maximum Gain	Maximum gain of radio-relay antenna (dBi):	36
Minimum Gain	Minimum gain of radio-relay antenna (dBi):	-10
Is THIS A PERISCOPE Antenna (Yes, No):	Type of antenna	No
Latitude Step	Nominal patch size in degrees. This number is generally 3 degrees for most applications	

The description of power-flux-density on the surface of the earth is identical to that described above for the GM program. The entries in the above under the data column are the values used in the calculation of the limits discussed in the report.

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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.)*

The analysis technique developed and discussed in two earlier NTIA reports (Farrar, 1984; Farrar, 1983) was used in conjunction with the data obtained from a number of different countries to calculate the power-flux density (pfd) levels in the 2 GHz band. The data included the characteristics of satellites in the space services and fixed service systems in the band. Sharing criteria with other services, such as mobile, are not addressed.

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

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