CCIR Papers on Telecommunications for Deep Space Research

N. F. deGroot

Telecommunications Systems Section

Three papers on telecommunications for deep space research have been adopted by Study Group 2 of the International Radio Consultative Committee (CCIR). In this article, we present the paper that considers the sharing of radio frequency bands between deep space research and other radio service.

I. Introduction

Study Group 2 of the International Radio Consultative Committee (CCIR) is concerned with the technical aspects of telecommunications for space research and radio astronomy. Three JPL papers on deep space research were submitted by the United States for consideration at a meeting held in Geneva during September, 1977. The papers were adopted and are:

Doc. 2/296 Telecommunication Requirements for Manned and Unmanned Deep Space Research

Doc. 2/269 Preferred Frequency Bands for Deep Space Research Using Manned and Unmanned Spacecraft

Doc. 2/279 Protection Criteria and Sharing Considerations Relating to Deep Space Research

The first of these papers was included in the September-October 1977 issue of the Deep Space Network Progress Report. Also in that report was a description of the role of CCIR papers in the establishment of worldwide regulations that determine the use of the radio frequency spectrum.

The paper on preferred frequency bands was included in the November-December 1977 issue.

This article presents the third paper, which considers interference protection and band sharing with other users.

UNITED STATES OF AMERICA

Draft New REPORT*
PROTECTION CRITERIA AND SHARING CONSIDERATIONS
RELATING TO DEEP SPACE RESEARCH
(Draft Question 1/2 (Rev. 76))

1.   Introduction

        This report considers the sharing of frequency bands in the range 1-20 GHz
between deep space research stations and stations of other services. Deep space earth
and space station protection criteria are discussed. Potential interference is considered,
and conclusions are drawn about the feasibility of sharing.

        The 1-20 GHz range includes current allocations applicable to deep space research
and some of the frequencies desired for future operational use. Preferred frequencies are
given in Doc. 2/168. U.S. earth and space station characteristics are given in Doc. 2/167.

2.   Earth station factors pertinent to sharing

        The principal earth station parameters which pertain to interference and sharing are
transmitter power, antenna gain and pointing, receiver sensitivity (including noise tempera-
ture) and bandwidth. Typical values of these parameters are given in Doc. 2/167. This
section of the report considers some aspects of antenna pointing, and develops protection
criteria for receivers at deep space earth stations. The section finishes with remarks about
coordination. Consideration of transmitter power are given in a later section.

2.1   Intersections of satellite orbits and antenna beams from deep space earth stations.

        The locations of the US deep space earth stations are given in Doc. 2/167. The
stations are spaced approximately equally in longitude (120° apart) with two stations in the
northern hemisphere, and the third in the southern hemisphere. Spacecraft in deep space
currently remain in or near the plane of the ecliptic, which is tilted at 23-1/2° from the
Earth's equatorial plane. The daily rotation of the Earth causes the antenna beam of at least
one earth station to intersect the equatorial plane and hence the geostationary orbit when
tracking a given spacecraft. The earth station may be subjected to interference from satel-
lites within the antenna beam and operating in or near the allocated deep space bands.

        Satellites that are not geostationary can pass through the one or more deep space
tracking teams each day. Details of visibility statistics and in-beam duration times are con-
tained in draft Report AH/2.

        In the future the United States plans to deliver deep space probes into orbits out of
the plane of the ecliptic. These missions will also result in some earth station tracking
beams passing through the orbits of both geostationary and non-geostationary satellites.

2.2   Susceptibility of deep space earth station receivers to interference

        A deep space telecommunication system is typically a phase-sensitive system. The
earth station receiver utilizes phase-locked loops for carrier tracking and data recovery.
CW or noiselike interference in these loops can result either in degradation or loss of track-
ing and data. Report 544 contains information on the effects of interference in phase-locked
loops. Report 545 presents information on the degradation of telemetering performance
caused by interference.

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*Proposed replacement for Report AL/2

2.2.1 CW signal interference

2.2.1.1 Receiver capture. The changing Doppler shift of a received desired signal can cause the receiver pass band to move past a fixed frequency unwanted CW signal. Depending upon rate of motion and the amplitude of the unwanted signal, the receiver may lock to the interfering signal if R, the ratio of the CW signal power to the desired signal power, satisfies the relation:

$$R > \frac{df}{\pi f_n^2} \tag{1}$$

where df is the rate of frequency change in Hz/s and f_n is the loop natural frequency in Hz.

An interfering CW signal that is 10 dB above a strong signal and is moving through the receiver passband at 100 Hz/s would cause the receiver to lock to the interfering signal. At a lower rate of movement, the required interfering signal level is proportionately lower until at a signal-to-interference ratio greater than one, the interfering signal will no longer capture the receiver, even if the movement rate is zero. Undesired CW signals not strong enough to cause receiver capture may cause interference to carrier tracking.

2.2.1.2 Carrier tracking degradation. An interfering CW signal can induce a phase modulation on the desired carrier signal when the frequency separation between the two signals is comparable to or less than the phase locked loop bandwidth. A maximum acceptable phase modulation of 10° amplitude results from an interference-to-carrier power ratio of -15 dB. The design margin for carrier tracking is typically 10 dB with reference to the noise power in the carrier tracking loop bandwidth. For maximum acceptable carrier tracking degradation, the power in a CW interfering signal that may be within the phase locked loop bandwidth must not be greater than the amount shown in Table I.

TABLE I

CW interference with carrier tracking

Frequency (GHz)	Noise in 1 Hz Loop (dBW)	Minimum Carrier Power (dBW)	Maximum CW Interference (dBW)
2.3	-216.6	-206.6	-221.6
8.5	-215.0	-205.0	-220.0
15.0	-213.4	-203.4	-218.4

2.2.1.3 Telemetering degradation. Telemetering degradation is defined as the amount by which the signal-to-noise ratio must be increased to make the bit error rate, when an interfering signal is present, equal to what it would be if the interfering signal was absent. The maximum allowable degradation for deep space telemetering is 1 dB. For coded telemetering with a threshold signal-to-noise ratio of 2.3 dB, CW interference 6.8 dB below the noise power will result in 1 dB degradation. For uncoded telemetering with a threshold signal-to-noise ratio of 9.8 dB, CW interference 5 dB below the noise will result in 1 dB degradation. The noise power is proportional to the data bandwidth and the receiver noise spectral density. Examples of allowable level of CW interference are shown in Table II.

TABLE II

CW Interference with telemetering

Frequency (GHz)	Data (bits/s)	Noise Power in Data Bandwidth (dBW)	Interference-to-Noise Ratio for 1 dB Degradation (dB)	Maximum CW Interference (dBW)
2.3	40, uncoded	-200.6	-5.0	-205.6
8.4	40, coded	-200.0	-6.8	-206.8
	115k, coded	-164.4	-6.8	-171.2
15.0	40, coded	-197.4	-6.8	-204.2
	115k, coded	-162.8	-6.8	-169.6

2.2.2   Wideband interference

Wideband signals or noise that reduce the signal-to-noise ratio affect both the carrier tracking and the data channels. In the case of the telemetering channel, the spectral density of the interfering signal must be at least 5.9 dB below the spectral density of the receiver noise in order not to degrade the threshold performance by more than 1 dB. Maximum levels of wideband interference are shown in Table III.

TABLE III

Wideband interference with telemetering

Frequency (GHz)	Noise Spectral Density (dB(W/Hz))	Interference-to-Noise Ratio (dB)	Maximum Wideband Interference (dB(W/Hz))
2.3	-216.6	-5.9	-222.5
8.4	-215.0	-5.9	-220.9
15.0	-213.4	-5.9	-219.3

2.2.3   Interference to maser operation

Mixing of signals with the idler frequency of the maser pump can cause interference and saturation in the receiver passband. There are many frequencies at which such mixing can occur, all of which are far removed from the normal frequency of reception. Table IV gives possible interference frequencies for the two frequency bands currently used for reception at deep space research earth stations.

Interfering signals must be above -120 dBW in the idler bandwidth (which is very broad) at the maser input to be significant.

TABLE IV

Frequencies at which interference may be caused by mixing in the maser

Receiver frequency band	2 290 - 2 300 MHz	8 400 - 8 500 MHz
Maser pump frequency	12.7 GHz	19.3 and 24.0 GHz
Interference frequencies	15.0 GHz 10.4 7.5 5.2	32.4 GHz 27.8 15.6 10.9

2.2.4 Adjacent channel receiver saturation

The cryogenically cooled maser of the deep space receiver has a bandpass of approximately 50 MHz. Adjacent channel signals, if received at total power levels greater than

-120 dBW, can generate intermodulation products in the mixer and other receiver elements, causing saturation of the receiver.

2.2.5   Interference protection for Earth station receivers

Interruption of telecommunications can result from interference that is strong enough to cuase receiver capture or saturation. Weaker interference may result in degraded carrier tracking and telemetering performance. The level of interference that can be tolerated is determined by acceptable performance degradation. To protect Earth station receivers, the power spectral density of wideband interference, or the total power of CW interference, in any single band and all sets of bands 1 Hz wide, should not be greater than the values shown in Table V, for an aggregate of five minutes in any one day.* Table V also shows the maximum power flux density of interference, considering the effective area of a 70m earth station antenna.

TABLE V

Interference protection for earth station receivers

Band (GHz)	Maximum Power Spectral Density (dB (W/Hz))	Maximum Power Flux Density (dB (W/m^2 Hz))
2.3	-222.5	-256..2
8.4	-220.9	-253.8
15.0	-219.3	-250.2

2.3

2.3   Coordination considerations

The practicability of coordination is determined partially by the number of stations with which coordination must be effected. This is in turn controlled by the coordination distance. For deep-space research, the practicable coordination distance is currently considered to be 1,500 km.

Coordination distance may be calculated by the method of Appendix 28 of the Radio Regulations. An alternate method is given in Doc. 5/225 (Geneva, 1977). The two ways of determining distance give different results. For example, assuming a transhorizon station (i.e., 93 dB(W/10 kHz), in the 2.3 gHz band), the distances are 2,100 and 800 km, respectively.

A decision on the practicability of sharing with transhorizon stations is thus not possible, and further study is necessary.

3.   Space station parameters and protection pertinent to sharing

The principal space station parameters which pertain to interference and sharing are antenna gain and pointing, transmitter power and receiver sensitivity. Details of these parameters are given in Doc. 2/167.

Space station and Earth station receivers for deep space research function in a similar manner, except that the space station does not include a maser. Space stations are susceptible to interference as described earlier for Earth stations.

The criterion for protection of space station receivers is that interference power must be no stronger than receiver noise power. Compared to Earth station criteria, this is less severe and is a consequence of generally larger performance margins on the Earth-to-space link. For protection of space stations, the power spectral density of wideband interference, or total power of CW interference, in any 1 kHz band should be no larger than the amount shown in Table VI for an aggregate of 5 minutes per day.

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*Five minutes per day is generally taken as 0.001% of the time, as discussed in Report 546 (Geneva).

TABLE VI

Interference protection for space station receivers

Frequency (GHz)	Maximum Interference Level (dB(W/kHz))
2.1	-170.8
7.2	-169.6
15.0	-168.1

Space station e.i.r.p. is normally reduced while near Earth, minimizing the potential for interference to other stations.

4.   Sharing considerations

The following paragraphs consider the possibility of interference between deep space research stations and those of other services. There are 8 possibilities to be considered, as shown in Table VII.

Table VII and the following paragraphs consider the possibility of interference in the deep space research Earth-to-space bands.

TABLE VII

Potential interference in Earth-to-space bands

Source	Receiver
Earth station	Terrestrial station
Earth station	Near Earth satellite
Terrestrial station	Earth station
Terrestrial station	Space station
Space station	Terrestrial station
Space station	Near Earth satellite
Near Earth satellite	Earth station
Near Earth satellite	Space station

4.1   Potential interference to terrestrial receivers from earth station transmitters

The normal maximum total power for current U.S. earth stations is 50 dBW. For a typical minimum elevation angle of 10 degrees, the e.i.r.p. directed towards the horizon does not exceed 57 dB(W/4 kHz), assuming the reference earth station antenna radiation pattern of Recommendation AA/2. For spacecraft emergencies, the maximum total power may be increased to 56 dBW, giving not more than 63 dB(W/4 kHz) at the horizon. These values of e.i.r.p. meet the requirements of RR 470F.

Aircraft stations within line-of-sight of a deep-space earth station will encounter total power flux densities as shown in Figure 1. For an aircraft altitude of 12 km, the maximum line-of-sight distance to an earth station is 391 km and the total power flux density at the aircraft can never be lower than -83 dB(W/m^2), again assuming the antenna pattern of Recommendation AA/2. Depending on distance and earth station antenna direction, the aircraft station may experience much higher flux densities and interference levels. Coordination with airborne stations is generally not practicable.

Tropospheric and rain scatter may couple deep-space earth station transmitting signals into trans-horizon, space system and other surface stations. When practicable, coordination should provide sufficient protection for terrestrial receivers and earth station receivers. See § 2.3 for coordination considerations.

4.2   Potential interference to satellite receivers from deep-space earth station transmitters

Satellites that come within the earth station beam will encounter power flux densities as shown in Figure 1. When an earth station is tracking a spacecraft such that the antenna beam passes through the geostationary satellite orbit, the flux density at a point on that orbit will vary with time as shown in Figure 2. For example, the total power flux density will be -95 dB(W/m^2) or more for 32 minutes. The figure assumes a transmitter power of 50 dBW, a 64 m antenna, and the reference earth station antenna pattern of Recommendation AA/2. An important observation is that the minimum flux density at the geostationary satellite orbit within line of sight of a deep space earth station is -122 dB (W/m^2), regardless of antenna pointing direction.

The duration and magnitude of signals from deep space earth station transmitters that may interfere with satellites in non-geostationary orbits depends on those orbits and the particular deep space tracking at that time.

4.3   Potential interference to deep-space station receivers from terrestrial or earth station transmitters

Terrestrial or earth station transmitters within sight of a deep space station are potential sources of interference. Figure 3 shows the space station distance at which interference power density from such a transmitter equals the receiver noise power density. For example, a transhorizon station with 93 dB(W/10 kHz) e.i.r.p. in the 2.1 GHz band could interfere with a space station receiver at ranges up to 4.1 x 10^9 km (600 K noise temperature, 3.7 m spacecraft antenna). The possibility of interference at such great distance poses a threat to space missions to planets as far away as Uranus. Stations with lower e.i.r.p or with antennae pointing away from the ecliptic plane will have less potential for interference.

4.4   Potential interference to space station receivers from near-Earth satellite transmitters

Near-Earth satellites typically have antennae directed at the Earth or at other satellites. Interference with deep-space station receivers may occur for those brief periods when the satellite antenna is directed near the ecliptic plane. As received at deep space stations, signals from satellites will usually be relatively weaker than those from earth stations.

5.   Sharing considerations: space-to-Earth bands

Table VIII and the following paragraphs consider the possibility of interference in the deep space research space-to-Earth bands.

TABLE VIII

Potential interference in space-to-Earth bands

Source	Receiver
Deep space station	Terrestrial or earth station
Deep space station	Near Earth satellite
Terrestrial or earth station	Deep space earth station
Near Earth satellite	Deep space earth station

5.1 <u>Potential interference to terrestrial or earth station receivers from deep-space station transmitters</u>

Figure 4 shows power flux-density at the surface of the Earth caused by deep-space stations with characteristics as shown in Doc. 2/167. These stations typically use low gain, wide beam antennae while near Earth. After a time not exceeding six hours from launch, they are usually at a sufficient distance for the flux density at the surface of the Earth to be less than the maximum permitted by Radio Regulations for protection of line-of-sight radio-relay systems. For example, the Mariner Jupiter Saturn spacecraft is expected to use the low gain antenna until 4.2×10^7 km from Earth, at which time the flux density would be -198 dB(W/m^2) in 4 kHz after switching to the high gain antenna.

When the transmitting space station is using a higher gain directional antenna, there is the potential for interference with sensitive terrestrial receivers if their antennae are directed in the ecliptic plane. A space station operating at 2.3 GHz with an e.i.r.p. of 51 dBW at a distance of 5×10^8 km could create an input of -168 dBW to a transhorizon receiver (27 m antenna, main beam). The duration of such interference would be of the order of a few minutes because of the rotation of the Earth.

5.2 <u>Potential interference to near-Earth satellite receivers from deep-space station transmitters</u>

Considerations of this interference are similar to those for the space station to terrestrial receiver case, §5.1, with the exception of the path geometry. Depending on the changing conditions of that geometry, occasional brief interference is possible.

5.3 <u>Potential interference to deep-space earth station receivers from terrestrial or earth station transmitters</u>

Interference to deep-space earth station receivers may come from terrestrial or earth stations over line-of-sight paths, by tropospheric phenomena, or by rain scatter. For coordination considerations see § 2.3.

Other services with high power transmitters and high gain antennae are potential interference sources. Radiolocation stations are an example. Earth station transmitters are less likely sources of interference, depending on e.i.r.p. in the direction of the deep-space earth station. Coordination should provide adequate protection from radio-relay stations.

Aircraft transmitters within sight of a deep-space earth station may cause serious interference. At maximum line-of-sight distance in any direction (391 km for an aircraft at 12 km altitude), an e.i.r.p. of -26 dB(W/Hz) (for example, 10 dB(W/4 kHz) and 0 dBi antenna) will exceed the earth station interference limit by at least the amount shown in Table IX, assuming the reference earth station antenna pattern.

Coordination with airborne stations is generally not practicable.

<div align="center">TABLE IX</div>

<div align="center">Interference from assumed aircraft transmitter</div>

Frequency (GHz)	Deep-space Earth Station Interference Limit (dB (w/Hz))	Harmful interference from Aircraft* (dB)
2.3	-222.5	35.7
8.4	-220.9	22.1
15.0	-219.3	15.5
*Aircraft signal less deep-space earth station interference limit		

5.4   Potential interference to deep-space earth station receivers from near Earth satellite transmitters

An analysis of the case for satellites in highly eccentric orbits may be found in Report AJ/2. It is concluded there that sharing is not feasible. This conclusion is also valid for satellites in circular and moderately eccentric orbits.

6.   Discussion

Sharing with stations that are within line-of-sight (LOS) of deep-space earth stations is not feasible. Stations within LOS will create excessive interference to receivers of deep-space earth stations, or will be exposed to excessive interference from transmitters of these stations. Aeronautical mobile stations and near-Earth satellites frequently come within LOS of deep-space earth stations.

Sharing of deep-space Earth-to-space bands with stations utilizing high average e.i.r.p. is not feasible because of potential interference to stations in deep space. It is currently considered that stations with an e.i.r.p. that is more than 30 dB below the implemented or planned e.i.r.p. for space research earth stations do not pose a significant problem. From the data in 2/167, this means an average e.i.r.p. no greater than 82 dBW at 2 and 7 GHz. The deep-space earth station e.i.r.p. for other frequencies is not now known.

7.   Conclusion

Criteria and considerations presented in this Report lead to the following conclusions:

7.1   Sharing of Earth-to-space bands

Deep-space research cannot share Earth-to-space bands with:

(a) receiving aeronautical mobile stations,

(b) receiving satellite stations, and

(c) transmitting terrestrial stations and earth stations utilizing high average e.i.r.p., for example, transmitting transhorizon stations, and transmitting fixed-satellite earth stations.

When coordination is practicable, sharing is feasible with other stations of all services. In some cases, coordination distances may be unacceptably great.

7.2   Sharing of space-to-Earth bands

Deep-space research cannot share space-to-Earth bands with:

(a) transmitting aeronautical mobile stations, and

(b) transmitting satellite stations.

When coordination is practicable, sharing is feasible with other stations of all services. In some cases, coordination distances may be unacceptably great.

The matter of unacceptably long coordination distance requires further study.
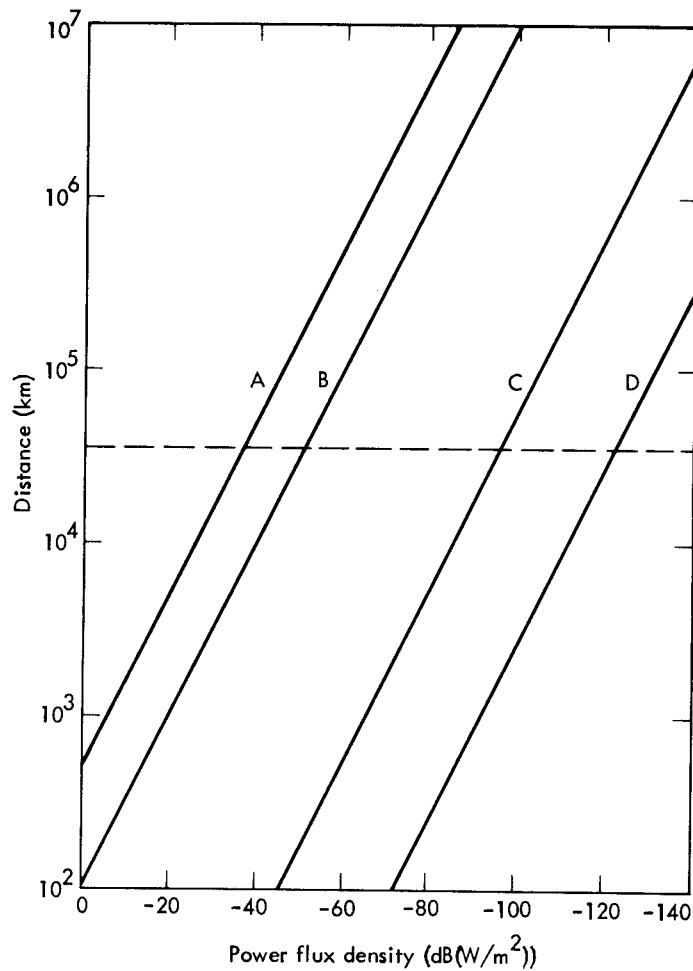
FIGURE 1.

Power flux density from Earth station transmitter
100 kW, 64 m antenna

A: Main beam, 15 GHz

B: Main beam, 2.1 GHz

C: 5 deg off axis
(14.5 dB gain, Rec. AA/2)

D: $\geqq$ 48 deg off axis (-10 dB gain, Rec. AA/2)

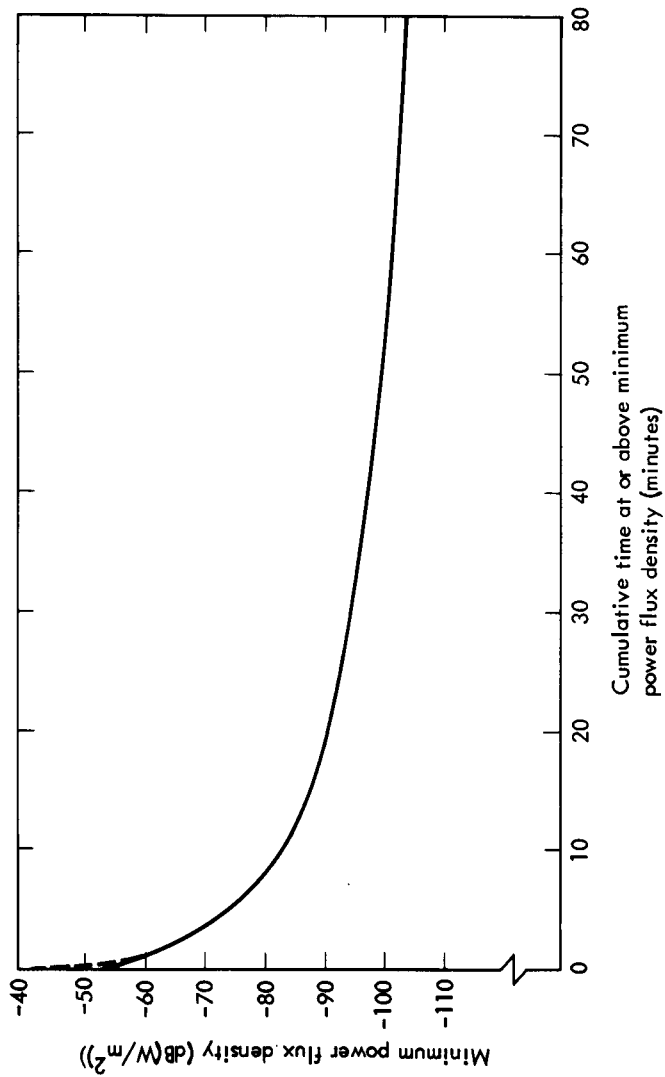— —: Altitude of geostationary satellite
orbit, 3.56×10^4 km

FIGURE 2.

Duration of potential interference to geostationary satellite intersecting beam axis from Earth station with 100 kW transmitter and 64 m antenna
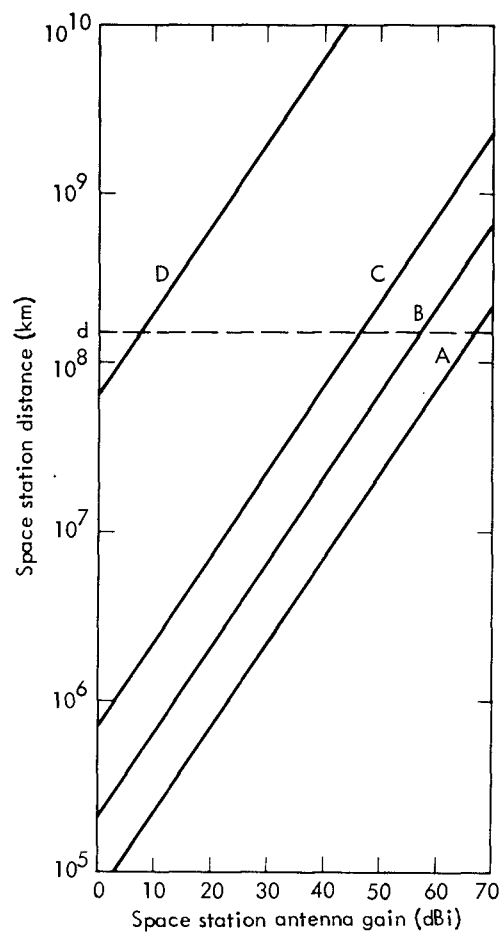
———— : 2.1 GHz

— — — : 15 GHz

FIGURE 3.

Space station distance from terrestrial transmitter for interference power equal to receiver noise power

A: 15 GHz relay transmitter, 55 dB(W/10 kHz); −168 dB(W/kHz) receiver noise power

B: 7.2 GHz relay transmitter, 55 dB(W/10 kHz); −170 dB(W/kHz) receiver noise power

C: 2.1 GHz relay transmitter, 55 dB(W/10 kHz); −171 dB(W/kHz) receiver noise power

D: 2.1 GHz transhorizon transmitter, 93 dB(W/10 kHz); −171 dB(W/kHz) receiver noise power

d: Space station range of 1 astronomical unit, 1.5×10^8 km
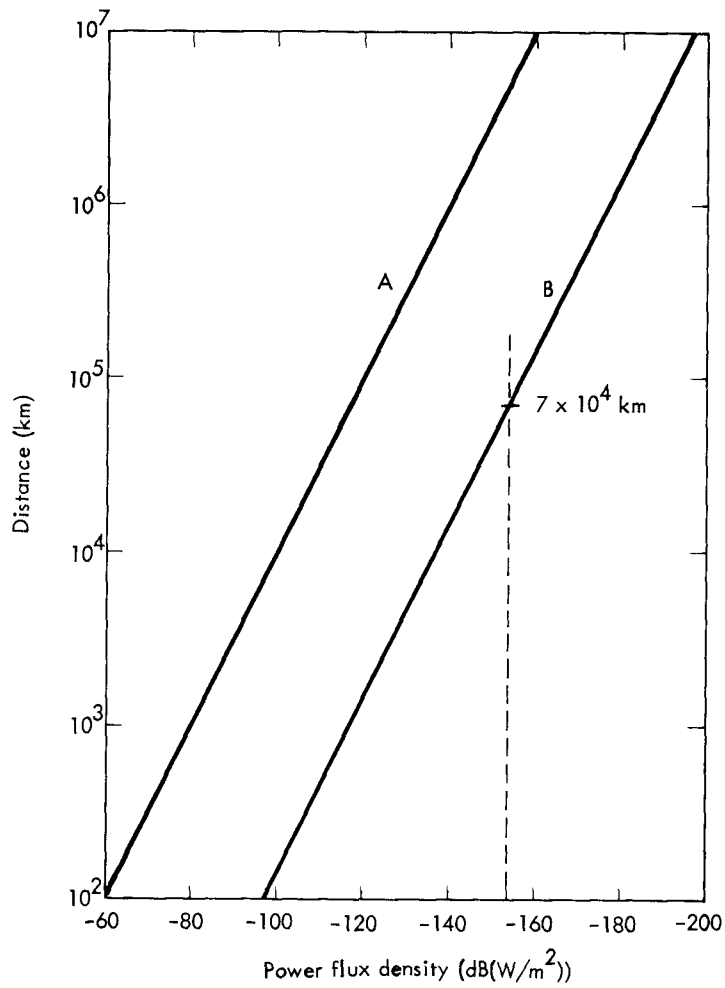
FIGURE 4.
*Power flux density at surface of Earth from
space station transmitter*

A: 14 dBW transmitter, 37 dBi antenna

B: 14 dBW transmitter, 0 dBi antenna

— — — : −154 (dB(W/m^2))   (RR 470 NE)