New CCIR Papers on Telecommunications for Deep Space Research

N. F. de Groot
Telecommunications System Section

Eight JPL papers dealing with telecommunications for deep space research were recently adopted by Study Group 2 of the International Radio Consultative Committee (CCIR). In this article we present a brief description of the circumstances leading to the preparation and adoption of the papers. One of the papers is then presented. It deals with the selection of frequency bands that would be useful for deep space communication links in the 20 – 120 GHz range.

The use of the radio frequency spectrum is regulated by international treaty. The treaty embodies the consensus of more than 150 nations that are members of the International Telecommunication Union (ITU). Technical aspects of the treaty are based upon reports and recommendation of the International Radio Consultative Committee (CCIR), a part of the ITU.

In recent years, JPL has played an increasingly active role in CCIR affairs. This participation is for the purpose of protecting and enhancing the regulations and agreements that permit and protect the telecommunication links associated with deep space research.

CCIR Study Group 2 deals with space research and radio astronomy. The study group held a three-week meeting in Geneva during October 1981. The purpose of the meeting was to consider and approve Study Group 2 papers that will be published in the 1982 edition of the 13-volume set of Reports and Recommendations of the CCIR. Approximately 50 papers were submitted by six countries. Eight papers dealing with deep space telecommunications were approved. These papers were based on input documents prepared by the JPL Spectrum Engineering Group and are:

Doc. 5010 New Report	Frequency Bands in the 20-120 GHz Range That Are Preferred for Deep-Space Research.
Doc. 5007 New Recommendation	Protection Criteria and Sharing Considerations Relating to Deep-Space Research.
Doc. 5008 New Recommendation	Preferred Frequencies and Bandwidths for Deep-Space Research.

Doc. 5015 Revision of Report 683	Frequency Bands in the 1-20 GHz Range That Are Preferred for Deep-Space Research.
Doc. 5023 Modification of Question 14	Feasibility of Frequency Sharing Within and Among Space Research Systems.
Doc. 5024 Revision of Report 685	Protection Criteria and Sharing Considerations Relating to Deep-Space Research.
Doc. 5025 New Report	Potential Interference Between Deep-Space Telecommunications and the Fixed-Satellite and Broadcasting Satellite Services in Harmonically Related Bands.
Doc. 5026 Modification of Study Program 14B	Frequency Sharing Between Deep-Space and Other Space Research systems.

In this issue of the *TDA Progress Report* we begin the presentation of 6 of the adopted papers.[1] Document 5010 is a new CCIR report that identifies bands in the 20-120 GHz range that would be useful for deep-space research. The report summarizes work that was done in preparation for the 1979 World Administrative Radio Conference. The report is shown in its CCIR form and not in the usual TDA style.

Until it is adopted by a Plenary Assembly of the CCIR, the report is considered to be a draft. The next Plenary Assembly will be held in February 1982. Adoption of reports by that body is usually an administrative formality. Following the February meeting, the report will be published in Volume II of the 1982 edition of *Recommendations and Reports of the CCIR*.

[1] Documents 5015 and 5024 are revisions of material that appears in the 1978 edition of *Reports and Recommendations of the CCIR* (Ref. 1) and also in Refs. 2 and 3. The nature and scope of the revisions suggest that these documents need not be included in the TDA Progress Report.

References

1. International Radio Consultative Committee, Recommendations and Reports of the CCIR, 1978, Vols. I-XIII, International Telecommunications Union, Geneva, 1978.

2. de Groot, N. F., "CCIR Papers on Telecommunications for Deep Space Research," *DSN Progress Report 42-43*, Jet Propulsion Laboratory, Pasadena, Calif., Feb 15, 1978.

3. de Groot, N. F., "CCIR Papers on Telecommunications for Deep Space Research," *DSN Progress Report 42-44*, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1978.

Documents
CCIR Study Groups
Period 1978-1982

Doc. 2/5010-E
(Ref. 2/192)
15 October 1981
Original: English/
French/
Spanish

Working Group 2-B

Draft REPORT AH/2

FREQUENCY BANDS IN THE 20 - 120 GHz RANGE THAT ARE PREFERRED FOR DEEP-SPACE RESEARCH*

(Question 22/2, Study Programme 22A/2)

1. Introduction

This report pertains to the selection of preferred frequency bands for deep-space telecommunications in the 20-120 GHz range. The performance of links between earth stations and stations in deep-space is affected by the atmosphere of the Earth. Attenuation and emission by the atmosphere generally limits deep-space telecommunications to frequencies below 20 GHz. There are, however, certain frequency bands in the 20-120 GHz range where atmospheric attenuation is low enough to permit links between earth stations and deep-space stations. Additionally, there are certain other bands in the 20-120 GHz range that would be particularly suitable for links between an earth-orbiting relay station and deep-space stations.

The selection of preferred frequency bands below 20 GHz is given in Report 683 (2/139).

1.1 Performance Advantages of Higher Frequencies

Radio frequencies above 20 GHz can provide advantages for deep-space telecommunications. The advantages are higher link performance, reduced errors in measurements that depend on the velocity of propagation, and the possibility of shielding from terrestrial interference.

*Information in this report is based on reports 205-4, 263-4, 563-1, 584-1, 718 and 721 from the 1978 Kyoto volumes. This report (5010) is brought to the attention of Study Groups 5 and 6 with a view towards their comment on how the analysis might be affected by recent changes in propagation data.

The net gain of a free space link between perfect antennae with fixed apertures varies in direct proportion to the frequency squared. For certain frequencies where the attenuation of the atmosphere is low, links between Earth and space can benefit from the use of frequencies above 20 GHz.

The increased performance of higher frequency links may be utilized for command, telemetering and radiometric functions. Alternatively, the higher performance may be traded for smaller and lighter spacecraft antennae and transmitters.

Accurate navigation of deep-space probes depends upon determination of their position and velocity by means of phase and group delay measurements of received signals. These measurements are influenced by the velocity of propagation along the transmission path. The velocity of propagation is a function of the presence of charged particles along the path. The effect of these particles varies inversely with the square of the frequency and hence higher frequencies are preferable for purposes of navigation and certain other radio measurements.

1.2 Shielding from Terrestrial Interference

In the future it may be desirable to employ a geostationary relay station for signals to and from deep-space probes. The links between such a station and deep-space probes would be free of the perturbing effects of the atmosphere. These links could be protected from terrestrial interference by choosing frequencies where the atmosphere is relatively opaque to radio signals. There are such frequencies in the 20-120 GHz range.

1.3 Basis for Frequency Selection

Selection of preferred frequencies is based on link performance as determined by propagation and equipment characteristics. In the next three sections of the report we examine the factors that influence frequency selection. Some of these factors provide the information needed to calculate an index of link performance. This index is expressed as P_R/N_0, the ratio of total received power to noise spectral density for a particular set of propagation conditions and equipment parameters.

2. Frequency Dependent Characteristics of Interplanetary Propagation

Interplanetary propagation characteristics determine the performance of links between a deep-space probe and a relay satellite located outside of the atmosphere of the Earth. These characteristics also affect the performance of links between Earth stations and deep-space.

2.1 Sky Noise Temperature

The sky noise temperature seen by a relay satellite will be determined by the cosmic background (3K) and quantum noise as shown in curve A of Figure 1, except when noise from the Earth, other planets or the Sun enters the antenna.

The sky noise temperature seen by a spacecraft will also be that shown in A of Figure 1. Earth will generally be within the main lobe of a spacecraft antenna pointed at a relay satellite. The presence of Earth within the antenna beam will contribute to the noise temperature. For example, for a spacecraft at 4×10^7 km from the Earth (the minimum distance to Venus), the Earth subtends an angle of 1.8×10^{-2} degrees. If the spacecraft antenna is limited to a minimum beamwidth of 0.15 degrees by pointing accuracy, then the Earth can fill less than 1/69 of the antenna main lobe. The effect of the black body temperature of the Earth, (approximately 250 K at 2.3 GHz) is correspondingly reduced to a value that is small compared to the 600-1500 K noise temperature of a typical spacecraft receiving system.

The increase in noise temperature when an antenna is pointed at the Sun is large. This can affect the timing and design of some deep-space missions and experiments.

For calculation of P_R/N_0 as a function of frequency, the sky noise temperature seen by a relay satellite or deep-space probe will be considered a negligible part of the system temperature.

2.2 Attenuation

A review of gaseous absorption and scattering by dust particles outside of planetary atmospheres indicates that neither will attenuate the signal by as much as 0.1 dB in the 20-120 GHz range as long as the propagation path is restricted to our solar system. Attenuation by interplanetary space will be considered a negligibly small factor in the selection of preferred bands.

Attenuation in dB due to charged particles varies as the inverse frequency squared ($1/f^2$) and thus favours the highest frequency available.

2.3 Velocity of Propagation

Charged particles along the communication path cause changes in the velocity of propagation. Figure 2 shows an example of the apparent range measurement error as a function of frequency and of the angle between the ray path and a line between the Sun and the Earth station. This figure is based on the relationships described in Report 683 (2/139). It is apparent from Figure 2 that high frequencies are desirable for the most precise ranging.

2.4 Scintillation

Amplitude and phase scintillation from solar plasma will be a factor for ray paths close to the sun. The magnitude of the scintillation decreases with increase in frequency.

3. Frequency Dependent Characteristics of Propagation Through an Atmosphere

The foregoing interplanetary propagation factors affect links between deep-space and a relay station in the geosynchronous satellite orbit. For links between deep-space and Earth, the atmosphere plays a dominant role in the selection of preferred frequencies in the 20-120 GHz range.

Atmospheres of other planets can affect paths that graze or penetrate the atmosphere in question.

3.1 Attenuation

3.1.1 Earth Atmosphere

Attenuation of signals passing through the ionosphere of the Earth is negligible at frequencies above 20 GHz, but the neutral atmosphere plays a major role at these frequencies. The attenuation for transmission through the atmosphere is shown in Figure 3 (Report 719). Above 20 GHz, minimum attenuation on links between Earth and spacecraft would be obtained at frequencies near 30 GHz.

The specific attenuation due to rain at rates greater than a few millimeters per hour is generally larger than that of the gaseous atmosphere and increases monotonically with frequency in the range of interest. The rain rate for 0.001% of the time in rain climate 4 is 55 mm/hr (Report 563-1). The attenuation in the 20-120 GHz region during rain at this rate is so high that propagation is not practicable and will not be considered further as a determinant of preferred frequencies.

For the satellite-to-spacecraft links, the line-of-sight propagation paths will be obscured at times by the interposition of the Earth or some portion of the Earth's atmosphere. From the geostationary satellite orbit the solid Earth subtends an angle of 17.34 deg. If the atmosphere to 100 km altitude were opaque to radio waves the obscuration angle would increase by 0.27 deg., too small a difference to influence band selection.

The objective of protecting the paths between deep-space probes and an Earth orbiting satellite from terrestrial interference may be satisfied by taking advantage of the high atmospheric attenuation in the 60 and 119 GHz regions. Molecular oxygen absorption lines at these frequencies are responsible for the high attenuation observed in Figure 3.

A pair of links (deep-space to Earth satellite) could be accommodated in the high attenuation region between 54 and 64 GHz. A frequency separation of approximately 7% is required (Report 683 (2/139)). The absorption line at 119 GHz is much narrower and only one link of a pair could enjoy the maximum shielding. Shielding of the down-link is most important.

3.1.2 Planetary Atmospheres

From the standpoint of attenuation, the nature of planetary atmospheres does not influence the selection of communication frequencies in the 20-120 GHz range. This is not to say that the atmospheres of some planets do not contain spectral lines of scientific interest in the 20-120 GHz range, for example ammonia.

3.2 Sky Noise Temperature

Sky noise temperature as seen by an Earth station is a function of frequency and elevation angle. Noise temperature from absorption-related emission from the gaseous atmosphere of the Earth pertinent to the standard atmosphere and elevation angle of 30° is shown in Figure 1. Attenuation caused by rain also influences sky noise temperature in a manner analogous to gaseous absorption. The 0.001% curve of Figure 1 showing rain-related sky temperature has been computed from the attenuation experienced during 55 mm/hr rainfall.

When the Earth station antenna is pointed near the Sun, the noise temperature will increase.

3.3 Scintillation

Amplitude and phase scintillation from the neutral atmosphere of the Earth at frequencies in the 20-120 GHz range can cause fading at a parabolic receiving antenna of a few meters in diameter as shown below (Report 718).

Peak-to-Peak Fades for Clear Air

Elevation Angle (deg)	Fade at 35 GHz (dB)	Fade at 100 GHz (dB)
>45	±2	±4
10	±6	±12

Scintillation due to the Earth's ionosphere will not be a selection factor for frequencies above 20 GHz (Report 263), and the same conclusion can be drawn relative to planetary ionospheres. For some missions, scintillation caused by the solar corona could affect the choice of frequency.

4. Frequency Dependent Equipment Factors

Equipment characteristics which determine link performance include transmitter power, antenna size, surface accuracy and pointing accuracy, and receiver noise temperature. These characteristics usually depend upon frequency to some degree. In the frequency range 20-120 GHz, propagation factors influence the link performance so strongly that the frequency dependent equipment factors have only a minor effect on the selection of preferred frequencies. For this reason, only the propagation factors are considered in the following link analyses; the arbitrarily selected equipment parameters are assumed to be independent of frequency.

5. Link Performance

Figures 4-7 illustrate link performance as a function of frequency. Curves A are for a path in free space. Curves B include the effect of the atmosphere of the Earth. The index of performance P_r/N_o was calculated on the basis of data in Figures 1 and 3 and the following parameter values:

Communication distance	8×10^8 km
Earth station transmitter	100 kw
Satellite transmitter	100 watts
Spacecraft transmitter	25 watts

Antenna parameters used in the calculation are as shown in Figures 4-7. The antennae are assumed to be ideal with gain that is proportional to frequency squared.

These values are illustrative only; other values could be used. Different numerical results would be obtained, but the shape of the performance curves and the corresponding frequency selection would not change.

Comparison of curves A and B shows the advantage in link performance that results from utilizing higher frequencies when the path is entirely in space. This is a principal reason for establishing a relay station in a near-Earth satellite.

Curves B show that frequency bands within the 20-120 GHz range can provide for transmission through the atmosphere, and for the shielding of paths between a relay satellite and deep-space probes from terrestrial signals.

6. Preferred Frequency Bands

The preferred frequency bands for deep-space research in the 20-120 GHz range are listed in Table 1. The bands were selected on the basis of the index of performance curves and the requirement to provide links between a satellite and a station in deep space that are shielded from terrestrial signals, and links that permit communication between a deep-space station and either a near Earth satellite or an Earth station. The feasibility of band sharing and the existing allocations in the Radio Regulations were not factors in the selection of bands. The frequency dependent characteristics of scintillation and velocity of propagation were not used as determinants of preferred frequency bands. These factors could influence the use of certain allocated bands for particular space research missions, but communication performance was considered the dominant factor in preferred band selection. Similarly, equipment characteristics that vary with frequency were not used to influence band selection. Bands that may be allocated will likely remain for many years, and equipment technology will develop to make best use of those frequencies, as limited by natural phenomena. The bandwidth and frequency separation requirements are discussed in Report 536-1 (MOD I).

TABLE 1

Preferred frequencies and their uses

Range of Preferred Frequencies	General Applicability	Other Requirements (1)
28.5-39 GHz	Deep-space-to Earth during clear weather, and deep-space-to satellite.	500 MHz bandwidth.
34-50 GHz	Earth-to-deep space during clear weather, and satellite-to-deep space.	500 MHz bandwidth, spaced at approximately 7% from the space-to-Earth band in the 28.5 - 39 GHz range.
56-64 Ghz	Deep-space-to-satellite and satellite-to-deep space shielded from terrestrial signals.	A pair of 500 MHz wide bands spaced at approximately 7% within the 56-64 range.
117.7-119.8 GHz	Deep space-to-satellite shielded from terrestrial signals.	500 MHz bandwidth.
98-110 GHz	Satellite-to-deep space (uplink for 119 GHz downlink).	500 MHz bandwidth, spaced at approximately 7% from the space-to-satellite band in the 117.7 - 119.8 GHz range.

(1) The requirements shown are based on characteristics of telecommunication systems utilized or planned by several administrations.

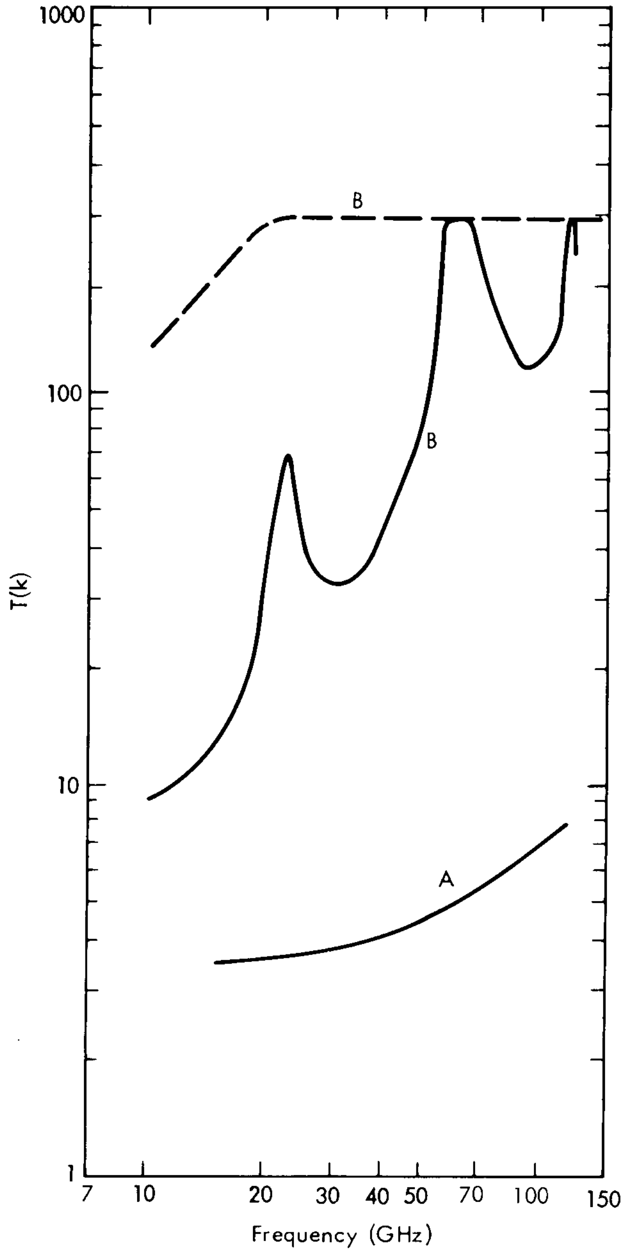

FIGURE 1.

Sky noise temperature

A: As seen by deep space station

B: As seen by earth station, antenna at 30° elevation angle

——— *Gaseous atmosphere*

– – – *Composite of gaseous atmosphere plus rain exceeded 0.001% of time (55 mm/hr, rain climate 4)*

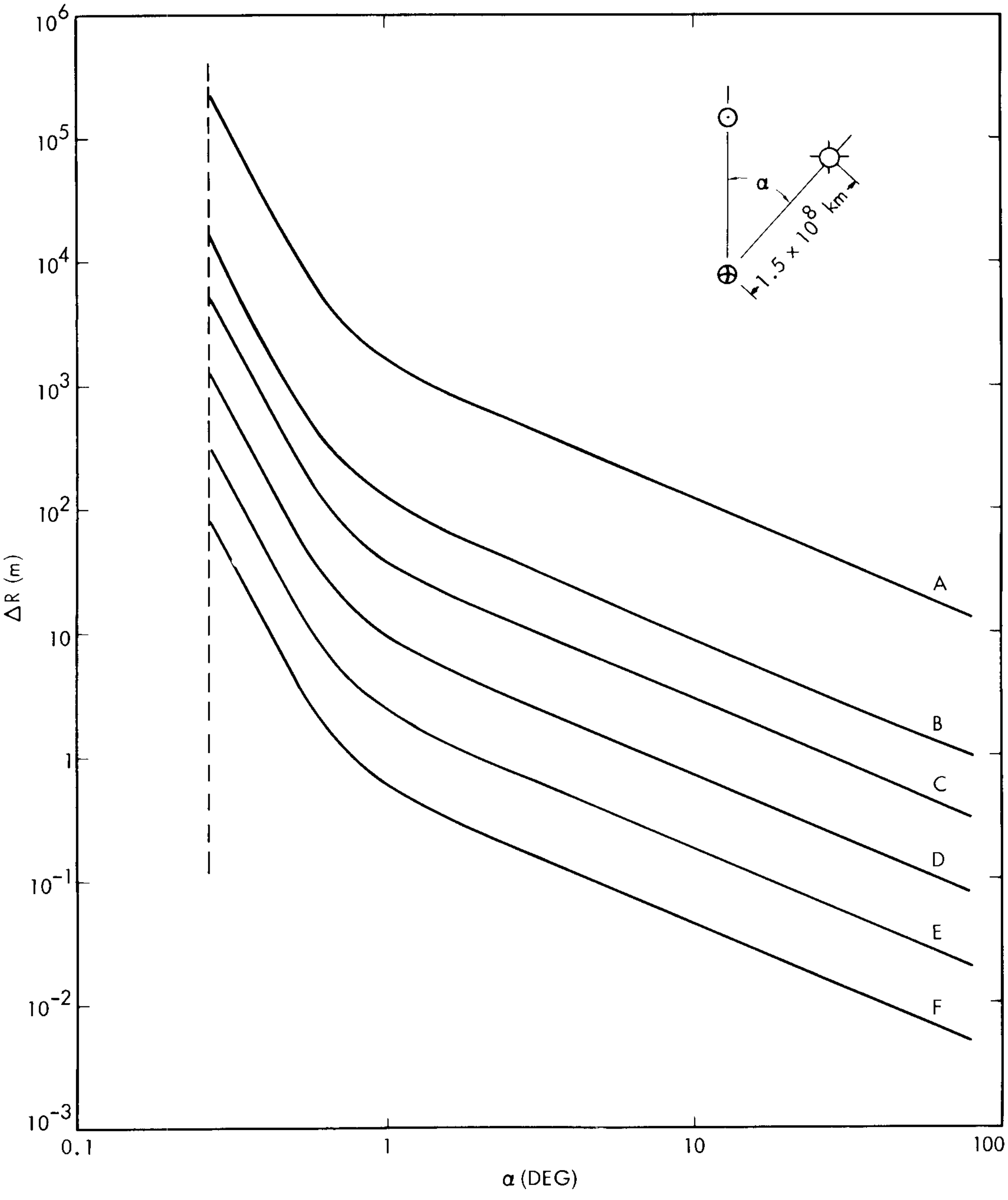

FIGURE 2.

Approximate error (ΔR) in measured spacecraft range caused by charged particles along a 1.5 X 10^8 km path, as a function of angle from center of sun (α)

A:	*2.295 GHz*	*D:*	*30 GHz*	⊙ :	*SUN*
B:	*8.450 GHz*	*E:*	*60 GHz*	⊕ :	*EARTH*
C:	*15.0 GHz*	*F:*	*120 GHz*	-◇- :	*SPACECRAFT*

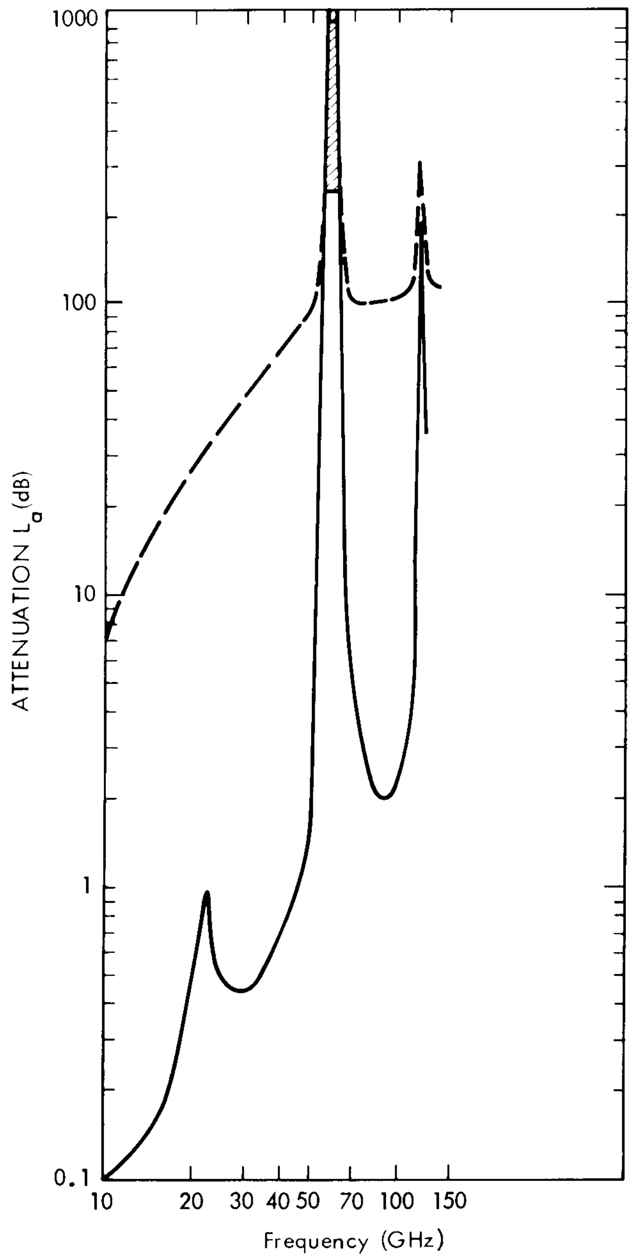

FIGURE 3.

Attenuation due to the gaseous atmosphere and rain for an antenna elevation angle of 30° at an earth station

——————— *Gaseous atmosphere (7.5 g/m³ water vapor at surface)*

– – – – – – *Composite of gaseous atmosphere plus rain exceeded 0.001% of time (55 mm/hr. rain climate 4)*

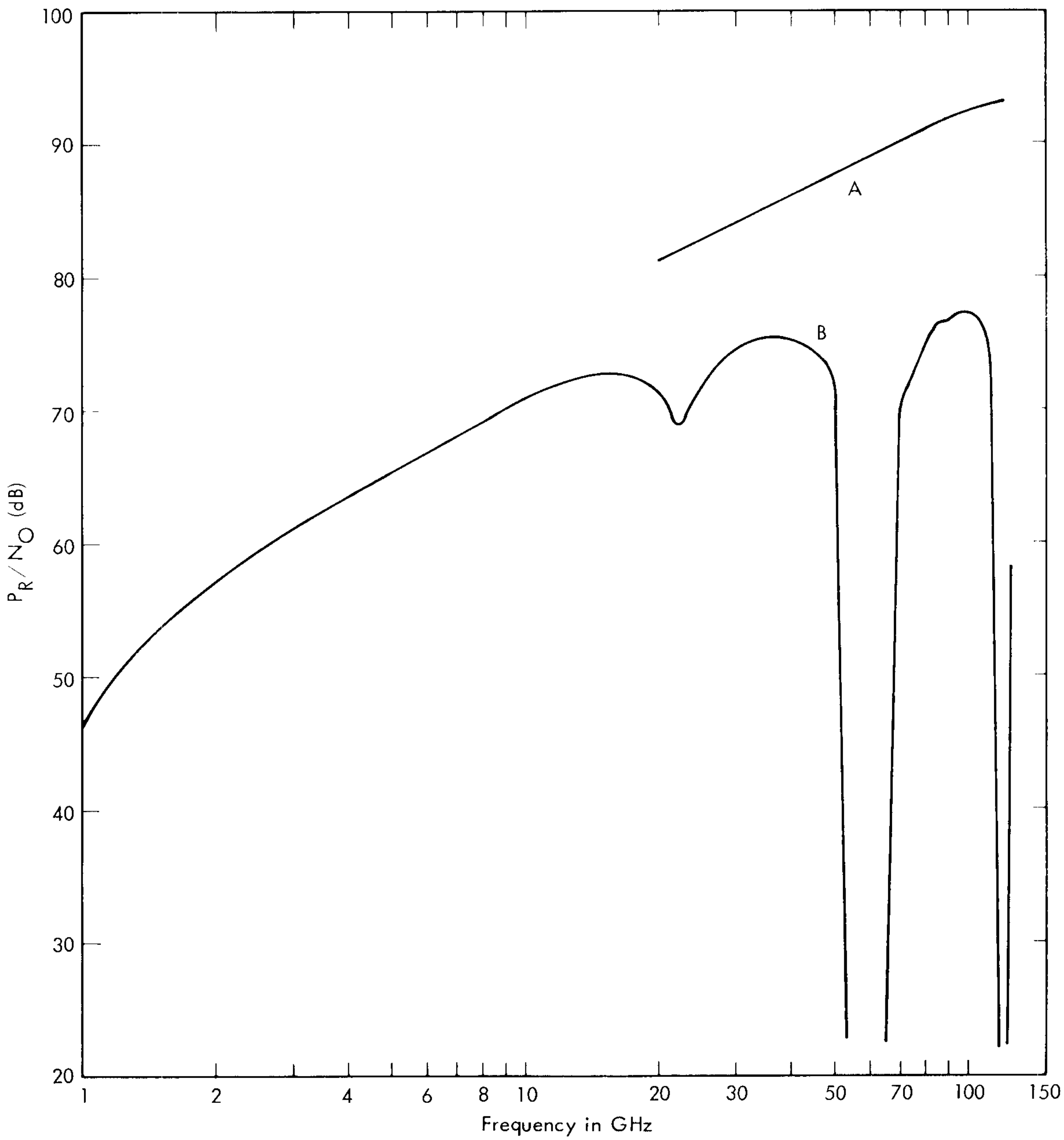

FIGURE 4.

Link performance (P_R/N_O) limited by natural phenomena only.
Two fixed diameter antennas: 3.7m on deep space station, 64m at receiving station.

A: Deep space-to-satellite
B: Deep space-to-earth station

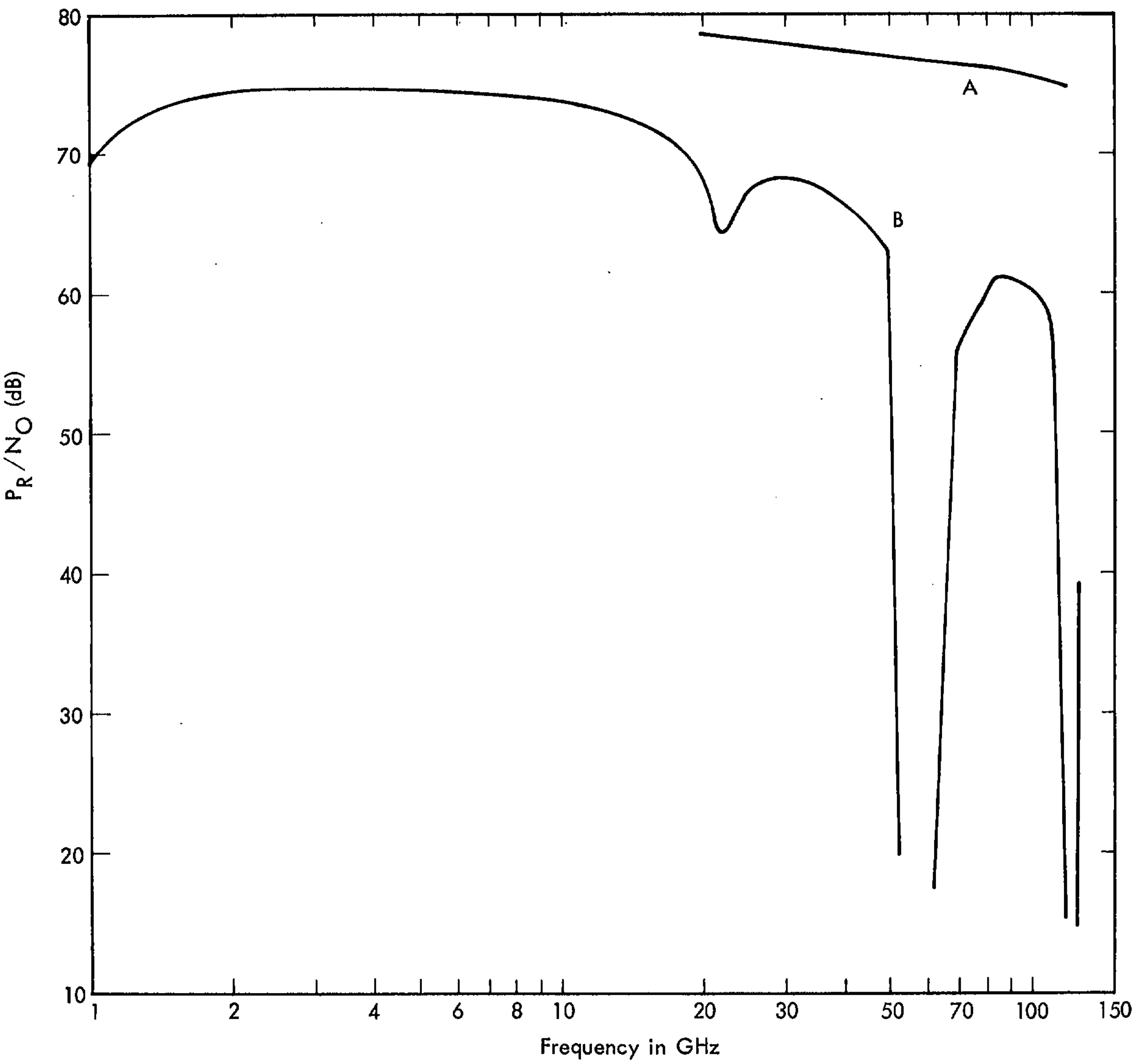

FIGURE 5.

Link performance (P_R/N_O) limited by natural phenomena only.
Fixed beamwidth (55 dBi gain) antenna on deep space station.
Fixed diameter (64m) antenna at receiving station.

A: Deep space-to-satellite
B: Deep space-to-earth

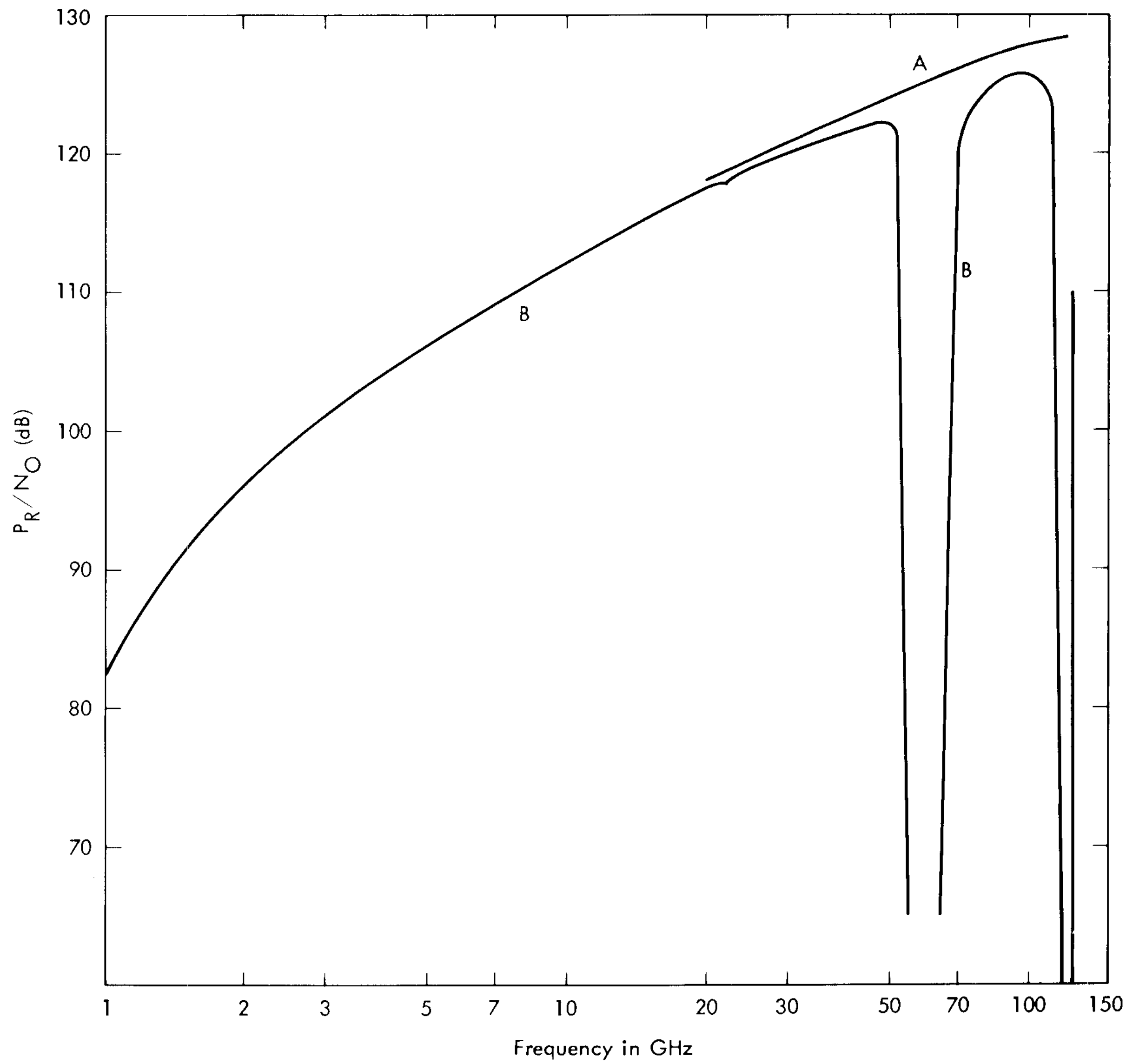

FIGURE 6.

Link performance (P_R/N_O) limited by natural phenomena only.
Two fixed diameter antennas: 3.7m on deep space station, 64m at transmitting station.

A: Satellite to deep space
B: Earth station to deep space

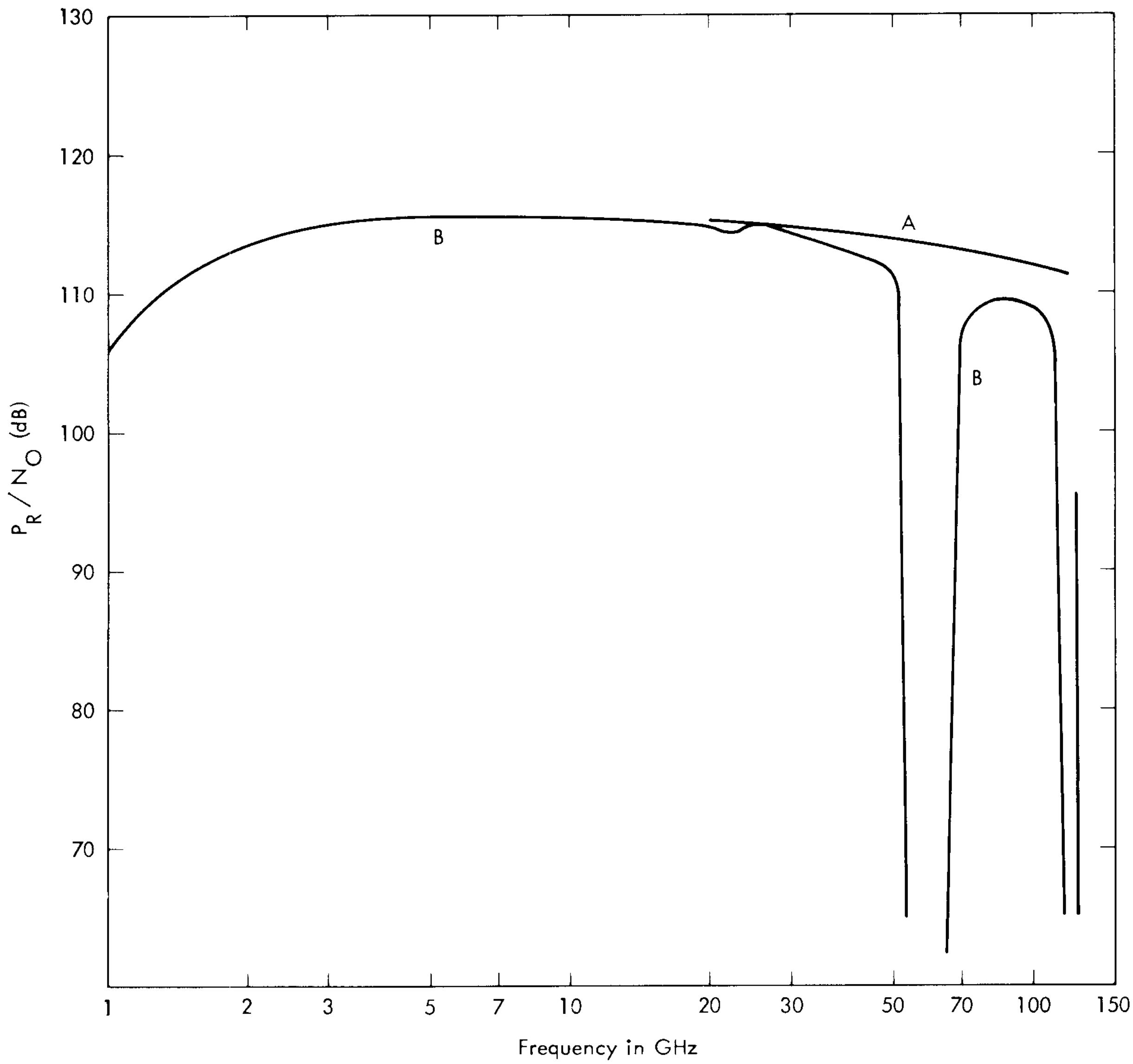

FIGURE 7

Link performance (P_R/N_O) limited by natural phenomena only.
Fixed beamwidth (55 dBi gain) antenna on deep space station.
Fixed diameter (64m) antenna at transmitting station.

A: Satellite to deep space
B: Earth station to deep space