RECOMMENDATION ITU-R SA.364-5*

PREFERRED FREQUENCIES AND BANDWIDTHS FOR MANNED AND UNMANNED NEAR-EARTH RESEARCH SATELLITES

(Question 132/7)

(1963-1966-1970-1978-1986-1992)

The CCIR,

considering

a) that suitable operating frequencies and required radio-frequency bandwidths for near-Earth space research missions are determined by propagation factors and technical considerations;

b) that two-way communication is required for many near-Earth missions, and is vital for manned missions;

c) that requirements for telecommunication reliability must be satisfied during periods of adverse atmospheric conditions;

d) that it is practical and desirable to effect telecommunication functions on a single link;

e) that to effect precision tracking, a pair of coherently related Earth-to-space and space-to-Earth frequencies is desirable;

f) that for simultaneous transmit/receive operations involving a single antenna, the paired Earth-to-space and space-to-Earth frequencies should be separated by at least 7%;

g) that space-to-space and Earth/space relay satellite telecommunications are necessary to accommodate the growth and development of near-Earth investigations in the space research service;

h) that particular modulation and channel coding techniques may be required for some links in order to comply with power flux-density limits or to guard against multipath and/or interference effects,

recommends

1. that frequency bands for near-Earth missions in the space research service be located, with due regard to the purpose of the link and to the feasibility of sharing, in the preferred frequency ranges listed in Table 1;

2. that the widths of the allocated bands at preferred frequencies satisfy the individual link bandwidth requirements listed in Table 2 in order to provide for present and future near-Earth telecommunications in multi-spacecraft, multi-mission systems, within the space research service.

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* This Recommendation should be brought to the attention of Study Groups 1, 4, 7, 8, 9, 10 and 11.

ANNEX 1*

Procedure for the selection of frequency bands preferred for transmission to and from manned and unmanned spacecraft for near-Earth space research

1. Background – propagation effects

This Annex discusses the procedure used for the selection of frequencies preferred for near-Earth missions, based upon propagation and technical considerations within the range of 100 MHz-350 GHz. The link performance is critically dependent upon the propagation conditions which are determined primarily by atmospheric gases and by precipitation. Parameters which model these effects are derived from Study Group 5 texts. Typical values of attenuation and sky noise have been obtained for clear-sky conditions and for rain rates of 20, 50, 100 and 140 mm/h for elevation angles of 5° and 20°. Ionospheric effects arise due to the interaction of the transmitted radio wave, the Earth's free electron density, which varies as a function of geomagnetic latitude, diurnal cycle, yearly and solar cycle, etc., and the Earth's magnetic fields. Ionospheric effects above 10 GHz are generally small and not considered significant. In the absence of precipitation, tropospheric effects are unlikely to produce serious fading in space telecommunications systems at frequencies below about 10 GHz. Signal attenuation due to absorption by molecular oxygen and water vapour and due to absorption and scattering by rain can severely affect link performance and therefore the selection of frequencies.

2. Technical and operational considerations

Technical considerations may be divided into two categories, namely mission requirements and hardware or equipment factors.

2.1 Mission frequency support requirements

2.1.1 Telecommand and maintenance telemetering

The basic requirement of any mission is its safety and success. In order that this requirement be met, the telecommand and maintenance telemetry link must function with the spacecraft in any orientation. As this can only be achieved through the use of a broad-beam, omni-type antenna aboard the spacecraft, the use of such an antenna must be considered when selecting frequencies.

Telecommand bandwidths of 10-50 kHz are adequate for most missions, although more sophisticated spacecraft may require link bandwidths of the order of 500 kHz or more. Maintenance telemetry link bandwidths range from several kilohertz to several hundred kilohertz.

2.1.2 Mission telemetry

For many missions, telemetry data are gathered and stored for play-back to Earth. For some of these missions, there may only be a single opportunity for the spacecraft to transmit the recorded data; these missions must therefore be capable of operating under all weather conditions. For missions which do not need to operate under such constraints, a frequency may be selected where data rate can be maximized for clear-sky conditions.

Link bandwidths depend on the complexity and sophistication of the spacecraft. For direct spacecraft-to-Earth station links, bandwidths of 100 kHz to 100 MHz can be expected. Bandwidths for relay satellite space-to-Earth links presently range from 225 to 650 MHz; however, this is expected to increase to above 1 GHz to meet future requirements.

* Note from the Director, CCIR – Report 984 (Düsseldorf, 1990) was used in the preparation of this Annex.

Space-to-space link bandwidths presently range from about 5 to 225 MHz for direct user satellite to relay satellite communications. Inter-relay satellite bandwidths will be considerably wider, possibly greater than 1 GHz.

2.1.3 Tracking

Near-Earth space research involves various methods for determining spacecraft orbital information. For interferometer tracking, consideration of factors such as a good omnidirectional antenna on a spacecraft, transmitter efficiency, and earth-station antenna beamwidth, usually favours a frequency below 1 GHz. More elaborate moving antenna interferometers have been built for frequencies greater than 5 GHz, but atmospheric attenuation and noise usually limit their performance at frequencies greater than 6 GHz. Typical bandwidths range from several hundred hertz to several kilohertz.

Range and range-rate systems which must operate with the minimum of disturbances from ionospheric and trans-atmospheric effects are in the 1-8 GHz range for precision tracking systems. The main factor which dictates the maximum bandwidth needed per one-way channel is the range resolution required. Range resolutions of the order of metres can be obtained by using appropriate modulation with bandwidths of about 1-3 MHz.

Radar tracking is also employed although atmospheric attenuation usually limits the use of frequencies above about 6 GHz for tracking by primary radar systems. For many of these systems, a bandwidth in the range of 1-10 MHz is usually sufficient.

Bilateration ranging is designed to supply precise information on the location of a relay satellite so that its movement can be taken into account when determining the orbital parameters of user spacecraft via the relay satellite. Typical links must be weather independent, and have bandwidths of about 5 to 6 MHz.

2.2 Equipment factors

Equipment factors which have an effect on link performance and whose characteristics depend on frequency to some extent are transmitter power, antenna gain (for a fixed-size antenna) and the receiver noise temperature. Of these three, the antenna gain is a function of the square of the frequency, whereas the transmit power and receiver noise are indirectly coupled to the frequency of operation. Their performance is therefore considered uniform over a wide frequency range.

The existence of proven space equipment and systems must also be considered in the selection of frequency bands to provide operational consistency.

Because of practical limits of diplexers, Earth-to-space and space-to-Earth pairs of frequencies should be separated by at least 7% to allow simultaneous transmit/receive operations using a single antenna.

3. Link performance

In this Annex, the impact of propagation effects on the signal strength and system noise in a basic link equation has been considered, and an index of link performance, determined as the ratio of received signal power to noise spectral-density (P_r / N_0), has been established as the criterion for frequency selection.

The link analyses which follow are based upon a fixed diameter earth-station antenna, and cover both a fixed diameter and a fixed beamwidth space-station antenna. The fixed-diameter space station antenna is included to account for situations where a large antenna is employed on the spacecraft, and there are no pointing limitations. The fixed beamwidth case is included to account for situations where antenna pointing accuracy determines the minimum beamwidth, or where an antenna must provide wide coverage to permit communication without regard to spacecraft orientation as in the case of an emergency telemetry or command link.

In the analyses, the effects of precipitation are considered only for frequencies below about 22 GHz. The effects of precipitation above 22 GHz are not considered because even low rain rates can seriously degrade communications on trans-atmospheric links. Therefore only clear weather usage is assumed above 22 GHz. The results apply to an elevation angle of 5° which represents a "worst case" situation.

Maximum data rate capability is obtained by using the frequency bands where P_r / N_0 is a maximum for the weather conditions and space-station antenna limitations considered. A concise presentation of preferred frequency bands is shown in Table 1 and is obtained from the normalized P_r / N_0 curves given in this Recommendation. The general width of the bands was determined by noting the frequencies corresponding to the levels approximately 1 dB below the peaks of the curves. A high rain rate was assumed when determining the width of all-weather frequency bands in Table 1 in order that the results be applicable worldwide. Bands outside this range may be suitable for areas of lower rain rates.

3.1 Calculation of link performance as a function of frequency

The index of link performance, received power-to-noise spectral density ratio, is given by the basic link equation:

Error! dB (1)

where:

P_r : received power (W)

N_0 : noise spectral density (W/Hz)

P_t : transmitted power (W)

G_t : transmitting antenna gain

L_s : free-space loss

L_a : transmission loss due to attenuation in the clear atmosphere

L_r : transmission loss due to rain attenuation

G_r : receiving antenna gain (dBi)

k : Boltzmann's constant (J/K)

T : total system noise temperature (K).

Assuming no waveguide loss T is given by:

$$T = T_r + T_s + T_g$$

where:

T_r : receiver noise temperature (K)

T_s : sky contribution (due to atmospheric and precipitation effects) to antenna noise temperature (K)

T_g : ground contribution to antenna noise temperature (K).

By isolating the frequency-dependent terms in equation (1), the equation may, for a fixed distance between space and earth station, be written as follows:

Case 1: Earth and space-station antenna diameters are fixed:

Error! dB (2)

Case 2: Earth-station antenna diameter is fixed, space-station antenna beamwidth is fixed:

Error! dB (3)

where:

C and C_1 are constant in equations (2) and (3) respectively and expressed in dB and the terms in the brackets are the frequency-dependent terms. Any change in the value of the constant will merely raise or lower the P_r/N_0 curves, the overall shape of the curves will remain unchanged.

3.2 Application to near-Earth space research missions

Assumed system and receiver noise temperatures for space and earth stations are shown in Figs. 1 and 2 respectively. The noise temperatures are depicted as a step function because of the assumption that the receiver noise temperature will not change significantly over its frequency of operation, but rather remain fairly constant over the operating frequency ranges for which it is designed.

FIGURE 1

Assumed satellite system noise temperature

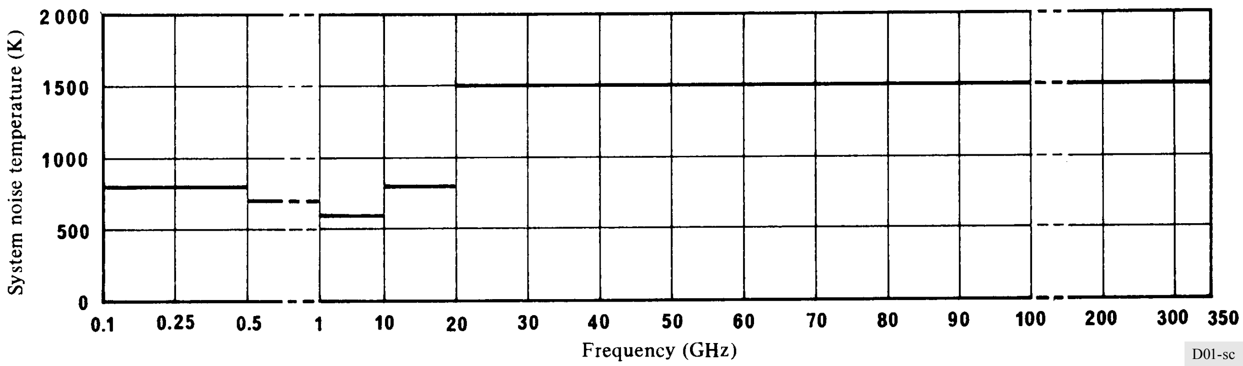
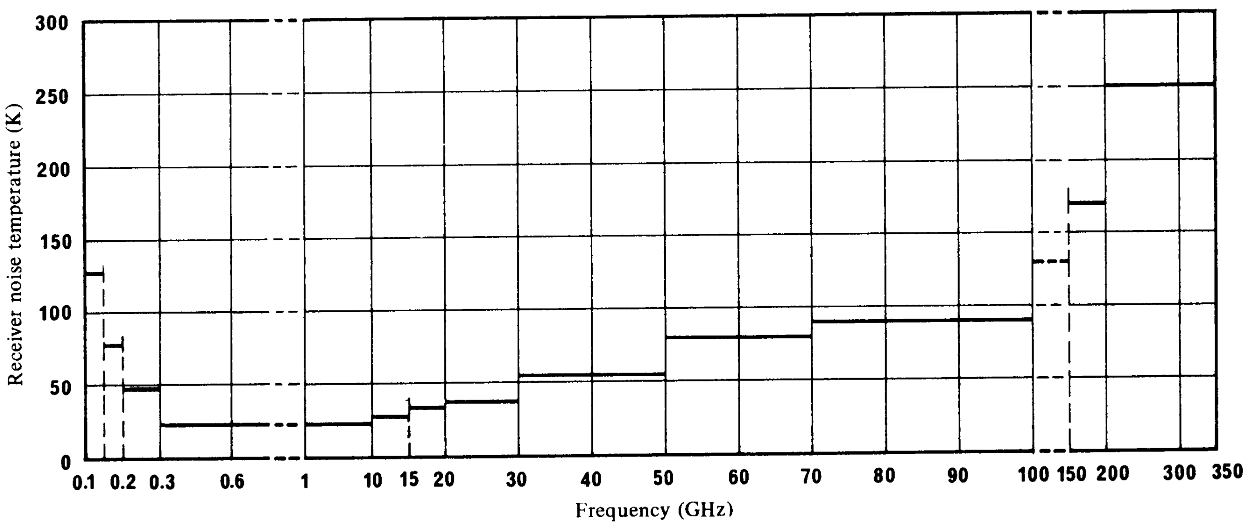


FIGURE 2

Assumed earth-station receiver noise temperature



Note 1 – The values in Figs. 1 and 2 are derived from a number of technical references. They are typical of existing equipments in bands below about 20 GHz and represent anticipated developments in bands above 20 GHz.

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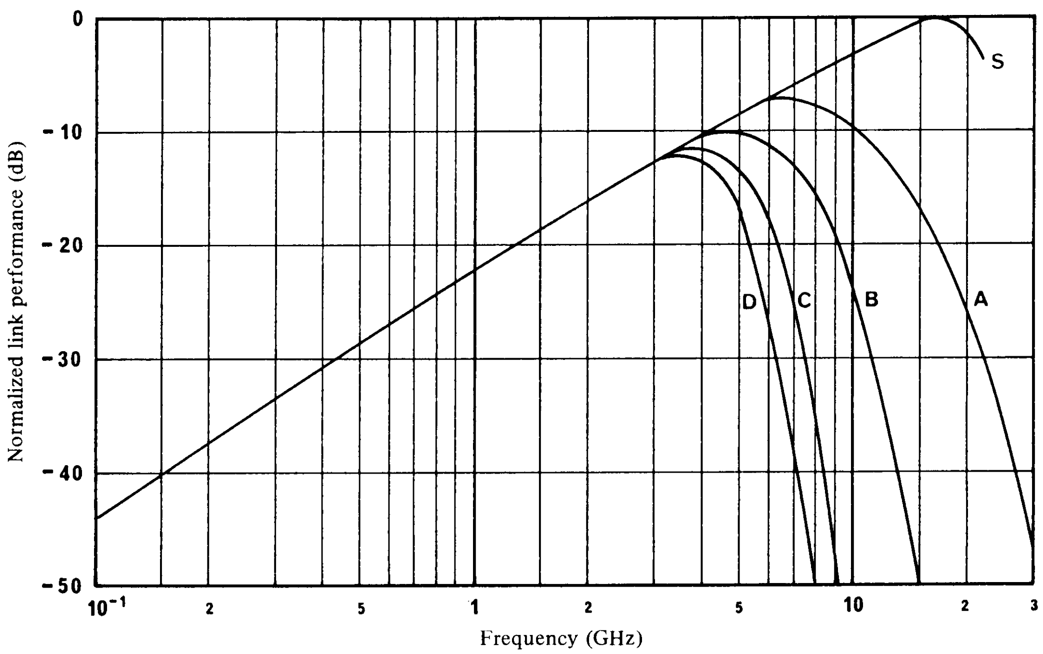
Using the above data together with the relevant propagation data from Study Group 5 and the formulae derived in § 3.1, a set of normalized link performance values was computed for bidirectional propagation through the atmosphere and for the two cases of antenna restrictions. These normalized link performance values are plotted in Figs. 3 to 6 for the frequency range 0.1-22 GHz, and in Figs. 7 to 10 for the frequency range 22-350 GHz.

FIGURE 3

Normalized Earth-to-space link performance. Space station antenna diameter fixed



Curves A: rain rate = 20 mm/h
B: rain rate = 50 mm/h
C: rain rate = 100 mm/h
D: rain rate = 140 mm/h
S: clear sky

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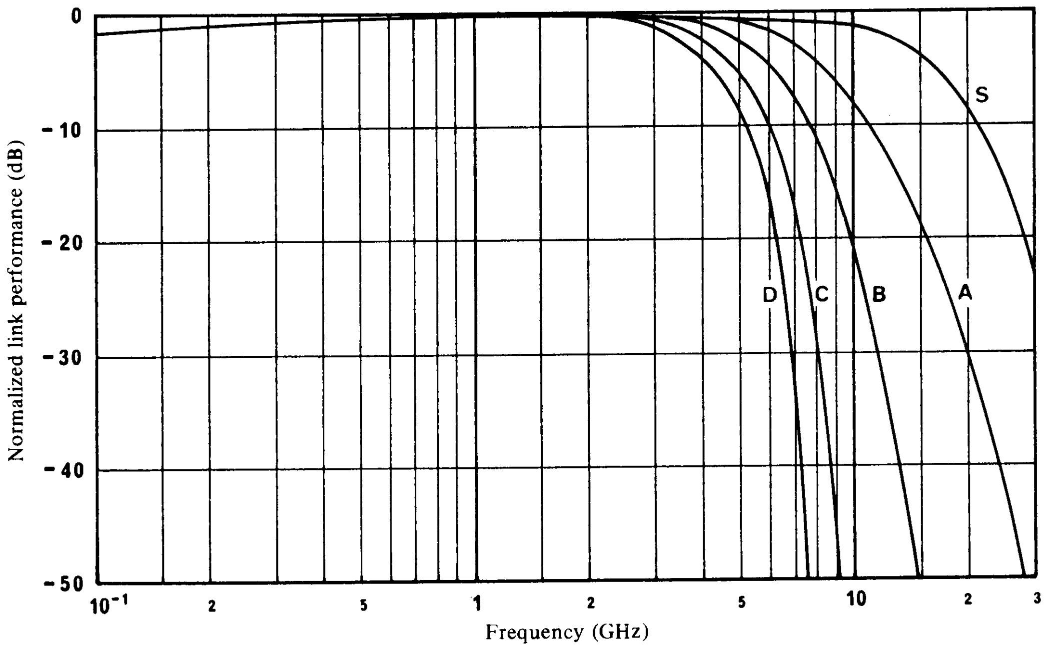
4. Discussion and conclusions

In each of Figs. 3 to 6, a set of parametric curves is shown for precipitation conditions with rain rates of 20, 50, 100 and 140 mm/h and for clear-sky conditions. From these figures, it can be seen that rain has a pronounced effect on the optimum range of frequencies, shortening and shifting the optimum range to lower frequencies for higher rain rates. For countries located in regions of high rain rate, the choice of suitable frequencies is critical if they are to maintain a high quality of performance despite adverse weather conditions. For the frequency range 22-50 GHz, Figs. 7 to 10 show a series of normalized link performance curves for clear-sky conditions only.

The important features of the link performance curves are the locations of the maxima and the effect of the weather on the optimum frequency range. The optimum frequency range was determined by noting those frequencies on either side of a curve maximum, which correspond to a link performance value of approximately 1 dB below that of the maximum. A decrease of the order of 1 dB below a curve maximum was considered sufficient to represent a relatively flat portion of the curve about its maximum.

FIGURE 4

Normalized Earth-to-space link performance. Space station antenna beamwidth fixed



Curves A: rain rate = 20 mm/h
B: rain rate = 50 mm/h
C: rain rate = 100 mm/h
D: rain rate = 140 mm/h
S: clear sky

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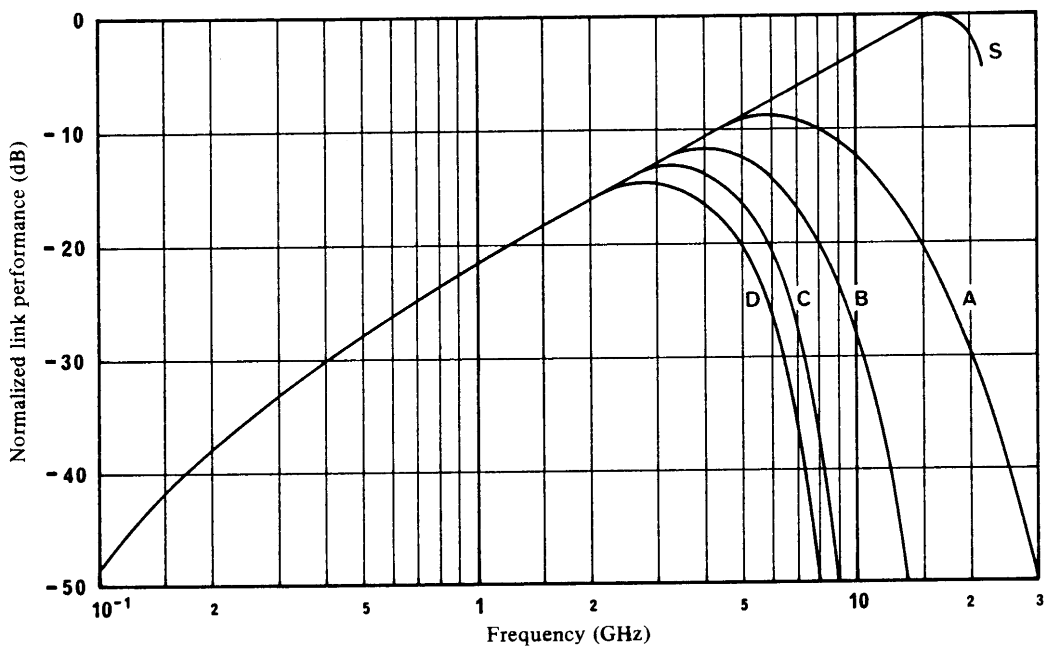
FIGURE 5

Normalized space-to-Earth link performance. Space station antenna diameter fixed



Curves A: rain rate = 20 mm/h
B: rain rate = 50 mm/h
C: rain rate = 100 mm/h
D: rain rate = 140 mm/h
S: clear sky

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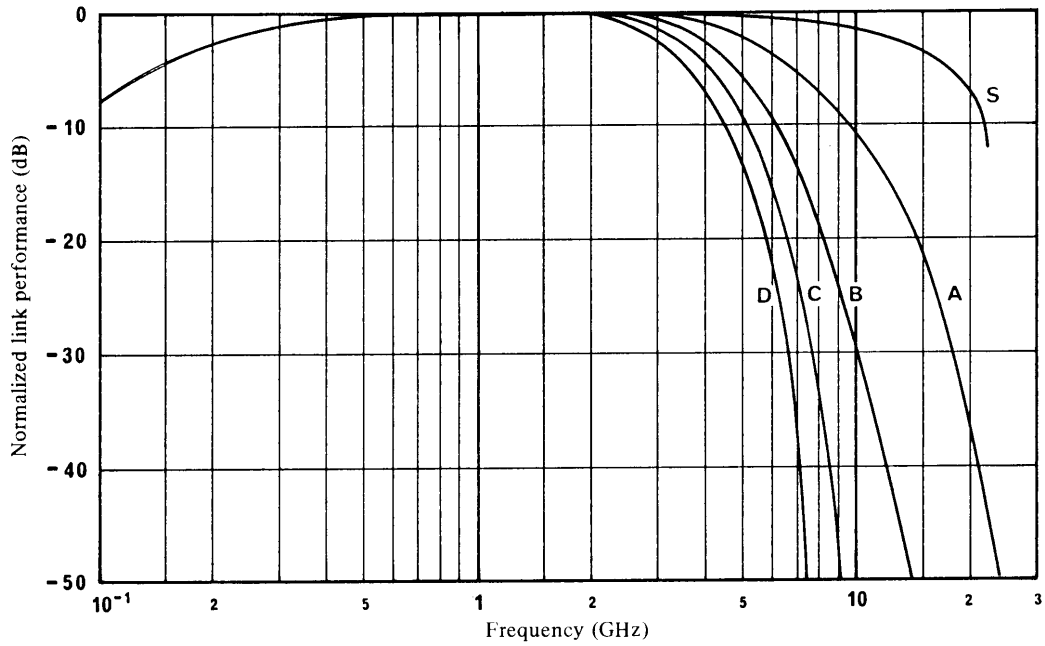
FIGURE 6

Normalized space-to-Earth link performance. Space station antenna beamwidth fixed



Curves A: rain rate = 20 mm/h
B: rain rate = 50 mm/h
C: rain rate = 100 mm/h
D: rain rate = 140 mm/h
S: clear sky

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FIGURE 7

Normalized Earth-to-space link performance. Space station antenna diameter fixed

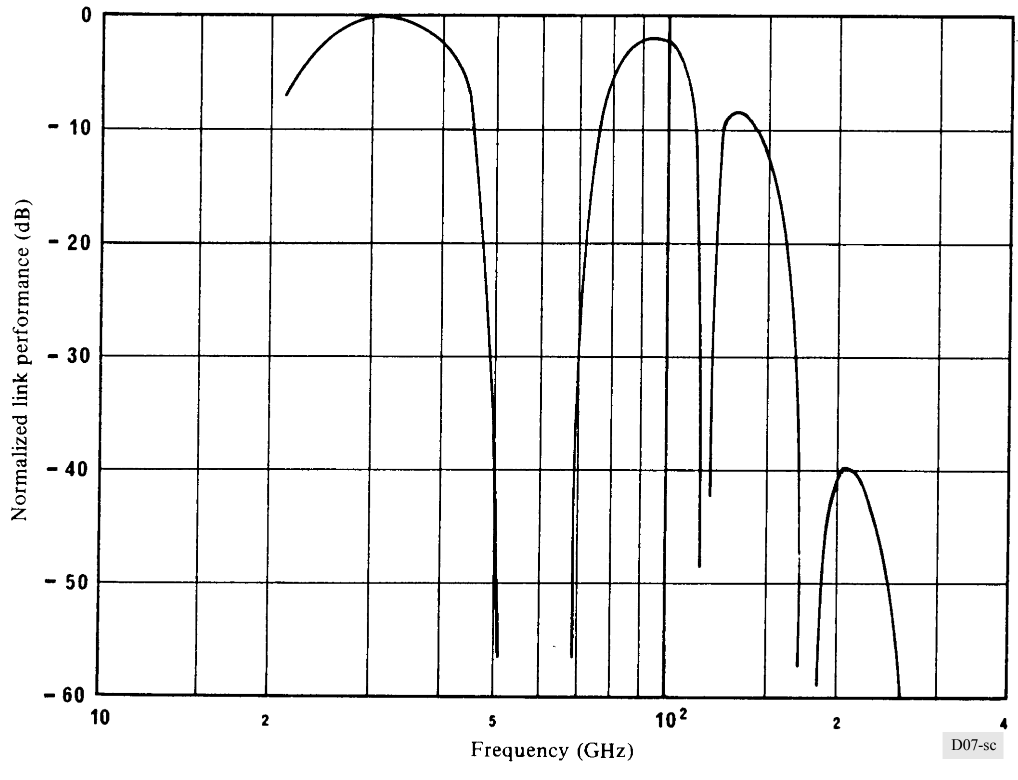

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FIGURE 8

Normalized Earth-to-space link performance. Space station antenna beamwidth fixed

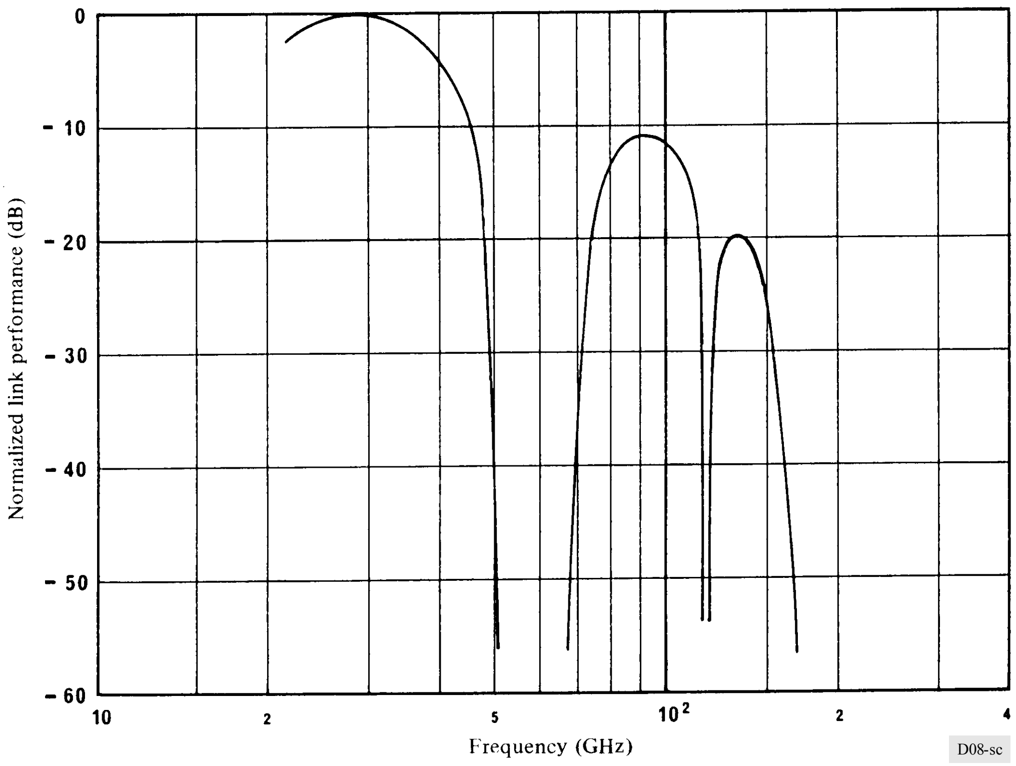


FIGURE 9

Normalized space-to-Earth link performance. Space station antenna diameter fixed

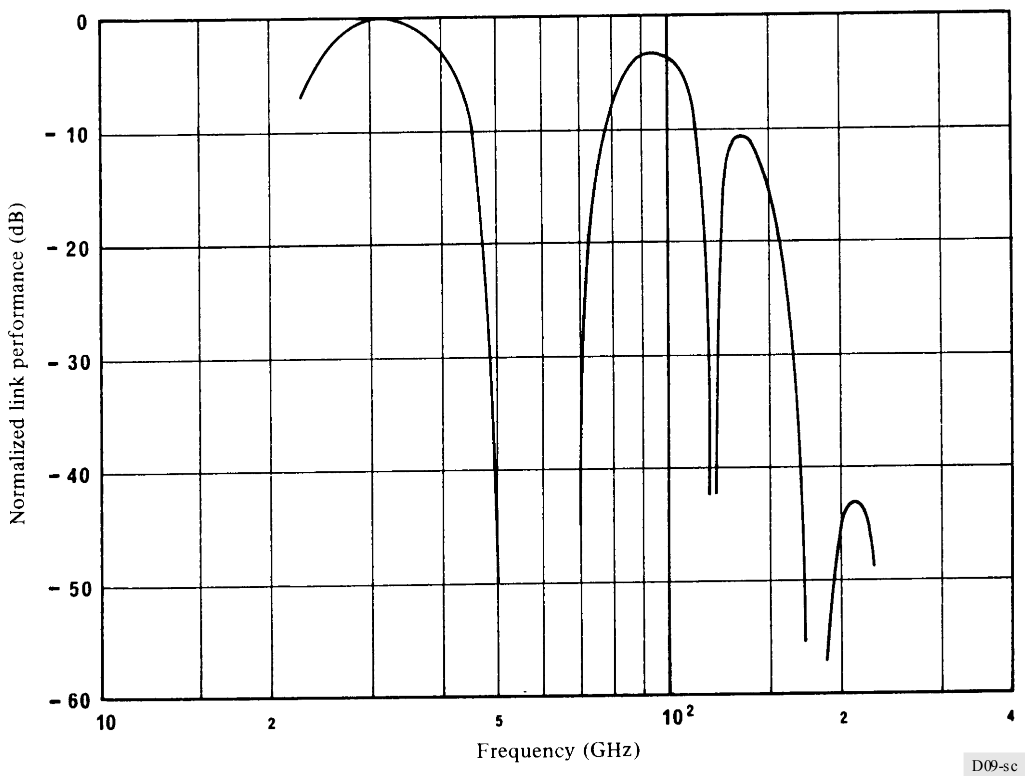
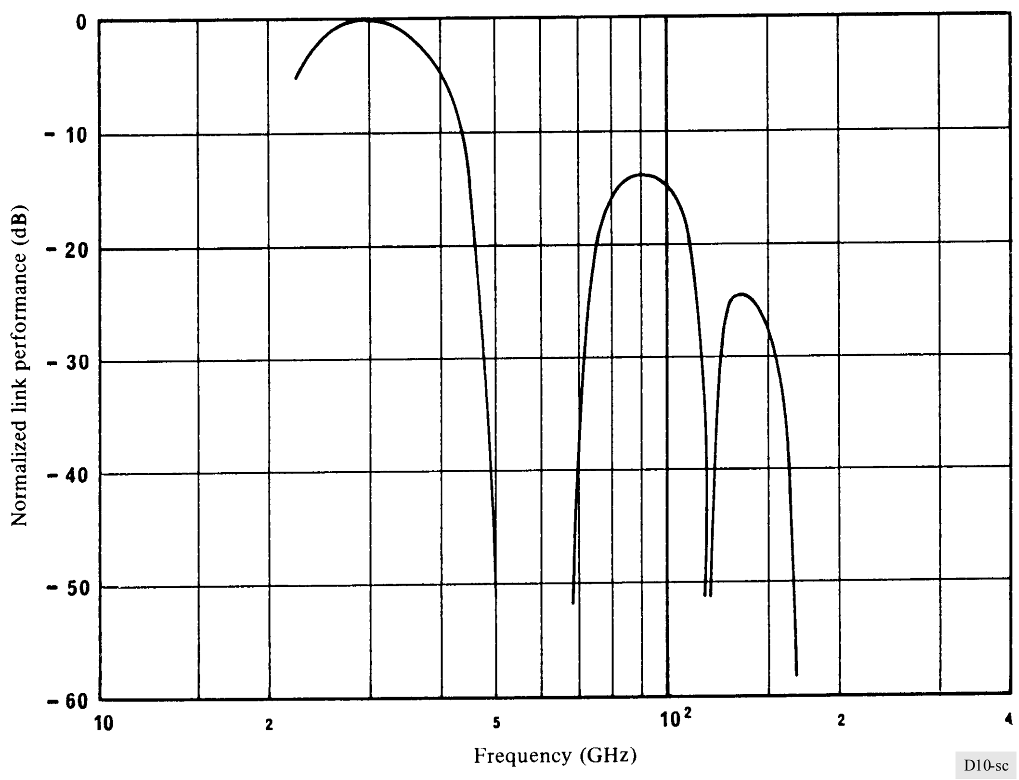


FIGURE 10

Normalized space-to-Earth link performance. Space station antenna beamwidth fixed



Maximum data rate capability is obtained by using frequency bands where P_r / N_0 is a maximum for the weather conditions and space-station antenna limitations considered. Table 1 summarizes the frequency bands preferred for various applications. A high rain rate was assumed when determining the width of all-weather frequency bands in order that the results be applicable worldwide. Bands outside this range may be suitable for areas of lower rain rates.

Space-to-space links are best located in the frequency ranges of high atmospheric attenuation as this virtually eliminates any problem of interference to and from terrestrial sources. These ranges, located in the troughs between successive maxima shown in Figs. 7 to 10 correspond to the region around the oxygen and water vapour absorption peaks.

Above about 150 GHz, trans-atmospheric communications are subject to a high level of signal attenuation when the elevation angle is low. However, the range of frequencies above 150 GHz may be considered for links through the atmosphere, where the elevation angle of operation is not low.

The list of frequency bands given in Table 1 is intended to identify those frequency ranges which are preferred from a technical standpoint. The inclusion of a band in the table is not intended to indicate that there will be sufficient available link margin or bandwidth. Also, exclusion of other frequencies from the table does not necessarily preclude operations in these bands where frequency sharing considerations and state of the art equipment limitations dictate their use.

The list of typical individual link bandwidths given in Table 2 is intended to reflect link bandwidths which can be supported with current technology. The inclusion of a link bandwidth in the table is not intended to indicate the frequency band in which the individual link may be required to operate nor to limit the numbers of such links that may be required to support any particular spacecraft or mission systems.

TABLE 1

Preferred frequency bands and their uses

Frequency (GHz)	Direction	Comments
0.3-2.5 0.1-3.0	S-E E-S	An all-weather link, optimum also when communications must be established regardless of spacecraft orientation
0.3-10 0.1-10	S-E E-S	A clear-weather link, optimum when a broad or fixed beamwidth antenna is required on the spacecraft
2-4 2-5	S-E E-S	An all-weather link for use with directive antennas
2-3 13.5-23	S-S S-S	Bands necessary to provide space-to-space communications with existing and proven space equipment and technology. Also necessary to provide continuity of service until other bands show practical and technical usability
12-20 14-20 28-35 27-32 85-100 127-137	S-E E-S E-S S-E E-S and S-E E-S and S-E	A clear-weather link, optimum for a high or medium gain antenna on the spacecraft
54-70 117-120 178-188 318-328	S-S S-S S-S S-S	Bands affording maximum clear-sky interference protection to space-to-space links from terrestrial applications, optimum for high to medium gain spacecraft antennas

TABLE 2

Typical individual link bandwidths and their uses

Use	Direction	Typical bandwidth	Comments
Telecommand	E-S	10-500 kHz	
Maintenance telemetry	S-E	5-500 kHz	
Telemetry	S-E (direct)	100 kHz-100 MHz	Direct satellite to Earth
Telemetry	S-E (relay)	225-650 MHz	Relay satellite to earth station, data from one or more user satellites
Telemetry	S-S	5-225 MHz	User satellite to relay satellite
Telemetry	S-S	> 1 GHz	Relay satellite to relay satellite
Tracking	S-E	500 Hz-500 kHz	Interferometry
Tracking	E-S	1-3 MHz	Range and range rate systems
Tracking	E-S	1-10 MHz	Radar
Tracking	E-S	5-6 MHz	Bilateration ranging