RECOMMENDATION ITU-R SA.1015

BANDWIDTH REQUIREMENTS FOR DEEP-SPACE RESEARCH

(Question ITU-R 209/7)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that maximum symbol rates required for deep-space telecommunications in both directions, space-to-Earth and Earth-to-space, have been well established (see Annex 1) for the foreseeable future;

b) that, utilizing currently practicable techniques, the corresponding required bandwidths have been established;

c) that the required width of allocated bands is influenced by the requirements of individual links and by the number of links that are simultaneous within the beamwidth of a deep-space research earth station antenna;

d) that, in the future, the bandwidth required for some telecommunication functions of deep-space research may be reduced by utilizing newer techniques,

recommends

1. that band allocations for deep-space research take into account the bandwidth requirements listed in Annex 1;

2. that all feasible steps that will reduce the required bandwidth be considered for future telecommunication systems for deep-space research.

ANNEX 1

Bandwidth requirements for deep-space research

1. Introduction

The total bandwidth suitable for deep-space telecommunications is a function of the required symbol rates, the number of spacecraft links in each mission, the number of missions, and the extent to which frequencies may be shared without mutual interference.

2. Link bandwidth

Earth-to-space and space-to-Earth bandwidths are governed by required telemetering symbol rates, and by the required precision of angular and ranging measurements.

Needed symbol rates and corresponding bandwidths for the different functions projected to be used in deep-space research are summarized in Table 1.

TABLE 1

Maximum required symbol rates and bandwidths for a deep-space mission

Direction and function	Symbol rate (MS/s)	RF bandwidth (MHz)
Earth-to-space		
Telecommand	0.002	0.040[(1)]
Computer programming	0.2	1
Voice	0.045	0.225
Television	100	500
Ranging	100	500
Space-to-Earth		
Maintenance telemetering	0.2	1
Scientific data	10	50
Voice	0.045	0.225
Television	100	500
Ranging	100	500

(1) Typically a sub-carrier will be used.

The extremely precise navigation technique using very long range interferometry (VLBI) requires the transmission of tones widely spaced from the carrier. Typically the spacing may vary from 1/200 to 1/600 of the spacecraft transmitted frequency and the relative power of these tones to the carrier is typically –15 dB. Transmission of these tones will not be continuous. Therefore, spectral line separation of frequency tones used in VLBI need not be considered a determinant of required bandwidth.

Spacecraft design simplicity, reliability and optimum performance of the telecommunications links, have led to the use of bi-phase modulation with residual carrier as the traditional deep-space technique for the transmission of information. To pass a periodic square modulation waveform with no more than 0.3 dB loss, the bandwidth must include the fifth harmonic of the modulating square wave. For the telemetering signal, the radio-frequency bandwidth must be wide enough to pass the fifth harmonic of the sub-carrier frequency plus the fifth harmonic of the clock rate (1/2 the symbol rate). With present techniques, the sub-carrier frequency must be high enough to provide at least 1.5 sub-carrier cycles per symbol. The total maximum radio-frequency bandwidth required is therefore:

$$BW = 2\left[(SR \times 1.5 \times 5) + 5 \times 0.5\, SR\right] = 20\, SR$$

where:

BW: RF bandwidth

SR: symbol rate.

As telemetering symbol rates increase, the need for a sub-carrier to keep the data power outside the carrier tracking loop bandwidth becomes less important. This is because the carrier loop bandwidth is a relatively smaller fraction of the symbol spectrum bandwidth and the symbol power being tracked out by the carrier phase lock loop becomes negligible. By the use of appropriate coding, symbol power near the carrier frequency also can be minimized so that sub-carriers are not necessary. Elimination of sub-carriers reduces the total radio frequency bandwidth requirement to:

$$BW = 2\,(5 \times 0.5\, SR) = 5\, SR$$

The current implementation of ranging uses square wave bi-phase modulation. The bandwidth required for the transmitted ranging signal is determined by the highest code frequency. A bandwidth equal to six times the code frequency is usually considered acceptable. For some deep-space missions, the maximum bandwidth requirement will be determined by ranging accuracy considerations.

Future requirements for very high telemetering and ranging code rates may result in the need for additional reduction of transmitted spectrum bandwidth in order to accommodate one or more spacecraft within a particular band allocation. Suitable techniques include quadri-phase modulation, minimum shift keying, and utilization of waveforms with highly reduced harmonic power.

The maximum radio-frequency bandwidth needed for a particular mission is determined by the total symbol rate required to permit simultaneous functions, and by the method of modulation. The ranging function is usually the most significant determinant of the maximum symbol rate. For current implementation, the maximum radio-frequency bandwidth for a single unmanned spacecraft is approximately 6 MHz. For the VLBI function a pair of spectral lines spaced up to 115 MHz from the carrier frequency may be a part of the transmitted signal. Future requirements for the higher rates shown in Table 1 will result in required transmission bandwidths up to several hundred MHz.

3. Mission bandwidth

Some deep-space missions use two or more spacecraft. At some times during the mission, several spacecraft may be simultaneously within the beamwidth of the earth station antenna. A mission where the spacecraft are placed in orbit around a planet is an important example of this condition. Under these circumstances, the simultaneous operation of the telecommunications links results in a requirement for radio-frequency bandwidth sufficient to accommodate the several signals without mutual interference.

Typical mission design, along with consideration of the simultaneous functional requirements of each spacecraft, result in the conclusion that expected deep-space missions can be conducted within a total allocated bandwidth of approximately 500 to 1 000 MHz.

4. Multiple mission bandwidth

Several deep-space missions to different parts of the solar system may share the same radio frequencies except during those times when mutual interference results. This interference can occur for brief periods when one spacecraft is close to the Earth, resulting in a very high signal strength, or when spacecraft from different missions are within the earth station beamwidth. Analysis of current and proposed missions shows that periods of mutual interference are brief enough so that they may be avoided by time-sharing the use of telecommunications links.

The conclusion that a 500 to 1 000 MHz allocation width will accommodate the maximum requirements of future deep-space missions is also appropriate for multi-mission environments.

5. Link reliability and the utilization of allocated bands

The foregoing section set forth the maximum bandwidth required for the conduct of deep-space research. Existing allocations near 2 and 8 GHz cannot accommodate these maximum requirements. These allocations do, however, provide an essential capability for deep-space research.

The 10 MHz wide allocations near 2 GHz provide for links that are relatively immune to adverse effects of rain and cloud. Past and currently-planned spacecraft often include the equipment needed to make use of these allocations to ensure at least partial mission success in the event of adverse weather that precludes the use of higher frequency bands.

Current missions rely primarily on the 50 MHz wide allocations near 8 GHz to provide the links for normal mission operations. Where maximum possible symbol rates are not required for a particular mission, these allocations will continue to provide needed deep-space links.

The 500 MHz allocations near 32 GHz provide for future high performance links that meet the maximum bandwidth requirements specified in Table 1.