# RECOMMENDATION ITU-R SA.1015-1

## Bandwidth requirements for deep-space research

(Question ITU-R 209/7)

(1994-2007)

**Scope**

This Recommendation presents bandwidth requirements for the space research service (deep space), to be taken into account in band allocations to space research service (deep space) in the future. The technical basis for these bandwidth requirements is also explained.

The ITU Radiocommunication Assembly,

*considering*

a) that maximum symbol rates required for deep-space telecommunications in both space-to-Earth and Earth-to-space directions, 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 should take into account the bandwidth requirements listed in Annex 1;

**2** that all feasible steps that will reduce the required bandwidth should 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 the 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 (Msymbol/s) | RF bandwidth (MHz) |
|---|---|---|
| Earth-to-space | | |
| Telecommand | 0.002 | 0.040(1) |
| Computer programming | 0.2 | 0.8 |
| Voice | 0.045 | 0.18 |
| Television | 30 | 120 |
| Ranging | 100(2) | 400 |
| Space-to-Earth | | |
| Maintenance telemetering | 1.2(3) | 4.8 |
| Scientific data | 600(4) | 1 200(5) |
| Voice | 0.27(3) | 1.08 |
| Television | 60(4) | 240 |
| Ranging | 100(2) | 400 |

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

(2) The unit is MHz for sinewave ranging and Mchip/s (mega chips per second) for pseudo-noise (PN) ranging.

(3) Assuming rate 1/6 error correction code will be used.

(4) Assuming rate 1/2 error correction code will be used.

(5) Assuming QPSK modulation will be used.

The extremely precise navigation technique using very long baseline 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 two and half times 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:

$$BW = 2\,[(SR \times 1.5 \times 5) + 2.5\,SR] = 20\,SR$$

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:

$$BW = 2\,(2\,SR) = 4\,SR$$

For high data rates, QPSK modulation can be used to reduce the bandwidth requirement in half.

Current implementation of ranging uses square wave or sinewave clock signals phase modulated on the carrier. Some future missions are planning to use PN ranging. The bandwidth required to achieve acceptable ranging performance is four times the clock frequency for the sine or square wave ranging and four times the chip rate for the PN ranging. Ranging used to dominate the bandwidth requirement of a mission. With the rapid increase of required telemetering rates, ranging is no longer the dominant factor of bandwidth requirement for many new missions.

Future requirements for very high telemetering rates may need additional reduction of transmitted spectrum bandwidth in order to accommodate more spacecraft within a particular band allocation. Suitable techniques may include minimum shift keying and other bandwidth efficient modulation techniques.

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. For current implementation, the maximum radio-frequency bandwidth for a single unmanned spacecraft is approximately 12 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 Bandwidth for missions around a planet

When there are several spacecrafts around a planet, they are often within the beamwidth of an earth station. 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 multiple deep-space missions could require a total bandwidth of approximately 4 000 to 5 000 MHz, assuming that three or four missions operate simultaneously at the highest science data rate. The aggregate bandwidth may be reduced significantly, potentially by a factor of two to four, if bandwidth efficient modulation techniques can be implemented at high data rates in the future.

## 4 Link reliability and the utilization of allocated bands

The foregoing section sets 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 allocation near 32 GHz provides additional bandwidth for deep-space missions, although that does not meet the maximum bandwidth requirements specified in Table 1 for scientific data.