

RECOMMENDATION ITU-R SA.1742

Technical and operational characteristics of interplanetary and deep-space systems operating in the space-to-Earth direction around 283 THz

(Question ITU-R 235/7)

(2006)

Scope

This Recommendation specifies technical parameters (frequencies, link, signal and data characteristics, antenna parameters, etc.) and operational characteristics of interplanetary and deep-space systems operating in the space-to-Earth direction around 283 THz, which could be used in sharing studies.

The ITU Radiocommunication Assembly,

considering

- a) that telecommunication links are being planned for use on some satellite systems for deep-space and interplanetary radiocommunications at frequencies in the region of 283 THz;
- b) that, using recent technological developments, astronomers are making a concerted effort to build telescopes and make observation in this segment of the spectrum;
- c) that this segment of the spectrum is also being used for other terrestrial and space services;
- d) that this segment of the spectrum is also being used for scientific and industrial purposes other than radiocommunication;
- e) that mechanisms of interference between satellites operating in deep-space and passive systems such as astronomy operating above 20 THz may differ from those in the radio-frequency portion of the spectrum,

recognizing

- 1 that No. 78 of Article 12 of the ITU Constitution states a function of the Radiocommunication Sector includes, "... carrying out studies without limit of frequency range and adopting Recommendations ...";
- 2 that, under Note 2 of No. 1005 in the Annex to the ITU Convention, Study Groups may consider "radiocommunication" to include electromagnetic spectrum above 3 000 GHz propagated through space without artificial guide in the course of their studies and in the creation of draft new Recommendations;
- 3 that use and sharing of this segment of the spectrum has not been thoroughly studied within the ITU-R,

recommends

- 1 that sharing studies considering space research satellites operating in the space-to-Earth direction around 283 THz in deep space should take into account the technical and operational parameters presented in Annexes 1 and 2.

Annex 1

1 Introduction

The increased pressure for use of the radio spectrum and the advancement of technology, there is more attention being given to the use of frequencies above 3 000 GHz for free space radiocommunications. Radiocommunication links have become a reality in the frequency bands above 3 000 GHz as a result of many recent technological developments in the field of optical fibre telecommunication especially in the area of lasers, modulation and receiver technology. Free space radiocommunication at frequencies above 3 000 GHz has the ability to support higher data rates with less mass than traditional radio-frequency systems as well as meet gain and directivity requirements of beams used for deep-space applications.

1.1 Frequency considerations

Currently, most of the interest in free space radiocommunication links above 3 000 GHz is focused around the frequencies 200, 283, 311 and 353 THz¹, whose corresponding wavelengths are approximately 1.5, 1.06, 0.965 and 0.850 μm . These frequencies are the same as those most widely used for telecommunications in optical fibres. For interplanetary and deep-space radiocommunication in the space-to-Earth direction, attention is being focused on use of Ytterbium-doped (Yb) fibre-optical amplifier at 1.06 μm in a Master-Oscillator-Power Amplifier (MOPA) configuration, Q-switched, Neodymium: Yttrium Aluminium Garnet (Nd:YAG) or Neodymium: Yttrium Vanadate (Nd:YVO₄) lasers operating around 283 THz (1.06 μm) though, depending on mission requirements, other frequencies are feasible. The use of Yb, Nd:YAG and Nd:YVO₄ are of primary use due to availability and reliability.

1.2 Generic mission parameters

Technical parameters suitable for interference analyses should be based on generic interplanetary missions to Mars and Jupiter. For the purposes of minimizing weight and power consumption, the links must support radiocommunication requirements beginning shortly after launch and continuing throughout the duration of the mission negating the need for additional radiocommunication systems. Therefore, link distances will vary from a few thousand km to several Astronomical Units (AU²). Distances from the Earth to Mars or Jupiter vary from 0.5 to 6.2 AU. A summary of the fundamental technical parameters of a 283 THz deep-space link operating in the space-to-Earth direction is provided in Table 1.

2 Link considerations

Deep-space links operating at 283 THz in the space-to-Earth direction may utilize Yb, Nd:YAG or Nd:YVO₄ lasers. The beam would be transmitted from a 30 cm telescope on board the spacecraft and received by a telescope on the Earth with an effective diameter of 4.2 m to 10 m.³

¹ 1 THz = 1 000 GHz.

² 1 AU $\approx$ 149 597 870 km.

³ For the purposes of telecommunication through free space at around 283 THz, a telescope is effectively an antenna.

TABLE 1

**Technical parameters of two reference deep-space missions
operating at 283 THz in the space-to-Earth direction**

Parameter	Mars	Jupiter
Transmitter power	5 W (average)	
Transmitter aperture	30 cm	
Transmitter frequency (wavelength)	283 THz (1.06 μm)	
Modulation	Pulse position modulation (PPM) ($M = 64$ to 256) with concatenated coding	
Pointing accuracy	0.35 μrad	
Range	0.5 to 2.5 AU	4.2 to 6.2 AU
Data rate (during the day at Earth terminal) ⁽¹⁾	3 to 30 Mbit/s (4.2 m Earth terminal)	1.5 to 3 Mbit/s (10 m terminal)
Receiver aperture	4.2 to 10 m equivalent size	
Detector type	An array of Geiger-mode InGaAsP/InP APDs	
Required link margin	2 to 3 dB	

⁽¹⁾ Night-time data rates on Earth are about 30% (1.13 dB) higher.

2.1 Link performance

Like a deep-space system operating in the traditional radio-frequency spectrum, performance of a link operating at 283 THz is measured in terms of data rate and bit error rate (BER). Performance is calculated as a function of power, telescope quality, propagation considerations, noise and receiver sensitivity. Each of these parameters is function of additional variables.

2.1.1 Data rate

Unlike a deep-space system operating in the traditional radio-frequency spectrum, when all other parameters are held constant, the data rate is not exactly inversely proportional to the square of the propagation distance; however, it is a very close approximation for links operating from the vicinity of Mars and Jupiter and thus a good rule of thumb. Data rates from Mars will vary depending on many parameters including link range and geometry with the sun. Data rates from Mars will generally be around an order of magnitude higher than from Jupiter.

2.1.2 BER

Frames of data must have a BER of less than 10^{-6} after error correction in order to be retained. A link must retain 99% of data frames.

2.1.3 Margin requirement

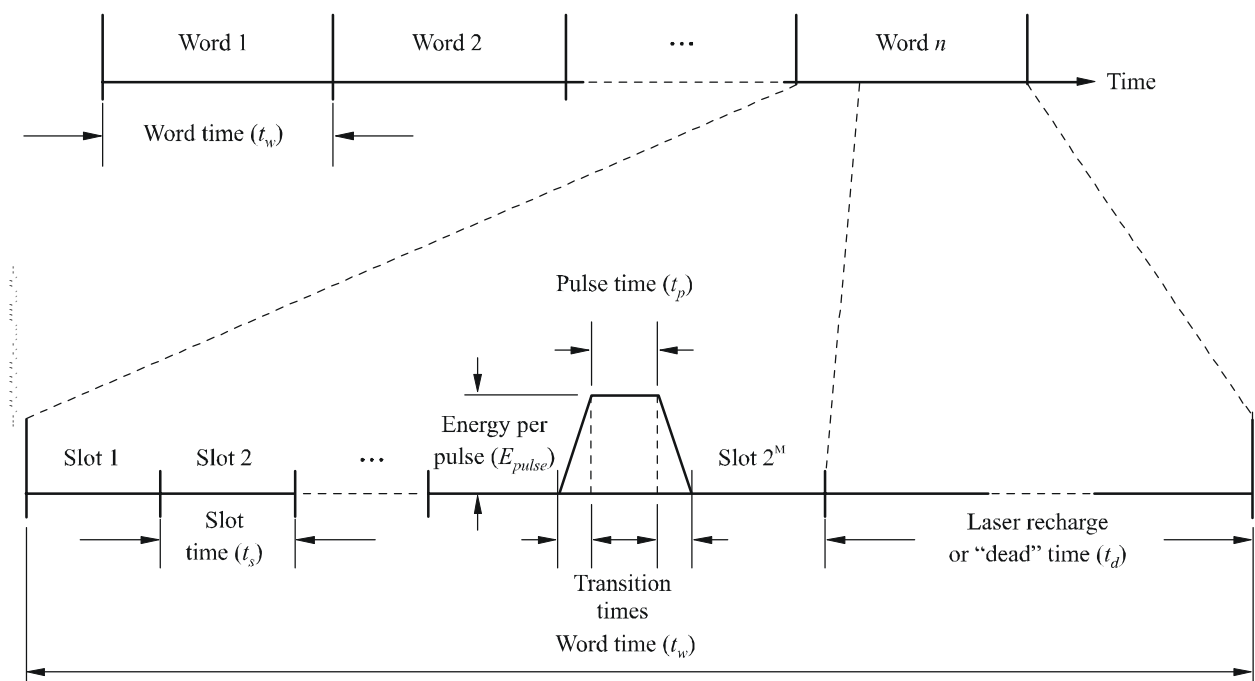
The typical margin requirement of a deep-space or interplanetary link operating at 283 THz in the space-to-Earth direction is on the order of 2 to 3 dB. Conditions are dependent on factors which include *inter alia* weather, time of day and elevation angle.

2.2 Modulation

Deep-space and interplanetary links operating around 283 THz will utilize PPM. This modulation technique allows for direct detection (specifically photon counting) by the receiver rather than implementing coherent receivers. The PPM signal will be encoded with a concatenated code.

PPM uses a single pulse of energy within the time of a word. M bits of data may be transmitted with a single pulse of energy temporally located within 2^M time slots of a word. A portion of the total word time is used for recharging the laser and will never contain a pulse. This recharging or “dead” time often accounts for the majority of the word time at low data rates but becomes less of a factor at higher data rates. The temporal characteristics of a PPM signal and its relevant measures are illustrated in Fig. 1.

FIGURE 1
Characteristics of a PPM signal



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2.3 Deliverable power

The Yb, Q-switched, Nd:YAG or Nd:YVO₄ transmitter will typically produce 5 W of average power. Peak power will vary with data rate but may be on the order of 30 to 40 dBW. The following procedure calculates the peak power, P_{peak} , of a PPM transmitter. The following parameters are required:

- M : modulation index
- P_{ave} : average transmitter power (W)
- t_d : dead time (s)
- t_p : transmitter pulse time (s)
- t_s : slot time (s).

Step 1: Calculate the word time, t_w , by:

$$t_w = M \cdot t_s + t_d \quad (1)$$

Step 2: Calculate the energy per word, E_{word} , by:

$$E_{word} = P_{ave} \cdot t_w \quad \text{J} \quad (2)$$

NOTE 1 – As only one pulse occurs during each word time, the energy per pulse is equivalent to the energy per word (i.e. $E_{pulse} = E_{word}$).

Step 3: Calculate the peak transmitter power, P_{peak} , by:

$$P_{peak} = \frac{E_{pulse}}{t_p} \quad \text{W} \quad (3)$$

2.4 Received signal

The general method for calculating the signal level at 283 THz received by the earth station is the same as that used with traditional radio-frequency systems.

$$P_S = P_t + G_t + G_r + L_t + L_r + L_p + L_a + L_s \quad \text{dBW} \quad (4)$$

where:

- P_S : receiver signal power
- P_t : average laser output power (typical value is 4.7 to 7.0 dBW)
- G_t : transmitter antenna gain (typical value is 119 dB) is discussed in detail in § 2.6.2
- G_r : receiving antenna gain (typical value is 129 to 149 dB) is discussed in detail in § 2.6.3
- L_t : transmitter losses
- L_r : receiver losses
- L_p : pointing losses
- L_a : atmospheric losses along the space-to-ground link
- L_s : free space loss.

2.5 Link losses

There are five primary sources of link losses:

- internal transmitter losses, L_t , that include the effects of absorption, scattering and reflection losses in the optical train of the transmitter;
- internal receiver losses, L_r , that include the effects of absorption, scattering and reflection losses in the optical train of the receiver;
- pointing losses, L_p , that include the effects of antenna or spacecraft jitter and mispointing of the transmitting antenna;
- atmospheric losses, L_a , that include the effects of atmospheric scatter and turbulence;
- free space loss, L_s , that is due to the physical separation between the transmitter and receiver.

Values of each source of loss will vary with hardware design, hardware age, mission requirements and the phase of the mission. Suggested values of losses to be used in generic interference analyses are provided in Table 2. Atmospheric propagation in this region of the spectrum has been addressed in detail by Radiocommunication Study Group 3 through Recommendations ITU-R P.1621 and ITU-R P.1622.

TABLE 2

**Technical parameters of two reference deep-space missions
operating at 283 THz in the space-to-Earth direction**

Mechanism of loss	Typical value
Transmitter losses, L_t	0.63 (= -2 dB)
Receiver losses, L_r	0.63 (= -2 dB)
Pointing losses, L_p	0.63 (= -2 dB)
Atmospheric losses, L_a	0.89 (= -0.5 dB) at 90° 0.56 (= -2.5 dB) at 30°

Free space loss, L_s , is calculated at 283 THz in the same manner as with traditional radio-frequency systems:

$$L_s = \left(\frac{\lambda}{4\pi R} \right)^2 = \left(\frac{c}{4\pi f R} \right)^2 \quad (5a)$$

which, at 283 THz, reduces to:

$$L_s = \frac{7.169 \times 10^{-15}}{R^2} \quad (5b)$$

where:

R : distance between the transmitter and receiver (m).

2.6 Transmit/receive telescope parameters

Deep-space and interplanetary radiocommunication links operating at around 283 THz will utilize telescopes as transmitting and receiving antennas. The typical parameters of the transmitting and receiving telescopes will differ greatly from each other. These differences will effect each telescope's respective gain pattern. The transmitter and receiver antenna patterns are also different since the transmitter optics are usually fed by a Gaussian distributed beam while the receiver optics have a planar detector. For an envelope of the antenna gain patterns of transmitting and receiving antennae operating around 283 THz, refer to Annex 2.

2.6.1 Diameter

For the purposes of interference analyses, the diameter of the transmitting antenna should be assumed to be 30 cm. The transmitting aperture will either be unobstructed or have a 3 cm obscuration.

The effective diameter of the receiving antenna may vary between 1 and 10 m, but for most applications will be at least 4.2 m. For the purposes of interference analyses, antennas of 1, 4.2 and 10 m should be considered. The primary receiving aperture will have a secondary obscuration with a diameter of no more than 20% of the diameter of the primary aperture.

2.6.2 Transmitting gain pattern

The transmitter utilizes a telescope that is fed by a laser. Such lasers normally operate only in the lowest cavity mode, TEM₀₀, which results in a beam that has a Gaussian distribution of energy with a maximum intensity along its axis of transmission. The beam pattern is tailored such that as the intensity of the beam falls off in amplitude with angular separation from the axis of transmission, no more than a few percent of the beam power is wasted. Two points of reference are the angles at