

RECOMMENDATION ITU-R S.1590

**Technical and operational characteristics of satellites operating
in the range 20-375 THz**

(Question ITU-R 264/4)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that telecommunication links are being used and planned for use on some satellite systems for inter-satellite communications at frequencies within the range of 20-375 THz;
- b) that the viability of fixed-satellite service telecommunication systems operating in the 20-375 THz range of the spectrum using Earth-to-space and space-to-Earth links is currently being investigated;
- c) that astronomers are making observations in this part of the spectrum;
- d) that this part of the spectrum is also being used for other science services;
- e) that this part of the spectrum is also being used for scientific and industrial purposes other than communication;
- f) that mechanisms of interference between satellites and passive systems such as astronomy operating above 20 THz may differ from those in the radio frequency part of the spectrum,

recognizing

- a) that No. 78 of Article 12 of the ITU Constitution states that the functions of the Radiocommunication Sector include, "... carrying out studies without limit of frequency range and adopting recommendations ...";
- b) that, under Note 2 of 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;
- c) that as of the end of 2001, use and sharing of this part of the spectrum has not been thoroughly studied within ITU-R,

recommends

- 1 that sharing studies of satellites operating in the frequency range 20-375 THz take into account the technical and operational parameters presented in Annex 1.

ANNEX 1

1 Introduction

The term “radio waves” is defined in the Radio Regulations as “Electromagnetic waves of frequencies arbitrarily lower than 3 000 GHz propagated in space without artificial guide”. With the increased pressure for use of the radio spectrum and the advancement of technology, more attention is being given to the use of frequencies above 3 000 GHz for free space telecommunications. Telecommunication links have become a reality in the frequency bands above 3 000 GHz as a result of many recent technological developments in optical communication devices such as optical fibre, solid state lasers (GaAs, InP)¹, modulators (electro-optic modulators) and detectors (photodiodes). Free space telecommunication at frequencies above 3 000 GHz has the ability to support data rates in the tens of Gbit/s as well as meet gain and directivity requirements of beams used for deep space applications.

For telecommunications, attention is being focused on frequencies in the band 20-375 THz (15-0.8 μm). Though some links have been demonstrated, much of the technology for these links is still in development but evolving rapidly. Such links can provide telecommunication signals on Earth-to-space, space-to-Earth, and space-to-space paths as well as on terrestrial links. They are being considered for satellites in geostationary orbit (GSO) as well as those in non-geostationary orbit (non-GSO) such as low Earth orbits.

Technical and operational characteristics are required for the free space telecommunication links operating in these spectral regions for use in future sharing studies. The specifications and operations of some systems in this region are described in the following sections. The purpose of this Recommendation is to identify system parameters required for conducting interference analyses for space applications.

2 Frequency considerations

Not all frequencies are equally suitable for free space telecommunications since the transparency of the atmosphere varies strongly with frequency. Earth-to-space and space-to-Earth links should operate in a region of low absorption while space-to-space links may want to choose a region of high absorption to achieve isolation from interference on the Earth and reduce the probability of causing interference to astronomical observations.

The use of near infrared lasers (0.850 μm) are more efficient in terms of signal-to-noise ratio. Medium infrared detectors near 15 μm need strong cooling in order to reduce thermal noise.

¹ Lasers used in telecommunication are manufactured from III-V semiconductor compounds. The materials used are alloys of Gallium Arsenide (GaAs) and Indium Phosphide (InP). The wavelengths of such lasers are respectively 0.85 μm and 1.5 μm .

Figure 1 shows the frequency dependence of atmospheric absorption of an optical signal along a vertical path. This Figure assumes the path begins at sea level, and the line of sight continues into space through a standard atmosphere. Below about 15 THz (20 μm), the sky is effectively opaque. With increases in frequency toward the visible band, 400-750 THz (0.75-0.40 μm), there are numerous bands of various width and transparency that occur due to the presence of gaseous components in the atmosphere. These gases are not necessarily uniformly mixed and the proportions can vary as a function of altitude. The strength of the absorption lines is also generally dependent on pressure and temperature. At about 300 THz (1 μm), the envelope of the absorption starts to increase, due primarily to O_2 and O_3 . The absorption increases up through the visible band, to about 1000 THz (0.3 μm) where the atmosphere again becomes effectively opaque due to molecular absorption.

Currently, most of the interest in telecommunications links is focused around the frequencies 200, 283, 311 and 353 THz, whose corresponding wavelengths are approximately 1.5, 1.06, 0.965 and 0.850 μm . These frequencies are the same as those that are most widely used for communications in optical fibres.

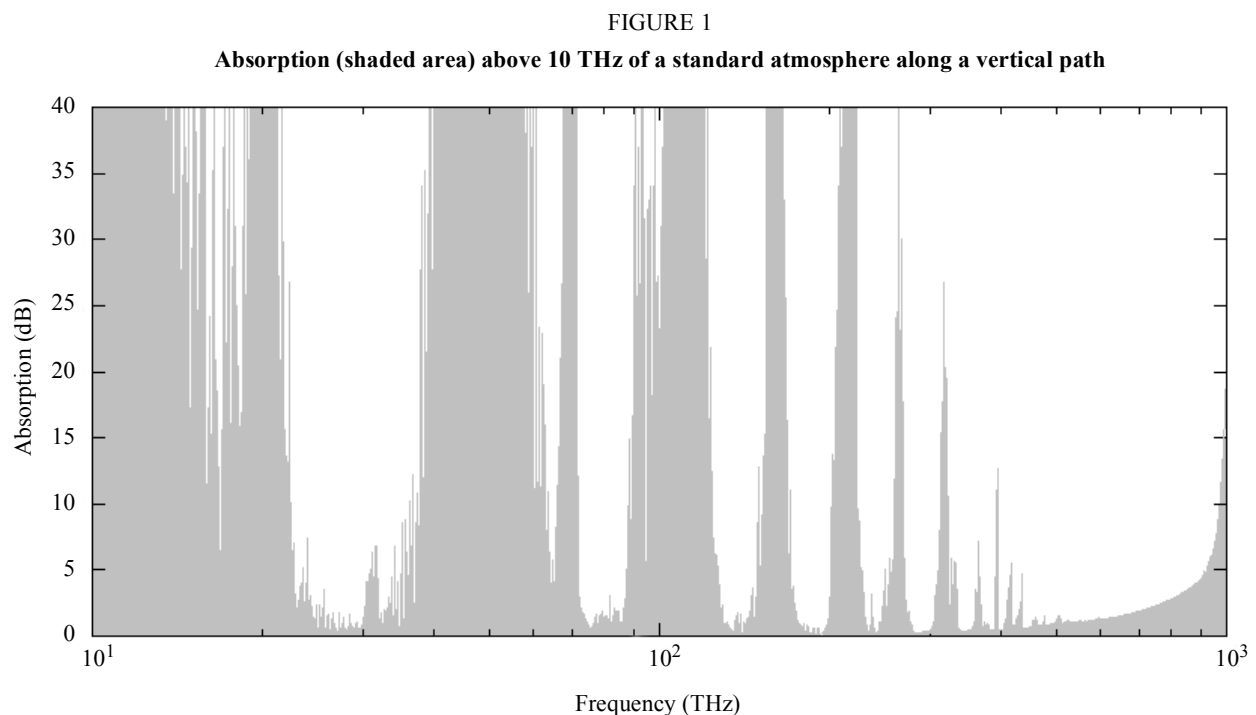


Table 1 shows some characteristics for typical lasers used in terrestrial optical communications.

TABLE 1

Typical characteristics of solid-state lasers in the range of 0.75 μm to 1.6 μm

Laser medium	Transition wavelength	Typical maximum output power (W)	Continuous-wave (CW) or pulsed	Single mode (S) Multimode (M)	Transition linewidth
$\text{In}_{1-x}\text{Ga}_{1-y}\text{P}_y^{(1)}$ Semiconductors	1.1 μm to 1.6 μm	1	CW	S/M	A few GHz up to 10 THz
$\text{Nd}^{3+}:\text{YAG}^{(2)}$ Glass	1.064 μm	10	CW	S/M	120 GHz
$\text{In}_x\text{Ga}_x\text{As}$ Semiconductors	0.965 μm	1	CW	S/M	A few GHz up to 10 THz
$\text{Al}_x\text{Ga}_x\text{As}$ Semiconductors	0.75 to 0.87 μm	10	CW	S/M	A few GHz up to 10 THz

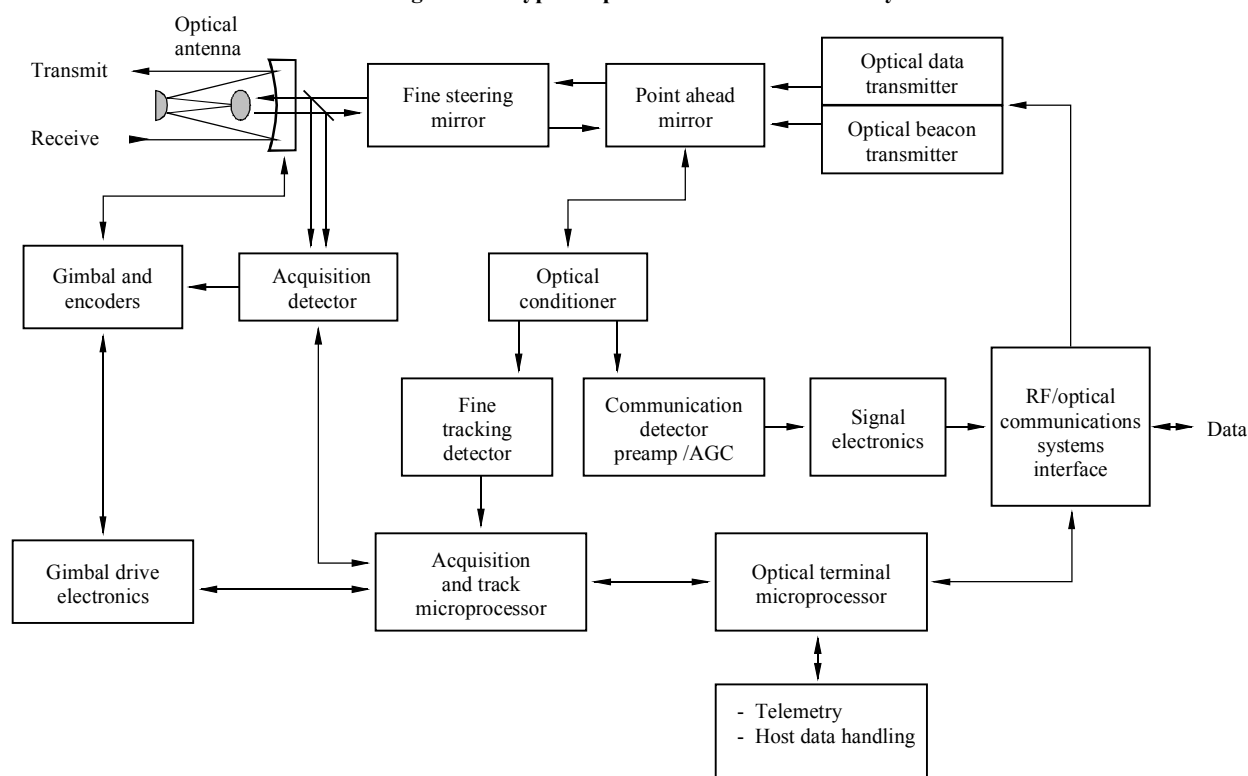
(1) $0 < y < 1$ and $0 < x < 1$

(2) YAG: yttrium aluminium garnet.

3 Generic block diagram

A generic block diagram of a typical optical telecommunications system is provided in Fig. 2.

FIGURE 2

Block diagram of a typical optical telecommunications system

AGC: automatic gain control

It is noted that for nearly every optical link there is a return link to provide feedback for correcting the optical pointing. That is, the two links operate as a closed loop control network to maintain optical alignment.

It is desirable to examine the parameters the optical terminal designer has available. Obviously not all optical satellite terminals are the same. Rather their specific usage or applications drive their designs. In this section the basic components of optical terminals are described and details of the specific design characteristics that are unique to particular applications are discussed.

3.1 Transmitter

The data transmitter, a laser, is shown in the upper right corner of Fig. 2. The typical power of existing space qualified lasers is about 1 W. The use of higher power units is inhibited by lifetime and reliability concerns, but the technology is continually evolving. A requirement for data rates of tens of Gbit/s will require the designer to limit the selection to the tuneable class of lasers and most likely to use wavelength division multiplexing components. For the heterodyne and homodyne telecommunication systems, there is a need for lasers having narrow laser linewidths and minimal phase noise. In addition the lasers have to be frequency stable and highly tunable to address the problem of optical Doppler. In the case of a GSO to non-GSO link, Doppler considerations could require shifts that approach ± 10 GHz.

3.2 Receiver

The receiver is comprised of the block in the middle of Fig. 2 labelled “Communication detector: preamp/AGC”. Most current receivers are based on either the avalanche photodiode (APD) or a *Pin* diode. For applications where the incident optical power on the detector is weak, such as in a direct detection receiver, the APD with its internal gain is preferred. For an APD, detection sensitivity on the order of 100 received photons per bit can be achieved. The APD can support link data rates up to 40 Gbit/s. Although the APD has reached a bandwidth limit, its sensitivity is being extended with the development of the optical fibre amplifier. *Pin* diodes are simpler to operate and easier to fabricate than APDs but have a low gain. These diodes are typically used in heterodyne or homodyne detection systems.

3.3 Detection

Detection in optical systems works in much the same way as radio-frequency systems. The three techniques are: direct detection, heterodyne detection, and homodyne detection. Thus far, most systems have used direct detection, which is accomplished by converting the energy per photon (optical intensity) into charge carriers or electrical current. The signal is directly demodulated at the receiver back into the transmitted signal at baseband. The heterodyne receiver detects both amplitude and phase of the signal by first mixing the received optical signal with a strong local oscillator output, then detecting the combined optical signal. Homodyne detection is a special case of heterodyne detection where the local oscillator is matched with the incoming signal both in frequency and phase.

3.4 Acquisition

Acquisition is a complex process controlled by the “Acquisition and track microprocessor” block as well as blocks representing the gimbaling functions on the left of Fig. 2. To establish an optical link, the units go through an acquisition phase to align the optics and lock on any carriers. During this phase, a beacon is usually used for a signal and a charge coupled device (CCD) array is used to detect any misalignment. This technology has reached a high level of maturity. CCDs will probably remain the primary technology used to support this facet of optical communications.

3.5 Beacon transmitter

The beacon transmitter is shown with the data transmitter in the upper right corner of Fig. 2. During the acquisition phase each terminal emits a beacon with a beam significantly wider than the communications beam to assist in the initial alignment of the optics. The beacon laser technology is well in hand, with the terminal designer having various approaches available that are all supported by mature technology.

3.6 Tracking/servo

Tracking and servo are the precision pointing operations made by the “fine steering mirror” and “point ahead mirror” as shown in Fig. 2. These operations are taken together because the function they perform is integrally connected. It is extremely difficult to achieve optical crosslink pointing and tracking requirements while experiencing spacecraft jitter and motion. The penalty paid for failure to carry out this function is burst errors a condition that could cause a major loss of data.

3.7 Electronics

Although electronics is probably the most mature technology supporting optical telecommunication the terminal designer has to be aware that links supporting tens of Gbit/s digital telecommunications require slot widths of around 10 ps and rise and fall times of 2 ps or less. This performance requirement poses a technological challenge.

4 Satellite links

This section addresses the optical link parameters used in several typical applications and gives typical values for these parameters. These links represent both potential interferers and victims. The technical characteristics of the transmitters and receivers used with both Earth-space links and inter-satellite links operating at frequencies above 20 THz vary with data requirements and orbital parameters.

4.1 Inter-satellite links

GSO/GSO crosslinks are relatively stable as the two satellites are moving slowly with respect to each other in terms of range and azimuth angle. This is due to the basic fact that they remain relatively stationary over a location on the Earth's surface and have a small azimuth and elevation