

RECOMMENDATION ITU-R P.1814*

**Prediction methods required for the design
of terrestrial free-space optical links**

(Question ITU-R 228/3)

(2007)

Scope

This Recommendation provides propagation prediction methods for planning terrestrial free-space optical systems. It includes methods to estimate attenuation in clear air, fog, and rain and snow precipitation. It also covers scintillation and impairments by sunlight.

The ITU Radiocommunication Assembly,

considering

- a) that the visible optical and infrared spectrum is available for radiocommunications in the Earth's environments;
- b) that for the proper planning of free-space optical (FSO) radiocommunication systems operating in visible optical and infrared spectrum, it is necessary to have appropriate propagation data;
- c) that methods have been developed that allow the calculation of the most important propagation parameters needed in planning free-space optical systems operating in the visible optical and infrared spectrum;
- d) that these methods have been tested against available data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in the planning of systems operating in visible optical and infrared spectrum,

recognizing

- a) that No. 78 of article 12 of the ITU Constitution states that a function of the Radiocommunication Sector includes, "... carrying out studies without limit of frequency range and adopting recommendations ...",

recommends

- 1** that the methods for predicting the propagation parameters given in Annex 1 should be adopted for planning free-space optical systems, in the respective ranges of validity indicated in the Annex.

NOTE 1 – Supplementary information related to propagation prediction methods in visible optical and infrared spectrum may be found in Recommendation ITU-R P.1817 – Propagation data required for the design of terrestrial free-space optical links.

* This Recommendation should be brought to the attention of Radiocommunication Study Groups 1 and 9

Annex 1

1 Introduction

In the design of FSO links several effects must be considered including the losses due to atmospheric absorption, scattering and turbulence, microclimate environment and localized effects, link distance and link misalignment. The selection of wave length, data rate, eye-safety issues, and ambient solar radiation must also be considered.

FSO system operation requires line-of-sight (LOS). When testing for LOS, as FSO systems use beam expansion and a collimated beam, the clearance needed between the centre of the beam and any obstructions is essentially equal to the beam radius. This is in contrast to RF systems where Fresnel zone clearance is needed.

The primary disadvantage of FSO systems are their vulnerability to atmospheric effects such as attenuation and scintillation, which can reduce link availability. The narrow beam also makes alignment of the laser communications terminal more critical than is usual for RF systems.

A key parameter in the design of FSO links is the consideration of the power budget. The link margin, M_{link} (dB), which is the power available above the sensitivity of the receiver, can be found from equation (1):

$$M_{link} = P_e - S_r - A_{geo} - A_{atmo} - A_{scintillation} - A_{system} \quad (1)$$

where:

- P_e (dBm): total power of the emitter
- S_r (dBm): sensitivity of the receiver which also depends on the bandwidth (Data rate)
- A_{geo} (dB): link geometrical attenuation due to transmit beam spreading with increasing range
- A_{atmo} (dB): atmospheric attenuation due to absorption and scattering
- $A_{scintillation}$ (dB): attenuation due to atmospheric turbulence
- A_{system} (dB): represents all other system dependent losses including misalignment of the beam direction, receiver optical losses, loss due to beam wander, reduction in sensitivity due to ambient light (solar radiation), etc.

The definition and computation of these terms and the initial consideration for planning an FSO link are given in the following sections.

2 Initial considerations in designing an FSO link

The choice of a suitable link location is an important issue for a successful operation of an FSO system. The installation of FSO links has to account for prevailing weather conditions, physical obstructions and surface types along the path, and transceiver mounting arrangements to ensure optimum link performance.

2.1 Weather

- Weather conditions, and in particular the local climate, in the vicinity of the chosen link path will influence the occurrence of snow, rain, drizzle fog, haze, aerosol and dust/sand that will lead to absorption and scattering of the transmitted signal.

2.2 Path characteristics

- Physical obstructions to the path between emitter and receiver are clearly to be avoided. It is well worth noting that mature trees can increase in height by between 0.5 and 1 m in one year and vary in foliage density over the year.
- Links between buildings should account for thermal vents that could result in hot air rising through the link path, and the resulting turbulence could lead to significant scintillation at the receiver.
- The topography and the type of surface beneath an FSO line-of-sight path can significantly impact the performance of the link. FSO links across river valleys, or across areas of open sea, will often experience increased incidents of fog. Building structures beneath the link may cause additional thermal activity in the air above them that may then lead to increased scintillation on the received signal.

2.3 Transceiver mounting

- Most FSO systems have very narrow beam widths, and, as a result, the accurate alignment of the emitter and receiver is critical; any misalignment causes significant signal loss. The telescope mounts must be stable and direct mounting to substantial walls, or to the top of a single column, is considered essential for reliable performance over a period of time. Movement as the result of differential thermal expansion, or buffeting by wind, should be minimized.

3 Geometrical attenuation

Even in clear weather conditions, the beam diverges and, as a result, the detector receives less signal power. The attenuation due to transmit beam spreading with increasing range is called geometrical attenuation and is given by the formula (2):

$$A_{geo}(\text{dB}) = 10 \log_{10} \left(\frac{S_d}{S_{capture}} \right) \quad (2)$$

where:

$S_{capture}$: receiver capture surface (m^2)

S_d : surface area of transmit beam at range d , which is approximated by:

$$S_d = \frac{\pi}{4} (d \cdot \theta)^2$$

where:

θ : beam divergence (mrad)

d : emitter-receiver distance (km).

It is possible on short links for the capture area to be greater than the beam area. In these cases the value of A_{geo} should be set to zero as all of the beam energy is collected.

4 Specific atmospheric attenuation due to absorption and scattering γ_{atmo}

The specific atmospheric attenuation γ_{atmo} (dB/km) can be written as the sum of two terms:

$$\gamma_{atmo} = \gamma_{clear_air} + \gamma_{excess} \quad (3)$$

where:

- γ_{clear_air} : specific attenuation under clear air (due to the presence of gaseous molecules)
- γ_{excess} : specific attenuation due to the occasional presence of fog, mist, haze, drizzle, rain, snow, hail, etc.

The atmosphere is a time-varying transmission medium and as a result γ_{atmo} is a stochastic process. However, as shown in equation (1), imposing limits on system availability and its effects are generally treated statistically. Link margin, M_{link} , represents the amount of attenuation which can be tolerated by a given system at a given range.

4.1 Specific clear-air attenuation γ_{clear_air}

Attenuation under clear-air conditions is mainly the attenuation due to the absorption by gaseous molecules. Atmospheric absorption at specific optical wavelengths results from the interaction between photons and atoms or molecules (N_2 , O_2 , H_2 , H_2O , CO_2 , O_3 , etc.) which leads to the absorption of the incident photon and an elevation of the temperature. The absorption coefficient depends on:

- the type of gas molecules; and
- their concentration.

Molecular absorption is a wavelength-selective phenomenon which results in atmospheric transmission windows, and atmospheric absorbing regions. The important atmospheric molecules that have high absorption in the IR band include water, CO_2 , O_3 and O_2 .

Because the size of the gaseous molecules is much smaller than the wavelength, scattering attenuation from the gaseous molecules is negligible.

Usually the laser wavelengths are selected to fall inside atmospheric transmission windows, so γ_{clear_air} is negligible. The wavelengths generally used in FSO systems are near 690, 780, 850, and 1 550 nm. However, in comparison to relatively unpolluted suburban locations, applications in dense urban areas with high aerosol contents might benefit from a different wavelength.

4.2 Specific excess attenuation

Excess attenuation is the attenuation caused by the occasional presence of fog, mist, haze, drizzle, rain and snow particles. The presence of these particles causes an angular redistribution of the incident flux, known as scattering, and reduces the flux propagation in the original direction. However, there is no loss of energy similar to absorption. The physical size of the scatterers with respect to the transmission laser wavelength determines the type of scattering. Table 1 shows the three different scattering regimes depending on the scatter's size and the approximate relationship between wavelength and scatter's attenuation coefficient (effective-cross section). Also shown in Table 1 are the type of scatters in each regime for the visible and IR wavelengths.