International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.525-3

(09/2016)

Calculation of free-space attenuation

P Series

Radiowave propagation

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R P.525-3

Calculation of free-space attenuation

(1978-1982-1994-2016)

Scope

Recommendation ITU-R P.525 provides methods to calculate the attenuation in free space.

Keywords

Free space, attenuation, telecommunication links

The ITU Radiocommunication Assembly,

considering

a) that free-space propagation is a fundamental reference for radio-engineering,

recommends

1 that the methods in Annex 1 be used for the calculation of attenuation in free space.

Annex 1

1 Introduction

As free-space propagation is often used as a reference in other texts, this Annex presents relevant formulae.

2 Basic formulae for telecommunication links

Free-space propagation may be calculated in two different ways, each of which is adapted to a particular type of service.

2.1 Point-to-area links

If there is a transmitter serving several randomly-distributed receivers (broadcasting, mobile service), the electric field is calculated at a point located at some appropriate distance from the transmitter by the expression:

$$e = \frac{\sqrt{30p}}{d} \tag{1}$$

where:

- e: r.m.s. field strength (V/m) (see Note 1)
- p: equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (W) (see Note 2)
- d: distance from the transmitter to the point in question (m).

Equation (1) is often replaced by equation (2) which uses practical units:

$$e_{mV/m} = 173 \frac{\sqrt{p_{kW}}}{d_{km}} \qquad (2)$$

where:

- $e_{mV/m}$: r.m.s field strength (mV/m)
- p_{kW}: equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (kW)
- d_{km}: distance from the transmitter to the point in question (km).

For antennas operating in free-space conditions the cymomotive force may be obtained by multiplying together *e* and *d* in equation (1). Its dimension is volts.

Note 1 – If the wave is elliptically polarized and not linear, and if the electric field components along two orthogonal axes are expressed by e_x and e_y, the left-hand term of equation (1) should be replaced by $\sqrt{e_x^2 + e_y^2}$. e_x and e_y can be deduced only if the axial ratio is known. *e* should be replaced by $e\sqrt{2}$ in the case of circular polarization.

Note 2 – In the case of antennas located at ground level (typically at relatively low frequencies) with vertical polarization, radiation is generally considered only in the upper half-space. When the ground is assumed to be plane and perfectly conducting, the power flux-density for a given radiated power is doubled, as compared with an antenna in free space. (Alternatively, when considering field strengths, the field strength is similarly increased by 3 dB.) This should be taken into account in determining the radiated power (and is already included in Recommendations ITU-R P.368 and ITU-R P.341, Annex 2).

2.2 Point-to-point links

With a point-to-point link it is preferable to calculate the free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf} or A_0), as follows (see Recommendation ITU-R P.341):

$$L_{bf} = 20 \log\left(\frac{4\pi d}{\lambda}\right) \quad \text{dB} \qquad (3)$$

where:

- L_{bf}: free-space basic transmission loss (dB)
- d: distance
- λ: wavelength, and
- d and λ are expressed in the same unit.

Equation (3) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \quad \text{dB} \qquad (4)$$

where:

- f: frequency (MHz)
- d: distance (km).

2.3 Relations between the characteristics of a plane wave

There are also relations between the characteristics of a plane wave (or a wave which can be treated as a plane wave) at a point:

$$s = \frac{e^2}{120\pi} = \frac{4\pi\, p_r}{\lambda^2} \qquad (5)$$

where:

- s: power flux-density (W/m^2)
- e: r.m.s. field strength (V/m)
- p_r: power (W) available from an isotropic antenna located at this point
- λ: wavelength (m).

3 The free-space basic transmission loss for a radar system (symbols: L_{br} or A_{0r})

Radar systems represent a special case because the signal is subjected to a loss while propagating both from the transmitter to the target and from the target to the receiver. For radars using a common antenna for both transmitter and receiver, a radar free-space basic transmission loss, L_{br}, can be written as follows:

$$L_{br} = 103.4 + 20 \log f + 40 \log d - 10 \log \sigma \qquad \text{dB} \qquad (6)$$

where:

- σ: radar target cross-section (m^2)
- d: distance from the radar to the target (km)
- f: frequency of the system (MHz).

The radar target cross-section of an object is the ratio of the total isotropically equivalent scattered power to the incident power density.

4 Conversion formulae

On the basis of free-space propagation, the following conversion formulae may be used.

Field strength for a given isotropically transmitted power:

$$E = P_t - 20 \log d + 74.8 \qquad (7)$$

Isotropically received power for a given field strength:

$$P_r = E - 20 \log f - 167.2 \qquad (8)$$

Free-space basic transmission loss for a given isotropically transmitted power and field strength:

$$L_{bf} = P_t - E + 20 \log f + 167.2 \qquad (9)$$

Power flux-density for a given field strength:

$$S = E - 145.8 \qquad (10)$$

where:

- P_t: isotropically transmitted power (dB(W))
- P_r: isotropically received power (dB(W))
- E: electric field strength (dB(μV/m))
- f: frequency (GHz)
- d: radio path length (km)
- L_{bf}: free-space basic transmission loss (dB)

S: power flux-density (dB(W/m^2)).

Note that equations (7) and (9) can be used to derive equation (4).