



Recommendation ITU-R P.525-5

(11/2024)

P Series: Radiowave propagation

Calculation of free-space attenuation

Foreword

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RA	Radio astronomy
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S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

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.525-5

Calculation of free-space attenuation

(1978-1982-1994-2016-2019-2024)

Scope

This Recommendation provides methods to calculate the attenuation in free space.

Keywords

Free space, attenuation, telecommunication links

Related ITU Recommendations

Recommendation ITU-R P.341

Recommendation ITU-R P.368

NOTE – In every case the latest edition of the Recommendation in force should be used.

The ITU Radiocommunication Assembly,

considering

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

recommends

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

Annex**1 Introduction**

For the purposes of radiocommunication, free space is defined as a perfect vacuum which may be considered of infinite extent in all directions, so that free space propagation is the propagation of a radio wave radiating in free space¹.

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

¹ The International Standards Organisation in its electrotechnical vocabulary (electropedia) has a more general definition:

Free space propagation: propagation of an electromagnetic wave in a homogeneous ideal dielectric medium which may be considered of infinite extent in all directions

NOTE – For propagation in free space, the magnitude of each vector of the electromagnetic field in any given direction from the source is proportional to the reciprocal of the distance from the source beyond a distance determined by the size of the source and the wavelength.

2 Basic formulae for telecommunication links

Free-space propagation may be calculated in 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:

$$e = \frac{\sqrt{30p}}{d} \quad (1)$$

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:

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

where:

$e_{\text{mV/m}}$: 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 electromotive 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 Recommendation ITU-R P.368 and in Annex 3 to Recommendation ITU-R P.341).

2.2 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:

$$s = \frac{e^2}{120\pi} = \frac{30p}{120\pi d^2} = p \times \frac{1}{4\pi d^2} \quad (3)$$

where:

s : power flux-density (W/m²)

e : r.m.s. field strength (V/m)

p : equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (W).

2.3 Point-to-point links

For a point-to-point link between isotropic antennas, it is necessary to consider the power at the output of the receiving isotropic antenna p_r at the point in question:

$$p_r = s \times a = \frac{p}{4\pi d^2} \times \frac{\lambda^2}{4\pi}, \quad (4)$$

where:

a : effective aperture of a receiving isotropic antenna (m^2).

Introducing free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf} or A_{bf}), it can be calculated as follows (see Recommendation ITU-R P.341):

$$L_{bf} = -10 \log_{10} \left(\frac{1}{4\pi d^2} \times \frac{\lambda^2}{4\pi} \right) = 20 \log_{10} \left(\frac{4\pi d}{\lambda} \right) \quad \text{dB} \quad (5)$$

where:

L_{bf} : free-space basic transmission loss (dB)

d : distance

λ : wavelength, and

d and λ are expressed in the same unit.

Equation (5) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.4 + 20 \log_{10} f + 20 \log_{10} d \quad \text{dB} \quad (6)$$

where:

f : frequency (MHz)

d : distance (km).

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

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:

$$L_{br} = 103.4 + 20 \log_{10} f + 40 \log_{10} d - 10 \log_{10} \sigma \quad \text{dB} \quad (7)$$

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:

$$E = P_t - 20 \log_{10} d + 74.8 \quad (8)$$

Available power received through a conjugately matched isotropic receiving antenna for a given field strength:

$$P_r = E - 20 \log_{10} f - 167.2 \quad (9)$$

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

$$L_{bf} = P_t - E + 20 \log_{10} f + 167.2 \quad \text{dB} \quad (10)$$

Power flux-density for a given field strength:

$$S = E - 145.8 \quad (11)$$

where:

P_t : isotropically transmitted power (dB(W))

P_r : available power received through a conjugately matched antenna (dB(W))

E : electric field strength (dB(μ V/m))

f : frequency (GHz)

d : radio path length (km)

L_{bf} : free-space basic transmission loss (dB)

S : power flux-density (dB(W/m²)).

Note that equations (8) and (10) can be used to derive equation (6).
