

## CALCULATION OF FREE-SPACE ATTENUATION

(1978-1982-1994)

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 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:

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

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.

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\* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

*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 and operating on relatively low frequencies with vertical polarization, radiation is generally considered only in the upper half-space. This should be taken into account in determining the e.i.r.p. (see Recommendation ITU-R P.368).

## 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:

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

where:

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

$d$ : distance

$\lambda$ : wavelength, and

$d$  and  $\lambda$  are expressed in the same unit.

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

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

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:

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

where:

$s$ : power flux-density ( $\text{W}/\text{m}^2$ )

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

$p_r$ : power (W) available from an isotropic antenna located at this point

$\lambda$ : 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:

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

where:

$\sigma$ : radar target cross-section ( $\text{m}^2$ )

$d$ : 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:

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

Isotropically received power for a given field strength:

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

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

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

Power flux-density for a given field strength:

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

where:

$P_t$ : isotropically transmitted power (dB(W))

$P_r$ : isotropically received power (dB(W))

$E$ : electric field strength (dB( $\mu$ V/m))

$f$ : frequency (GHz)

$d$ : radio path length (km)

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

$S$ : power flux-density (dB(W/m<sup>2</sup>)).

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

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