International Telecommunication Union

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Radiocommunication Sector of ITU

Recommendation ITU-R P.341-7

(08/2019)

The concept of transmission loss for radio links

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.341-7[*, **]

The concept of transmission loss for radio links[1]

(1959-1982-1986-1994-1995-1999-2016-2019)

Scope

This Recommendation provides the definitions and associated symbols that describe the main and subsidiary terms of a radio link composed of a transmitter, receiver, antennas, associated circuits, and propagation effects.

Keywords

Radio Link, antenna parameters, loss, environment influence

The ITU Radiocommunication Assembly,

considering

a) that in a radio link between a transmitter and a receiver, the ratio between the power supplied by the transmitter and the power available at the receiver input depends on several factors such as the losses in the antennas or in the transmission feed lines, the attenuation due to the propagation factors, the losses due to faulty adjustment of the impedances or polarization, etc.;

b) that it is desirable to standardize the terminology and notations employed to characterize transmission loss and its components;

c) that Recommendation ITU-R P.525 provides the free-space reference conditions for propagation,

recommends

that, to describe the characteristics of a radio link involving a transmitter, a receiver, their antennas, the associated circuits and the propagation medium, the following terms, definitions and notations should be employed:

1 Main terms

1.1 Free-space basic transmission loss[2] (symbols: L_{bf} or A_{bf})

The ratio, usually expressed in decibels, for a radio link between the power radiated by the transmitting antenna and the power that would be available at a conjugately matched receiver antenna input if the actual antennas were replaced by loss free isotropic antennas located in a perfectly

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[*] This Recommendation should be brought to the attention of the Coordination Committee for Vocabulary (CCV).

[**] Radiocommunication Study Group 3 made editorial amendments to this Recommendation in the year 2023 in accordance with Resolution ITU-R 1.

[1] Throughout this Recommendation, capital letters are used to denote the ratios (dB) of the corresponding quantities designated with lower-case type, e.g., $P_t = 10 \log p_t$. P_t is the input power to the transmitting antenna (dB) relative to 1 W when p_t is the input power (W).

[2] A graphical depiction of this and subsequent definitions is shown in Fig. 1.

dielectric, homogeneous, isotropic and unlimited environment, the distance between the antennas being retained (see Recommendation ITU-R P.525).

NOTE – If the distance d between the antennas is much greater than the wavelength λ, the free-space attenuation in decibels will be:

$$L_{bf} = 20 \log \left(\frac{4\pi\, d}{\lambda} \right) \quad \text{dB} \tag{1}$$

1.2 Basic transmission loss (of a radio link) (symbols: L_b or A_b)

The ratio, usually expressed in decibels, for a radio link between the power radiated by the transmitting antenna and the power that would be available at a conjugately matched receiver antenna input if the antennas were replaced by isotropic antennas with the same polarization as the real antennas, including the attenuation effects on the propagation path, but with the effects of obstacles close to the antennas being disregarded.

$$L_b = L_{bf} + L_m \quad \text{dB} \tag{2}$$

where L_m is the loss relative to free space (symbols: L_m or A_m).

NOTE – The loss relative to free space, L_m, may be divided into losses of different types, such as:

– absorption loss (ionospheric or atmospheric gases, precipitation, clouds, etc.);

– diffraction loss as for ground waves;

– effective reflection or scattering loss as in the ionospheric case including the results of any focusing or defocusing due to curvature of a reflecting layer;

– polarization coupling loss; this can arise from any polarization mismatch between the antennas for the particular ray path considered;

– aperture-to-medium coupling loss or antenna gain degradation, which may be due to the presence of substantial scatter phenomena on the path;

– beam spreading loss;

– effect of wave interference between the direct ray and rays reflected from the ground, other obstacles or atmospheric layers;

– clutter loss;

– building entry loss.

1.3 Transmission loss (of a radio link) (symbols: L or A)

The ratio, usually expressed in decibels, for a radio link between the power radiated by the transmitting antenna and the power that would be available at a conjugately matched receiver antenna input if actual antenna radiation patterns are substituted with no losses in the radio-frequency circuits.

NOTE 1 – The transmission loss may be expressed by:

$$L = L_b - G_t - G_r \ \text{dB} \tag{3}$$

where G_t and G_r are the directivity gains (see Annex 1) of the transmitting and receiving antennas, respectively, in the direction of propagation.

NOTE 2 – The effect of the local ground close to the antenna is included in computing the antenna gain, but not in the basic transmission loss.

1.4 System loss (symbols: L_s or A_s)

The ratio, usually expressed in decibels, for a radio link of the radio-frequency power input to the terminals of the transmitting antenna and the resultant radio-frequency signal power available at the terminals of the receiving antenna.

$$L_s = L + L_{tc} + L_{rc} \quad \text{dB} \tag{4}$$

where L_{tc} and L_{rc} are the losses, expressed in decibels, in the transmitting and receiving antennas circuits respectively, excluding the dissipation associated with the antennas radiation, i.e. the definitions of L_{tc} and L_{rc} are 10 log (r'/r), where r' is the resistive component of the antenna circuit and r is the radiation resistance.

NOTE 1 – The available power is the maximum real power which a source can deliver to a load, i.e. the power which would be delivered to the load if the impedances were conjugately matched.

NOTE 2 – The system loss may be also expressed by:

$$L_s = 10 \log (p_t/p_a) = P_t - P_a \qquad \text{dB} \tag{5}$$

where:

p_t: radio-frequency power input to the terminals of the transmitting antenna

p_a: resultant radio-frequency signal power available at the terminals of the receiving antenna.

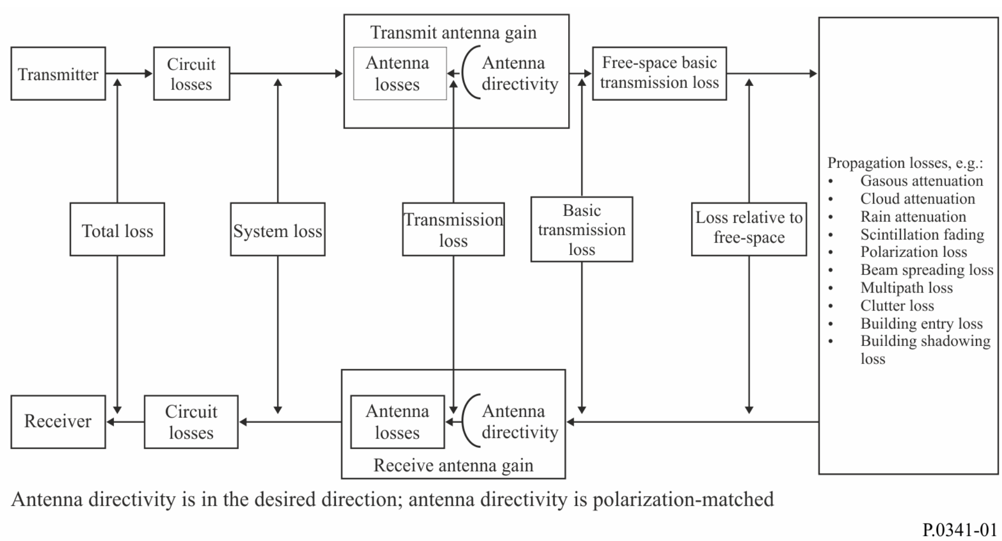
NOTE 3 – The system loss excludes losses in feeder lines but includes all losses in radio-frequency circuits associated with the antenna, such as ground losses, dielectric losses, antenna loading coil losses, and terminating resistor losses.

1.5 Total loss (of a radio link) (symbols: L_l or A_l)

The ratio, usually expressed in decibels, between the power supplied by the transmitter of a radio link and the power supplied to the corresponding receiver in real installation, propagation and operational conditions. This is determined at the input or at the output of the transmitting and receiving antenna feed lines. The feed lines may include radio-frequency filters or multiplexers.

FIGURE 1

Graphical depiction of terms used in the transmission loss concept



2 Subsidiary term

2.1 Ray path transmission loss (symbols: L_t or A_t)

The transmission loss for a particular ray propagation path taking into account the antenna gains in that ray path direction (see Annex 1). The use of this term is restricted to those cases, for example for multipath propagation, where several propagation ray paths are considered separately.

NOTE – The ray path transmission loss may be expressed by:

$$L_t = L_b - G_{tp} - G_{rp} \quad \text{dB} \tag{6}$$

where G_{tp} and G_{rp} are the plane-wave directive gains (see Annex 1) of the transmitting and receiving antennas for the directions of propagation and polarization considered.

Annex 1

1 Antenna directivity

Directivity in a given direction is defined as the ratio of the intensity of radiation (the power per unit solid angle (steradian)), in that direction, to the radiation intensity averaged over all directions.

When converting transmission loss, or, in specific cases, ray path transmission loss to basic transmission loss the plane wave directivities for the transmitting and receiving antennas at the particular direction and polarization must be taken into account. In cases where the performance of the antenna is influenced by the presence of local ground or other obstacles (which do not affect the path) the directivity is the value obtained with the antenna *in situ*.

In the particular case of ground wave propagation with antennas located on or near the ground, although the directivity of the receiving antenna, G_r , is determined by the above definition, the aperture for signal capture, and hence the available power, is reduced below its free-space value. Thus the value to be used for G_r must be reduced (see Annex 2).

2 Antenna gain

The power gain of an antenna is defined as the ratio, usually expressed in decibels, of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or the same power flux-density (pfd) at the same distance. When not specified otherwise, the gain refers to the direction of maximum radiation. The gain may be considered for a specified polarization.

3 Reference standard antennas

In the study of propagation over radio links in different frequency bands, a number of reference antennas are used and referred to in ITU-R texts.

Depending on the choice of the reference antenna a distinction is made between:

– absolute or isotropic gain (G_i), when the reference antenna is an isotropic antenna isolated in space;

– gain relative to a half-wave dipole (G_d), when the reference antenna is a half-wave dipole isolated in space, whose equatorial plane contains the given direction;

– gain relative to a short vertical antenna (G_v), when the reference antenna is a linear conductor much shorter than one quarter of the wavelength, normal to the surface of a perfectly conducting plane which contains the given direction.

(The power gain corresponds to the maximum directivity for lossless antennas.)

Table 1 gives the directivity, G_t, for some typical reference antennas. The corresponding values of the cymomotive force are also shown for a radiated power of 1 kW.

TABLE 1

Directivity for typical reference antennas and its relation to cymomotive force

Reference antenna	g_t	G_t (1) **(dBi)**	**Cymomotive force for a radiated power of 1 kW (V)**
Isotropic in free space	1	0	173
Hertzian dipole in free space	1.5	1.75	212
Half-wave dipole in free space	1.65	2.15	222
Hertzian dipole, or a short vertical monopole on a perfectly conducting ground (2)	3	4.8	300
Quarter wave monopole on a perfectly conducting ground (2)	3.3	5.2	314

(1) $G_t = 10 \log g_t$

The values of G_r (g_r) equal the values of G_t (g_t) for antennas in free space. See Annex 2 for values of G_r for antennas on a perfectly conducting ground.

(2) In these cases, it is assumed that the antenna is near a perfectly conducting plane ground, so that radiation is confined to the half space above the ground.

Annex 2

pfd and field strength

Some radiocommunication applications use incident pfd or field strength to describe the limitations of service range.

The field strength, in decibels relative to one volt per metre, is given by:

$$E = 14.77 + Q \tag{7}$$

and the pfd, in decibels relative to one watt per square metre, is given by:

$$S = -11.02 + Q \tag{8}$$

where:

$$Q = G_{iT} - 20 \log d - L_m + 10 \log p - L_{tc} \tag{9}$$

and

$E = 20 \log e$	(dB(V/m)) and e the field strength (V/m)
$S = 10 \log s$	(dB(W/m^2)) and s the pfd (W/m^2)
G_{iT}	transmitting antenna gain relative to an isotropic radiator (dB)
d	distance from the transmitting antenna (m)
L_m	"loss relative to free space" as defined above
P	transmitter power (W)
L_{tc}	transmitting antenna circuit loss (dB).

Annex 3

Influence of the environment on the antennas

When antennas are installed on or near the ground (i.e. $h < \lambda$, particularly when using frequencies less than 30 MHz) the free-space value of the antenna radiation resistance is modified by the presence of the ground. Consequently the pfd at the receiving antenna (resulting from the vector sum of direct and reflected rays) is dependent on the height of the transmitting antenna, and the effective capture area of the receiving antenna is dependent on the height of the antenna above the ground.

The influence of the environment on the operation of a pair of antennas (forming an elementary circuit) is illustrated by considering the transmission loss between two vertical loss-free short electric dipoles at heights h_t and h_r above a plane perfectly conducting surface. The separation, d, along the surface is very large compared to the wavelength λ.

1 The pfd s (W/m^2) at height h_r is given by:

$$s = \frac{p_t' \cos^4 \psi}{4\pi\, d^2 \,(1 + \Delta_t)} \times 1.5 \left[2 \cos (k\, h_t \sin \psi) \right]^2 \tag{10}$$

where:

p_t':	power radiated by the transmitting antenna (W)
d, h_t, h_r, λ	are expressed in metres;
$k =$	$\frac{2\pi}{\lambda}$

$$\psi = \arctan \frac{\lvert h_r - h_t \rvert}{d}$$

and

$$\Delta_t = \frac{3}{(2\,k\,h_t)^2} \left[\frac{\sin 2\,k\,h_t}{2\,k\,h_t} - \cos 2\,k\,h_t \right] \tag{11}$$

with $\Delta_t = 1$, when $h_t = 0$.

Equation (10) assumes that h_t, h_r and λ are all much less than d.

The following should be noted:

– the distance between the antennas is increased to d sec ψ,

– the electric field due to the dipole varies as cos ψ,

– the free-space radiation resistance is multiplied by $(1 + \Delta_t)$,

– due to the vector addition of the direct and reflected rays the free-space value of the power flux is multiplied by:

$$\frac{\left[2 \cos (k\, h_t \sin \psi)\right]^2}{(1 \;+\; \Delta_t)}$$

This is equivalent to the change in directivity due to the presence of the reflecting surface. The multiplying factor has the value of 2 when $h_t = h_r = 0$.

2 The effective capture area of the receiving antenna is given by:

$$\alpha_\varepsilon = \frac{1.5\lambda^2 \cos^2 \ \psi}{4\pi(1+\Delta_\rho)} \tag{12}$$

where:

$$\Delta_r = \frac{3}{(2kh_r)^2}\left[\frac{\sin 2kh_r}{2kh_r} - \cos 2kh_r\right]$$

The following should be noted:

– since g_t has the value 2 × 1.5 (by definition) when $h_t = h_r = 0$ it is important to note that this is not the appropriate value to use for g_r; the correct value for g_r is $1.5/2 = g_t/4$;

– the capture area in the direction of the transmitting antenna is multiplied by $\cos^2 \psi$ due to directional effects;

– the change in radiation resistance is based on equation (11), where Δ_t and h_t are replaced by Δ_r and h_r;

– the free-space value of the capture area is multiplied by $1/(1 + \Delta_r)$ by the presence of the reflecting plane; thus the presence of the reflecting plane reduces the capture area below its free-space value by a factor of 2 when $h_t = h_r = 0$.

3 Since the total power collected by the receiving antenna is given by $p_a^{'} = sa_e$, equations (10) and (12) may be combined to give an expression for the transmission loss between two short vertical loss-free electric dipoles above a plane perfectly conducting surface.

$$L \;=\; L_{bf} \;-\; 6.0 \;-\; 10 \log \left[(1.5 \cos^2 \psi)^2 \, \frac{\cos^2 (k\, h_t \sin \psi)}{(1 \;+\; \Delta_r)\,(1 \;+\; \Delta_t)}\right] \qquad \text{dB} \tag{13}$$

In the limiting cases where the antennas are short monopoles on the surface:

$$h_t \;=\; h_r \;=\; 0; \quad \Delta_t \;= \Delta_r \;=\; 1; \quad \psi \;=\; 0$$

$$L \;=\; L_{bf} \;-\; 3.5 \qquad \text{dB}$$