

## RECOMMENDATION ITU-R P.341-5\*

## THE CONCEPT OF TRANSMISSION LOSS FOR RADIO LINKS\*\*

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

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 mechanisms, 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 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.

NOTE 1 – It is necessary to specify in each case the points at which the power supplied by the transmitter and the power supplied to the receiver are determined, for example:

- before or after the radio-frequency filters or multiplexers that may be employed at the sending or the receiving end;
- at the input or at the output of the transmitting and receiving antenna feed lines.

## 2 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.

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 expressed by:

$$L_s = 10 \log (p_t/p_a) = P_t - P_a \quad \text{dB} \quad (1)$$

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.

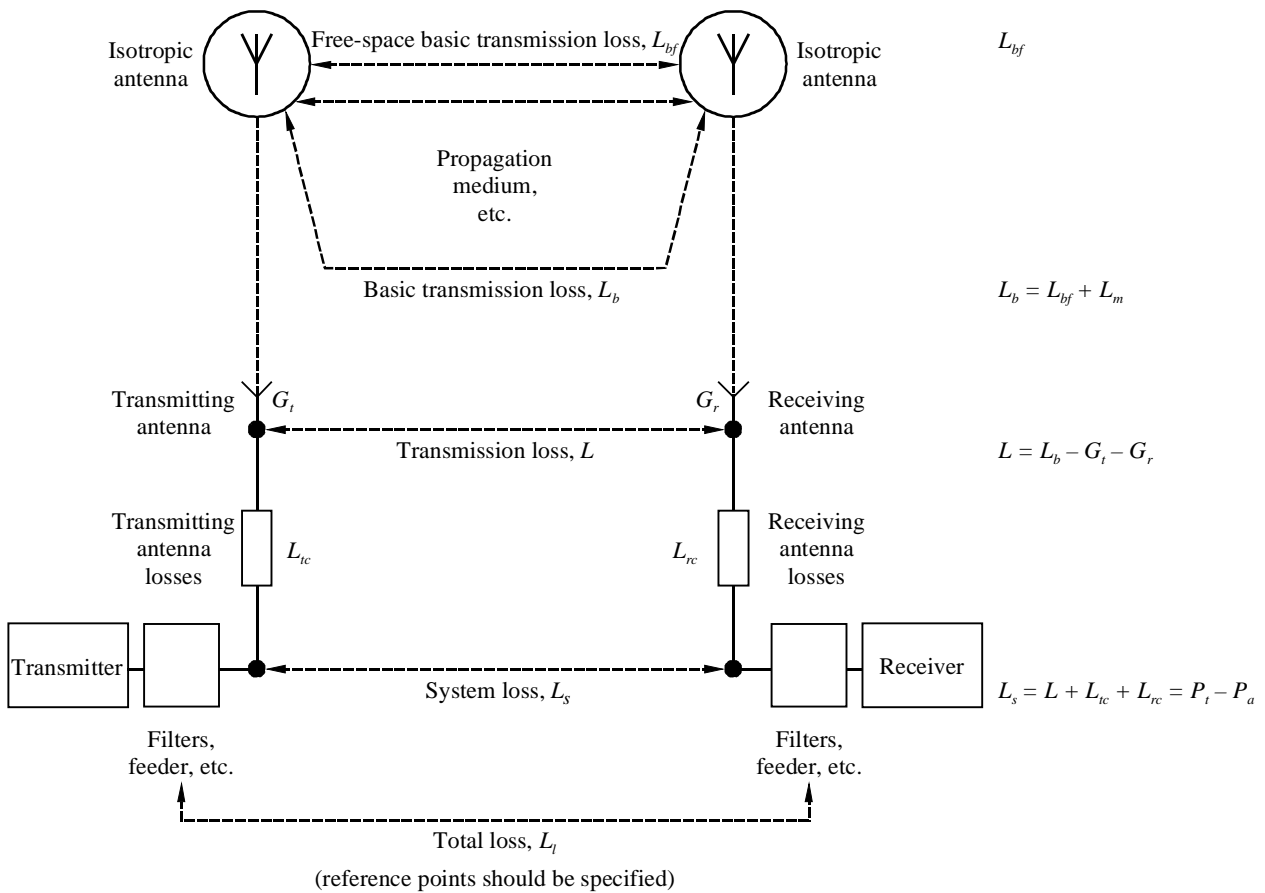
\* This Recommendation should be brought to the attention of the Coordination Committee for Vocabulary (CCV).

\*\* 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).

\*\*\* A graphical depiction of this and subsequent definitions is shown in Fig. 1.

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.

FIGURE 1  
Graphical depiction of terms used in the transmission loss concept



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### 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 the receiving antenna output if there were no loss in the radio-frequency circuits, assuming that the antenna radiation diagrams are retained.

NOTE 1 – The transmission loss may be expressed by:

$$L = L_s - L_{tc} - L_{rc} \quad \text{dB} \quad (2)$$

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 2 – Transmission loss is equal to system loss minus the loss in the radio-frequency circuits associated with the antennas.

#### 4 Basic transmission loss (of a radio link) (symbols: $L_b$ or $A_i$ )

The transmission loss that would occur if the antennas were replaced by isotropic antennas with the same polarization as the real antennas, the propagation path being retained, but the effects of obstacles close to the antennas being disregarded.

$$L_b = L + G_t + G_r \quad \text{dB} \quad (3)$$

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 1 – The basic transmission loss is equal to the ratio of the equivalent isotropically radiated power of the transmitter system to the power available from an isotropic receiving antenna.

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.

#### 5 Free-space basic transmission loss (symbols: $L_{bf}$ or $A_0$ )

The transmission loss that would occur if the antennas were replaced by isotropic antennas located in a perfectly dielectric, homogeneous, isotropic and unlimited environment, the distance between the antennas being retained (see Recommendation ITU-R P.525).

NOTE 1 – If the distance  $d$  between the antennas is much greater than the wavelength  $\lambda$ , the free-space attenuation in decibels will be:

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

#### 6 Ray path transmission loss (symbols: $L_t$ or $A_t$ )

The transmission loss for a particular ray propagation path, equal to the basic transmission loss minus the transmitting and receiving 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 1 - The ray path transmission loss may be expressed by:

$$L_t = L_b - G_{tp} - G_{rp} \quad \text{dB} \quad (5)$$

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.

#### 7 Loss relative to free space (symbols: $L_m$ or $A_m$ )

The difference between the basic transmission loss and the free-space basic transmission loss, expressed in decibels.

NOTE 1 – The loss relative to free space may be expressed by:

$$L_m = L_b - L_{bf} \quad \text{dB} \quad (6)$$

NOTE 2 – Loss relative to free space,  $L_m$ , may be divided into losses of different types, such as:

- absorption loss (ionospheric, atmospheric gases or precipitation);
- 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;
- effect of wave interference between the direct ray and rays reflected from the ground, other obstacles or atmospheric layers.

## 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 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 electromotive 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	$g_t$	$G_t^{(1)}$ (dB)	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 <sup>(2)</sup>	3	4.8	300
Quarter wave monopole on a perfectly conducting ground	3.3	5.2	314

<sup>(1)</sup>  $G_t = 10 \log g_t$

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.

<sup>(2)</sup> In the case of the hertzian dipole, it is assumed that the antenna is near a perfectly conducting ground.

## ANNEX 2

**Influence of the environment on the antennas**

When antennas are installed on or near the ground and the ground-wave propagation mode is used (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 power flux-density 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  $\lambda$ .

**1** The power flux-density  $s$  (W/m<sup>2</sup>) at height  $h_r$  is given by:

$$s = \frac{p'_t \cos^4 \psi}{4\pi d^2 (1 + \Delta_t)} \times 1.5 \left[ 2 \cos(k h_t \sin \psi) \right]^2 \quad (7)$$

where:

$p'_t$ : power radiated by the transmitting antenna (W)

$d, h_t, h_r, \lambda$  are expressed in metres

$$k = \frac{2\pi}{\lambda}$$

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

and

$$\Delta_t = \frac{3}{(2 k h_t)^2} \left[ \frac{\sin 2 k h_t}{2 k h_t} - \cos 2 k h_t \right] \quad (8)$$

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

Equation (7) assumes that  $h_t$ ,  $h_r$  and  $\lambda$  are all much less than  $d$ .

The following should be noted:

- the distance between the antennas is increased to  $d \sec \psi$ ,
- the electric field due to the dipole varies as  $\cos \psi$ ,
- 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:

$$a_e = \frac{1.5 \lambda^2 \cos^2 \psi}{4\pi (1 + \Delta_r)} \quad (9)$$

The following should be noted:

- 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 (8), where  $\Delta_t$  and  $h_t$  are replaced by  $\Delta_r$  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  $h_t = h_r = 0$ ;
- since  $g_t$  has the value  $2 \times 1.5$  (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  $1.5/2 = g_t/4$ .

3 Since the total power collected by the receiving antenna is given by  $p_a' = sa_e$ , expressions (7) and (9) 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.

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

Consider two limiting cases:

a) *Antennas on the surface*

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

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

b) *Very large antenna heights*

$$h_t = h_r \gg \lambda; \quad \Delta_t = \Delta_r \rightarrow 0; \quad \psi \rightarrow 0$$

$$L = L_{bf} - 3.5 - 6.0 \quad \text{dB}$$

NOTE 1 – It should be noted that the formulae taking into account the presence of an infinite reflective plane cannot tend to the free-space formulae even when the antenna heights tend to infinity.