

RECOMMENDATION ITU-R P.833-4

Attenuation in vegetation

(Question ITU-R 202/3)

(1992-1994-1999-2001-2003)

The ITU Radiocommunication Assembly

considering

a) that attenuation in vegetation can be important in several practical applications,

recommends

1 that the content of Annex 1 be used for evaluating attenuation through vegetation between 30 MHz and 60 GHz.

Annex 1**1 Introduction**

Attenuation in vegetation can be important in some circumstances, for both terrestrial and Earth-space systems. However, the wide range of conditions and types of foliage makes it difficult to develop a generalized prediction procedure. There is also a lack of suitably collated experimental data.

The models described in the following sections apply to particular frequency ranges and for different types of path geometry.

2 Terrestrial path with one terminal in woodland

For a terrestrial radio path where one terminal is located within woodland or similar extensive vegetation, the additional loss due to vegetation can be characterized on the basis of two parameters:

- the specific attenuation rate (dB/m) due primarily to scattering of energy out of the radio path, as would be measured over a very short path;
- the maximum total additional attenuation due to vegetation in a radio path (dB) as limited by the effect of other mechanisms including surface-wave propagation over the top of the vegetation medium and forward scatter within it.

In Fig. 1 the transmitter is outside the woodland and the receiver is a certain distance, d , within it. The excess attenuation, A_{ev} , due to the presence of the vegetation is given by:

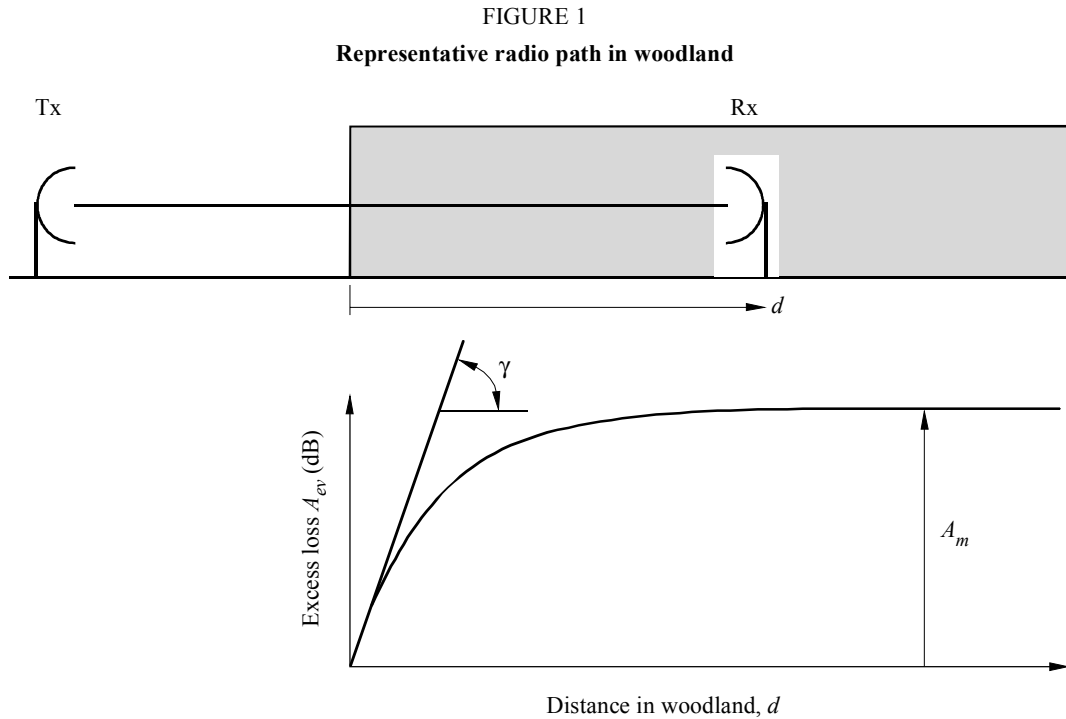
$$A_{ev} = A_m [1 - \exp (-d \gamma / A_m)] \quad (1)$$

where:

d : length of path within woodland (m)

γ : specific attenuation for very short vegetative paths (dB/m)

A_m : maximum attenuation for one terminal within a specific type and depth of vegetation (dB).



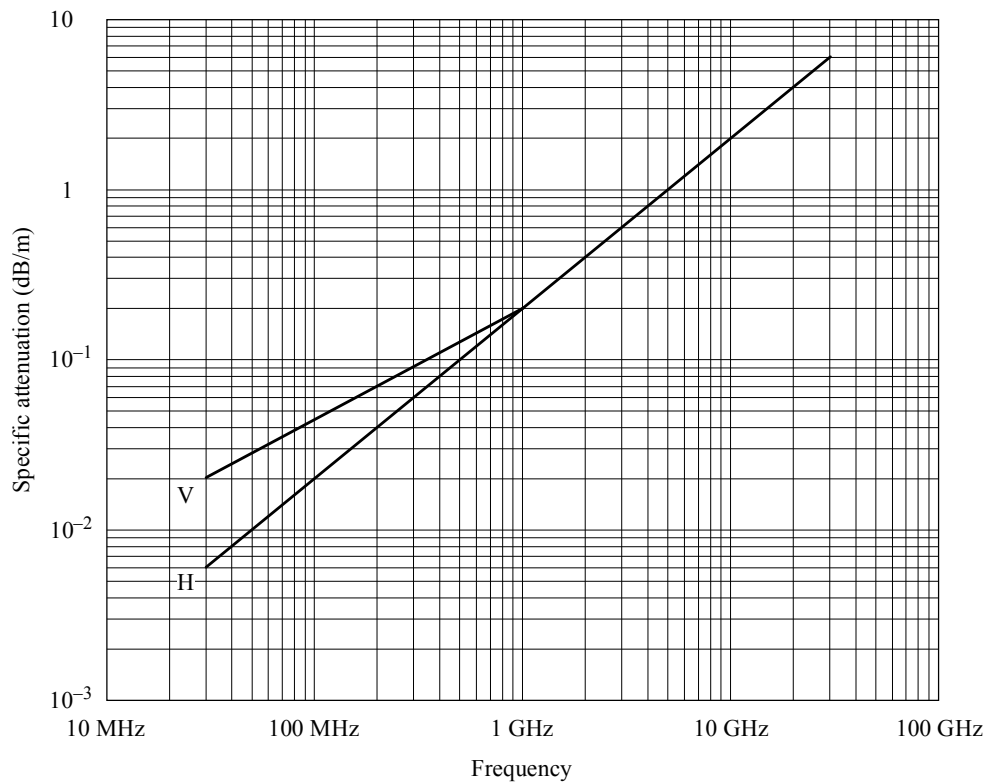
It is important to note that excess attenuation, A_{ev} , is defined as excess to all other mechanisms, not just free space loss. Thus if the radio path geometry in Fig. 1 were such that full Fresnel clearance from the terrain did not exist, then A_{ev} would be the attenuation in excess of both free-space and diffraction loss. Similarly, if the frequency were high enough to make gaseous absorption significant, A_{ev} would be in excess of gaseous absorption.

It may also be noted that A_m is equivalent to the clutter loss often quoted for a terminal obstructed by some form of ground cover or clutter.

The value of specific attenuation due to vegetation, γ dB/m, depends on the species and density of the vegetation. Approximate values are given in Fig. 2 as a function of frequency.

Figure 2 shows typical values for specific attenuation derived from various measurements over the frequency range 30 MHz to about 30 GHz in woodland. Below about 1 GHz there is a tendency for vertically polarized signals to experience higher attenuation than horizontally, this being thought due to scattering from tree-trunks.

FIGURE 2
Specific attenuation due to woodland



V: vertical polarization
H: horizontal polarization

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It is stressed that attenuation due to vegetation varies widely due to the irregular nature of the medium and the wide range of species, densities, and water content obtained in practice. The values shown in Fig. 2 should be viewed as only typical.

At frequencies of the order of 1 GHz the specific attenuation through trees in leaf appears to be about 20% greater (dB/m) than for leafless trees. There can also be variations of attenuation due to the movement of foliage, such as due to wind.

The maximum attenuation, A_m , as limited by scattering from the surface wave, depends on the species and density of the vegetation, plus the antenna pattern of the terminal within the vegetation and the vertical distance between the antenna and the top of the vegetation.

A frequency dependence of A_m (dB) of the form:

$$A_m = A_1 f^\alpha \quad (2)$$

where f is the frequency (MHz) has been derived from various experiments:

- Measurements in the frequency range 900-1 800 MHz carried out in a park with tropical trees in Rio de Janeiro (Brazil) with a mean tree height of 15 m have yielded $A_1 = 0.18$ dB and $\alpha = 0.752$. The receiving antenna height was 2.4 m.
- Measurements in the frequency range 900-2 200 MHz carried out in a forest near Mulhouse (France) on paths varying in length from a few hundred metres to 6 km with various species of trees of mean height 15 m have yielded $A_1 = 1.15$ dB and $\alpha = 0.43$. The receiving

antenna in woodland was a $\lambda/4$ monopole mounted on a vehicle at a height of 1.6 m and the transmitting antenna was a $\lambda/2$ dipole at a height of 25 m. The standard deviation of the measurements was 8.7 dB. Seasonal variations of 2 dB at 900 MHz and 8.5 dB at 2 200 MHz were observed.

3 Single vegetative obstruction

3.1 At or below 3 GHz

Equation (1) does not apply for a radio path obstructed by a single vegetative obstruction where both terminals are outside the vegetative medium, such as a path passing through the canopy of a single tree. At VHF and UHF, where the specific attenuation has relatively low values, and particularly where the vegetative part of the radio path is relatively short, this situation can be modelled on an approximate basis in terms of the specific attenuation and a maximum limit to the total excess loss:

$$A_{et} = d \gamma \quad (3)$$

where:

d : length of path within the tree canopy (m)

γ : specific attenuation for very short vegetative paths (dB/m)

and $A_{et} \leq$ lowest excess attenuation for other paths (dB).

The restriction of a maximum value for A_{et} is necessary since, if the specific attenuation is sufficiently high, a lower-loss path will exist around the vegetation. An approximate value for the minimum attenuation for other paths can be calculated as though the tree canopy were a thin finite-width diffraction screen using the method of Recommendation ITU-R P.526, § 4.2.

It is stressed that equation (3), with the accompanying maximum limit on A_{et} , is only an approximation. In general it will tend to overestimate the excess loss due to the vegetation. It is thus most useful for an approximate evaluation of additional loss when planning a wanted service. If used for an unwanted signal it may significantly underestimate the resulting interference.

3.2 Above 5 GHz

Attenuation through vegetation is important for broadband wireless access systems. These systems are typically based on a star network, with a well positioned hub (or base station) serving many individual users with rooftop antennas. In many cases, signals will be obscured by vegetation close to the user antenna. For simplicity, the hub antenna will be referred to as the transmitter and the user antenna as the receiver.

An empirical model of propagation through vegetation has been developed for frequencies above 5 GHz. The model gives the attenuation through vegetation as a function of vegetation depth, taking into account the dual slope nature of the measured attenuation versus depth curves.

The model predicts the excess loss due to the presence of a volume of vegetative foliage which will be experienced by the signal passing through it. In practical situations the signal beyond such a volume will receive contributions due to propagation both through the vegetation and diffracting around it. The diffracted signal can be estimated using the method given in Recommendation ITU-R P.526, § 4.2. The dominant form of these two propagation mechanisms will then limit the total vegetation loss.

The model was derived from a database of measured data over a range of frequencies 9.6-57.6 GHz, but also takes into account the site geometry in terms of the extent of illumination of the vegetation, defined by the minimum illumination area, A_{min} . The attenuation for a vegetation depth, d (m), (in addition to free space loss) is given by:

$$A_{scat} = R_{\infty}d + k \left(1 - \exp \left\{ \frac{-(R_0 - R_{\infty})}{k} d \right\} \right) \quad (4)$$

Here, the initial slope is:

$$R_0 = af \quad (5)$$

and the final slope is:

$$R_{\infty} = \frac{b}{f^c} \quad (6)$$

where f is the frequency (GHz) and the turnover value of attenuation, at which the scattered component of the received field becomes of the same order as the attenuated coherent component,

$$k = k_0 - 10 \log_{10} \left(A_0 \left(1 - \exp \left\{ \frac{-A_{min}}{A_0} \right\} \right) \left(1 - \exp \left\{ -R_f f \right\} \right) \right) \quad (7)$$

and the parameters a, b, c, k_0, R_f and A_0 are given in Table 1.

TABLE 1

Parameter	In leaf	Out of leaf
a	0.2	0.16
b	1.27	2.59
c	0.63	0.85
k_0	6.57	12.6
R_f	0.0002	2.1
A_0	10	10

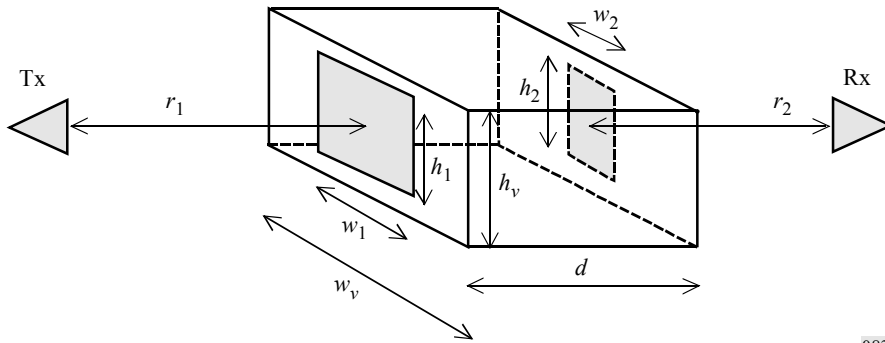
A_{min} , is the minimum illumination area defined as the product of the minimum width of illuminated vegetation, $\min(w_1, w_2, w_v)$ and the minimum height, $\min(h_1, h_2, h_v)$ which corresponds to the smaller of the two antenna spot areas on the front and rear faces of the vegetation. These heights and widths are determined by the elevational and azimuthal 3 dB beamwidths of the transmit antennas and the physical width, w_v , and height of the vegetation, h_v , shown in Fig. 3, where the vegetation is

assumed to be a rectangular block. If the transmit antenna has elevational beamwidth, φ_T , and azimuthal beamwidth, θ_T , and the receive antenna φ_R and θ_R then the minimum illumination area is defined as:

$$A_{min} = \min(h_1, h_2, h_v) \times \min(w_1, w_2, w_v)$$

$$A_{min} = \min\left(2r_1 \tan\left(\frac{\varphi_T}{2}\right), 2r_2 \tan\left(\frac{\varphi_R}{2}\right), h_v\right) \times \min\left(2r_1 \tan\left(\frac{\theta_T}{2}\right), 2r_2 \tan\left(\frac{\theta_R}{2}\right), w_v\right) \quad (8)$$

FIGURE 3
Geometry to determine the minimum illuminated vegetation area, A_{min}
(see equation (8))



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In practice $r_1 \gg r_2$ and the beamwidth of the receiver, B_{rx} , is expected to be only a few degrees. Under these conditions the parts of equation (8) containing r_1 will not normally be required.

The diffraction loss for double isolated knife-edges A_{difw} due to diffraction around the sides of the vegetation and A_{difh} due to diffraction over the top of the vegetation is calculated as in Recommendation ITU-R P.526, § 4. The vegetation loss, A , which is then found as the minimum value of A_{difw} , A_{difh} and A_{scat} .

Figure 4 shows an example of the model for two cases of minimum illumination area (0.5 m^2 and 2 m^2) and three frequencies 5, 10 and 40 GHz for vegetation in and out of leaf.

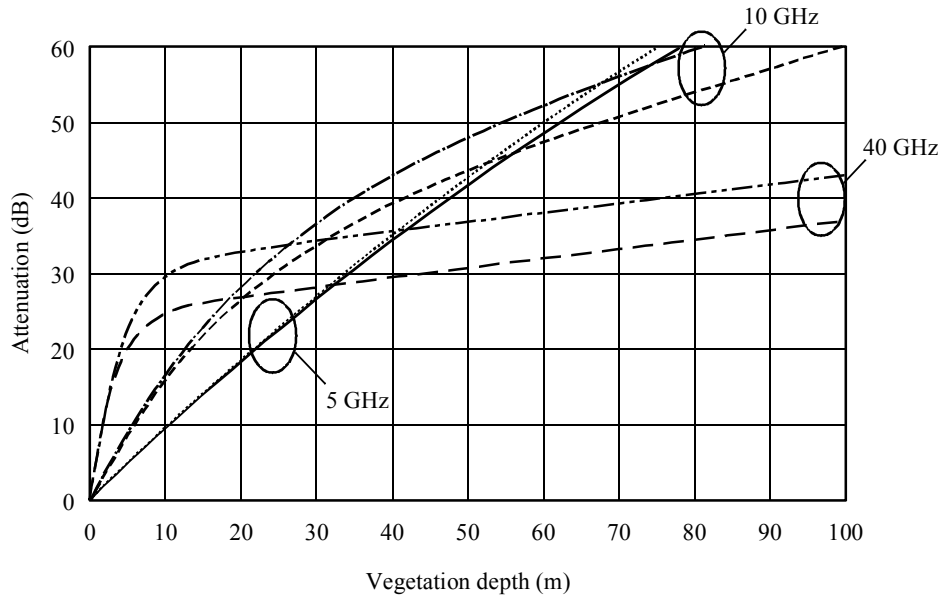
This model for the attenuation due to vegetation as a function of depth through the vegetation can be incorporated into deterministic models (such as ray-based tools using a 3D database of the local building and tree locations) to give a more realistic prediction of the extent of coverage for a given transmitter location.

4 Depolarization

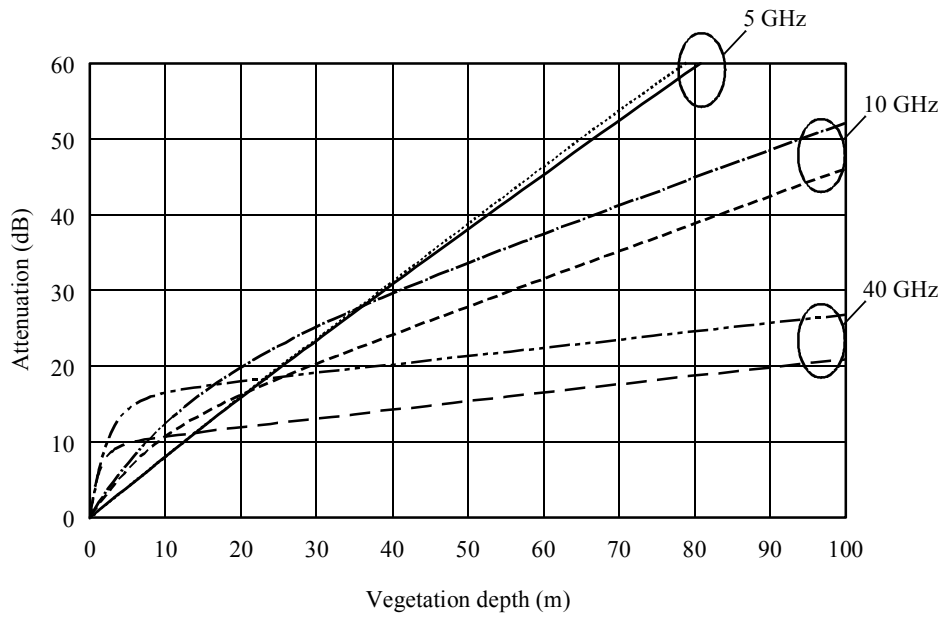
Previous measurements at 38 GHz suggest that depolarization through vegetation may well be large, i.e. the transmitted cross-polar signal may be of a similar order to the co-polar signal through the vegetation. However, for the larger vegetation depths required for this to occur, the attenuation would be so high that both the co-polar and cross-polar components would be below the dynamic range of the receiver.

FIGURE 4

Attenuation for 0.5 m² and 2 m² illumination area, a) in leaf, b) out of leaf*



a)



b)

- | | | | |
|-----------|----------------------------|-----------|----------------------------|
| | 5 GHz, 0.5 m ² | ----- | 10 GHz, 2 m ² |
| ———— | 5 GHz, 2 m ² | - · - · - | 40 GHz, 0.5 m ² |
| - · - · - | 10 GHz, 0.5 m ² | ----- | 40 GHz, 2 m ² |

* The curves show the excess loss due to the presence of a volume of foliage which will be experienced by the signal passing through it. In practical situations the signal beyond such a volume will receive contributions due to propagation both through the vegetation and diffracting around it. The dominant propagation mechanism will then limit the total vegetation loss.