# Propagation of Electromagnetic Waves in Amazon Rain Forest Environment

Victor Dmitriev[1], Domingos Sávio das Virgens Alves[2]
1 Universidade Federal do Pará 2 Instituto Tecnológico de Aeronáutica

**ABSTRACT -** For development of wireless systems for vegetation regions, the detailed knowledge of the involved propagation mechanisms is essential. The physical and geometric parameters of the vegetation are random. Calculating the mean signal amplitude decay, both absorbing and multiple scattering effects must be taken into account. Statistical parameters of rough terrain and vegetation are important but they are not always available. In our investigations, we use a deterministic model for calculation of the losses of point-to-point paths in order to estimate the influence of some of the medium forest parameters on transmission losses.

***Palavras-chaves* — FDTD, random media.**

## I. ASPECTS OF THE WAVE PROPAGATION IN FOREST

From the point of view of electromagnetic wave propagation in forest, the Amazon region has some specific features. First of all, it is high humidity. The vegetation and terrain possess dynamic morphology that change in particular, in accordance with periodic annual climatic variations, modifying some physical properties. For calculation of electromagnetic waves that propagate in this environment, the vegetation itself should be characterized by some parameters [1], such which, (1) type of vegetation: average height, shape and distribution of the elements (trunks, branches and leaves); (2) space density (number of trees per unit of area) (3) vegetation water content: volume of water deposited in the surface of the elements and the interior of the trunks and branches. Another parameter important to consider is the variation of the electric characteristics of the soil with the moisture and salinity [2]

The losses associated with the electromagnetic scattering and absorption in the trunks and branches can be separately calculated considering each element as cylindrical scatterer (absorber) with circular cross-sections of different diameters. The distribution functions of the diameters of the elements in the analysis can be taken into account [3]-[6]. The foliage can be considered as a uniform media with losses [7]-[8].

For the frequency range where the scatterers are small compared with the wavelength, the scattering can be estimated using effective parameters of the media. The dielectric constant can be obtained by theoretical models or by semi-empirical formulas. However, such formulas in many cases possess little versatility, being appropriate for the specific cases (type of vegetation, climatic conditions and range of frequency) for which they have been implemented. The variation of the complex electric permittivity of the vegetation with parameters as frequency, moisture and salinity can be calculated using dielectric mixture models [9]-[10]. An example is the approach for dielectric constant proposed by Peake [11]:

$$\varepsilon = m_v \varepsilon_w + (1 - m_v) 2.5 \approx m_v \varepsilon_w \tag{1}$$

where $\varepsilon_w = \varepsilon'_w + j\varepsilon''_w$ is the relative complex dielectric constant of water. The dielectric constant of saline water is calculated by the Debye relaxation formulas [9]:

$$\varepsilon'_w = \varepsilon_{w\infty} + \frac{\varepsilon_{ws} - \varepsilon_{w\infty}}{1 + \left(\frac{f}{f_0}\right)^2} \tag{2}$$

$$\varepsilon''_w = \frac{\left(\frac{f}{f_0}\right)(\varepsilon_{ws} - \varepsilon_{w\infty})}{1 + \left(\frac{f}{f_0}\right)^2} + \frac{\sigma}{2\pi\varepsilon_0 f} \tag{3}$$

where

$\varepsilon_{ws}$ - static limit of $\varepsilon'_w$

$\varepsilon_{w\infty}$ - high-frequency limit of $\varepsilon'_w$

$\sigma$ - ionic conductivity of the aqueous solution (S/m), determined by the salinity of the solution.

$f$ - frequency (Hz).

## II. PROPAGATION MODEL FOR FOREST ENVIRONMENT

The Amazon rain forest presents a characteristic distribution of vegetation with the peculiarities that can be taken into account to develop a model of electromagnetic propagation in this environment. The model using four dielectric layers, considered by Cavalcante[12], has been adopted in various works [13]-[16]. However, we shall consider a three layers model [17]-[19], that is, the forest represented only by one dielectric layer. This is because the Amazon rain forest, in contrast to the Europe and USA forests, is typically dense with the foliage interwining with the trunks, composing only one layer in which the electric characteristics of each constituent (trunks, branches and leaves) should de considered. Thus, our stratified model consists of three horizontal dielectric layers. The first layer is the semi-infinite free space, the second region represents the forest and the last region is the soil.

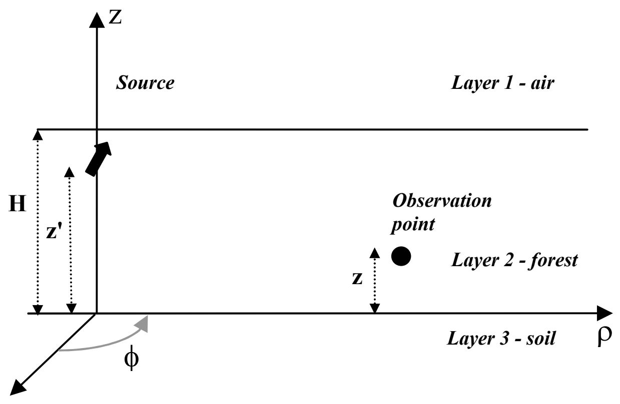


Figure 1. Three layer forest model.

## III. MATHEMATIC FORMULATION

The mathematical model, in accordance with Fig. 1, can be implemented using the method of dyadic Green's functions. The following expressions for the electric field in the far zone of the dipole antennas are valid:

$$\overline{E}_2\left(\overline{R}\right)= j\omega\mu_0 \iiint_{V'} \overline{\overline{G}}_e^{(21)}\left(\overline{R},\overline{R}'\right)\!.\overline{J}\left(\overline{R}'\right)\!dV'$$

for $\quad H \geq z \geq 0 \quad$ (3)

$$\overline{\overline{G}}_e^{(21)}(\overline{R},\overline{R}') = \frac{j}{4\pi}\int \frac{d\lambda}{h_1\lambda}\sum_{n=0}^{\infty}(2-\delta_0)\,\mathrm{x}$$

$$[\left(\frac{2h_1}{h_1+h_2}\frac{1}{D^H}\overline{M}(-h_2)+\frac{2h_2}{h_1+h_2}\frac{R_2^H e^{j2h_1H}}{D^H}\overline{M}(h_2)\right)\overline{M'}(h_2)$$

$$+\left(\frac{2k_2k_1h_1}{k_2^2h_1+k_1^2h_2}\frac{1}{D^V}\overline{N}(-h_2)+\right.$$

$$\left.+\frac{2k_2k_1h_1}{k_2^2h_1+k_1^2h_2}\frac{R_2^H e^{j2h_1H}}{D^H}\overline{N}(h_2)\right)\overline{N'}(h_2)] \qquad (4)$$

$$R_2^V = \frac{k_3^2h_2 - k_2^2h_3}{k_2^2h_3+k_3^2h_2} \quad \text{e} \quad R_2^H = \frac{h_2-h_3}{h_3+h_2} \quad \text{e}$$

$$D^{V,H} = 1 + R_1^{V,H}R_2^{V,H}e^{j2h_2H} \qquad (5)$$

The vector wave eigenfunctions $\overline{M}$ e $\overline{N}$ are given in [20]. To obtain a compact solution and to reduce the computational efforts, some approximate formula can be deduced from the above expressions. The integral in (3) for example, can be substituted by asymptotical expressions using the method of saddle point and branch cuts integration. In this case, the electromagnetic fields are presented in the form of series of reflections in the dielectric interfaces of the layers. The direct and multireflected waves are obtained by application of the method of saddle point, while the lateral waves are as the results of the integration on branch cuts. Details on the asymptotic methods and procedure of field calculations can be found in references [20]-[22].

## IV. NUMERICAL RESULTS

The forest model described above is employed to predict the behavior of the electromagnetic signal of communications systems operating inside the forest.

The transmission loss $L$ for the field radiated by dipole is given by formula:

$$L(dB) = 32.4 + 20\log_{10}\left[d(Km)\right] + 20\log_{10}\left[f(MHz)\right] + 20\log_{10}\left|\frac{E_0}{E}\right| \quad (6)$$

where the first three terms defines the free space loss, derived of Friis transmission formula [22]. The horizontal distance between transmitting and receiving antennas $d$ is given in kilometers and the frequency $f$ in MHz. The last term in (6) is the loss associated with the forest layer, where, $E_0$ is the unattenuated electric field (in the absence of the forest layers), and $E$ is the total field computed by (3).

In the calculation of the total field, the values of the direct wave, multireflected and the lateral wave in the interface between layers 1 (air) and 2 (forest) had been taken into account. The number of the jumps of the multireflected waves which has been taken into account is 40, and the number of the hops of the lateral wave is 6.

Numerical results are computed in this work using the frequency range of 0.2-2 GHz. The parameters of the problem are as follows: the position of the transmitting antenna (dipole) above the ground is z'=10 m, the position of the receiving antenna z = 1.5 m, the height of the vegetation layer H = 25 m, ϕ = 0º and α = 90º (vertical polarization). The effective permittivity of forest layer $\varepsilon_2 = 1.12$ and conductivity $\sigma_2 = 0.12$ mS/m have been adopted. The soils parameters used are, permittivity $\varepsilon_3 = 50$ and conductivity $\sigma_3 = 100$ mS/m.

In Fig. 2, the radio-losses of the total field for 4 different frequencies are presented in function of the radial distance between the transmitter and the receiver antennas. For relatively short distances, the contribution of bigger relevance for composition of the signal is the multireflected waves. For example, for frequency 1.8 GHz, the curve presents a fast growth, that is, the loss levels increase with the increment of the horizontal distance between the transmitter and the receiver until about 2 km. The observed peaks can be explained by multireflected waves that are overlapped. However, for long distances (2-10 Km) the response is flat, where the mechanism of propagation of lateral waves is preponderant.

The electric conductivity changes with the variation of the amount of water in each element that constitutes the forest layer. It is known that the Amazon region presents a high moisture index, thus constituting a highly absorving medium for radiowaves. To verify the variation of the transmission loss in function of the conductivity and concomitant moisture, the curves in Fig.3 have been plotted. The conductivity range was of 0.01-0.5 mS/m, being the typical extremities, values for dry forests and with high humidity, respectively. The losses have been calculated for distance of 6 km. The observed difference between the levels of reply for the dry forest and the humid one is of the order of 90 dB.

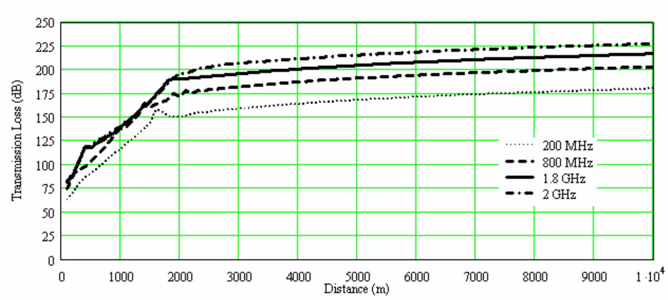

Figure 2. Transmission loss of the total field.

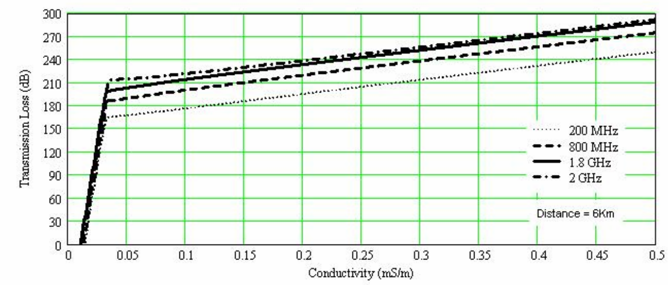

Figure 3. Transmission loss versus conductivity.

For frequency range of 0.2-2 GHz, and the distance between transmitter and receiver in 6 Km, the curves of losses are presented in Fig. 4. The parameters of the forest are the same used in Fig. 2.

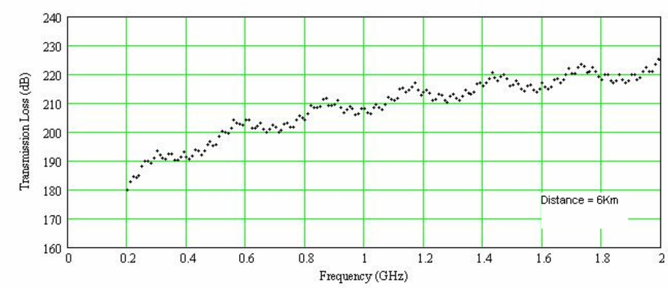

Figure 4. Transmission loss versus frequency.

## V. FUTURE WORKS

The model can be improved using the following methods:

1. Taking into account the anisotropy of the forest layer (trunks).

2. Calculating the effective parameters of the forest layer using the methods of the diffraction theory.

3. To introduce the tensor of permittivity in the model for study of the depolarization.

4. To consider random irregularity in the surfaces of the soil and top of the trees.

5. Use Monte Carlo method for modeling of distribution of the vegetation.

6. To improve the model using techniques of generation of trees as *Honda Tree* and *L-systems*.

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