Ground-to-Air Propagation in a Dense Jungle

#Mauro S. Assis
Department of Telecommunications, Fluminense Federal University
Rua Passo da Pátria 156, Niterói, Brazil
msassis@openlink.com.br

1. Introduction

People engaged in a military or a scientific mission in a forest environment normally dispose of radio sets to be used for communication between then. In the case of a dense jungle, sometimes it happens that all group or part of it may become lost in this environment. It should be pointed out that even the GPS signal can suffer a very strong attenuation due to the vegetation and a precise localization of this group becomes unfeasible. In this context, the availability of radio sets is of paramount importance to carry out a successfully search and rescue operation. A similar situation is the case of an airplane crash in the jungle. In such scenario, the radio equipment to be localized must be capable to operate with a voice channel or emitting a help radio signal put in action by some automatic device. The unknown position of the radio station can be settled by air with the aid of a search equipment mounted in an airplane or helicopter, complemented by another equipment on the ground, inside the forest or outside of it in a vehicle on a road or in a boat along a river. The option to be considered depends on the access available in the region where the operation is being carried out.

A crucial problem in the above scenario is the evaluation of the coverage area of the equipment to be localized. In a dense jungle, this coverage is limited by the high signal attenuation due to vegetation. This attenuation depends on the operating frequency and on the values of the electrical parameters of vegetation (electrical permittivity and conductivity). A study developed in the Brazilian Amazon region has shown that the optimum frequency to be used in operations inside the jungle is around 10 MHz [1,2]. On the other hand, the electrical characteristics of vegetation were estimated through an experimental procedure which involves the comparison of direct measurements of field strength decay versus distance with numerical values derived from a theoretical model. The best fit were achieved for $\varepsilon_f = 1.2$ (electrical permittivity) and $\sigma_f = 0.2$ mS/m (conductivity) [3]. The evaluation of signal attenuation when both radio stations are on the ground is available elsewhere [4,5]. However, results for ground-to-air propagation are scarce and not well documented in the technical literature. Based on a theory developed by Brekhovskikh [6], this problem is discussed in this paper. An acceptable agreement was observed when comparing theoretical results with experimental data measured in the Brazilian Amazon jungle.

2. Ground-to-Air Propagation Model

According to Brekhovskikh [6], the electrical field intensity relative to free-space in a receiver located outside the forest (point C in Fig. 1) is given by,

$$\left|\frac{E}{E_0}\right| = \left|\frac{2\cos\theta}{m\cos\theta + \left(n^2 - sen^2\theta\right)^{1/2}} - j\frac{\lambda m sen^2\theta}{\pi r\left(n^2 - sen^2\theta\right)}\right| p \exp\left\{\frac{2\pi}{\lambda}\left[\mathrm{Im}(n^2-1)^{1/2}\right](h_f - h_1)\right\} \qquad (1)$$

where

E_0 – free-space field;

$n^2 = \varepsilon_f - j60\sigma_f\lambda$ – refractive index of the forest;

ε_f – relative permittivity of the forest; σ_f – conductivity of the forest; λ – wavelength;

$m = 1$ and $p=1$ for horizontal polarization;

$m = n^2$ and $p = sen^2\theta$ for vertical polarization;

Im [x] means imaginary part of x and the other parameters are shown in Fig. 1.

The physical interpretation of (1) is not difficult to be done. The exponential term corresponds to the attenuation of the radio path AB inside the jungle. The first parcel of the modulus in (1) represents the refracted wave associated to the geometric optical solution of the problem. The second one defines the lateral wave, being a diffraction correction to the refracted wave. It should be noted that the refracted wave disappears when θ = 90º. Around this value, the lateral wave predominates. The two waves have the same amplitude for a minimum height h_m given by,

$$h_m = \frac{\lambda m}{2\pi(n^2 - 1)} \tag{2}$$

It is quite easy to show that (2) corresponds to the minimum effective height defined by Bullington [7] several years ago when he was analyzing the behaviour of the surface wave in the theory of the propagation over a plane earth. In other words the lateral wave is a surface wave propagating along the boundary air – forest.

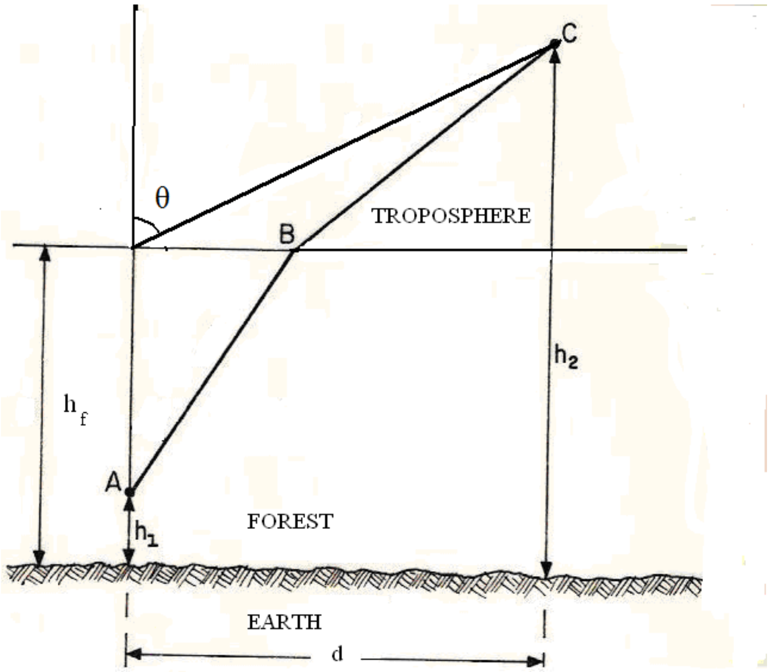

Figure 1: Ground-to-Air Propagation Path

3. Numerical Results

Table I shows a comparison between theoretical results and experimental data. Measurements were carried out in the Brazilian Amazon jungle in the frequency of 10 MHz with a helicopter flying at an average height of 150m, i.e. 120m above the forest top. Taking as reference the position of the radio terminal inside the jungle, these measurements have covered a maximum horizontal distance of 16 km. The ground terminal was 1.5m above the earth.

Regarding the theoretical results, two observations can be made: a) There is no difference between horizontal and vertical polarizations; b) The effect of the lateral wave is negligible when compared to the refracted wave. In this case, once the lateral wave decays with r^{-2}, its effect can be disregards when

$$h_2 - h_f >> |h_m| \qquad (3)$$

Considering that the measurements were done at 10 MHz (see Section 1) and taking into account the values of the electrical parameters of the forest, ε_f = 1.2 and σ_f = 0.2 mS/m, the minimum height is 12m for horizontal polarization and 14.5m for vertical polarization, justifying the above result.

As can be observed in Table 1, the comparison with experimental data shows quite acceptable results. In this context, however, it should be pointed out that it was not easy to maintain the helicopter in a fixed point. Probably, the most important source of error in the above measurements was the poor stabilization of the helicopter.

TABLE 1: Comparison between Theoretical Results* and Experimental Data

Distance (km)	Full solution (dB)		Refracted wave (dB)		Measurements** (dB)
	Hor. Pol.	Vert. Pol.	Hor. Pol.	Vert. Pol.	
1	26.5	27.0	26.9	27.3	36.1
2	32.0	32.4	32.3	32.6	38.8
4	37.7	37.9	38.0	38.1	38.6
8	43.1	43.3	43.4	43.4	41.5
16	50.0	50.0	50.3	50.3	46.5

* Attenuation relative to free-space

**Average values for several measurements around the reference distance.

4. Concluding Remarks

Based on a mathematical model developed by Brekhovskikh [6], this paper has discussed the problem of ground-to-air propagation when the ground radio terminal is located inside a forest. This problem is quite important once constitutes the theoretical basis for the evaluation of the electrical field intensity when executing search and rescue missions in areas covered by dense vegetation. The experimental part of this work was carried out in the Brazilian Amazon jungle.

From this study, two important conclusions can be highlighted: a) Referring to the mathematical model, it was verified that the refracted wave of equation (1) is sufficient to evaluate the field intensity when the airplane or the helicopter is flying several tens of meters above the forest top. In this situation, as it was shown previously, the lateral wave can be disregard; b) A reasonable agreement was observed when comparing theoretical and experimental results. In this context, it was pointed out that an important source of error in these measurements was related to the difficulty to stabilize the helicopter in a fixed point.

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