RADIO WAVE PROPAGATION IN THE AMAZON JUNGLE

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INTRODUCTION

Amazon Region

DENSE RAIN FOREST

Annual precipitation of the order or higher than 2000 mm

HOT AND HUMID CLIMATE

Median temperature along the year approximately constant between 25 and 28º C

LARGE NUMBERS OF RIVERS

INTRODUCTION

Amazon Region

INTRODUCTION

Amazon Region (Aerial View)

INTRODUCTION

Amazon Region (Igarapé – Small River)

INTRODUCTION

Radio wave attenuation due to vegetation is the major constraint to the path range of a communication system operating in a jungle environment.

Three propagation paths should be considered in the analysis of this problem.

1) Both stations immersed in the jungle;
2) Both stations on the ground, but one outside the jungle;
3) Ground-to-air link.

INTRODUCTION

The signal attenuation depends critically on the operating frequency and on the values of the electrical parameters of vegetation.

The optimum frequency is chosen as the best compromise between low signal attenuation, an acceptable level of atmospheric noise and the physical dimension of a portable transceiver compatible with the mobility required for operation within the forest.

The electrical characteristics of vegetation is estimated through an experimental procedure which involves the comparison of direct measurement of field strength decay versus distance with numerical values derived from the theoretical model of the lateral wave.

LATERAL WAVE

PROPAGATION MECHANISMS

1. **FOREST GEOMETRIC-OPTICAL COMPONENTS (DIRECT AND REFLECTED RAYS)**

   d < 0.5 km

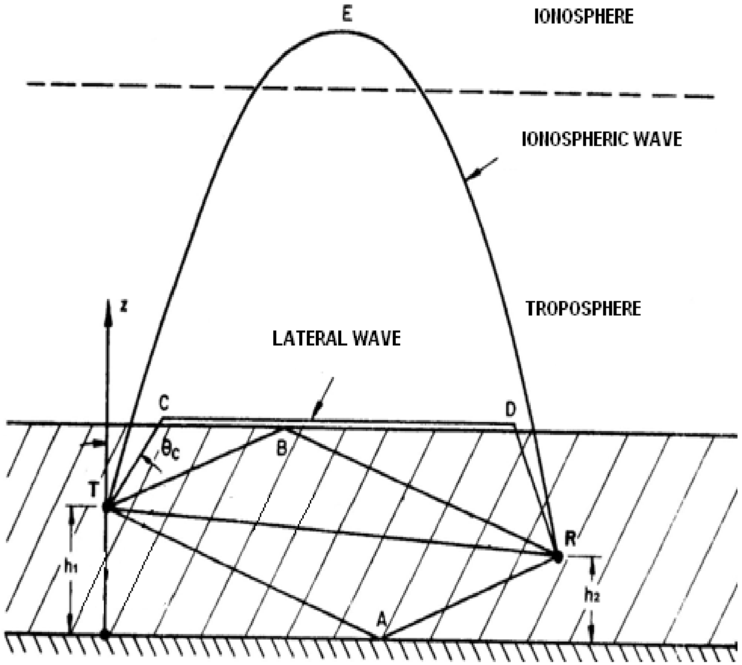
2. **SKY-WAVE COMPONENT**

   d > 10 ~ 20 km

3. **LATERAL WAVE**

   PREDOMINANT MECHANISM

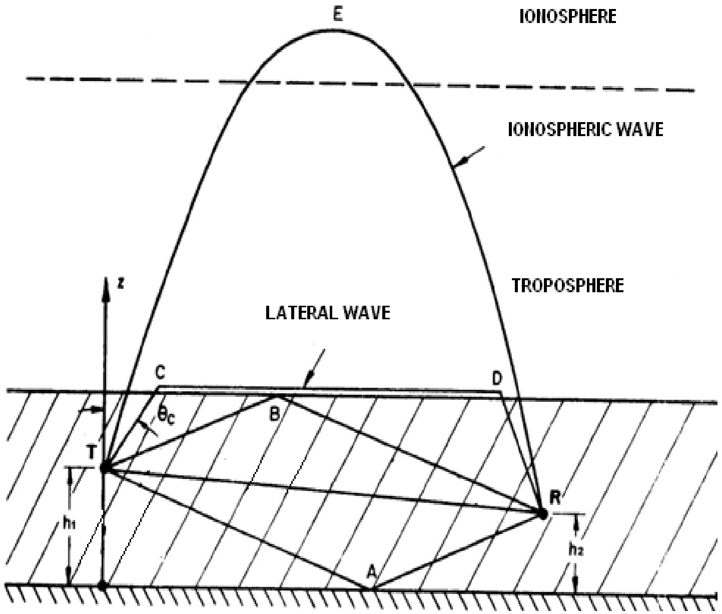
   d < 10 km



LATERAL WAVE

$$\sin\theta_c = \frac{1}{n_f}$$

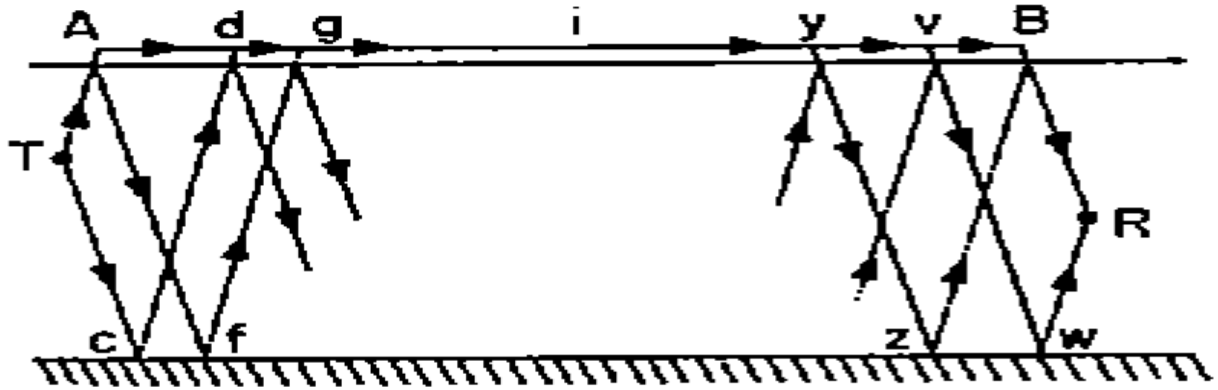
$$n_f = (\varepsilon_f - j60\sigma_f\lambda)^{1/2}$$



is the index of refraction of the forest, λ is the wavelength and ε_f and σ_f are the relative permittivity and the conductivity of the forest, respectively.

LATERAL WAVE

RAYS FOR THE LATERAL WAVES IN THE PRESENCE OF A REFLECTING GROUND PLANE



PRIMARY RAY TABR IS PREDOMINANT

LATERAL WAVE

$$A_f\,(dB) = -20\log\left|2F_A\, f(h_1)\, f(h_2)\right|$$

$$F_A = \frac{\lambda}{2\pi d}\frac{1}{n_f^2 - 1}$$

F_A – lateral wave attenuation function

$$f(h_{1,2}) = \exp\left\{-\frac{2\pi}{\lambda}\operatorname{Im}\left[(n_f^2 - 1)^{1/2}(h_f - h_{1,2})\right]\right\}$$

$f(h_1,h_2)$ – high gain function

d – distance between transmitter and receiver

h_f – forest height; $h_{1,2}$ – antenna heights

LATERAL WAVE

Electrical Characteristics of the Vegetation

Transmitting antenna: vertical monopole 5 meters long;

Path distances: 2 to 16 km;

Frequencies: 2.691 / 3.821 / 4.614 / 5.935 / 8.042 / 10.254 / 13.4012 / 18.170 / 22.851 MHz;

Receiving site: calibrate receiver with a vertical monopole mounted on a reflecting plane;

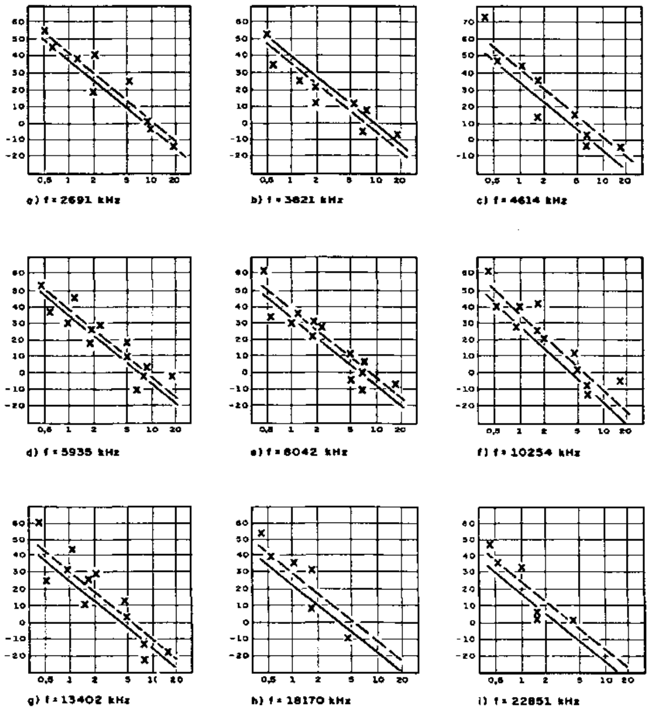
Average tree height: 30 meters.

The next figure shows the measured values of the electric field intensity (x) and the corresponding median curve for each frequency (dashed curves). In using the lateral wave model, the best fit to these experimental data was achieved for ε_f = 1.2 and σ_f = 0.2 mS/m.

COMPARISON BETWEEN THE THEORETICAL MODEL (SOLID LINES) AND THE EXPERIMENTAL RESULTS (X)

Horizontal scale: distance in km;

Vertical scale: Field intensity in dBμ/m



LATERAL WAVE

Optimum Frequency

COMPROMISE

LOW ATTENUATION → LOW FREQUENCY

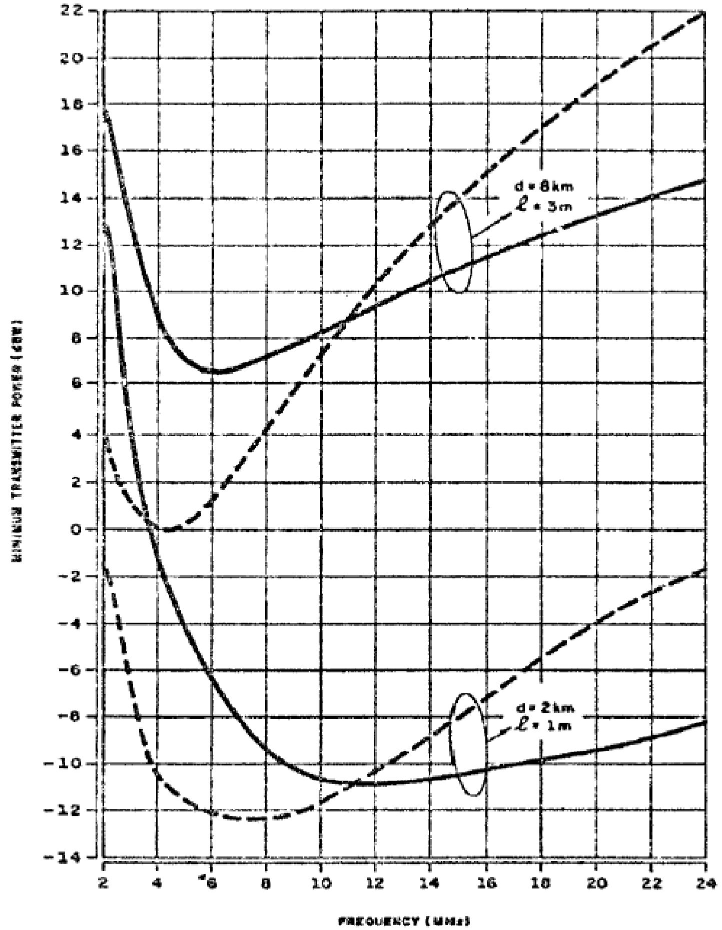
↙ ↘

HIGH ATMOSPHERIC NOISE LEVEL ANTENNA LESS EFFICIENT

OPTIMUM FREQUENCY → AROUND 10 MHz

LATERAL WAVE

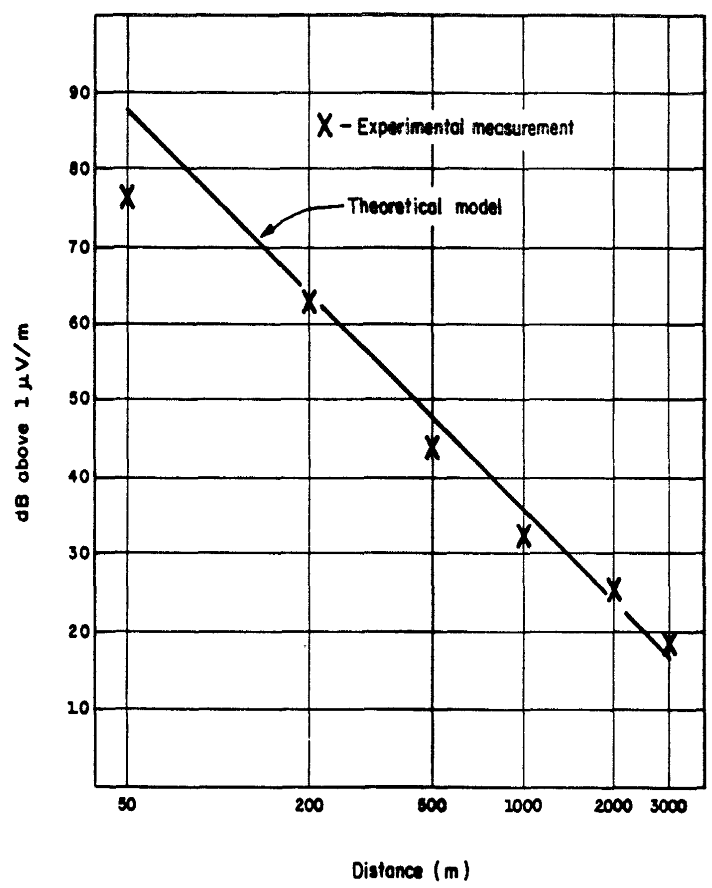
Optimum Frequency



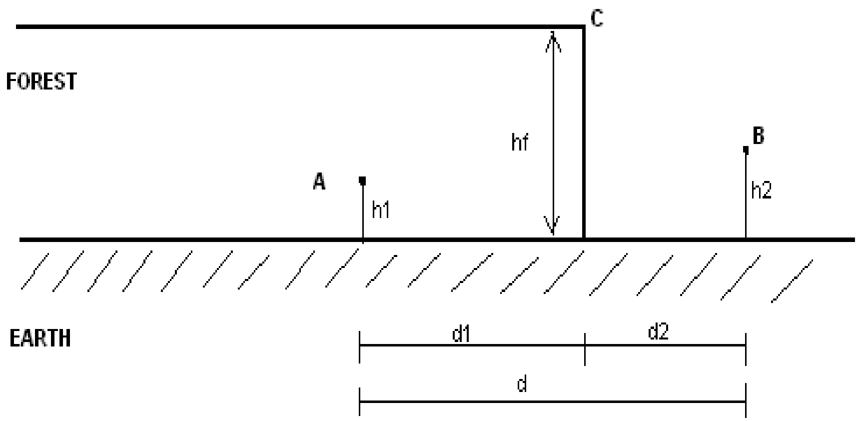
LATERAL WAVE

Validation Test

A 15 W transmitter and a receiver were located inside the forest. The receiver was fixed while and the transmitter was moved along a 3000 meters path. Several measurements were made from 50 to 3000 m. The frequency was 10.25 MHz. As depicted in the figure, the comparison between the theoretical results derived from the lateral wave model with the experimental data shows a very good agreement.



ONE RADIO STATION OUTSIDE THE FOREST



ONE RADIO STATION OUTSIDE THE FOREST

$$20\log|F| = -20\log\left|\sqrt{2}\int_0^{\nu}\exp\left(-j\frac{\pi u^2}{2}\right)du\right|$$

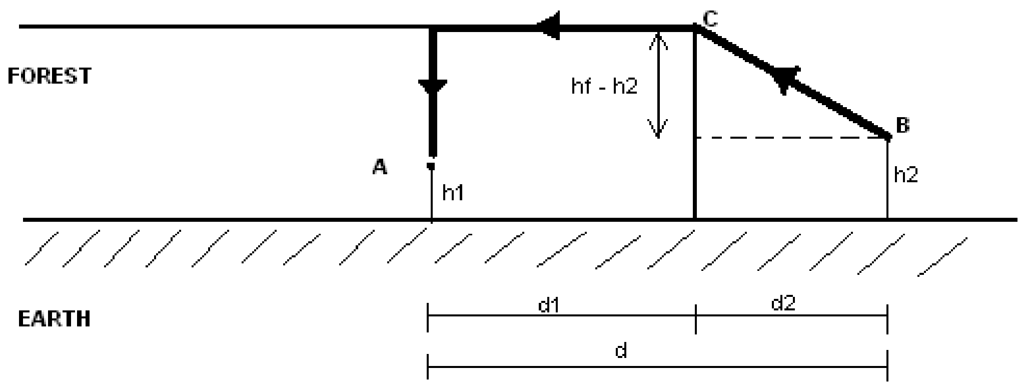
$$A(dB) = -20\log\left|\frac{\lambda}{2\pi d_1}\frac{1}{n_f^2-1}\right|$$

$$\nu = \sqrt{2}\,(h_f - h_2)/R$$

$d_1 >> d_2$

$$-20\log\left|\exp\left\{-\frac{2\pi}{\lambda}\operatorname{Im}\left[(n_f^2-1)^{1/2}(h_f-h_1)\right]\right\}\right| - 20\log|F|$$

R – Fresnel radius at C



ONE RADIO STATION OUTSIDE THE FOREST

COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS

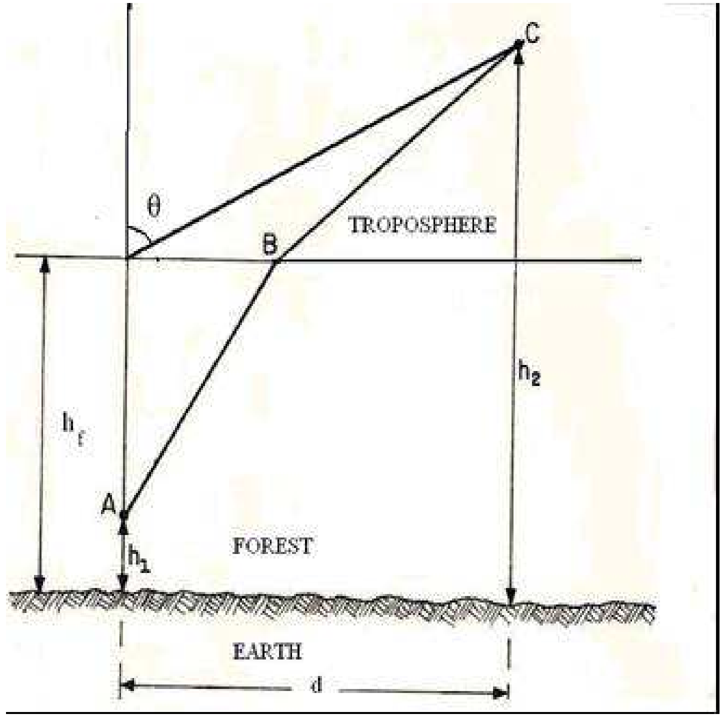
Distance (m)	A_t – Theoretical Attenuation (dB)	A_m – Measured Attenuation (dB)	Error $A_t - A_m$ (dB)
100	37.3	33.9	3.4
125	39.2	40.0	- 0.8
150	40.9	43.4	- 2.5

GROUND-TO-AIR PROPAGATION MODEL

$$\left|\frac{E}{E_0}\right| = \left|\frac{2\cos\theta}{m\cos\theta + \left(n^2 - sen^2\theta\right)^{1/2}} - j\,\frac{\lambda m sen^2\theta}{\pi r\left(n^2 - sen^2\theta\right)}\right| x$$

$$p\exp\left\{\frac{2\pi}{\lambda}\left[\mathrm{Im}(n^2-1)^{1/2}\right](H-h_1)\right\}$$

The physical interpretation of the above expression 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 sum 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 refracted wave. It should be noted that the refracted wave disappears when θ = 90º. Around this value, the lateral wave predominates.



Distance (km)	Full solution (dB)		Refracted wave (dB)		Measuments* (dB)
	HPol	Vpol	Hpol	Vpol	
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

GROUND-TO-AIR PROPAGATION - EXPERIMENTAL DATA

*Average values for several measurements around the reference distance

Measurements were carried out in the **Brazilian Amazon jungle** in the frequency of **10 MHz** with a helicopter flying at an **average height of 120 m.** The maximum horizontal distance of 16 km.

FINAL REMARKS

APPLICATIONS

Search and Rescue

The unknown radio equipment to be localized in the jungle must be capable to operate with a voice channel or emitting a help radio signal put in action by some automatic device.

Military and Scientific Missions

RESEARCH TO BE DEVELOPMENT

Interaction Antenna-Forest

Antenna efficiency

Optimum antenna design

Propagation Studies - Measurements

One station outside and the other inside the forest

Ground-to-air

VHF and UHF Bands

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RESEARCH UNDER DEVELOPMENT

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  - *Antenna efficiency*
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- Propagation Studies - Measurements
  - *One station outside and the other inside the forest*
  - *Ground-to-air*
- VHF and UHF Bands