

Analysis of Radiowave Propagation in Forest Media Using the Parabolic Equation

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Abstract—This paper presents preliminary results about path loss prediction in vegetation using the parabolic equation technique. The trees were modelled in a flat and a triangular format and their effect in the path loss was analysed. A real measurement scenario with trees was also modelled and compared with the PE simulation. The use of the parabolic equation method to study the path loss attenuation in forest environments seems to be very promise.

Index Terms—Parabolic equation, propagation, forest environment.

I. INTRODUCTION

The Parabolic Equation (PE) technique has been widely used to solve radio wave propagation problems [1]–[6].

The PE was performed in three stages. In the first stage, analytical methods were used to simplify the original wave equation, which is a non-linear electromagnetic problem. In the second step, the PE solution was implemented by a numerical method, using a Split-Step Fast Fourier Transform (SSFFT) which is based on the pseudo differential operator theory. In the third stage, PEM was applied in the specific study of radio wave propagation in the vegetation environment.

Studies involving radio wave propagation in forests has also been of a large interest. The influence of the canopy format of trees and also the presence of the forest litter has been considered to investigate the path loss in forests and the magnitude of electromagnetic field intensity under these conditions [7], [8].

The propagation environment influences the operation of radio systems. In this work we considered the parameters of permittivity and conductivity of foliage to estimate the losses of radio signals. Also, as an initial study of the application of the parabolic equation technique under forest environments, the effect of a flat and a triangular tree modelling in the path loss will be considered.

II. PARABOLIC EQUATION

The standard 2D Parabolic Equation (SPE) can be obtained from the Helmholtz's equation. This equation is in the form of Eq. 1 [5], [6]

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial z^2} + k_0^2 n^2 U = 0, \quad (1)$$

where k_0 is the wave-number in free space, n is the refractive index, x is the range and z is the height above ground

coordinates and $U(x, z)$ is the scalar electric or magnetic field component, depending on the polarisation of the field. It is defined a paraxial direction x , where a reduced auxiliary function, $u(x, z) = e^{-jk_0 x} U(x, z)$, is defined. Using the auxiliary function the Eq. 1 can be written as Eq. 2,

$$\left[\frac{\partial^2}{\partial z^2} + 2jk_0 \frac{\partial}{\partial x} + k_0^2 (n^2 - 1) \right] u(x, z) = 0. \quad (2)$$

The parabolic equation can be numerically solved using the Split-Step Fourier-Transform (SSFT) method and the method is named is known as Split-Step Parabolic Equation (SSPE) [5]. The standard PE can be numerically solved using a Fourier transform from the z domain to the spectral k_z domain [5], as it is a first-order ordinary differential equation.

The SSPE Narrow-Angle Parabolic Equation (NAPE) is numerically solved as in Eq. 3

$$u(x + \Delta x, z) = e^{[jk_0(n^2-1)\frac{\Delta x}{2}]} \times F^{-1} \left\{ e^{(jk_z^2 \frac{\Delta x}{2k_0})} F\{u(x, z)\} \right\}, \quad (3)$$

and the Wide-Angle Parabolic Equation (WAPE) is numerically solved as in Eq. 4,

$$u(x + \Delta x, z) = e^{[jk_0(n-1)\Delta x]} \times F^{-1} \left\{ e^{(jk_z^2 \frac{\Delta x}{k_0 + \sqrt{k_0^2 + k_z^2}})} F\{u(x, z)\} \right\}, \quad (4)$$

where F and F^{-1} denote the fast Fourier transform and the inverse fast Fourier transform, respectively, $k_z = k_0 \sin \theta$ and θ is the propagation angle.

A Gaussian antenna pattern in the vertical wave-number domain, as in Eq. 5 [5], is applied as initial field to the SSPE method, at a distance (z_s),

$$\tilde{u}(0, k_z) = g(k_z) \exp(-jk_z z_s) + \Gamma g^*(-k_z) \exp(-jk_z z_s), \quad (5)$$

where $g(k_z)$ is in the form of Eq. 6, z_s is the antenna height, θ_{bw} is the antenna 3 dB beamwidth and θ_{elv} is the tilt angle. The tilt is implemented using the transform $g(k_z) = g(k_z - k_0 \sin(\theta_{elv}))$ where

$$g(k_z) = \exp\left(-\frac{k_z^2 \ln 2}{2k_0^2 \sin^2(\theta_{bw}/2)}\right). \quad (6)$$

A vertical field profile is calculated as an iterative process, using the field values obtained in the previous position and boundary conditions are applied at the top and bottom boundaries of the domain [5].

An adequate discretisation must be implemented in the height and range increments, Δz and Δx , respectively. The height discretisation must satisfy $\Delta z \leq \lambda/(2\sin\theta_{max})$ and for the range increment, Δx , it can be applied a discretisation much larger than the wavelength [5].

III. RESULTS

Aiming the validation of the developed parabolic equation code, it was simulated an edge scenario, mixed with sea water as in [3]. The simulation was performed in a frequency of 100 MHz and the Gaussian antenna profile has a beamwidth of 100 degrees. The ground parameters was $\epsilon_r = 15$ and $\sigma = 0.012$ S/m and the sea water electrical parameters was $\epsilon_r = 81$ and $\sigma = 2$ S/m. Results can be seen in Figure 1 and was in accordance with the reference, validating the developed code.

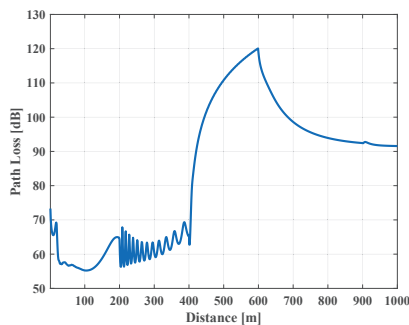


Fig. 1. SSPE validation under an edge scenario.

The propagation in forests was simulated in two different conditions. In a first scenario, it was considered a flat modelling of consecutive trees (with 10 meters height), with a range of 10 m, 20 m and 30 m, starting 100 m from the transmitter antenna and also with a range of 30 m of trees starting 500 m for the transmitter antenna. The field distribution over height and range for flat trees in a frequency of 800 MHz can be seen in Figure 2 and their effect in the path loss can be seen in Figure 3.

The effect of the presence of the flat trees can be clearly seen in the path loss. There is an oscillation in the path loss when the field interacts with the presence of the trees and an additional attenuation of almost 10 dB related to the flat earth scenario. Each increase of 10 m of trees presents and additional attenuation of almost 5 dB to the path loss. When the field interacts with a range of 30 m of trees in the range of 500 m, an additional loss of approximately 30 dB is added to the radio link.

In a second scenario it was considered a triangular modelling of consecutive trees (with 10 meters height), with

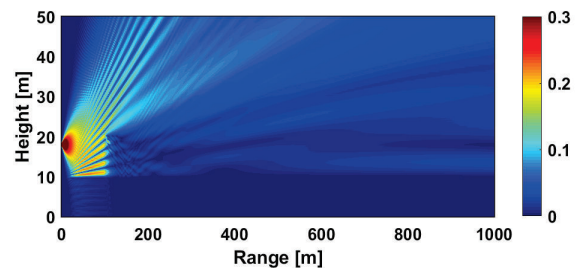


Fig. 2. The pattern of field distribution over height and range for flat trees.

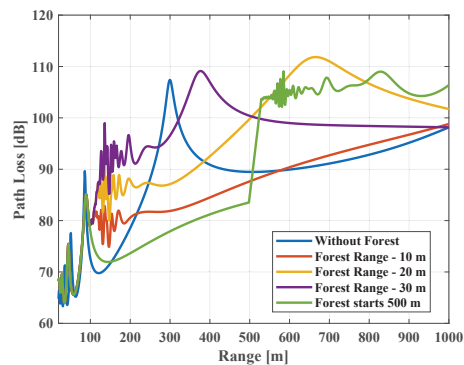


Fig. 3. Path loss as a function of range - flat trees.

a range of 10 m, 20 m and 30 m, starting 100 m from the transmitter antenna and also with a range of 30 m of trees starting 500 m for the transmitter antenna. The field distribution over height and range for triangular trees in a frequency of 800 MHz can be seen in Figure 4 and their effect in the path loss can be seen in Figure 5. Similar effects of the flat trees modelling can be found in this situation.

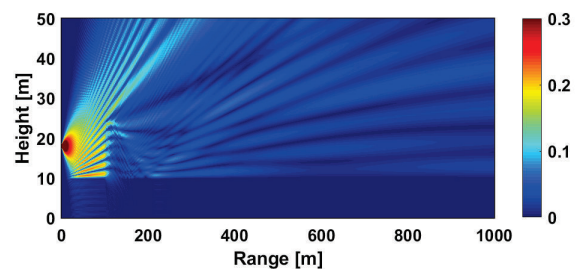


Fig. 4. The pattern of field distribution over height and range for triangular trees.

In both scenarios it was also considered an underlying surface with a thickness of 10 m. The electrical properties of the underlying surface was $\epsilon = 4.1 - i0.02$ and for the canopy and trunks an effective relative permittivity of $\epsilon = 1.1 - i0.009$ as found in [7]. In all simulations, the frequency was 800 MHz, the transmitter antenna height was 8 m and the receiver antenna height was 2 m above the ground. The discretisation

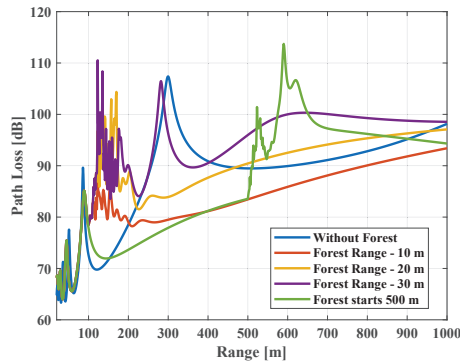


Fig. 5. Path loss as a function of range - triangular trees.

TABLE I
PE COMPARISON WITH REAL FOREST MEASUREMENT DATA.

Point	Total path (m)	Veg. depth (m)	Normalised Attenuation (dB)	PE (dB)
MP1	35.3	7.1	0.0	0.0
MP2	51.5	16.5	33.2	23.4
MP3	63.3	28.3	7.1	41.5
MP4	71.7	34.9	18.4	33.4
MP5	80.0	44.9	38.7	36.5
MP6	90.9	49.0	23.5	41.1
MP7	99.9	61.4	18.1	40.3
MP8	108.6	69.2	61.3	40.3
MP9	117.3	76.7	32.1	52.6
MP10	127.6	85.2	49.7	42.2
MP11	136.1	93.3	52.4	45.0
MP12	144.2	101.4	44.9	40.3

in range was 1 m and 0.1 m in height.

The parabolic equation simulation was also compared with real forest measurement data. The measurement scenario can be seen in Figure 6. The measurements were performed at 1.3 GHz in 12 trees at Fermi Avenue. The vegetation range of the measurement campaign was between 26.2 and 144.2 m and the height of the TX antenna was 3.5 m and RX antenna was 5.3 m.

In this preliminary analysis the trees were modelled in a rectangular format, with no spaces between the trees. So all the trees were model from 26.2 and 127.6 m, with a vegetation depth of 101.4 m. It was considered a medium ground with a thickness of 10 m, with electrical properties $\epsilon = 15 - i0.012$ and for the canopy and trunks an effective relative permittivity of $\epsilon = 1.1 - i0.009$. The discretisation was 0.1 m both in range and in height. Results can be seen in Table I and Figure 7 and shows a good agreement.

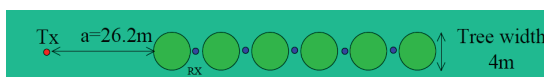


Fig. 6. Measurement campaign scenario.

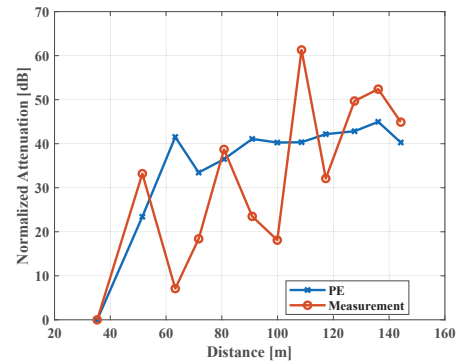


Fig. 7. Results for PE in comparison with measurements.

IV. CONCLUSION

The use of the parabolic equation method to study the path loss attenuation in forest environments seems to be very promising. It can be clearly seen the effect and importance in modelling the format of trees in a forest radio link. It is intended in the future to use the parabolic equation method for higher frequencies, to use other propagation scenarios and to compare the results with new measurements. A better model of trees also will be considered in future work.

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