PROPAGATION OF WAVES IN A FOREST : A TWO DIMENSIONAL FULL WAVE APPROACH

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INTRODUCTION

The forests represent the quarter of the emerged lands and have a great part in the climatology of the earth and the economy of several countries. Because of these characteristics, the study of the interaction beetween an electromagnetic wave and a forest medium represents a great interest particullarly in remote sensing.

More specifically in the microwave domain where the backscattered field depends for a large part on structures like leaves, twigs and branches, and is partially linked to the global woody volume[1]. At X-band and C-band, a phenomena of saturation appears for low values of biomass, thus limiting the possibilities of measurements[2]. At L-band and P-band, the wavelengths allow to increase the dynamic of the signal to higher biomass value, but even at P-band (300 MHz), the saturation point is below the 4/5 of the estimated total terrestrial biomass[3]. Nevertheless, these bands are frequently used in forestery. Recently the VHF band has been also used for this kind of study, for example with the SAR system CARABAS with good results concerning the measurement of forest parameters.

I. NUMERICAL MODEL

We consider a forest made of a finite and arbitrary number of parallel rows of trees, spaced regularly or not. The length of each row must be large with respect to the wavelength so as to be considered as infinite. In each row the trees are densely packed and thus can be considered as an infinite cylinder with a cross-section given by that of a tree, see Figure 1. The flight path is located in a plane perpendicular to the rows, the incident plane wave and the scattered field are propagating in this same plane and are invariant along the axis of the rows. With these hypotheses, we have defined a 2D scattering problem where only two polarizations need to be considered: TM, with the electric field parallel to the rows, and TE with the electric field in the cross-sectional plane. The frequency band of interest runs from 20 MHz to 90 MHz. We shall also consider the case of an object, a cylinder of arbitrary cross-section, placed in by the forest.

A. Domain Integral representation:

The computational domain is the incidence plane (x,y) divided into two half-planes D_1 and D_2. The upper one D_1 is where the trees are located and the lower one D_2 is the ground. The incidence plane wave propagates in D_1 at an incidence defined by the angle θ_{inc}. When the trees are removed from D_1, the total electric field in this half space is called the reference field and is given by:

$$\vec{E}_0(\vec{r}) = \vec{E}_{inc}(\vec{r}) + \vec{E}_{ref}(\vec{r}) \qquad (1)$$

Where $\vec{E}_{inc}(\vec{r})$ is the direct incident field and $\vec{E}_{ref}(\vec{r})$ is the field reflected by the ground plane. The total field in D_1 verifies equation (2) :

$$\vec{E}_1(\vec{r}) = \vec{E}_0(\vec{r}) + \left(k_1^2 + \nabla\nabla_r\right)\int_\Omega A(\vec{r}')\,\overline{\overline{G}}_1(\vec{r},\vec{r}')\,\vec{E}_1(\vec{r}')\cdot d\vec{r}' \qquad (2)$$

Where Ω is the domain occupied by the trees, $\vec{r}'$ the coordinate vector of a point in Ω and $A\ (\vec{r}') = \left(\varepsilon(\vec{r}') - \varepsilon_1\right)/\varepsilon_1$, $\varepsilon(\vec{r}')$ is the complex permittivity at $\vec{r}'$ and $\overline{\overline{G}}_1\ (\vec{r},\vec{r}')$ is the dyadic Green's function of the two-layered medium. Equation (2) allows to consider the two cases of polarization: the TM case – incident field is perpendicular to the (x,y) plane - and TE case – incident field is in the (x,y) plane.

B. Green's function :

The dyadic Green's function of a two layered medium is obtained by solving in the spectral domain the Helmoltz equation with the appropriate boundary conditions on the interface and by taking into account the symetry of the 2D model.

In order to solve (2) , the trees are discretized by the Method of Moments [4] into L elementary cells, like in Fig. 2, small enough to consider the electric field to be constant inside. Equation (2) reduces to a system of linear equations (3) where the unknows are the total field existing inside each cell:

$$[A_{m,n}][E_{1,n}]=[E_{0,m}] \qquad (3)$$

where m= 1,2...,L and n= 1,2...,L and where $\vec{E}_{1\,n} = \vec{E}_1(\vec{r}'_n)$, $\vec{r}'_n \in$ cell number n and $\vec{E}_{0,m} = \vec{E}_0(\vec{r}'_m)$, $\vec{r}'_m \in$ cell number m.

C. Parameters of the model.

Each tree is individualized and discrized into cells (figure 1). The trunk is defined by its height h, its diameter ∅ and the branches by their lenght and their diameter. The corresponding geometric parameters are obtained thanks to data computed by the AMAP software applied to maritime pines on a site in « Les Landes » forest in the southwest of France. The wood constituing the trunk and the branches have a permittivity equals to ε_{wood} = 7.98 + j 1.43 [5]. The frequency range, [20 MHz, 90MHz] over which the scattered field is computed allows us to model the main parts of a tree only, the others being too small compared to the illuminated wavelength ($<\lambda_0/10$). The dielectric parameter of the ground is ε_{soil} = 10 + j 3.6.

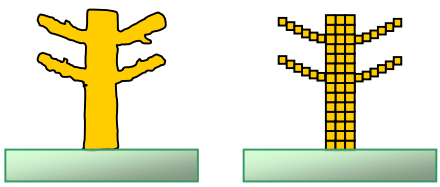


Fig. 1. Going from a continuous configuration to a discretized one

II. RESULTS

A. Backscattering coefficient

From Equation (4) we define the field scattered by the trees as:

$$\vec{E}_{scatt}(\vec{r}) = \vec{E}_1(\vec{r}) - \vec{E}_0(\vec{r}) \qquad (4)$$

Where $\vec{E}_0(\vec{r})$ includes the specular field reflected by the ground plane. We have subtracted this contribution because, at the operating frequencies considered here, its high amplitude (-5 dB) will dominate that of $\vec{E}_{scatt}(\vec{r})$ the field scattered by the

trees. It must be noted that $\vec{E}_{scatt}(\vec{r})$ takes into account the interactions between the trees and the ground. We compute $\vec{E}_{scatt}(\vec{r})$ over a half circle of radius $r = 3\,000\,m$ located in the upper half space D_1. as a function of the observation angle Φ (Figure 1):

$$\sigma_0 = 20\log_{10}\left|\vec{E}_{scatt}\right| \qquad (5)$$

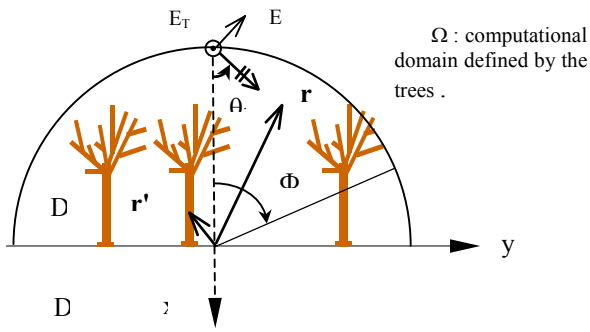


Fig. 2. The computational domain.

Two directions are particularly interesting : the backscattering direction ($\Phi = -\theta_{inc}$) and the specular one ($\Phi = \theta_{inc}$).

B. Contributions of elements of the tree.in the scattering field.

The electromagnetic modeling allows to study some basic configurations to isolate et understand the contributions of each element constituing the trees. To evaluate the different contributions of the trunk and the branches and identify the proportion of each kind of scattering, we study the case of a vertical and horizontal element of tree (object that represents a trunk or a branch with the same area and the same dielectric parameters). For each case, we compute the exact scattering field , the direct contribution, the ground-object contribution and the object-ground. To compare the exact scattering with these three contributions, we sum them together. The results are presented on the figures 3 (vertical trunk) and 4 (horizontal branches). The vertical trunk scatters more than the horizontal branches although they have the same area. In the two cases, the object-ground and ground-object contribution are equivalent but they represent the main part of the scattering field in the case of the vertical trunk and the direct contribution become neglectable.

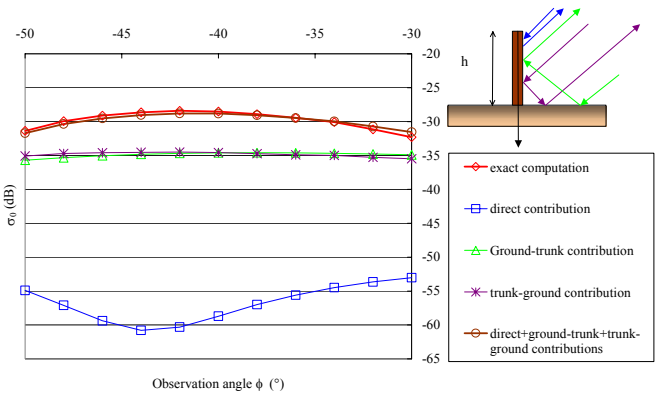


Figure 3 : TM contributions to the scattering field for a vertical objetc (h = 6 m) f = 50 MHz

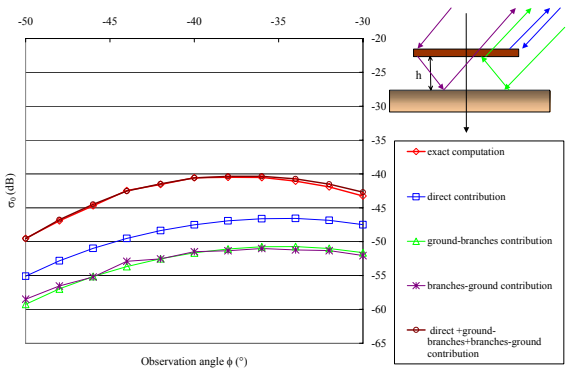
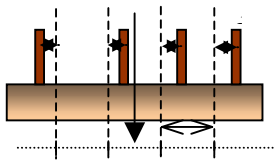


Figure 4 : TM contributions to the scattering field for a horizontal objetc (h = 6 m - lenght 6 m) f = 50 MHz

C. *Scattering field by an group of trees - approximate formula.*

In a previous work [6], approximate model using an interference formula was presented to reduce the computational time and the storage of data in the case of a regular array of trunks. In a real configuration, knowing the exact geomatric data may be a problem. The objectif of this section is to study the case where the trunk are not spaced regularly and to determine at the 50 MHz frequency what is the influence on the scattering field. Knowing the scattering pattern of one trunk allows to compute the scattering field by N trunks. The formula is given by :



$$E_{scatt.}(n) = E_{scatt.}(1) \times \left(1 + \sum_{i=1}^{i=N-1} e^{j\frac{2\pi}{\lambda_0}(\sin(\phi - \sin(\theta))d_{1\,i+1}} \right)$$

Figure 5 : Interference formula with an varaible spacing of the trunks (θ : incidence angle - ϕ observation angle)

Each Trunk is spaced of a distant of δd compared to the regular spacing case (figure 5). For 50 differents spacing of trunks, a statistical sum of the scattering field at an incidence angle of 40° is computed to study the sensibility at a modification of this parameter. The comparisons between the exact case and the interferences formula for 6, 8 and 10 trunks are given figure 6. The results are quite similar in the backscattering direction (ϕ = –40°).

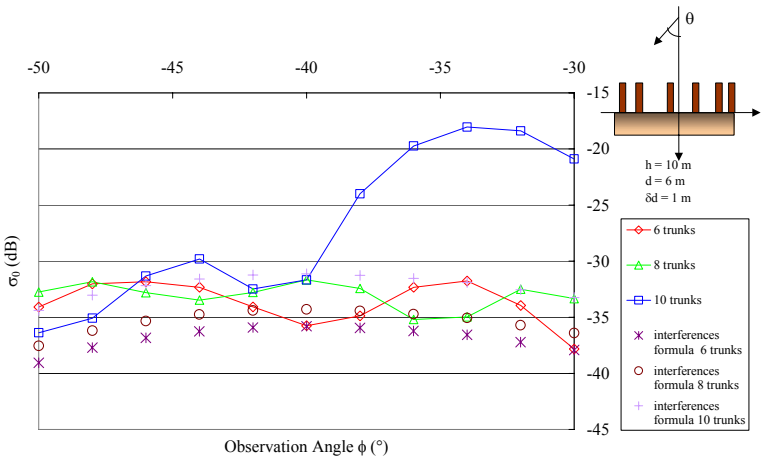


Figure 6 :Exact computations are obtained from the average of σ0 on computations with d = 6 m and δd = +/- 1 m (normalized distribution)

CONCLUSION

A two dimensional model of a forest is certainly a limitation by comparison to the reality of this complex media. But this simplification allows to show the efficiency of this method and . A generalization of the model for higher frequencies and 3D configurations of forests using an approximate formula is expected to provide acceptable results at a reasonable cost.

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