Precise and Efficient EM Modeling of Trees with WIPL-D Code

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Abstract: Electromagnetic tree modeling with metallic wires and plates, with distributed loadings, is presented in this paper. The approach proved to be useful at least for VHF frequency range and possibilities for extending frequency range are discussed. Stochastic algorithm for building WIPL-D models of trees is briefly described. Scattering from trees is calculated and presented for several tree examples to see how RCS clutter changes with involving more and more details in tree models. Limits for applications of proposed models are discussed, too.

Keywords: EM tree modeling, Monostatic RCS of trees, FOPEN radar

1. Introduction

Scattering of EM waves from trees plays important role in many civil and military applications. For instance: in remote sensing, designs of mobile communications, foliage-penetrating radar (FOPEN) etc. Capabilities of computers give opportunity to simulate not only human designed electromagnetic structures but also structures from nature, like trees for example. Having in minds tree simulations there are two basic tasks: 1) developing the stochastic algorithm that provides 3D models of trees and 2) arranging models to be as efficient as possible for EM simulations.

2. Tree modeling

Natural tree consists of branches that have different radii and orientations and leaves of relatively similar shape. Such tree can be modeled so that branches and leaves are made as dielectric bodies with appropriate electromagnetic properties. However, such models have too many unknowns and cannot be simulated time efficiently. Also, tree models can be used to simulate a part of the forest and such problems quickly grow beyond current capabilities of even the quickest computers today. For that reason many alternative ways of modeling a single tree have been developed [1-3]. The most of these models use 2D, 2.5D approach or simulate just the tree trunk as 3D dielectric body.

It is known that dielectric rods and plates can be efficiently modeled with metallic wires and plates with distributed loadings along them [4]. For the purpose of seeing the capabilities of such approach to tree modeling we performed numerical experiments. Let us consider the tree trunk 6 m high and 0.5 m in diameter. This trunk is modeled in two ways: 1) as dielectric rod and 2) wire of the same dimensions with distributed loading. Relative permittivity of wood is in the range of 5 to 15 [1], [2] so we adopted it to be 10. Dielectric losses are not included for this numerical experiment. Distributed capacitance along equivalent metallic wire is calculated as [4]

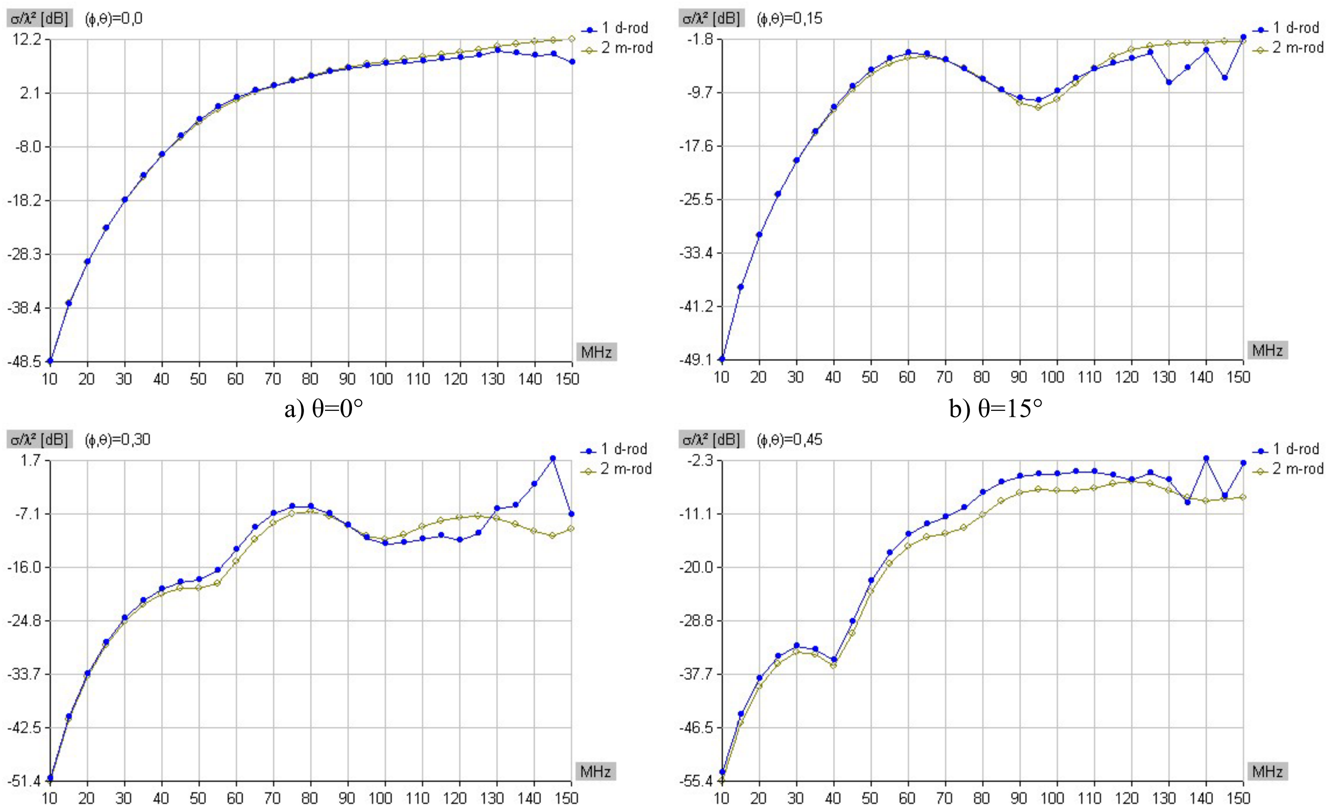
$$C_b = \varepsilon_0 \left(\varepsilon_r - 1\right) \frac{a}{2}, \tag{1}$$

where a is radius of the dielectric rod and ε_r is its relative permittivity, and distributed capacitance along plates is calculated as

$$C_l = \varepsilon_0 \left(\varepsilon_r - 1\right) \delta, \tag{2}$$

where δ is leaves thickness and ε_r is relative permittivity of leaves.

The rod and the wire are positioned along z-axis and RCS is calculated in one phi–cut due to rotational symmetry of the structure. Theta angle is measured from xOy plane. Results for three different theta angles along frequency are presented in Fig. 1.



a) θ=0°   b) θ=15°

c) θ=30°   d) θ=45°

Figure 1. Monostatic RCS for dielectric rod and its approximation with metallic wire with distributed loadings.

The best matching between these two models is obtained for the direction perpendicular to rod axis (θ=0°) and the worst matching is for the direction parallel to the axis (θ=90°). This is due to the fact that current along the wire is approximated with current at its axis and therefore there is no reflected wave in axis direction. From Fig 1. can be seen that metallic approximation of dielectric rod is very good for lower frequencies but for higher frequencies results start to deviate. Hence, there is some critical frequency up to that this approximation works. Roughly, this approach is well suited for all frequencies such that

$$a \le \frac{\lambda}{8}, \tag{3}$$

where λ is one wavelength at operating frequency and a is tree trunk radius.

Dielectric model at 150 MHz has around 1300 unknowns and metallic counterpart has 13 unknowns. Although results obtained with different models are not precisely equal, metallic model can give very good results with great reduction in the number of unknowns needed.

As usual tree do no have larger trunk than this supposed one, we calculate (3) the highest applicable frequency to be 150 MHz. This frequency could be even higher if the tree trunk is modeled as dielectric rod and other branches as metallic wires. Then the highest frequency is determined with the branch with highest radius. However, in this paper we considered only tree models made just from metallic wires and plates.

3. Stochastic Algorithm for Building Models of Trees

Stochastic algorithm for making full 3-dimensional tree models is developed. Each branch is considered as wire with different starting and ending radius. Starting radius is always greater or equal than ending radius. For each wire is defined distributed capacitance along it given with (1). Each leaf is made as flat rectangular plate with distributed capacitance given with (2) where leaves thickness is considered to be 1 mm. The tree is defined with a set of parameters such as range of lengths for branches, range of radius for branches, leaves width and length, maximal number of branching per each branch, number of branching levels, shrinkage factors for length and radius, range of angles in that next level branch is inclined due to previous level branch, maximal number of leaves per last level branches etc. Number of branching levels defines how many branching will be made after tree trunk. Shrinkage factors are in the range of zero to one and they control how next level branches lengths and radii are scaled due to range of previous level branches. Probability of branching increases as linear function from the beginning up to an end of the branch. Two examples of trees are given in Fig. 2 for the purpose of illustrating the outputs of described algorithm.

a) A tree model without leaves

b) A tree model with leaves

Figure 2. Stochastic tree models

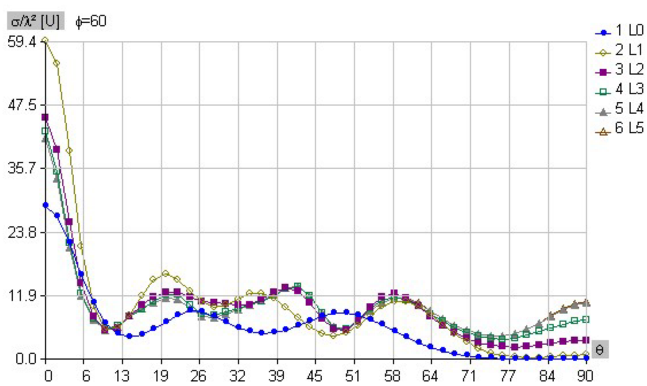
4. Monostatic RCS Clutter from Trees

Scattering from the trees is investigated as monostatic radar cross-section (RCS). Tree is positioned at the perfectly conducting plane (PEC) and illuminated with EM wave of $E_\phi = 1\,\mathrm{V/m}$ and $E_\theta = 1\,\mathrm{V/m}$. Relative permittivity of wood is considered to be 10 and for leaves 30. Numerical experiments are done at the frequency 130 MHz. Simulated tree trunk, the first, second, third, fourth level branches, and whole tree with leaves is shown in Fig. 3. Monostatic RCS for this tree for three different theta cuts is shown in Fig. 4. Presented data are obtained with WIPL-D code [5].

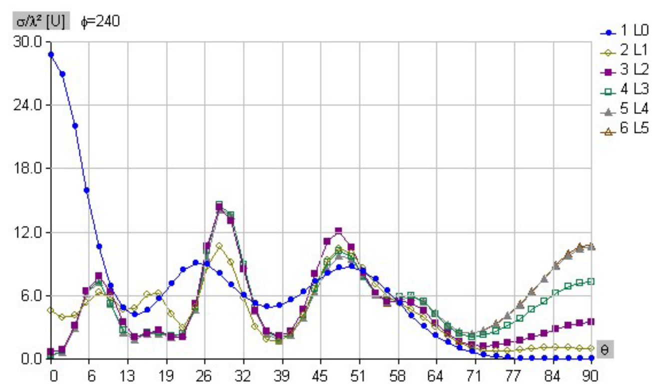
From the Fig. 4 it can be seen that if clutter from tree needs to be precisely modeled it is not enough to take just the tree trunk. Still for this frequency, with increase of the number of branching levels clutter converge and there is no need for taking into account more than five branching levels and leaves practically do not have any effect. For higher frequencies more branching levels and leaves should be taken into account if precise clutter is to be found.

a) L0 N=7 b) L1 N=25 c) L2 N=80 d) L3 N=272 e) L4 N=1263 f) L5 N=1928

Figure 3. Different tree models used for simulation and corresponding number of unknowns N



a) RCS for Φ=60°



a) RCS for Φ=240°

Figure 4. Monostatic RCS from tree models

5. Conclusion

Tree modeling with metallic wires and plates with distributed loading along them is time efficient way of modeling that gives reasonably well results. Modeling branches as dielectric bodies and all others branches as metallic wires can increase highest applicable frequency.

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