A simple scattering model for tree trunks

Nuno Leonor[#1], David Ferreira[#2], Rafael Caldeirinha[#*3] and Telmo Fernandes[#*4]

#Instituto de Telecomunicações, Polytechnic Institute of Leiria,
Alto do Vieiro – Leiria, Portugal

[1]2101533@my.ipleiria.pt
[2]david.ferreira@co.it.pt
[3]rafael.caldeirinha@ipleiria.pt
[4]telmo.fernandes@ipleiria.pt

[*]University of Glamorgan, Faculty of Advanced Technology,
CF 37 1DL Treforest, United Kingdom

Abstract

This paper presents the work carried out in an effort of modelling the scattering and absorption effects of single tree trunks with application to the discrete Radiative Energy Transfer (dRET) based model applications. The assessment of the proposed empirical model was performed against measurements of both metallic and dielectric cylinders, mimicking tree trunks, at several micro- and millimetre wave frequencies, i.e. 9.4, 18.8 and 37.6 GHz. These were carried out in a controlled environment, i.e. an anechoic chamber, so that frequency dependent effects could be evaluated.

1. Introduction

The discrete Radiative Energy Transfer (dRET) [1] based models have successfully been used to simulate radio wave propagation and scattering in vegetation environments, as presented in [2] and [3]. However, the existing models in the literature, which can be used for ground-to-ground propagation, do not account for the propagation mechanisms in the trunk layer of trees. In spite of the on-going work aimed at modelling of the scattering phenomena in inhomogeneous forests, as presented in [4] and [5], further improvements of the scattering modelling of single tree trunks are required, particularly in the side and back scattering regions of the trunk directional spectra. And thus, a refined scattering model for tree trunks is required to serve as input to the dRET framework. The formulation of the model presented in this paper was based on specific measurements carried out on metallic and dielectric (wood) rods inside an anechoic chamber, which otherwise would have been a rather difficult task if these were to be made outdoors in a real forest environment.

2. Single tree trunk characterisation

The dRET based models used to predict propagation phenomena associated to wave propagation through a formation of tree trunks, require as input parameters the scattering profile of each individual tree trunk [4, 5]. This paper presents an improved evaluation of the dRET input parameters associated to each trunk cell. Re-radiation patterns for both metallic and dielectric cylinders, mimicking tree trunks, were measured in a controlled environment, in order to characterise dRET trunk cells.

2.1. Measurement geometry

The geometry used in the measurement campaign is presented in Fig. 1. These measurements were carried out inside an anechoic chamber, of 5m wide by 6m long by 3m of height, in order to minimise interferences from unwanted signals and reflections.

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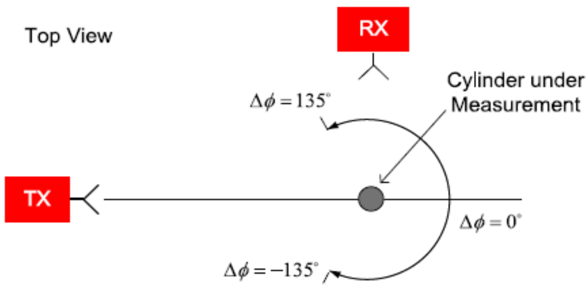

Fig. 1 – Measurement geometry.

The transmitter was placed at a distance of 1.85m from the cylinder (mimicking a tree trunk). This distance was chosen to ensure that the cylinder was illuminated by a plane wave. The receiver was rotated in an arc around the cylinder, from $\Delta\phi$ =-135 to $\Delta\phi$ =135º, with increments of 1º, at a constant radius of 0.7m. This rotation was performed by using a set of mechanical rigs and highly accurate turntables, fully controlled by a software application, therefore minimising errors which could be introduced while changing the receiver position.

2.2. Model development

The methodology followed in this study consisted of adapting the existing scattering profile as predicted by the RET theory [2], in order to obtain an overall better estimate of the signal scattering from tree trunks.

The original scattering model, also known as phase function, consists of a Gaussian function superimposed to an isotropic background level, as given (1), where α is the ratio of the forward lobe scattered power to the total power of the phase function, β represents the half power beamwidth of the forward lobe and γ is the rotation angle equivalent to $\Delta\phi$ as explained later.

$$p(\gamma) = \alpha \times \left(\frac{2}{\beta}\right)^2 \times e^{\left(\frac{\gamma}{\beta}\right)^2} + (1-\alpha) \tag{1}$$

The measured cylinders re-radiation patterns are slightly similar to that of a phase function. However there are some differences, particularly in the side and backscattering regions as for the case of dielectric cylinders. To overcome such discrepancies, the original model was adapted based on best curve fitting between measured and predicted scattering profiles, using a Root Mean Squared Error (RMSE) minimization criteria. The optimisation process has resulted in the model presented in (2), where $\Delta\phi$ is the rotation angle as depicted in measurement section, β is a function of frequency and cylinder material and α, which in turns depends on the cylinder radius. For the purpose of this work, α parameter was kept constant equal to 0.93. Finally, k_m is a twinkle factor that is also dependent of the cylinder material.

$$EM(\Delta\phi) = \left[\alpha \times \left(\frac{2}{\beta}\right)^2 \times e^{\left(-\left[\frac{2.\Delta\phi}{\beta}\right]^2\right)} + (1-\alpha)\right] \times [\sin(|\Delta\phi| \times 10^{-3})] \times e^{\left(\left|\frac{\Delta\phi}{55 \times k_m}\right|\right)} \tag{2}$$

Although this model is totally based on measurements with no theoretical foundations, the evaluated input parameters extracted through RMSE minimisation criteria for each one of measured re-radiation pattern, are related with the measurement frequency and trunk material. Table I presents the values of the developed model input parameters for each one of measured re-radiation patterns.

TABLE I
EMPIRICAL MODEL INPUT PARAMETERS

Re-radiation case		β	k_m
Frequency	**Cylinder material**		
9.4 GHz	Dielectric	$109.\lambda^{0.4656}$	0.55
	Metallic	$63.25.\ \lambda^{0.3592}$	2.5
18.8 GHz	Dielectric	$109.\lambda^{0.4656}$	0.55
	Metallic	$63.25.\ \lambda^{0.3592}$	2.5
37.6 GHz	Dielectric	$109.\lambda^{0.4656}$	0.55
	Metallic	$63.25.\ \lambda^{0.3592}$	2.5

2.3. Model performance evaluation and analysis

The developed empirical model was evaluated and assessed against measurement results for both metallic and dielectric tree trunks at all frequencies, as presented in Fig. 2.

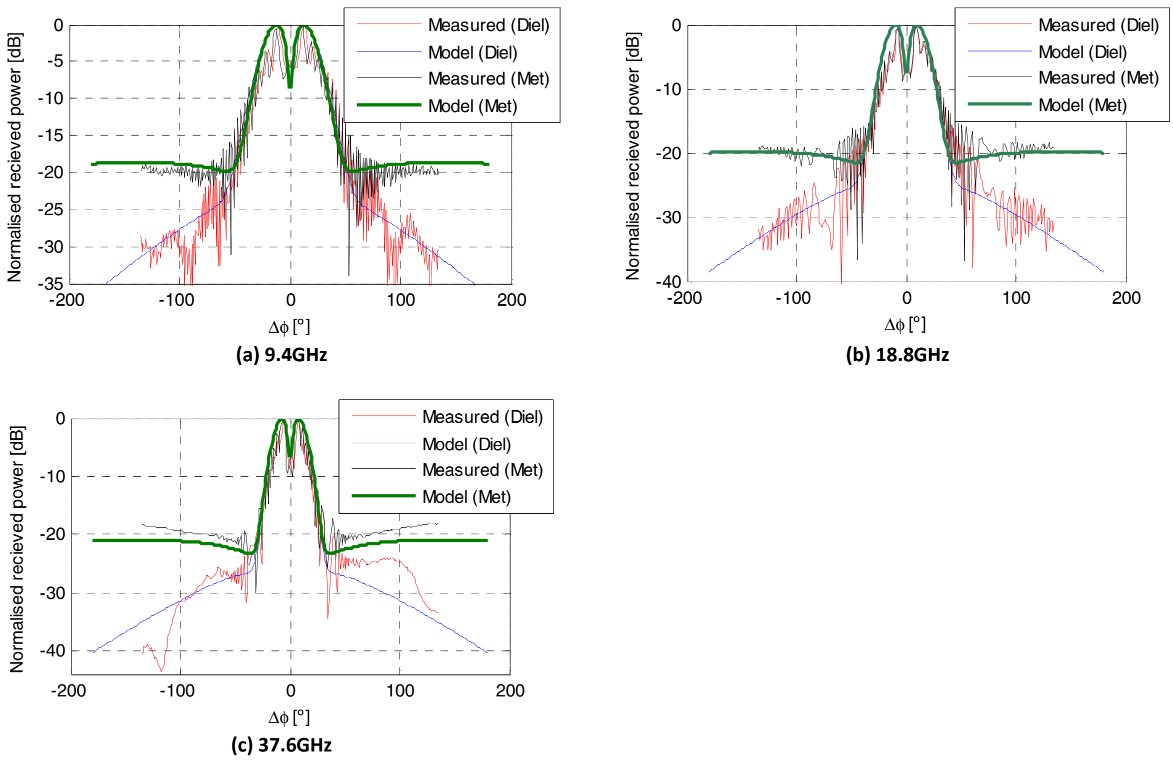

Fig. 2 – 37.6 GHz re-radiation measurement and model prediction comparison.

A comparative analysis was then performed based on an RMS error between measured and predicted by the refined model. This was obtained for both dielectric and metallic cylinders characterisation at 9.4, 18.8 and 37.6 GHz, a presented in Table II. From the table, one can observe that the proposed model refinement provides rather good improvements in terms of overall RMS error and therefore it is recommended to replace the original model.

TABLE II
EMPIRICAL MODEL PERFORMANCE

Re-radiation case		RMSE (dB)
Frequency	Cylinder material	
9.4 GHz	Dielectric	3.2242
	Metallic	2.7341
18.8 GHz	Dielectric	3.5192
	Metallic	3.0239
37.6 GHz	Dielectric	4.0426
	Metallic	2.5355

3. Conclusions

An important source of inaccuracy exhibited by the dRET modelling, is due to inaccuracies in the input parameter extraction procedures. Although the model seems to perform relatively well under a range of different situations, a better performance may be obtained. To this extent, the parameter extraction method has been refined in this paper, in order to provide a more accurate and reliable input parameters to the propagation model.

Further work will address appropriate measurements on real and/or realistic scenarios to characterise the radiowave propagation in the trunk region. More specifically, 3D re-radiation profile emanating from the trunk layer will be investigated on a scaled model inside an anechoic chamber for various trunk shapes and forms, diameter, roughness, height and spacing (regularly or arbitrarily distributed) and later on a real forest, typically on high raised canopy pine forests.

4. References

1. D. Didascalou, M. Younis, and W. Wiesbeck,“Millimeter-wave scattering and penetration in isolated vegetation structures", IEEE Transactions on Geo- science and Remote Sensing, vol. 38, pp. 2106-2113, 2000.

2. R. Caldeirinha, M. Al-Nuaimi, et al,“A generic model of 1–60GHz radio propagation trough vegetation - final report,” Tech. Rep.,Radiocommunications Agency, May 2002.

3. T.R. Fernandes "A discrete RET Model for Micro- and Millimetre Wave Propagation through Vegetation", Ph.D Thesis, University of Glamorgan, June, 2007.

4. T. Fernandes, N. Leonor, R. Caldeirinha, et al, “On the Applicability of the dRET Model to the Trunk Layer”, Proc European Conf. on Antennas & Propagation - EUCAP, Barcelona, Spain, April, 2010.

5. R. Caldeirinha, T. Fernandes, N. Leonor and D. Ferreira, “Extension of the dRET Model to include Scattering from Tree Trunks in Microcell Urban Mobile Scenarios, Proc IEEE Vehicular Technology Conference (VTC-Spring), Taipei, Taiwan, May, 2010.