PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

MILLIMETRE WAVE SCATTERING FROM VEGETATION TARGETS

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1. Introduction

Scattering and shielding of millimetre wave signals caused by vegetation targets are important factors in interference and path loss calculations for terrestrial and satellite communications [1-4]. There is a scarcity of data available on the millimetre wave scattering properties of vegetation targets. This paper reports attenuation through trees and the scattering pattern of tree foliage measured in an anechoic chamber at 20 GHz. Measurements are found to be in good agreement with a first-order multiple scattering model based on the radiative energy transfer theory.

2. Measurement System

The 20 GHz transmitter is composed of a 100 mW Gunn diode source, the output of which is fed to a standard horn antenna with 10 dBi of gain and 63° beamwidth. The receiver is a simple balanced mixer followed by a low noise intermediate frequency (IF) pre-amplifier. The received signal strength is recorded using a logarithmic amplifier the output of which is fed to a data acquisition board. The receiver uses a standard horn antenna with 20 dBi of gain and 21° beamwidth. The receiver noise floor is -70 dBm. The system is used inside a millimetre wave anechoic chamber which is equipped with a two-axis high precision rotary table.

3. Measurement of Foliage Attenuation and Bistatic Scattering

Three types of measurements were conducted for trees: 1) single tree measurements to evaluate the change in attenuation as a function of tree rotation angle, 2) transmission measurements to determine the attenuation rate as a function of the number of trees in the transmission path, and 3) bistatic scattering measurements to evaluate the azimuthal variation of bistatic scattering function. In all measurements, the transmit and receive antennas were set at the same height above ground and the transmitter remained stationary through the experiments.

Two distinctly different types of trees were selected for examination in this study: Ficus and Conifer. The Ficus tree has small, flat, simple leaves approximately 8 cm long and 4 cm wide. The tree, with a trunk diameter of 12 cm and a height of 1.5 m, has an average crown width of 75 cm. The Conifer tree, with needles rather than broad leaves, is 2.2 m high and has an average crown width of about 1 m.

3.1 Single-Tree Attenuation Measurements

For the single tree experiments, the tree was placed on a high precision two-axis rotary table at 2.35 m from the transmit and receive antennas. The antennas were set at an identical height of 1.6 m which provided transmission through Ficus at a height of 1.14 m and at 1.74 m through Conifers. The average foliage depth at those heights were approximately 75 cm and 1 m respectively. Thus, the distance between each of the antennas and the outer edge of the tree foliage was about 1.85 m. The far field distance D^2/λ of the receive and transmit antennas was 20 cm and 8 cm respectively.

The received signal was first measured with no tress obstructing the transmission path to provide the free space reference level. Then, with the tree standing on the two-axis rotary table between the transmitter and the receiver, the received signal was measured as a function of the tree rotation angle ψ over 360°. The tree was rotated in discrete increments of 0.5°. At each angle ψ the received signal was sampled at a rate of 10 KHz and the signal was averaged over 1 second. Fig. 1(a) and Fig. 1(b) show the measured attenuation, using vertically polarised antennas, versus tree rotation angle ψ for Ficus and Conifer respectively. The most distinctive of these results is the large fluctuations in attenuation. The mean attenuation measured for Ficus and Conifer is 18.2 dB and 26.9 dB respectively. For the Conifer tree, measurements were repeated under identical conditions but with horizontally polarised antennas. The attenuation was also found to exhibit large fluctuations with a mean value of 25.92 dB. This attenuation value is almost similar to that measured for vertical polarisation because of the random orientation of branches and needles.

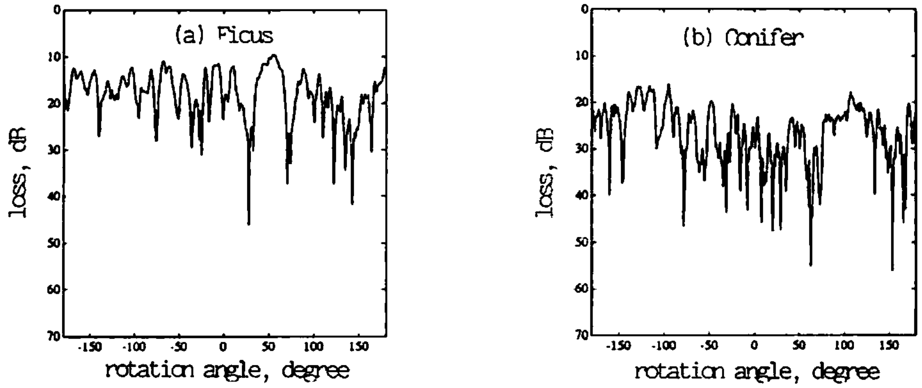

Fig. 1 Measured attenuation versus rotation angle using VV polarisation for Ficus and Conifer

Measurements were also made to examine depolarisation due vegetation targets. This was made, using the Conifer tree, by transmitting a vertically polarised wave while receiving the horizontal polarised component. It was found that the VH signal level measured with the tree in the transmission path, due to the random orientation of branches and needles, is about 4.89 dB higher than that obtained under similar conditions but with no trees obstructing the path.

3.2 Propagation Model

The random nature of tree foliage supports the use of transport theory [2-5] for characterising wave propagation through the canopy. The foliage is characterised in terms of the scatter cross section σ_s, absorption cross section σ_A, and the scatter function of the medium $p(\theta)$. In their analysis of millimetre wave propagation through foliage, Schwering and Johnson [5] proposed a scattering pattern of the form :

$$p(\theta) = \alpha f(\theta) + (1 - \alpha) \qquad 1$$

where $f(\theta)$ is the forward lobe of the scattering pattern and $(1 - \alpha)$ is its isotropic background. Ulaby et.al. [2] measured $f(\theta)$ of a tree and their results suggested a function of the form:

$$f(\theta) = 2(1 + \beta_s^{-2})e^{-|\theta|/\beta_s} \qquad 2$$

where β_s is the effective beamwidth of the forward lobe and is related to the 3dB beamwidth β_{3dB} by $\beta_{3dB} = 1.4\beta_s$.

In this study $f(\theta)$ for a Ficus tree was measured and found to be a Gaussian function given by:

$$f(\theta) = (2/\beta_s)^2 e^{-(\theta/\beta_s)^2} \qquad 3$$

where $\beta_{3dB} = 1.67\beta_s$.

The power received behind a foliage depth d is given by:

$$P = P_c + P_d \qquad 4$$

where P_c is the coherent component given by:

$$P_c = P_o e^{-\sigma_T d} \qquad 5$$

P_o is the free space signal power, σ_T is the extinction cross section $\sigma_T = (\sigma_s + \sigma_A)$ and P_d is the diffuse intensity. In their model, Schwering and Johnson [5], provide the formulation that relates the diffuse intensity P_d to the scattering properties of the medium which accounts for all order multiple scattering in the form of a series. In the analyses presented here, the same model is adopted but the formulation is limited to the first order solution, which takes the form:

$$P_d = P_o q e^{-\sigma_T d}\{\exp(\sigma_s \alpha d) - 1)\} \qquad 6$$

where q is a weighting factor related to the scattering pattern $p(\theta)$ and the radiation pattern of the receive antenna. For a receive antenna with a Gaussian pattern, q is given by:

$$q = \frac{\beta_a^2}{\beta_a^2 + \beta_s^2}$$

where β_a is the effective beamwidth of the receive antenna and is related to the 3 dB beamwidth β'_a by $\beta_a = 0.6\beta'_a$. The expression for q is valid only if $\beta_a \ll \beta_s$. For the experiments made in this study $\beta_a = 12°$ and $\beta_s = 30°$.

Substituting (5) and (6) in (4) gives:

$$P = P_o\left\{e^{-\sigma_T d} + q e^{-\sigma_T d}\{\exp(\sigma_s \alpha d) - 1\}\right\} \qquad 7$$

The expression for the received power given in (7) includes four unknown parameters: σ_T, σ_s, α and β_s. The value of α and β_s are found by measuring the scatter function $p(\theta)$ which is modelled by a Gaussian profile. The other two parameters are found from attenuation measurements as explained in section 3.2.2.

3.2.1 Scatter Function Measurement

With the transmitter remaining fixed in location and orientation and the tree remaining fixed in location, the receiver was moved to several locations on the perimeter of a circle. At each receiver position, θ (measured with respect to the line of sight), the tree was made to rotate about its vertical axis through 360° in discrete increments of 1°. The received power obtained at each rotation angle is the average of 10K samples. The scatter function is calculated by averaging the received signal power measured over 360° for each receiver position. Fig. 2 shows the scatter function measured for a Ficus tree together with the theoretical Gaussian function. The theoretical scatter function, with an effective beamwidth $\beta_s = 30°$ and $\alpha = 0.725$, is in good agreement with the measured one.

3.2.2 Variation of Attenuation With Foliage Depth

Attenuation measurements were made with one, two, three and four trees placed in the propagation path between the transmitter and receiver. The trees were placed close to one another, forming a continuous canopy. At each foliage depth, an azimuthal scan of the receiving antenna was performed over an angular range sufficient to cover the span of foliage and the received signal power was recorded. The measured points are normalised with respect to the free space signal level. The highest signal level measured during the azimuthal scan was used to determine the foliage loss. At small foliage depth, the received power is primarily determined by the coherent component P_c, and this decreases at a rate proportional to the extinction cross section of the trees. Based on transmission measurements for one tree, the extinction cross section can be computed by modelling the measured values as in equation (5). The value of σ_T obtained for Ficus is 6.75 Neper per metre. At larger foliage depths, however, multiple scattering becomes more important relative to the coherent component and eventually becomes the dominant mode. With β_s, α, and σ_T known, the expression of received power (7) ends up with one unknown σ_s. By comparing the expression to the measured values of attenuation for each of the four transmission measurements (one, two, three and four trees), four values of σ_s can be obtained. The average value, $\sigma_s = 4.5$ Neper per metre, is then used as an input into the computation to calculate the theoretical attenuation curve. Fig. 3 shows the measured attenuation values together with the theoretical curve where a good overall agreement has been established.

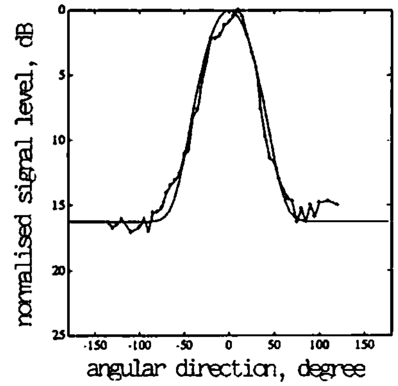

Fig. 2 scatter function measured for a Ficus together with a Gaussian modelled function

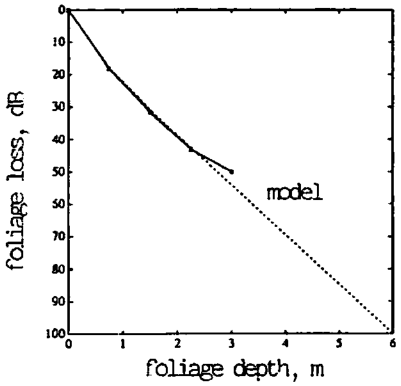

Fig. 3 comparison of measured attenuation of Ficus trees with theoretical model

4. Conclusions

Measurements at millimetric wavelengths inside an anechoic chamber have shown that attenuation due to foliage vary significantly with tree rotation angle. This is due to the physical asymmetry of trees. Attenuation of VV and HH polarised waves, because of the random orientation of branches, leaves and needles, is found to be almost similar. Cross-polarisation measurements have shown, however, that the VH component with a Conifer tree obstructing the path is about 4.86 dB higher than that obtained in free space.

The scatter function of a Ficus tree has been measured to have a narrow forward lobe with a Gaussian profile and an isotropic background. The change of attenuation rate is found to vary from a high value at small foliage depth to a smaller value at larger foliage depths. This behaviour is found to be in good agreement with the first order multiple scattering model based on transport theory, and is explained by the interplay between the coherent and diffuse component. Comparing experimental and theoretical results allow for the estimation of foliage propagation parameters.

5. References

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