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MEASUREMENTS OF RADAR BACKSCATTER FROM AN ARTIFICIAL TREE: AN INDICATION OF AZIMUTHAL VARIATIONS AND POLARISATION SENSITIVITY OF TREES

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ABSTRACT

Measurements of radar backscatter from an artificial tree were made in the laboratory at 6 and 10 GHz at horizontal incidence. The system has a resolution cylinder 18 cm in diameter and 11 cm long. The tree itself was only 30.5 cm high, so about half the tree was within the beam.

The scattering was azimuthally uniform. Tilted polarizations gave results favoring an angle corresponding with that of the branches. Measurements were made with and without leaves.

1. INTRODUCTION

The resolutions used in most previous measurements of vegetation precluded study of the effects of different plant components. Our recent measurements with a very-fine-resolution radar [1] and coarser-resolution measurements of trees by others [2-5] showed for the first time the contributions from parts of plants. We report here on controlled measurements in the laboratory using an artificial tree. This allowed us to control target parameters in a way not possible with a natural tree and to repeat measurements as necessary. The tree provided by Blanchard and Fung is like those used in their artificial forest [6].

Prior to the recent fine-resolution studies, theoretical scattering models for vegetation depended on comparison with gross scattering measurements. Several models use random variations of dielectric constant, treating the vegetation as a continuous inhomogeneous medium [7-8]. A "cloud model" [9] has been popular because it can fit some of the gross measured data, although it is clearly unrealistic. Other models use simple geometric shapes such as rods and disks [10-13]. Studies like this should allow more realistic models.

The trunk and branches of the artificial tree were rods of Lexan polycarbonate with a dielectric constant of about 2.5. The branches were about 6.35 mm in diameter and 10.2 cm long. The trunk was about 9.5 mm in diameter and 30.5 cm long. Branch locations were essentially random both in height and azimuth. The angle between branch and trunk was adjustable. Each branch had only a single aluminum leaf located at its end. The leaves were either circular (5-cm diamter) or elliptical (2.5x5 cm). The use of metallic leaves must have been significant, but no dielectric leaves were available for comparison.

Our SOURCESCAT FM-CW radar used a focused parabolic-reflector antenna to provide a narrow, nearly circular beam [14]. It operated at 6 GHz and 10 GHz with a range resolution of 11.5 cm and a footprint diameter less than 20 cm at 3.5 meters. The output of the radar was fed into a spectrum analyzer which gave signal vs. frequency, and therefore range. Data were recorded on tape for subsequent analysis. We measured at a distance of 3 meters with the antenna pointed horizontally at the target (normal to the trunk).

2. AZIMUTHAL ROTATION

To measure azimuthal dependence we rotated the tree over a full 360°, measuring every 5° with both linear polarizations (VV and HH) at X- and C-band and with cross-polarization (VH) at C-band. Each experiment was repeated three times and the average power calculated at each observation angle. We measured both with and without leaves to separate the contributions of the dielectric trunk and branches and the metallic leaves.

The returned power varied from -10 dBm to -33.5 dBm with a mean of -16.75 dBm. With leaves removed, the returned power was lower than when the leaves were present, but with similar fading characteristics. Similar results were obtained at C-band with both like- and cross-polarized measurements.

Autocorrelations of the returned power vs. azimuth angle indicated that adjacent points were uncorrelated. Chi-square tests indicated that returned power for azimuthal variation was exponentially distributed. Thus, even with the small resolution volume of SOURCESCAT, enough scatterers were present for the small artificial tree to assure satisfying the conditions for random scatter from a semi-infinite array of point targets [2].

3. POLARIZATION MEASUREMENTS

The metallic leaves apparently dominated the scattering when they were present. With circular leaves the mean returned power was independent of polarization, but with elliptical leaves the mean was higher at vertical polarization than at horizontal polarization, as might be expected since the major axes of the leaves were closer to vertical. Without leaves the measured mean was higher for VV than for HH, presumably because the vertical components of the branches were larger than the horizontal, and the trunk was totally vertical.

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In the polarization-angle measurements we changed the angle of the antenna E vector from 0° (vertical) to 90° in 5° increments. At each polarization angle the tree was rotated through 360° at 36° increments to obtain an average of the fading. At C-band only two measurements were averaged at each polarization angle.

Controlled observations of the effect of rotating the polarization are scarce, so this experiment provides a new dimension to the understanding of backscatter from trees. The results suggest that tilted polarization may be useful for discriminating trees with different branch elevation angles.

For both C-band and X-band like-polarized measurements, the returned power was maximum around 40°, the angle with vertical made by the branches. Even though the electric field at 0° (vertical) was parallel to the trunk of the tree, the backscatter at 0° was minimum. Some of the branches and leaves were parallel to the electric field at 40°, but others at different azimuth angles were not. The returned power without the leaves was maximum at 0° (parallel to the trunk). The lack of a peak at 40° (the branch angle) indicates that backscatter in this case was dominated by the trunk.

With cross polarization and no leaves the maximum return was at 45°. For this situation the E vector from the transmitter has a vertical component that can excite the trunk. The orthogonal receiving antenna also has sensitivity in the vertical direction. At 90° coupling between the field (normal to the tree) and tree was minimum, giving minimum return. We conclude that without leaves the trunk of the artificial tree was the major contributor.

4. CONCLUSION

The return from the artificial tree was shown to be statistically independent at azimuth angles as close together as 5 degrees. The mean backscatter, after removing fading, was shown independent of azimuth. The fading followed an exponential distribution, indicating that the tree consituted a random ensemble of scatterers. The mean returned power from the tree with leaves was always higher than that without leaves as expected. Due to the vertical nature of the tree, returned power at vertical polarization was higher than that at horizontal polarization.

We found that the radar backscatter was a strong function of the angle of the transmitted polarization relative to the orientation of the branches and leaves. The strongest return with leaves occurred when the E vector was aligned with the branch. The backscatter from the tree without leaves was mainly due to the trunk of the tree, as evidenced by maximum return for vertical polarization.

In recent years the research community has shown a great deal of interest in radar polarimetry [16]. Our results indicate the potential value of tilted polarizations in tree classification with such systems.

Use of the simulated tree allowed control over the target parameters with a relatively simple target geometry. It could be studied in the laboratory without the problems either a potted natural tree or a tree in the field would have had in keeping the moisture content and geometry constant over long periods. Moreover, trees in nature are usually surrounded by obstacles to ready access, a problem not present in the laboratory environment. On the other hand, the simple geometry of the artificial tree does not represent the complex geometry of natural trees well, and the metallic leaves could not truly model real dielectric leaves. Hence this experiment should be supplemented by other experiments in the natural environment.

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