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ATTENUATED DIRECT AND SCATTERED WAVE PROPAGATION ON SIMULATED LAND MOBILE SATELLITE SERVICE PATHS IN THE PRESENCE OF TREES

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ABSTRACT

Measurements have been made of direct path with no trees, attenuated direct, and tree scattered signal levels at 1.3 GHz. Signals were received in two small groves of mixed hardwood trees. In the groves studied, average total signal levels were about 13 dB below adjacent no-trees locations, with attenuated direct signal levels about 14.6 dB below the no-trees case and scattered signals about 17.3 dB below the no-trees case. A simple model for LMSS propagation in groves of trees is proposed. The model assumes a constant scattered signal contribution at 17 dB below no-trees levels added to an attenuated direct signal which varies, depending on the number and density of trees in the direct path. When total signal levels are strong, the attenuated direct signal dominates. When total signal levels are more than 15 dB below no-trees levels, the scattered signals dominate.

I. INTRODUCTION

Signals may arrive at a mobile receiver in the Land Mobile Satellite Service (LMSS) via several paths. Figure 1 shows a combination of absorption by one tree and scattering from another. In a grove of trees, the scattered signals may be received from many trees at once. This paper presents measurements of the levels of direct, attenuated direct, and scattered signals at 1.3 GHz on simulated LMSS paths.

II. COHERENT AND INCOHERENT INTENSITY

The direct, or coherent signal is characterized by deterministic amplitude, phase, and arrival angle. The complex envelope of the coherent field at the receiver is:

$$U_c = A_c e^{j\phi_c}$$

where A_c and ϕ_c are constants determined from the distance in wavelengths between the satellite and mobile receiver and any attenuation on the direct path.

The incoherent signal includes contributions from all the scatterers in the vicinity of the receiver. The incoherent signal is characterized by random amplitude, random phase, and a distribution of arrival angles. The complex envelope of the incoherent field is:

$$U_I = \sum_{i=1}^{N} A_i e^{j\phi i}$$

where N is the number of scatterers and A_i and ϕ_i are determined by the relative positions of the satellite, scatterer and receiver and the scattering function $\bar{f}(\hat{o},\hat{i})$.[1]

The total signal is the sum of the direct and all the scattered signals. The complex envelope of the total field is U_T. The total intensity is:

$$I_T = \langle U_T U_T^* \rangle$$

where the brackets <> indicate ensemble average and the asterisk denotes the complex conjugate. The coherent intensity is:

$$I_c = |\langle U_T \rangle|^2$$

The incoherent intensity is the total intensity minus the coherent intensity [2].

$$I_i = \langle U_T U_T^* \rangle - |\langle U_T \rangle|^2$$

The measurement technique employed here uses the fact that the direct wave arrival angle is deterministic and the arrival angles of the scattered waves are distributed. The distribution of arrival angles of the total field at the receiver is called the "Angular Spectrum" and is related to the previous definitions of coherent and incoherent intensity by a Fourier Transform [3].

III. MEASUREMENT OF THE ANGULAR SPECTRUM

If the signal transmitted from the satellite is at constant frequency f_o and the receiver is moving at velocity V_o, the signal will be received at the Doppler shifted frequency:

$$f=\frac{V_o}{\lambda_o}\cos\alpha+f$$

where λ_o is the transmitted wavelength and is the angle between the vehicle velocity V_o and the signal arrival angle. If the vehicle moves in a straight line, the direct signal will be received at constant frequency:

$$f_c=\frac{V_o}{\lambda_o}\cos\alpha_c+f_o$$

Similarly, the ith scattered wave will be received at:

$$f_i=\frac{V_o}{\lambda_o}\cos\alpha_i+f_o$$

Scatterers close to the receiver will have the largest contributions, since the scattered waves are spherical and the intensity falls of as $1/R^2$, where R is the distance from the scatterer to the receiver.

IV. EXPERIMENTAL APPARATUS

The transmitter and receiver must be highly frequency and amplitude stable, such that the relative drift is much less than the expected Doppler shifts in the direct and scattered signals. The required stability is obtained by deriving the transmitter and receiver local oscillator signals from a pair of proportional oven controlled 5 MHz crystal oscillators. Measured drift is on the order of 0.2 Hz per hour.

The receiver is described in [4]. The receiver intermediate frequency (IF) output at 0.3 to 3.0 kHz is recorded on analog tape and then played into a Fourier Analyzer for processing. Two Fourier analyzers are used, an HP3582A for diagnostics and field data analysis and an HP5451C for final data reduction. The receiver has two identical channels, which allows two orthogonal polarizations to be received at once. The output of each antenna is downconverted from 1.3 GHz to 700 Hz, where the two outputs are recorded on the right and left channels of a stereo cassette recorder. After processing, the two angular spectra are added to obtain an approximately isotropic horizontally polarized receive antenna pattern.

V. MEASUREMENTS

Two small groves of trees were chosen for this study. Vogel and Goldhirsch [5] have found that the total received signal power is commonly between 10 and 20 dB lower when trees are present. The two groves in this study have average total signal levels 12 and 14 dB less than the adjacent areas with no trees. There is a clear line of sight path between the transmitter and receiver, and the peak amplitude represents the total intensity when no trees are present. A top view drawing of Grove #1 is shown in Figure 2. The elevation angle to the transmitter is 7^{o}. The arrival angle α_c varies from 110^{o} relative to v_o at the west end of the path to 124^{o} at the east end. The variation in α_c causes some broadening of the coherent peak in the Angular spectrum. Figure 3 is the sum of the two spectra from the orthagonal horizontally polarized dipoles. Since the power pattern of one dipole is roughly $\sin^2\alpha$ and the power pattern of the other dipole is roughly $\cos^2\alpha$, the power pattern of the sum is approximately 1_o (isotropic). The coherent component is clearly visible between $\alpha=110^{o}$ and $\alpha=124^{o}$. The coherent intensity is approximately the total intensity in the spectrum between $\alpha=110^{o}$ and $\alpha=124^{o}$. The coherent intensity in Figure 3 is approximately 15.7 dB below the total intensity in the no-trees case. The incoherent intensity is the total intensity in the whole angular spectrum minus the coherent intensity. The total intensity is approximately 14.0 dB below the no-trees case. The incoherent intensity is approximately 18.4 dB below the no-trees case. Thus, for grove number one, with total received signal power 14 dB below the no-trees case, .3 of the received signal is due to scattering and .7 is due to the attenuated direct path.

VI. CONCLUSIONS

When a Land Mobile Satellite Service receiver is located in a grove of trees illuminated from above by a satellite transmitter, each tree becomes a source of scattered signals. It appears that the total scattered signal power is on the order of 17 dB below the unattenuated direct signal power. When there are no trees in the direct path, as in figure 3, the total signal power will be dominated by the direct signal. When attenuation in the direct path increases to more than 13 dB, however, as will be the case when several large trees are in the direct path, the scattered signals become significant. In the balloon studies by Vogel and Goldhirsch, average fades commonly exceed 13 dB but seldom exceed 20 dB. The deep average fades exhibit fast fading characteristic of multipath. These observations are consistant with the measurements of the relative levels of unattenuated total signal power, attenuated direct signal power, and scattered signal power reported here.

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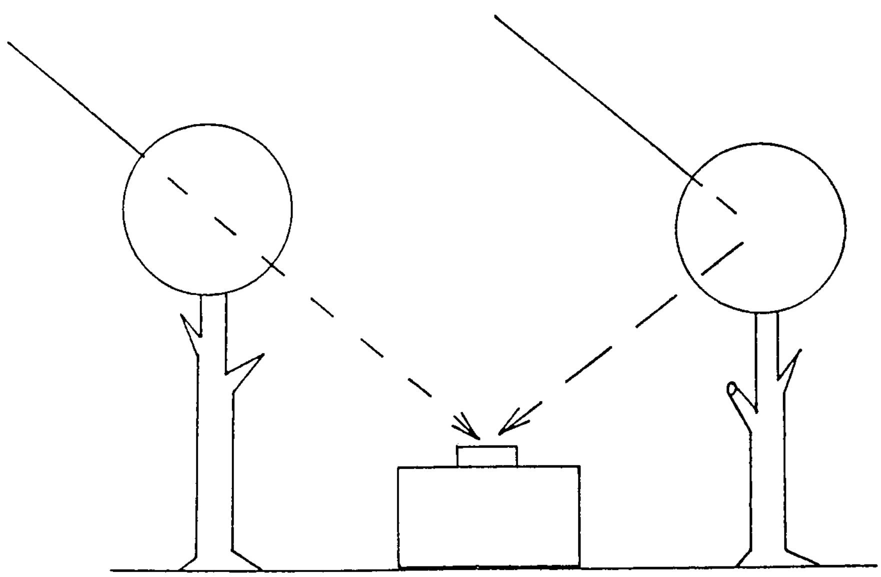
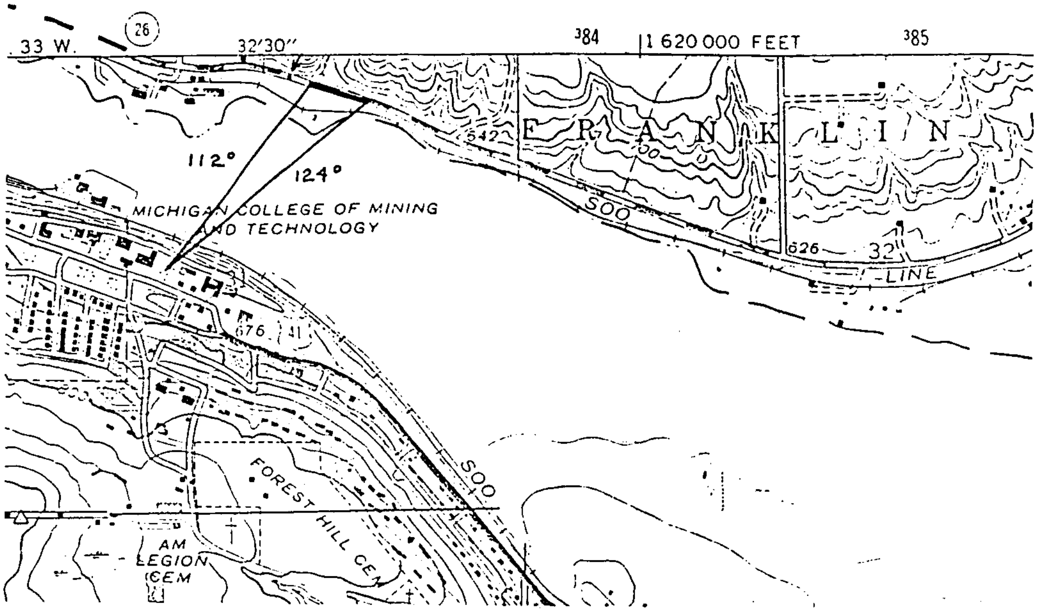


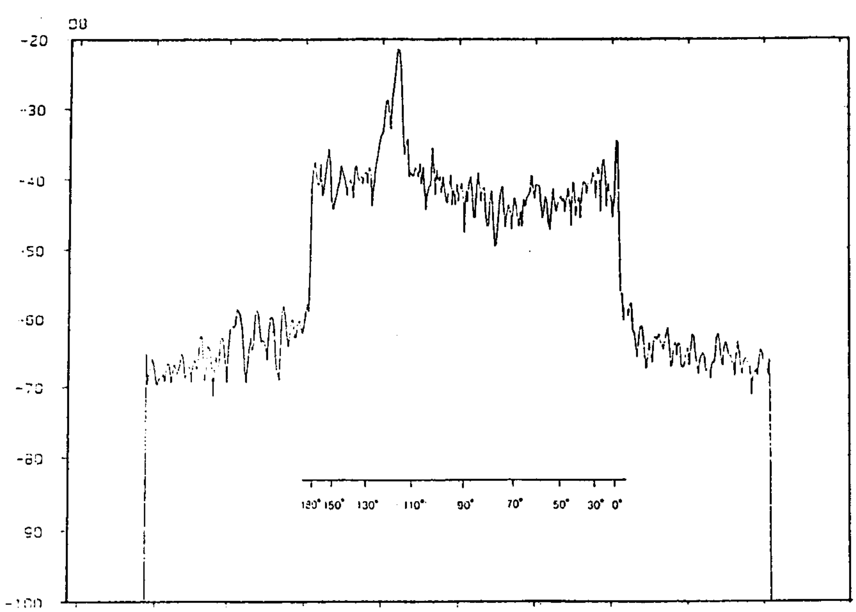
Direct Path with Absorption and Scattering

FIGURE 1



Grove Number One Location

FIGURE 2



Grove Number One Angular Spectrum

FIGURE 3