SINGLE TREE SCATTERING ON SIMULATED LAND MOBILE SATELLITE PATHS

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1. Introduction

Mobile Satellite systems are attractive for rural areas. It is very common for roadside trees to block and scatter the satellite signal as a vehicle moves through a rural area. Several studies have found that the average level of scattered signals is 17 dB to 20 dB below the unattenuated direct signal level, and that scattered signals arrive at all arrival angles with nearly equal probability. What is not clear from previous measurements is whether the scattered signals are mostly from nearby roadside trees or from large, distant scattering objects. This study uses a Doppler Spectrogram to resolve the scattered contributions to the received signal into Doppler Signatures that may be associated with individual trees or other nearby objects. In the few measurements performed to date, there is no evidence of scattering from distant objects.

2. Experiment Geometry

The experiment geometry is illustrated in Figure 1. A CW plane wave from a distant source illuminates a straight section of road and roadside trees. A car with a frequency stable, linear receiver moves along the road at constant velocity V_0. Signals arrive at the vehicle by the direct path, and by scattered paths. The direct and scattered contributions may be resolved in the arrival angle domain by using either a real directional receive antenna or a synthetic directional antenna in the Doppler domain.

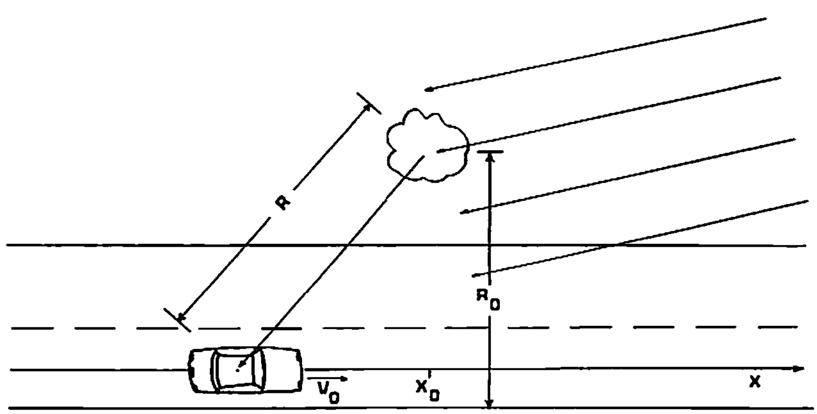

Figure 1 Experiment Geometry

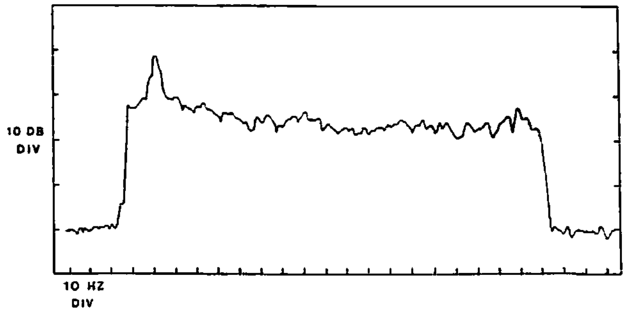

Figure 2 Average Received Doppler Spectrum

3. Experiment

A typical Doppler Spectrum for a 23 cm wavelength receiver moving at 80 kilometers per hour past roadside trees, averaged over several hundred meters of road, is shown in Figure 2. The direct wave contribution in Figure 2 is clearly visible near the left edge of the plot, and the scattered contributions are approximately uniformly distributed between the maximum positive and negative Doppler shifts Δf_{max}, where $\Delta f_{max} = V_0/\lambda$. While an averaged Doppler Spectrum like Figure 2 is useful as a measurement of average direct versus scattered wave intensity and scattered wave arrival angle distribution, it contains no range information. It does not distinguish between scattering from a series of nearby roadside trees and contributions from many large, unspecified distant scatterers.

Range information is usually obtained in the time domain by pulsing or spreading the transmitted signal. Range to nearby scatterers may also be obtained in the angle (Doppler) domain by triangulation. The information required for range determination is contained in the received Doppler Spectrum before averaging. As the vehicle moves past a scatterer, the received scattered signal changes from positive Doppler shift to negative Doppler shift, exactly in the manner of a passing train whistle. The instant of zero Doppler shift occurs when $x = x_0$ in the geometry of Figure 1. The rate of change of the Doppler shift depends on the minimum distance to the scatterer R_0. When x is near x_0, the rate of change of received frequency is well approximated by $\Delta f_{max}/R_0$ Hz per meter of vehicle travel. Thus the range R_0 to the scatterer may be found directly from the slope of the "Doppler Signature" where it crosses f_0. Figure 3 illustrates the shape of the Doppler Signatures for point scatterers 5 m, 10 m and 20 m from the receive antenna at the point of closest approach as the receiver moves along 100 m of road.

Of course trees are not point scatterers. They may be modeled as distributed scattering regions with some average dimensions. The extended dimensions will spread the Doppler Signature in both the frequency and x(t) directions. Incoherent scattering from the distributed region and the probability of path blockage by other roadside trees may eliminate pieces of the Doppler Signature for any individual tree. The inverse square law for signal intensity versus distance R also decreases the signal intensity for large R.

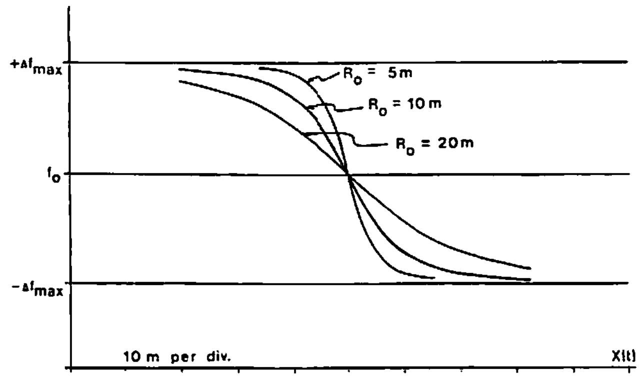

Figure 3 Doppler Signatures

3. Measurements

Figure 4 is a measured Doppler Spectrogram taken along 100 m of straight road with a few trees and a large utility pole with wires, insulators and a pole-mounted power transformer. The transmitted frequency is 1296.038000 MHz with a frequency drift of less than 1 Hz per minute. The upper-sideband receiver is tuned to a suppressed carrier frequency of 1296.037250 MHz with a frequency drift of less than 1 Hz per day. The receiver linearly down converts the unshifted received signal to 750 Hz. With the receiver moving at 80 kilometers per hour (about 22 m/s), Δf_{max} is 97 Hz, so the receiver audio output spreads between 650 and 850 Hz. The receiver audio is recorded on a cassette tape recorder for later processing using an IBM 486 PC with Aria 16 sound card and Sound Technology SpectraPLUS software. The constant direct wave contribution is visible across the top of the spectrum. The dominant Doppler Signature in the center of the plot is from the utility pole. Using the slope at f_0, the distance from the vehicle antenna to the top of the utility pole is about 10 m. This was confirmed with ground truth. Several trees near the utility pole may also be resolved in Figure 4.

Figure 5 shows a measured Doppler Spectrogram made with the same apparatus along a straight section of road with a small grove of trees to one side. The direct wave is blocked by the grove of trees. It is possible to resolve five or six separate tree Doppler Signatures in Figure 5, all with distances from the road of about 30 m. A time average of figure 5 would result in a nearly uniform scattered contribution Doppler Spectrum with a small direct wave contribution, very similar to Figure 1.

4. Conclusions

Measured Doppler Spectrograms that may be resolved into contributions from single roadside trees have been presented. The tree scattered signal level and arrival angle probability distribution are consistent with previous measurements, but new signal processing permits range-to-scatterer information to be obtained as well. For the few measurements performed to date, the scattered energy appears to arrive from objects within 100 m of the moving vehicle.

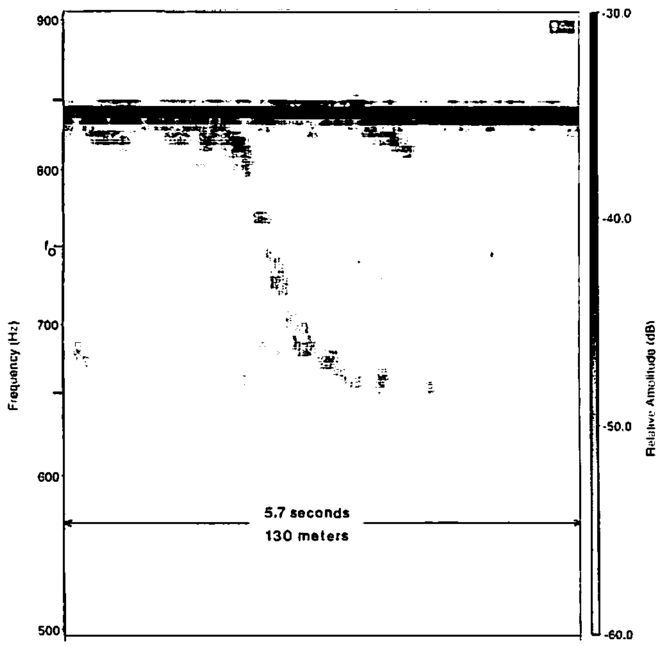

Figure 4

Measured Doppler Spectrogram for 23 cm wavelength signal received on a vehicle moving at 80 kph along a road with a few trees and a large utility pole.

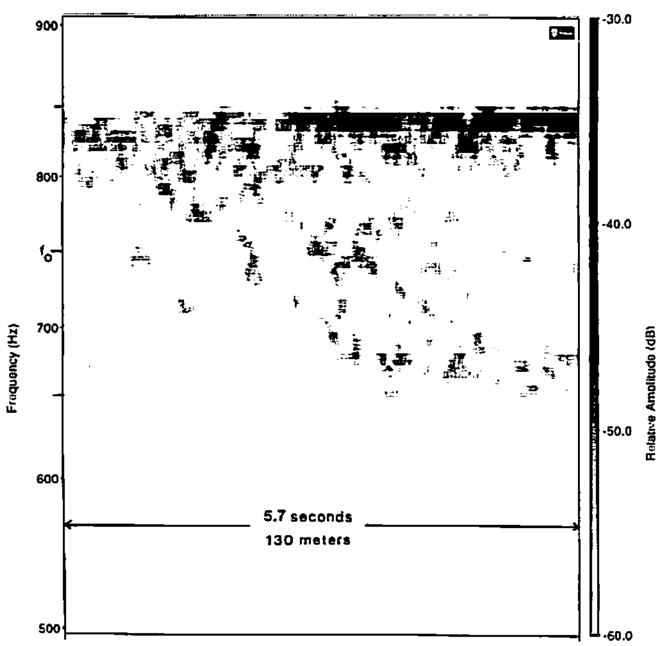

Figure 5

Measured Doppler Spectrogram for 23 cm wavelength signal received on a vehicle moving at 80 kph along a road past a small grove of trees.