P10.15 SPECTRAL CHARACTERIZATION OF GROUND CLUTTER USING THE NWRT

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1. INTRODUCTION

The electronic scanning capability of a phased array antenna allows for the collection of weather data without mechanical rotation. In contrast, radars with parabolic dish antennas need to rotate mechanically in both azimuth and elevation to collect volumetric weather data. This antenna rotation has the effect of broadening the spectra of ground clutter and therefore changing the spectral shape. An example of the effect of antenna rotation is shown in Figure 1. By taking advantage of the narrower spectra from a stationary antenna, we may be able to find novel techniques for mitigating the effects of ground clutter.

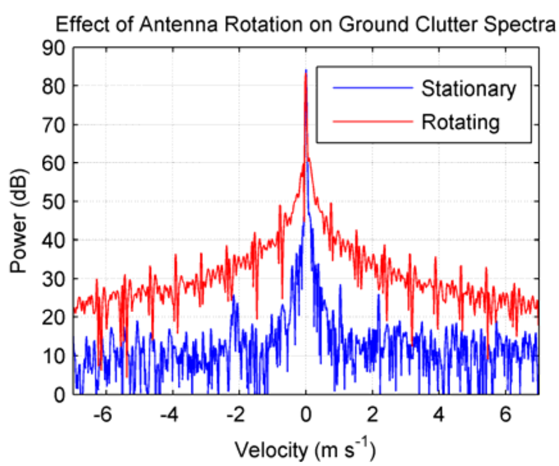

Figure 1. Comparison of ground clutter spectra from a stationary antenna. Rotation was simulated using the electronic scanning capability of the phased array antenna.

In this paper, a new clutter model is proposed to examine the shapes of ground clutter spectra. Data were collected using the National Weather Radar Testbed (NWRT) under different wind, terrain, and foliage conditions. The data were fit using the clutter model to find representative clutter spectra for each of the collected cases. The effects of wind, terrain, and foliage are then incorporated into the model which can then be used to examine the clutter width or for simulating time series data.

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2. DATA COLLECTION

As mentioned previously, data were collected under different wind, terrain, and foliage conditions. The three wind categories are defined as follows: Light Air (1-7 mph), Breezy (7-15 mph), and Windy (15-30 mph). A particularly windy day also led to one dataset collected at the low end of “Gale Force” conditions (30-60 mph). The two terrain types for which data were processed are “Urban” and “Prairie,” and data were collected under both “Full Foliage” and “Light Foliage” conditions. This results in a total of 14 cases that were studied.

For each case, three 90° sectors were collected consecutively. Only beam positions from the center 10° of each 90° sector were used when characterizing the ground clutter spectra to avoid the effects of beam broadening. Each 90° sector was collected at the lowest allowable elevation angle for the NWRT, 0.5°, and was made up of 90 beam positions separated by 1° in azimuth. The data were collected using the electronic scanning capability (i.e., step scan) of the phased array so the antenna was stationary. At each beam position, 4096 pulses were transmitted in the same azimuth direction using a PRT (Pulse Repetition Time) of 0.8 ms.

3. PRELIMINARY MODEL FITTING

For clutter characterization, finding an appropriate model for fitting the clutter spectra is essential. A promising model in *Low Angle Radar Land Clutter: Measurement and Empirical Models* by Billingsley (2002) was developed to characterize windblown clutter spectra. Measurements of ground clutter spectra at several frequencies and under varied wind conditions are presented. Billingsley proposes a two-part spectral model to fit the windblown clutter power spectral density (PSD). The first part is a DC (or zero-velocity) term that is added to an AC term. The AC part represents the wider part of the clutter spectrum. Billingsley uses an exponential model for the AC part of the spectrum which is linear when looking at the power in a dB scale. Figure 2 shows an example of the two-part exponential model.

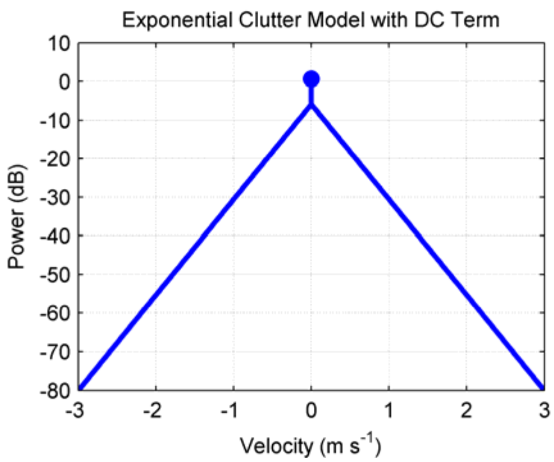

Figure 2. Billingsley windblown clutter model.

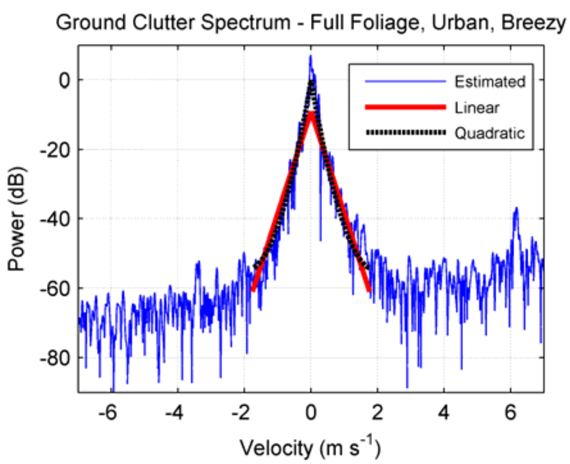

Figure 3. Two clutter spectra examples with both a linear and quadratic fit of the AC portion of the spectra.

Because of the curved shape of some of the spectra, a more general quadratic model was developed to fit the AC portion of the spectrum. Figure 3 shows an example spectrum with both a linear and quadratic fit. The AC part of the spectrum seems to be linear or curved with a slightly concave-up shape which differs from the concave-down shape of the Gaussian function used to model weather spectra. The quadratic fit matches the slightly curved shape better than the linear fit, and the quadratic fit also allows a better fit of the peak of the AC portion of the spectrum. The better fit at the peak should also lead to more accurate estimation of the DC term because this term is calculated as the power at zero velocity extending above the peak of the AC part of the spectrum.

4. QUADRATIC GROUND CLUTTER MODEL: SPECTRAL FITTING

A three-part model is used to fit the spectra: a DC term, a quadratic AC term, and a spectral floor. The spectral floor is sometimes larger than the system noise floor and can capture a characteristic of the spectrum that is related to the phase noise of the system. The spectra are fit in the dB domain, and four parameters are utilized. The *a* and *b* parameters model the quadratic AC term, the *c* parameter measures the distance between the peak of the AC portion of the spectrum and the spectral floor, and the *d* parameter the power above the AC portion of the spectrum. The following equation describes the model.

$$P_{dB}(v) = d \cdot \delta(v) + P_{AC}(v) \qquad (1)$$

The spectral floor is not included in (1) because it cannot be added directly in the log domain. The AC portion of the model is defined as follows:

$$P_{AC}(v) = -b|v| + \frac{a}{2}v^2 . \qquad (2)$$

Figure 4 shows the parameters using an example spectrum.

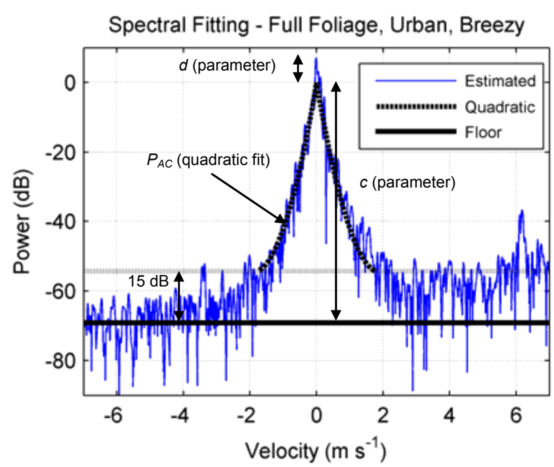

Figure 4. Example spectrum showing the quadratic fit, the spectral floor, and *c* and *d* parameters.

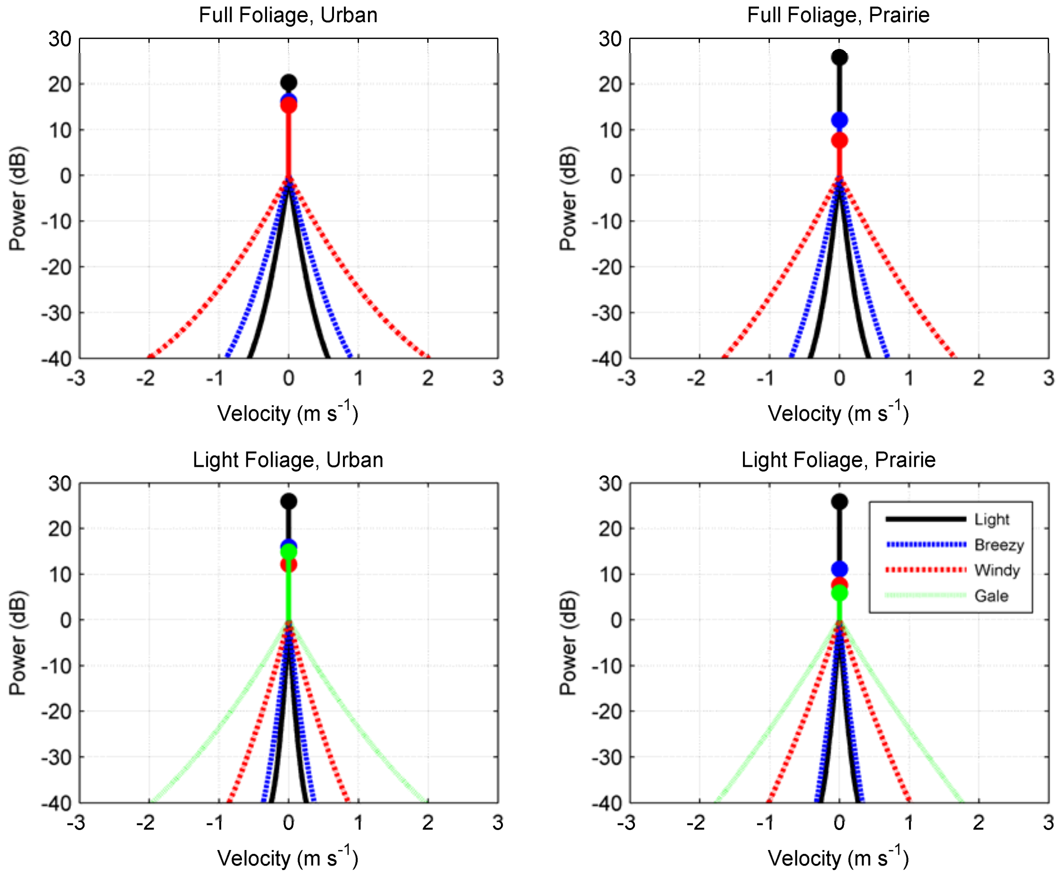

Figure 5. Representative clutter shapes for all 14 cases showing both the AC and DC parts of the spectral shapes.

For all 14 cases, between 150 and 1641 spectra were successfully fit using the quadratic clutter model. Figure 5 shows the representative spectrum for each of the 14 cases computed using a multi-dimensional median. The level of the spectral floor is not shown. The "Light Foliage" cases are narrower for a given wind speed as expected. The difference is approximately one wind category; the "Light Foliage, Gale, Urban" case is similar in width to the "Full Foliage, Windy, Urban" case.

5. MODELING THE EFFECTS OF WIND SPEED, FOLIAGE, AND TERRAIN

Using the results from the fitted spectra, the quadratic clutter model is extended based on the wind speed trends, relationships between the parameters, and the effects of foliage and terrain type. Two new parameters are added to the model: *f*, to capture the changes in spectral width with wind speed and P_0, which is related to the spectral floor. In order to use the model to simulate time series data, the AC portion is extended linearly beyond the quadratic part as shown in equation (3).

$$P_{AC}(v) = \begin{cases} -b|v| + \dfrac{a}{2}v^2 & \text{when } |v| < v_0 \\ S(|v| - v_0) + P_0 & \text{when } |v| \geq v_0 \end{cases} \quad (3)$$

The final model has 6 parameters: *a, b, c,* d_n, *f,* and P_0. The parameters are determined for a particular case based on the wind speed, *s*, and constants that depend on the foliage level and terrain type. The *a*, *b*, and *c* parameters match the ones from equations (1) and (2), and d_n is similar to the *d* parameter but is normalized to be independent of the length of the spectrum. The *f* parameter is used to determine the other parameters but is not used directly in the model.

The relationship between *f* and wind speed is illustrated in the Figure 6. The *f* parameter can be thought of as a slope parameter that decreases as width increases.

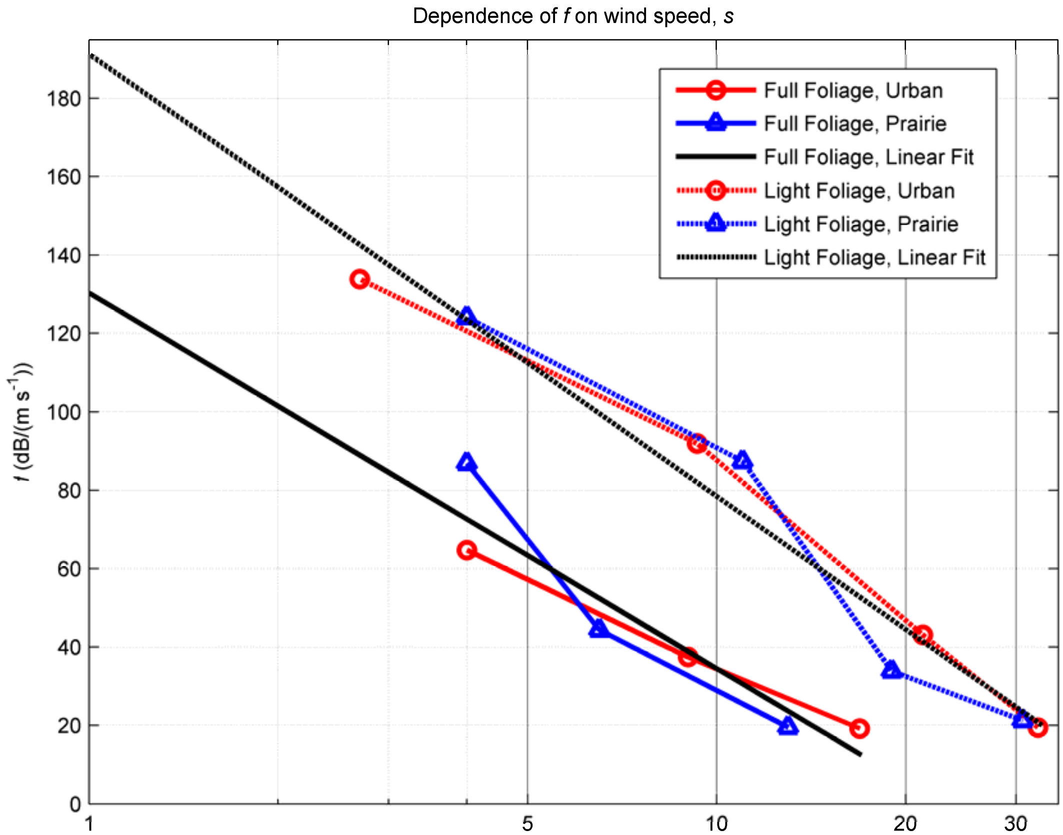

Figure 6. Relationship between *f* and wind speed, *s*.

The difference in the widths between the "Full Foliage" and "Light Foliage" conditions is clear. In contrast to the *f* parameter, the d_n parameter has an exponential dependence on the wind speed. For more details on how the other parameters were determined, see Curtis (2009).

The final model is described by the following equation.

$$d_n(s) = d_0 \exp(d_1 s) + d_2 \qquad b(s) = b_1 f + b_0$$
$$c(d) = c_0 - d_n \qquad P_0(c) = q_0 - c \qquad (4)$$
$$f(s) = f_0 + f_1 \log(s) \qquad a(b, f, P_0) = \frac{2f(f-b)}{P_0}$$

The *f* and d_n parameters directly depend on the wind speed. The other parameters depend on these two parameters and on constants. The constants are given in the table. The f_0 and f_1 constants are determined based on foliage level,

	Full Foliage		Light Foliage	
	Urban	Prairie	Urban	Prairie
b_0	14.2	14.2	14.2	14.2
b_1	1.92	1.92	1.92	1.92
c_0	65.3	65.3	65.3	65.3
d_0	40.4	417.7	40.4	417.7
d_1	-0.63	-0.95	-0.63	-0.95
d_2	2.7	0.8	2.7	0.8
f_0	130.3	130.3	191.3	191.3
f_1	-41.6	-41.6	-49	-49
q_0	15	15	15	15
s	1-17	1-17	1-33	1-33

but the d_0, d_1 and d_2 constants are determined based on the terrain type. The other constants do not change when the terrain type and foliage levels change. The model is only valid from 1-17 mph for the “Full Foliage” conditions and 1-33 mph for the “Light Foliage” conditions.

6. CONCLUSIONS AND FUTURE WORK

The quadratic clutter model can be used to examine the clutter width under different conditions or for simulating time series data. Future work will focus on simplifying the model and collecting additional data. A collection with full foliage and high winds could increase the understanding of the behavior of the b and f parameters, especially when a is close to zero.

7. REFERENCES

Billingsley, J. B., 2002: *Low Angle Radar Land Clutter: Measurement and Empirical Models*, William Andrew Publishing, 703 pp.

Curtis, C. D., 2009: Exploring the Capabilities of the Agile Beam Phased Array Weather Radar. Ph.D. dissertation, Dept. of Engineering, The University of Oklahoma, 187 pp.

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