

Sidelobe Clutter Modeling for Land-Based Radars in Mountainous Terrain

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Abstract— This paper will introduce a new technique for modeling sidelobe clutter in mountainous terrain, while expanding upon our previous work in modeling three-dimensional aspects of clutter. The method was developed, in part, to overcome the limitations of electromagnetic parabolic wave equation (PWE) models with regards to complex antenna patterns. This technique also produces a more accurate representation of the clutter versus our previous methods.

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I. MOTIVATION

This paper is an extension of our previous work in modeling the three dimensional aspects of clutter with site specific models [1]. The clutter modeling in this paper was motivated by a desire to gain insight into the amount of sidelobe ground clutter that a ground based radar might see in elevated beams. This is an important part of overall radar system design because land clutter coming into the sidelobes may cause the radar to use coherent waveforms and Doppler domain processing instead of more time efficient noncoherent waveforms and processing. Thus, it is imperative to know the amplitude of sidelobe clutter to determine if it will have a negative affect on target detection or false detection rate.

The previous manner in which we modeled elevated beam sidelobe clutter was to model the mainbeam clutter at zero degrees elevation and then de-weight it based on the two-way elevation sidelobes. This approach has two limitations. The first is that a zero degree azimuth cut through the three dimensional antenna pattern may not capture the worst case sidelobe clutter for a given azimuth. This is illustrated in Figure 1 where the radar mainbeam is pointing up and the ground below the beam intercepts the null just below the third elevation sidelobe below the mainbeam. However, at an azimuth offset of the beam, a sidelobe is intercepting the ground due to local terrain. Thus our previous approach could miss this contribution to the sidelobe clutter.

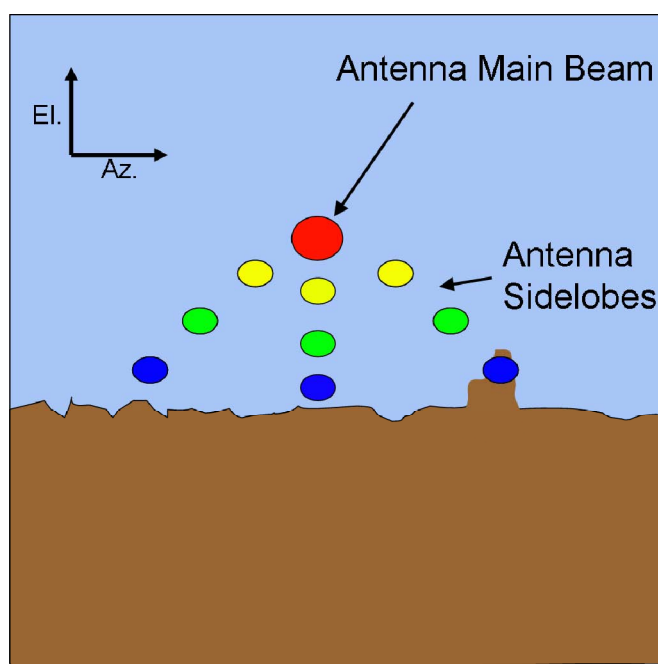


Figure 1. Antenna main beam pointed above the ground with one sidelobe intersecting the terrain.

The second problem with our previous approach is that some radar sites can have land clutter visible at elevations above the horizon. This is illustrated in Figure 2 where clutter is visible to the radar in beams above the horizon beam. Here, distant mountains rise above the radar. Hence, a clutter map at zero degrees elevation will not capture clutter above the horizon. This problem is a subtle one that is introduced because of the way that propagation models accept antenna patterns.

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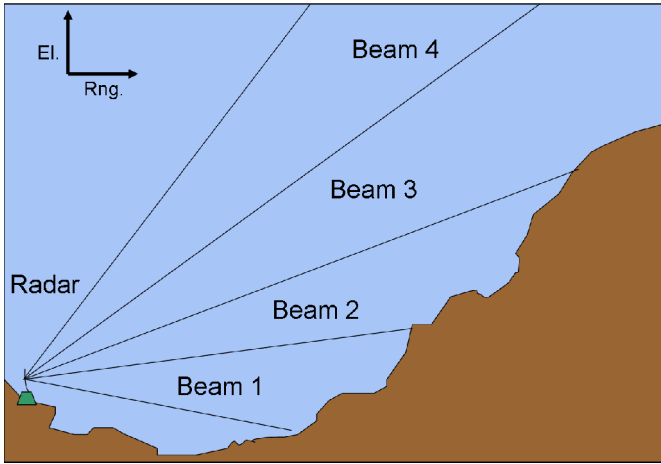


Figure 2. Ground clutter is visible to the radar at elevations above beam 1.

The propagation model that we use is TEMPER [2]. This model is fast and accurate and gives a two dimensional model of propagation (i.e., range vs. altitude). The issue in applying TEMPER to this problem is that TEMPER only accepts a real valued antenna pattern. While this is adequate for accurately modeling the mainbeam of the antenna it will not give an accurate representation of sidelobes for antennas that have aperture weighting and realistic errors. That is to say, modern radar antennas have aperture weighting and their sidelobes are thus limited by the errors in the aperture. Thus, their antenna voltage patterns have complex values. This means then that we can not use TEMPER to model propagation to clutter at elevation angles outside the mainbeam.

To overcome these limitations, our new approach is to develop mainbeam clutter maps at various elevation angles. Then we convolve them with constant elevation cuts from the three dimensional pattern. Finally these elevation maps are summed for each azimuth to provide the three dimensional contribution of clutter for a given azimuth and elevation of the mainbeam.

II. SYSTEM MODEL

The Littoral Clutter Model (LCM) is used as a basis for the sidelobe clutter modeling described in this paper. LCM is a robust, combined land and sea clutter model based upon site-specific radar reflectivity and topography. The model employs both the Billingsley land clutter model [3], and the GIT sea clutter model [4]. The principal output from LCM is estimated clutter power versus range, along each azimuth in the sector, which may be plotted as the PPI display of a clutter map [5].

Since LCM is typically used to predict mainlobe clutter returns from the surface, the model had to be modified for sidelobe clutter returns from various elevations.

The strategy employed here begins with determining the magnitude of the elevation antenna pattern at each of the pre-determined elevation angles. These values are used to de-weight the resultant propagation factors computed from TEMPER for each of the elevation slices. Blanking flags are then determined based on the LCM computed terrain data. Figure 3 further explains the blanking flag. If terrain is visible

(red line) within the 3dB beamwidth (solid lines flanking the dashed line) of a particular beam, then a flag is set at that point (1 for terrain, 0 for none). Note the use of the blanking flag prevents clutter from being counted twice. Thus for a given beam elevation, only clutter that falls in that beam (due to terrain) is included in that calculation.

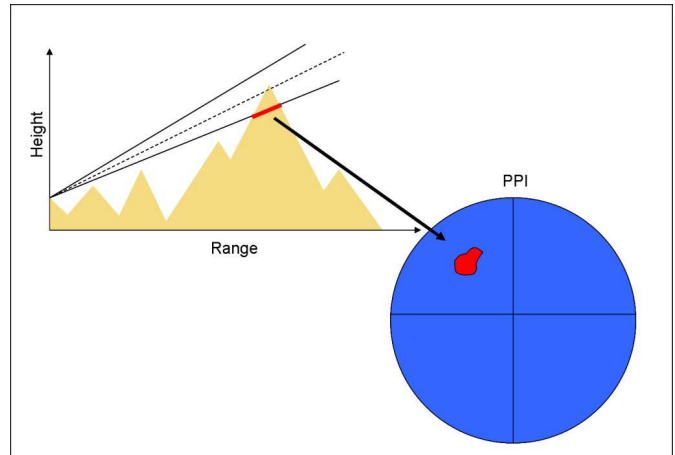


Figure 3. Description of Blanking Flag

Next, the propagation factor is computed for each elevation angle. This is accomplished by giving TEMPER the parameters for a sinc ($\sin(x)/x$) antenna pattern with the same elevation two-way beamwidth as the actual antenna pattern, and pointing the beam at the elevation of each slice. Since the concern for each TEMPER iteration is the clutter resultant from that specific slice, a sinc pattern is a simple and effective approximation. The resultant propagation factors are then de-weighted by the appropriate value computed above.

After calculating the propagation factor, the reflectivities (σ^0) for each cell are computed. These values are then combined with the previously computed blanking flag. This step ensures that only reflectivities resulting from terrain in a specific slice will be present in the clutter computations for said slice.

Finally, the σ^0 for each slice is convolved with the appropriate constant elevation azimuth cut from the antenna pattern. This step accounts for azimuth sidelobes. The CNR, based on the propagation factor and σ^0 , can then be calculated for each slice. The CNR is computed as follows:

$$\text{CNR} = (R_0/R)^4 D_0 A_c \sigma^0 |F|^4 \quad (1)$$

where R_0 is the single-pulse detection range, D_0 is the single-pulse detection threshold, A_c is the ground resolution cell area, σ^0 is the clutter reflectivity, and $|F|^4$ is the propagation factor. These CNR are then combined to form a single composite clutter map. This resultant clutter map is the final output.

III. MODELING ENVIRONMENT

For this analysis, a notional land-based radar operating in the S-band, with a center frequency of 3300 MHz was chosen. Given that this radar is not functionality specific (i.e. military,

weather, etc.), the antenna height was set arbitrarily to 50 ft (15.24 m) above local terrain.

As previously mentioned, the electromagnetic PWE program used within LCM to compute the propagation factor is known as TEMPER. The radar parameters required by TEMPER include the two-way elevation beamwidth (taken as 1.3°), antenna polarization (vertical), and the two-way antenna pattern (coscant transmit pattern with a sinc on receive). Figures 4 and 5 detail the elevation and azimuth antenna patterns respectively.

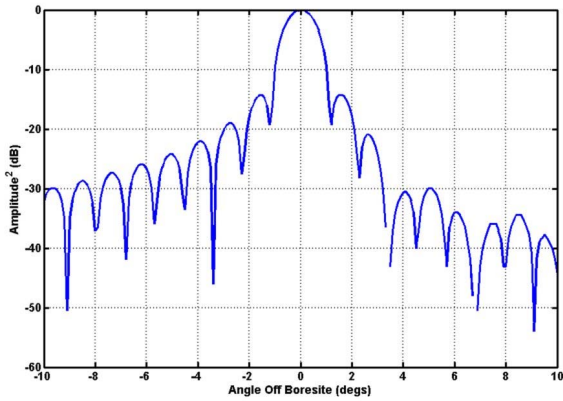


Figure 4. Two-Way Elevation Antenna Pattern

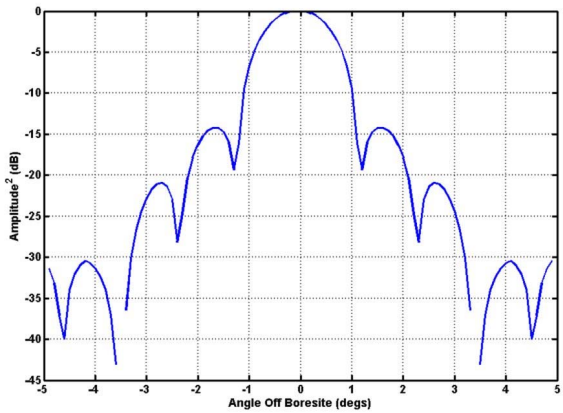


Figure 5. Two-Way Azimuth Antenna Pattern

To give the radar realistic detection sensitivity, the single-pulse detection range was set at 200 km, with a detection threshold of 6 dB. Additionally, the radar transmitted a $95\mu\text{s}$ pulse.

The location selected for the model is in the vicinity of Tucson, AZ. This site was chosen due to the mountainous terrain in the area, as well as being a realistic radar location (the NEXRAD (Next Generation Radar) is located nearby). The beam is pointed at 5° to ensure that the ground clutter is only present in the sidelobes. Furthermore, a resolution of ten slices was chosen, to provide good coverage and acceptable computational speed.

IV. RESULTS

The clutter maps from the 0° and 0.4° slices are shown in Figures 6 and 7 respectively.

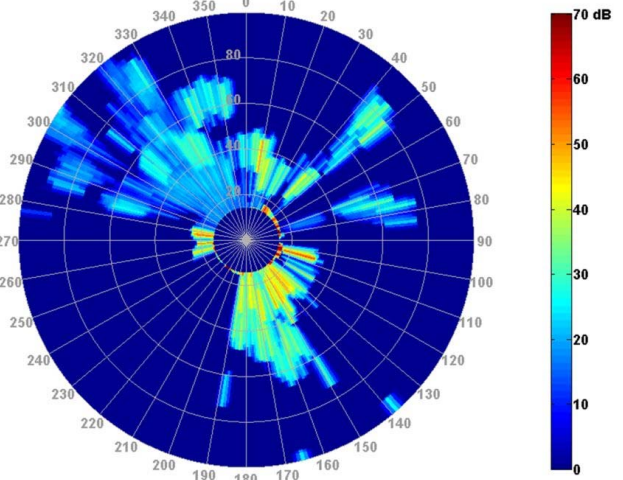


Figure 6. Clutter Map Resultant from Sidelobe Slice at 0.0°

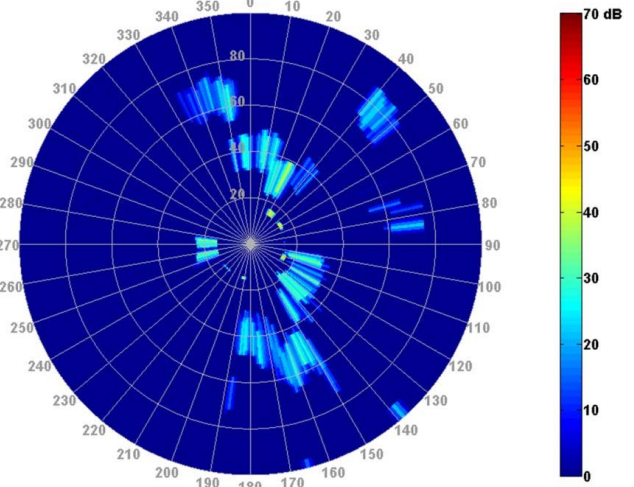


Figure 7. Clutter Map Resultant from Sidelobe Slice at 0.4°

Note how the map from the 0.4° slice contains less clutter than from 0° . This is the expected result. As we aim the beam higher, less terrain exists to create clutter. Figure 8 shows the final composite clutter map. This is a direct combination of all 10 clutter maps.

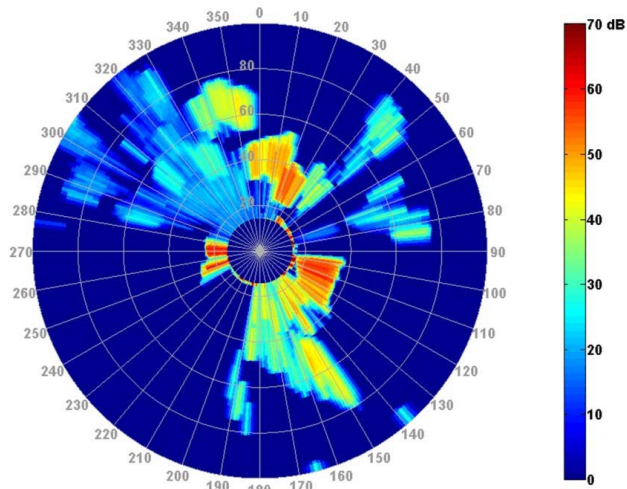


Figure 8. Final Composite Clutter Map

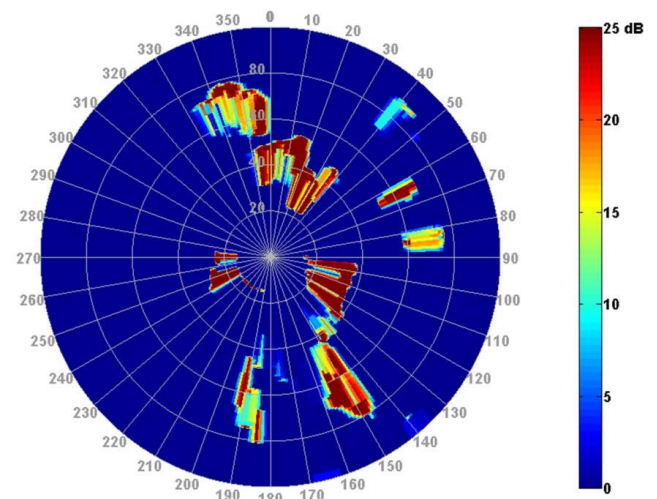


Figure 10. Delta Between the Two Clutter Maps

For comparison, Figure 9 shows a clutter map produced using the older sidelobe modeling approach defined in Section 1. While the two maps are similar, Figure 10 details the delta between the older and newer methods. In the areas where the terrain has the largest affect, the older method predicts upwards of 25 dB less sidelobe clutter than our new method. These areas of large delta directly correlate to high elevation terrain shown in Figure 11. Therefore, the modeling approach outlined in this paper produces a more accurate representation of the clutter.

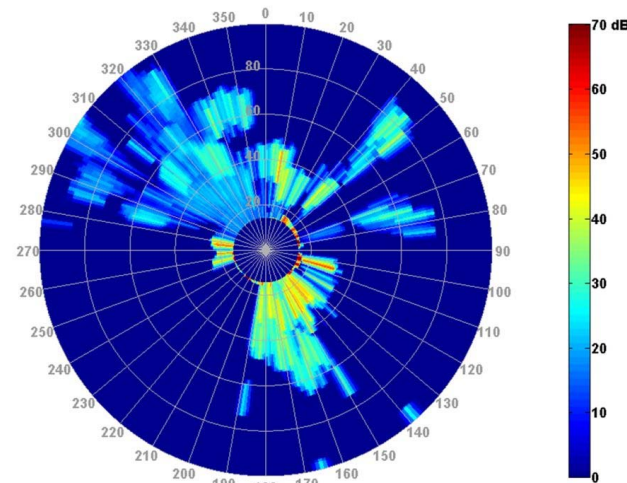


Figure 9. Clutter Map Produced Using Older Sidelobe Modeling Method

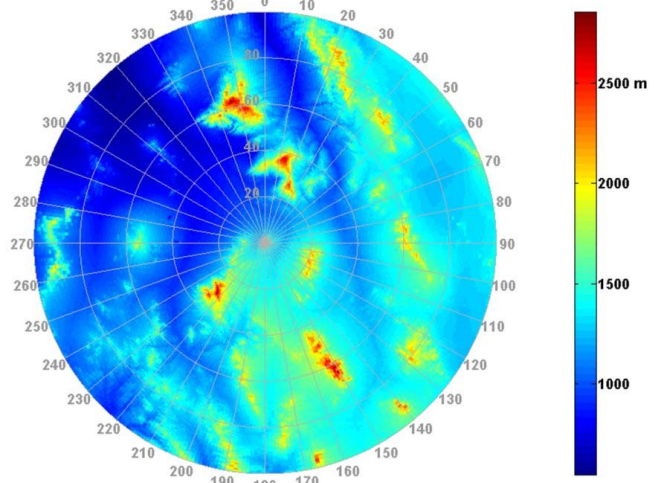


Figure 11. Terrain Heights

V. SUMMARY

This paper demonstrates a new technique for modeling sidelobe clutter in the presence of mountainous terrain. By using the approach, we are able to overcome the limitations of our PWE software with respect to complex antenna patterns. We have also shown that this method more accurately models clutter versus the simpler approach of aiming the mainbeam at the surface and de-weighting the propagation factor by the antenna pattern at the surface.

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