6B.5 USING THE MULTI-CHANNEL RECEIVER TO STUDY SIDELOBE CANCELLATION ON THE NATIONAL WEATHER RADAR TESTBED

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1. INTRODUCTION

The National Weather Radar Testbed (NWRT) provides a unique opportunity to study the effectiveness of sidelobe cancellation for mitigating ground clutter. The testbed is made up of a phased array antenna that has several receive-only auxiliary apertures that are separate from the main array and an eight-channel receiver for archiving multiple channels of time series data. This multi-channel receiver is a collaborative project between the OU Atmospheric Radar Research Center and the National Severe Storms Laboratory. Sidelobe channels have previously been utilized on wind profiling radars to mitigate ground clutter, and some of the same techniques should also be applicable to weather surveillance radars. The sum and sidelobe channel data can be recorded and processed to explore different approaches for addressing ground clutter contamination. This paper will examine some of the existing algorithms for employing sidelobe cancellers and apply these algorithms to collected time series data. This could lead to new ways to mitigate ground clutter on weather surveillance radars in the future.

For various technical reasons, it was impossible to collect sufficient time series data for processing. Instead, a new distributed clutter model is introduced to better simulate actual distributed ground clutter targets.

2. MOTIVATION

Ground clutter filtering is the conventional way to mitigate ground clutter for weather radars, but some types of data collection implemented with phased arrays do not easily lend themselves to clutter filtering. For example, surveillance collection with a small number of pulses is a difficult case to address with conventional clutter filtering. Additionally, any type of beam multiplexing is challenging whether for surveillance or weather collection.

The sidelobe cancellers on the NWRT phased array give us an opportunity to utilize spatial filtering to mitigate ground clutter in situations where conventional clutter filtering is not feasible.

3. MULTI-CHANNEL RECEIVER

The NWRT multi-channel receiver is designed to simultaneously collect eight channels of time series data and archive them to a RAID in real-time. Fig. 1 shows a picture of the multi-channel receiver installed at the NWRT.

Figure 1. A picture of the multi-channel receiver instrument rack installed at the National Weather Radar Testbed.

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Currently, only six channels are fully functional because of hardware issues, but OU recently modified the analog donwnconverters to be much more robust which should aid in getting all eight channels working in the future. The current six channels allow data collection from the sum channel and five of the sidelobe cancellers or collection of the sum, two difference channels, and three sidelobe cancellers. The multi-channel receiver enables data collection for the study of techniques such as ground clutter mitigation using sidelobe cancellers and crossbeam wind measurement using difference channels

4. THEORETICAL ANTENNA PATTERNS

Theoretical antenna patterns were computed based on the positions of the 4,352 main array elements and the six sidelobe cancellers. Future measurements of the actual antenna patterns will help in better quantifying the performance of the ground clutter mitigation algorithms.

Fig. 2 shows the locations of the 4,352 elements that make up the main array (each shown with a red x) and the 6 sidelobe canceller receive antennas (blue circles). This is the view when looking at the front of the antenna.

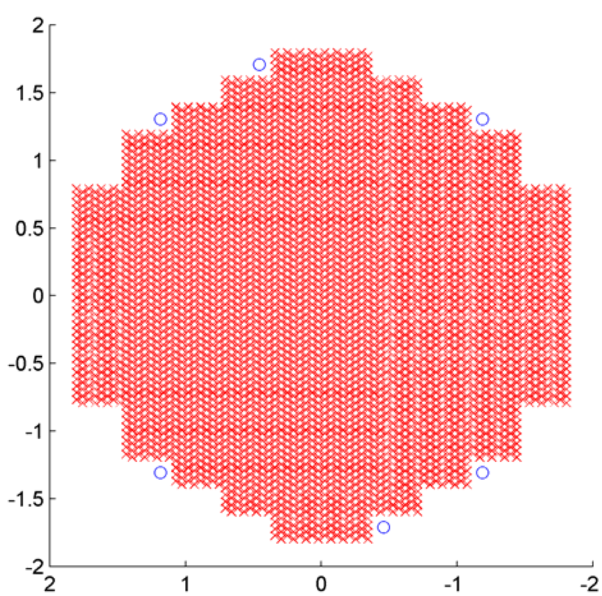

Figure 2. Locations of the main array antenna elements and sidelobe canceller receive antennas.

These elements were used as part of a theoretical antenna model to compute the shape of both the sum beam and sidelobe canceller antenna patterns. The sum pattern is a two-way pattern based on the main array elements while the sidelobe patterns are composite transmit/receive patterns that combine the sum pattern on transmit and the sidelobe channels on receive. Measurements of the sum receiver pattern and of the sum and sidelobe canceller gains were used to better match the model to the actual antenna patterns.

Fig. 3 shows the shape of both of the computed patterns. The sum pattern is in blue, and the sidelobe canceller pattern is in red. Spatial filtering is more successful when the sidelobes of the sidelobe canceller pattern are larger than the sidelobes from the sum pattern. Based on the theoretical patterns, the cancellation algorithms will be more effective further away from the mainlobe because of the higher sidelobes from the sidelobe cancellers.

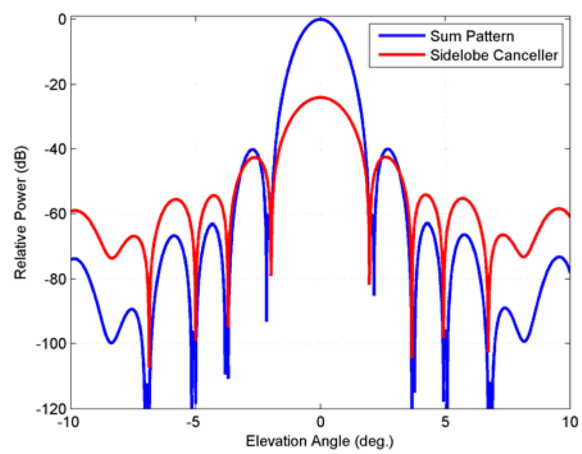

Figure 3. Theoretical antenna patterns calculated based on the location of the antenna elements and sidelobe canceller receive antennas.

5. SIDELOBE CANCELLATION ALGORITHMS

In general, sidelobe cancellation algorithms provide a set of weights, **w**, that when multiplied by a matrix of time-series data produce a single spatially-filtered array of time-series values. The weight vector, **w**, is an N x 1 vector, and the time-series matrix, **V**, is an N x M matrix where N is the number of channels and M is the number of pulses. The resulting 1 x M time series array is normally written as $\mathbf{w}^H \mathbf{V}$. The time-series matrix **V** corresponds to data from a single range gate; the algorithm is applied at each individual range gate to adapt to the ground clutter from that particular range.

After surveying several algorithms, the DCMP-CN (Directionally Constrained Minimum Power - Constrained Norm) algorithm introduced by Kamio and Sato (2004) seemed to fit the requirements of the NWRT phased array antenna relatively closely. This algorithm was developed for a wind profiler antenna and uses six additional sidelobe cancellers to mitigate ground clutter from mountains. The algorithm attempts to minimize effects on the main antenna sum pattern while still rejecting power from ground clutter sources.

This algorithm falls into a larger class described as quadratically-constrained LCMP (linear constrained minimum power) algorithms by Van Trees in *Optimum Array Processing* (2002). As the description makes clear, the algorithms have linear constraints with an additional quadratic constraint that controls the noise power and helps minimize effects on the antenna main beam.

One way of defining the quadratically-constrained LCMP algorithm is in terms of a covariance matrix, $\mathbf{R}$, a constraint matrix, $\mathbf{C}$, constraint vector, $\mathbf{g}$, and quadratic constraint T_0.

$$\min_{\mathbf{w}}\left(\mathbf{w}^H\mathbf{R}\ \mathbf{w}\right)$$

$$\text{subject to } \mathbf{w}^H\mathbf{C} = \mathbf{g}^H \text{ and } \mathbf{w}^H\mathbf{w} \le T_0$$

The linear constraint often contains a directional constraint to control the effects of the weights in the mainlobe steering direction. In the simulations, an additional constraint was added to force the weight for the main beam to be 1. This follows the work of Le in his dissertation (2009).

Without the quadratic constraint, there is a closed-form solution for $\mathbf{w}$. When the quadratic constraint is introduced, there is no closed form solution, and there are several ways to approach the problem. The DCMP-CN algorithm uses the penalty function method to satisfy the quadratic constraint. Another method is to use find the proper amount of diagonal loading. This can be shown to be the optimal solution to the quadratic constraint problem, but there is no closed-form solution to find the amount of diagonal loading needed. A simple search was used in the simulations to find the optimal amount of diagonal loading to satisfy the quadratic constraint.

6. DISTRIBUTED CLUTTER MODEL

An earlier simulation with only one target was developed to study the feasibility of using spatial filtering to mitigate ground clutter. Although this showed that spatial filtering could reduce the power from a single target, ground clutter can come from many directions and is made up of many targets. For the current simulation, multiple targets from multiple directions were utilized to better represent the true effects of ground clutter on spatial filtering.

Fig. 4 shows the difference between the two models. The blue circle shows the steering direction of the main beam. In this case, it is at an azimuth of 0° and an elevation of 7°. The blue line is a simple horizon line at 0° elevation, and the black “x” markers are the clutter targets.

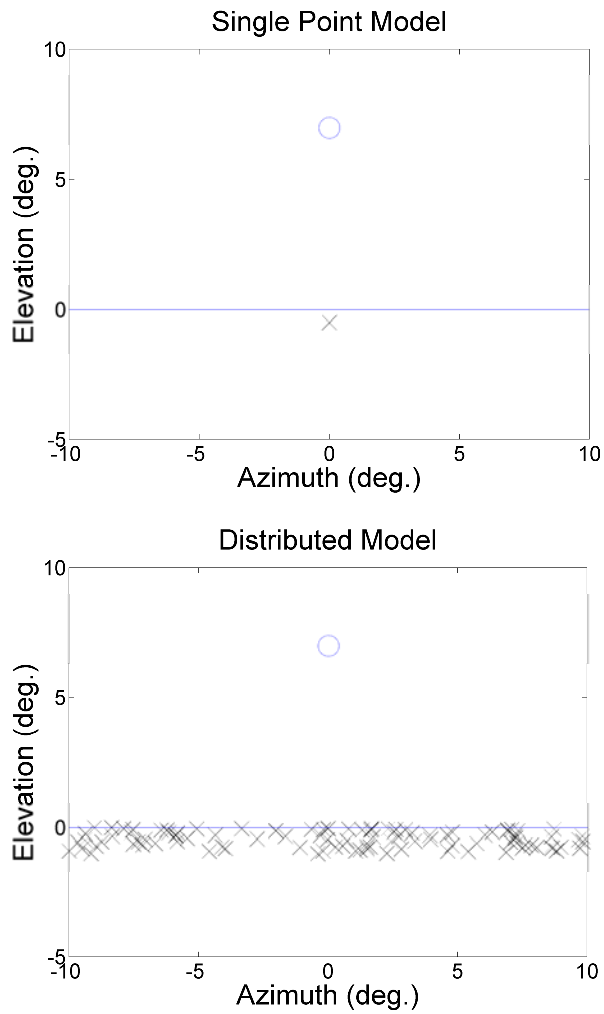

Figure 4. Comparison between the single point and distributed clutter models.

The single point model uses one clutter target, but the distributed model uses 100 randomly placed clutter targets between -10° and 10° in azimuth and between -1° and 0° in elevation. The number of targets is significantly larger than the number of degrees of freedom which depends on the number sidelobe cancellers. Even this distributed model is not completely accurate because the clutter targets that contribute to data at a particular range would not be randomly distributed in space but would correspond to targets on the ground at that specific range from the radar.

For this particular simulation, the clutter targets were assumed to have the same power. The weather was simulated with a spectrum width of 2 m s^{-1} and a velocity of 15 m s^{-1} and the clutter targets with a spectrum width of 0.5 m s^{-1} and zero velocity. Time series data with M = 256 were simulated, and the data were combined based on the previously described theoretical antenna patterns. The sample covariance matrix was computed from the time series data, and the algorithm was applied. The resulting spectrum and modified antenna pattern are shown below. A simulation with a single point target was also utilized for comparison.

Fig. 5 shows the spectra from the sum pattern and the weighted sum that was computed from the algorithm.

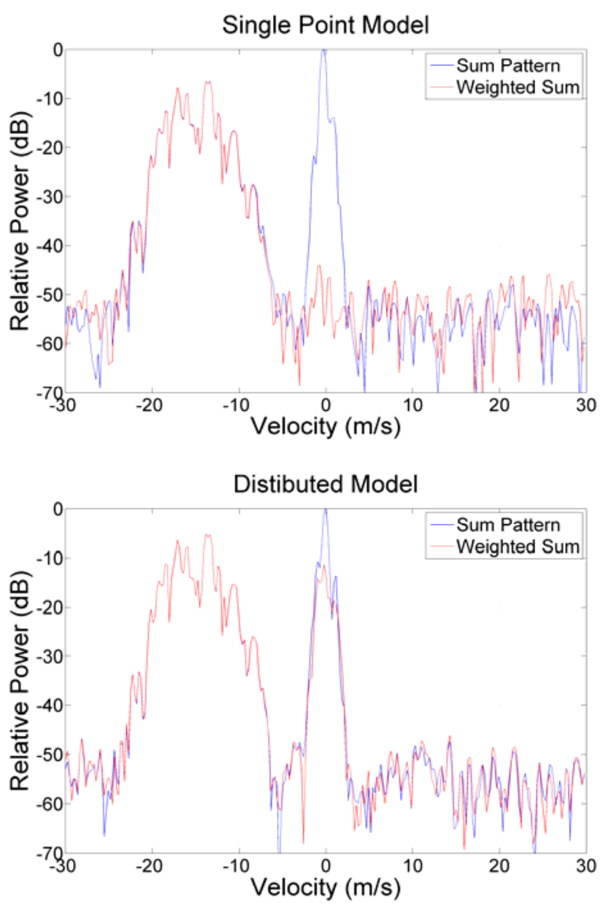

Figure 5. Spectra showing the performance of spatial filtering for both a single point and distributed clutter model.

For the single point model, the algorithm performed well and removed nearly all of the power from the clutter target. For the distributed model, significantly less power was removed. As expected, the few degrees of freedom afforded by the six sidelobe cancellers were not sufficient to mitigate the clutter.

For comparison, a similar simulation was run using 18 sidelobe channels with the same patterns as the original six receiver antennas. Fig. 6 shows the results.

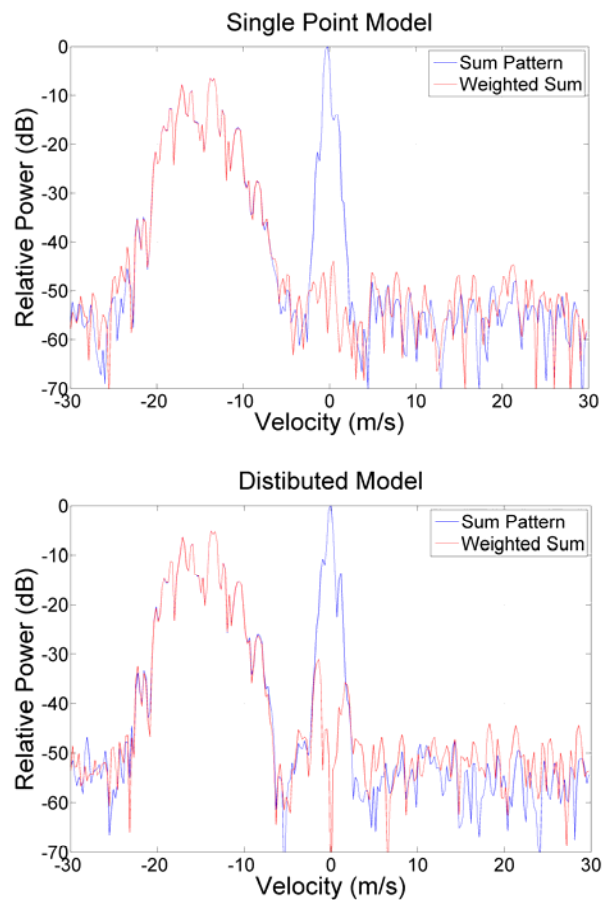

Figure 6. Spectra showing the performance of spatial filtering for both a single point and distributed clutter model using 18 sidelobe cancellers.

In the distributed case, much more of the clutter power is removed with a small amount of residual power left. Although this is a purely theoretical exercise, it shows how more degrees of freedom can lead to better clutter mitigation with distributed clutter.

7. CONCLUSIONS

The new distributed clutter simulation shows that the performance of the sidelobe cancellation algorithm is reduced compared to the previously utilized single point clutter model. It is important to remember that the distributed model is close to a worst case scenario for ground clutter. In some cases, there may only be a small number of significant clutter targets in the range gate of interest. Future data collection will show how well the six sidelobe canceller channels on the NWRT perform and should help in understanding the performance of other array architectures.

8. REFERENCES

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