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Signal to Noise Analysis of iRadar sensors

A. Fritzke, P. Top

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C1C Austin Fritzke
United States Air Force Academy
Lawrence Livermore National Laboratory
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Abstract

This document follows my process of testing; comparing; and contrasting several iRadars signal to noise ratios for both HH and VV polarization. A brief introduction is given explaining the basics of iRadar technology and what data I was collecting. The process section explains the steps I took to collect my data along with any procedures I followed. The analysis section compares and contrasts five different radars and the two different polarizations. The analysis also details the radars' viewing limitations and area. Finally, the report delves into the effects of two radars interfering with each other. A conclusion goes over the success and findings of the project.

Introduction

For this project, I worked with iRadar sensors. These radars differ from conventional radar in the fact that they are ultra-wideband radars. This large range of frequencies can be attributed to the fact that the radars send out an extremely narrow pulse. Each pulse is less than one nanosecond long. Because of the near instantaneous change from 'off' to 'on', the frequency range is quite large. This gives a higher resolution and creates greater accuracy. IRadars are also less susceptible to interference from other radars than their conventional counterparts. They also have the ability to range gate, which allows the radars to only 'see' a specified distance away. The range gating functions by only allowing the receiver antenna to receive the returning echo only after a specified amount of time, and only for a small range of time allowing the radar to see only at very specific distances. To view an entire area, the delay before the gate is varied accordingly. The radars I worked with can detect any changes (movement) at specified distances, and would continuously change the delay for the range gating to constantly be monitoring an entire area. Because of range gating, these motion-sensing iRadars can easily ignore background noise. Another benefit of iRadars is that because the pulses are so short, and there is a large amount of time between pulses (relative to the pulse size), the iRadars have extremely low power requirements. In fact, one type of iRadar can operate continuously for years on a single AA battery. Not only is this characteristic helpful in the field, but it also contributes to another advantage of the iRadar: cost. IRadars can be built with off-the-shelf components and therefore are cheap to build. With its accuracy, small size, low power, and inexpensive construction, there are definite advantages to the iRadar, but while not new, this technology has not been fully developed. A team at Lawrence Livermore National Laboratory is working to characterize and find uses for these radars, which this project contributes to.

For my project, I tested five "identical" units. Theoretically, the results should have mirrored one another, but due to the large amount of variables created within each unit, the results contained significant variances. I measured the signal to noise ratio of each radar over a two-dimensional space to determine the range and strength of the radars. The 'signal' that the radars received was an object moving through the parking lot in a specified pattern, and the noise was everything else in the background. I was able to determine the strength of each radar as well as the relative range. Once data was collected for the five radars to be compared, I went on to determine the viewing angle of a given radar. Finally, I experimented with whether two radars interfere with each other.

Process

To collect data, I set up a radar in the corner of a parking lot, and then the target was moved in the course as shown on Figure 1 in the Appendix. Data was collected 10 times. Data was also collected in stop motion fashion at 10 ft intervals to gauge the range calibration of each radar. Each dataset would then be analyzed, filtered and graphed in MATLAB as shown in Figure 2. The signal was usually a dark line, and the background noise was usually green. A simple MATLAB file is run to compare the strength of the signal to the median of the background noise, and a ratio is created. One hundred ratios are collected, creating a 10x10 matrix of signal to noise ratios. The ratios are collected in such a manner that if plotted, as shown in Figure 3, the signal to noise matrix represents the signal to noise ratio of the radar across the entire tested area. I would then rotate the radar along the z axis in order to increase the field of view, and switch the polarization of the antennas to measure both HH and VV polarization. Lastly, I measured the effects of the signal to noise ratio when one radar is receiving interference from another.

Analysis

Distance Calibration

Before looking at the signal to noise plots, it was important to determine the minimum and maximum distance that each radar could see. The results of the distance measurements are shown below in Table 1.

Table 1: Radar Distances

Radar #	Equation	Min. Distance	Max. Distance
1	y = 0.0351x + 8.98	8.98 ft	80.83 ft
	y = 0.0107x + 2.74	2.74 m	24.64 m
2	y = 0.0407x + 9.59	9.59 ft	92.90 ft
	y = 0.0124x + 2.92	2.92 m	28.30 m
3	y = 0.0403x + 7.61	7.61 ft	90.10 ft
	y = 0.0123x + 2.32	2.32 m	27.50 m
4	y = 0.0404x + 14.81	14.81 ft	97.51 ft
	y = 0.0123x + 4.51	4.51 m	29.69 m
5	y = 0.0344x + 15.12	15.12 ft	85.54 ft
	y = 0.0105x + 4.61	4.61 m	26.10 m

What affected the minimum and maximum distances was the time delay range gating. The radars only look at a specific distance depending on the time delay. The minimum and maximum distances then are derived from how long the delays are set in each radar between sending and receiving the pulse. Theoretically, the maximum and minimum distances should be equal between radars. However, there are many factors that can cause the differences in distances. Each radar has its own timing board, and those boards most likely have a degree of variability to them. Also, the radars are adjustable: the minimum and maximum distance can be adjusted using potentiometers. While generally calibrated to be the same, there is most likely a difference in the resistance between the potentiometers for the separate radars. There was also some variation in the sampling rates from the data acquisition system which has an impact of the distance measurement. However, the radars all followed a general pattern of having a minimum distance of around 10 feet and a maximum distance of around 90 feet.

Signal to Noise Ratios

The data collected was then graphed as shown in Figure 2, and I then ran a program in MATLAB that calculated the signal to noise ratio at a given time. The signal to noise ratio is in decibels, and theoretically all of the five radars should have similar results. The ratios are stored in ten by ten arrays and are plotted relative to where they were measured in relation to the radar being tested. The x and y axes are therefore in feet (from the radar), and the z axis is the decibel level at any given location. The decibel value is also represented by the color of the graph.

To begin, I measured all of the radars using HH polarization. HH polarization is where the transmitting and receiving antennas are next to each other. A picture of all five results can be found in Figure 4. Each result is actually three tests merged and averaged together to create a 180 degree view instead of one 90 degree view. It is important to note that the radars are always in the center of the plot and are looking towards the northeast corner. Figures 5-9 are better representations of each of the signal to noise ratios of the different radars for HH polarization.

From the plots, it can be seen that the signal to noise ratio pattern and strength are not the same between radars. Radar numbers one and five have high signal to noise ratios, while radar number 3 appears to be very consistent. This may be due to the fact that the antennas, while of the same configuration, are different for each radar. Also, the gain, similar to the distance, can be adjusted using a potentiometer. Each radar has its own set of unique circuits and components, and these combine to create the variations we see in the plots. However, there are important similarities as well. The strongest signal reception occurs directly in front of the radars with about a 90 degree field of vision. Once beyond that field of vision, the signal strength decreases usually by 10 to 15 decibels.

After collecting data using HH Polarization, I rotated the radars by 90 degrees so that the transmitter and receiver antennas were on top of each other. The VV polarization results for all five radars can be found in Figure 10. The individual plots for each radar are shown in Figures 11-15.

As with the HH polarization, there is a bit of variability between the radars. Radar number one and five have, as expected, greater signal strength like they did with HH polarization, and radar number three appears to be very consistent throughout. The VV polarization, however, appears to show more similarity between radars than HH polarization. It appears that VV polarization is more consistent.

When comparing the two types of polarizations, HH polarization tends to have a stronger signal to noise ratio than VV polarization. It also tends to have a wider range of maximum signal strength. VV polarization's maximum signal strength range looks to average less than 90 degrees, while HH polarization averages greater than 90 degrees. However, the VV polarization tends to be more consistent. The slope between measured points on the plots is less extreme, and therefore more realistic. One explanation that may be that VV polarization is less sensitive, and therefore does not pick up as many erroneous signals from the background noise as the HH polarization does.

While there will be always be variations between different radars, there are enough similarities to obtain reliable data. The two different polarizations also have their differences, and whichever one someone chooses to use will depend on the use and application of the radar. HH polarization has a greater signal strength and wider range, while VV polarization is more consistent with a narrower range.

Range Analysis

Up until now all of the plots have been 180 degrees. However, there is a good chance the actual range of the radars is greater than 180 degrees, so we ran a test measuring the 360 degree field of view of radar number three. Radar number three was chosen because of its consistency, and HH polarization was chosen because of its assumed greater range. The result is shown in Figure 16. Figures 17 and 18 are 3D representations of the same set of data to get a better idea of the actual range of the radar.

By looking at the plots, it is easy to see that the range of radar number three is around 200 degrees. While the signal strength decreases dramatically beyond a 110 degree viewing angle, it is still capable of picking up a signal at wide angles. As expected, the signal is strongest right in front of the radar. It is important to note that this test is not the average of all radars, but only radar number three and only HH polarization. Because of the relative similarities between radars and polarizations, it can be assumed the other radars would have similar, but not identical viewing angles. This test simply gives a rough idea of the viewing angle of the iRadars tested.

Interference

The iRadar systems send out millions of pulses a second, but the period between pulses is different in different radars in order to minimize interference from other devices or from any background noise. However, the system is not perfect, and the theory is that if two radars are used together, they will interfere with each other. To test this, we set up two tests: one with both radars pointed at each other, and one where both radars are looking in the same general direction but are rotated 45 degrees from each other. The test setup can be more clearly seen in Figure 19. The red line is the path of the signal being recorded.

Unfortunately, we ran out of time in our short five weeks to fully complete the interference tests. Most of the data was collected, but only a handful of tests were analyzed. The project will continue after I leave. The only tests analyzed were for radar number two, and only for the first setup where the two radars are facing each other. The other radar used in the tests but not analyzed was radar number four. Figure 20 shows the interference when both radars are in HH polarization. Figure 22 shows both radars in VV polarization. Figure 21 shows the interference when one radar is in VV polarization, and the other is HH polarized.

When both radars are set up with equal polarization, the amount of background noise increases dramatically. There is definitely interference between the radars. However, when the polarizations are different, there is almost no noise.

A better way to determine the amount of noise is to compare the signal to noise ratios of the interference tests with identically run tests without an interfering radar. Figure 23 is both radars are HH polarized. Figure 24 is with both VV polarized, and Figure 25 is where one is HH polarized, and one is VV polarized. The blue line is the signal with interference. There is a definite drop in signal strength when the polarizations are equal. The average drop per test can be found below in Table 2.

Table 2: Rise or Fall in Decibels from Interference

	HH Interference	VV Interference	VH Interference
Radar #2	-5.9 dB	-5.5 dB	1.2 dB

There is a decrease of around 5 dB from the signal to noise ratio due to another radar with the same polarization. It also appears to be a gain in the signal to noise ratio when there is another radar present with opposite polarization. However, one must consider that this is just one test, so most likely the real number should be around 0 dB, and the margin of error is something greater than 1.2 dB. By completing the analysis, one should find more conclusive data.

Conclusion

In the end, we were successful in visualizing and determining the signal to noise ratios of the five different radars. We were also able to determine the field of view of the radars, and the approximate range. This is important, for it helps us know that the target must be in front of the radar for the radar to see a strong signal, but peripheral targets can still be detected. Because of this, peripheral background noise must be considered when using the radars. All five radars differed from each other, and this is most likely due to the separate parts and settings that each radar has. However, the radars perform similarly enough that there are certain criteria that can always be assumed. Finally, there is significant interference from other radars, but not enough to make the radars inoperable. However, it would still be a good idea to orient two radars with opposite polarizations when using two iRadars simultaneously. This decreases interference dramatically.

Documentation

I worked under Dr. Philip Top who guided me through the entire process. James Slegers worked along-side me during most of the signal to noise ratio, 360° viewing, interference, and distance calibration data collecting.

Appendix

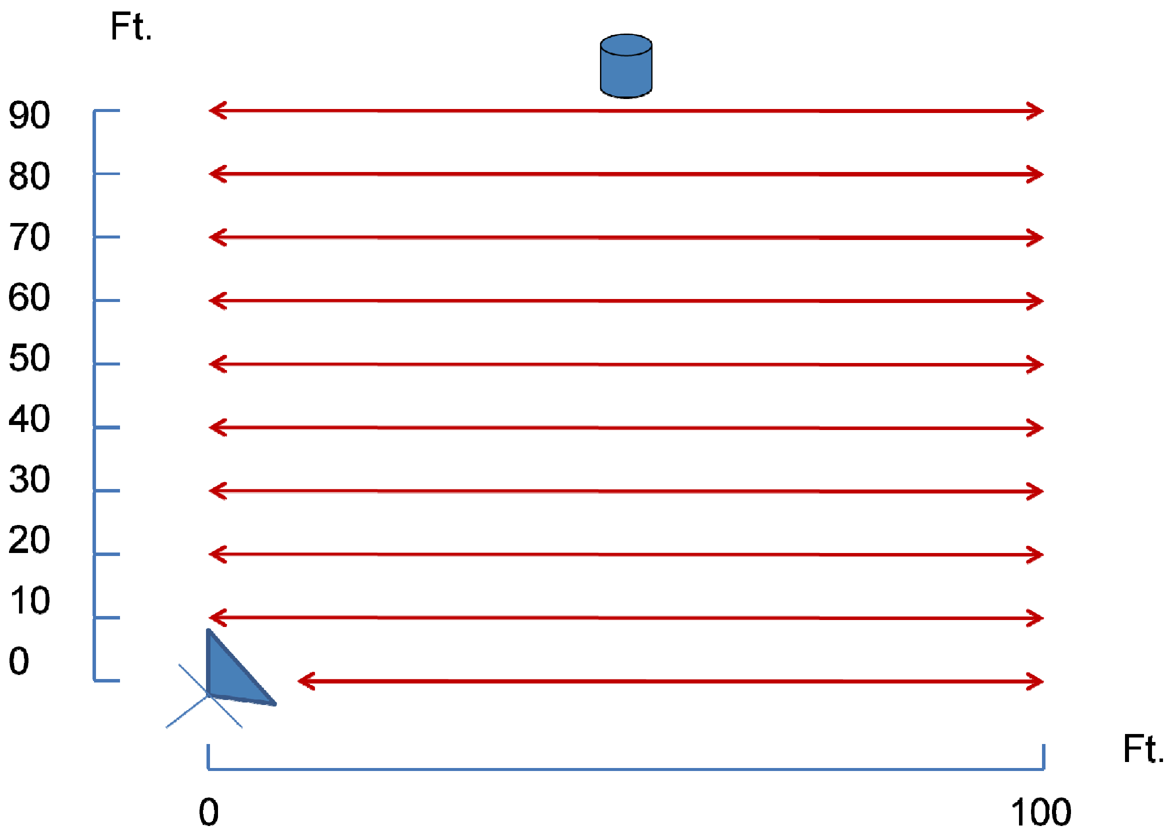

Figure 1: How the Data was Collected

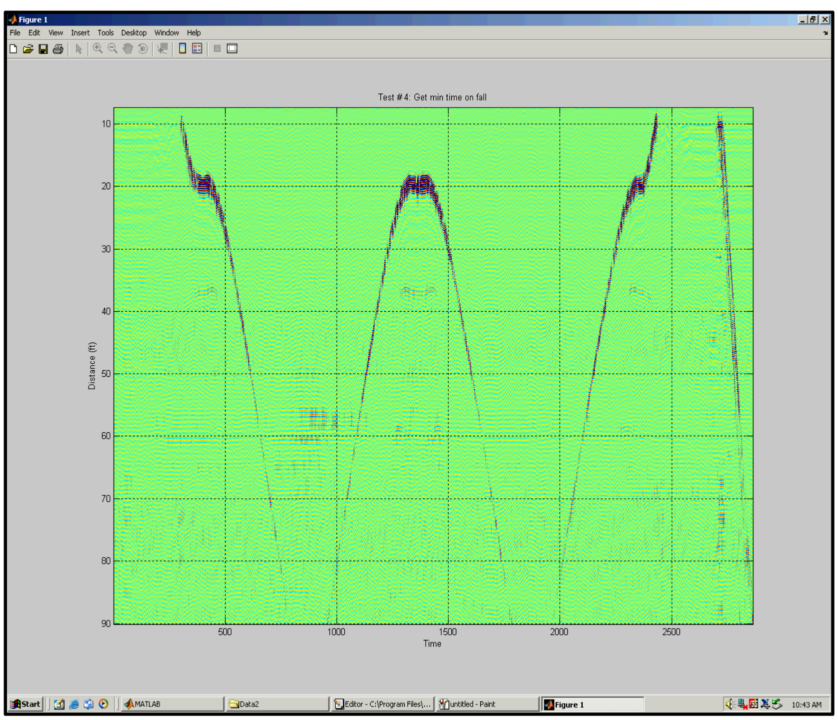

Figure 2: The Data in MATLAB

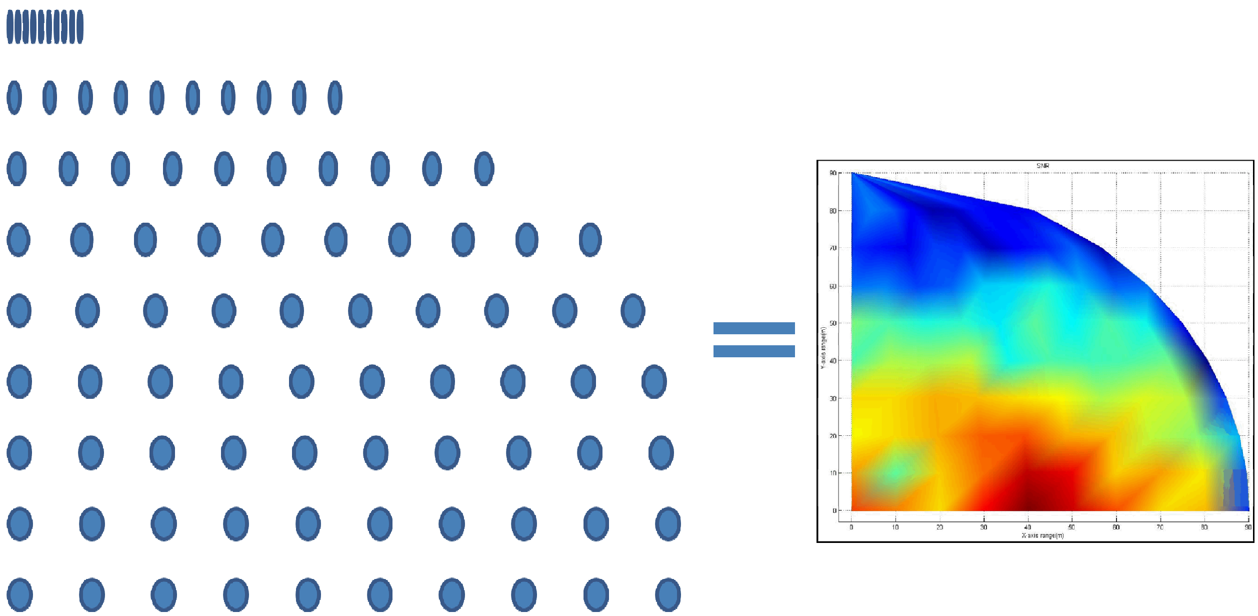

Figure 2: How the Data was Plotted

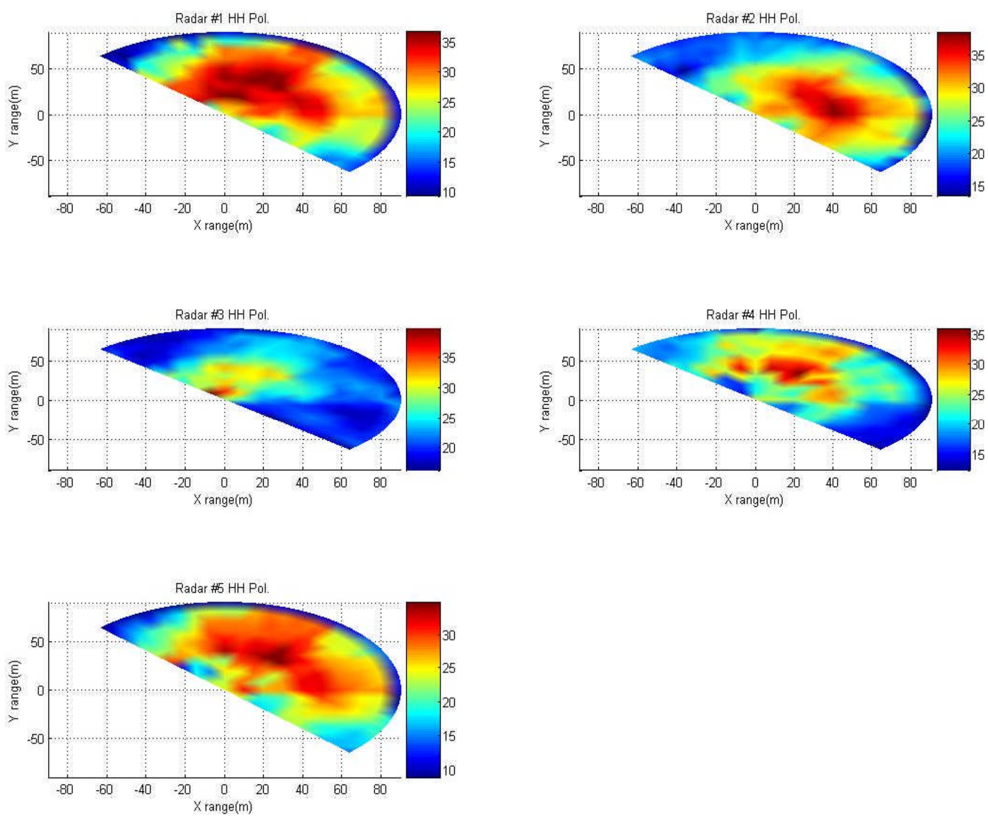

Figure 4: 180° View of Signal to Noise Ratios with HH Polarization

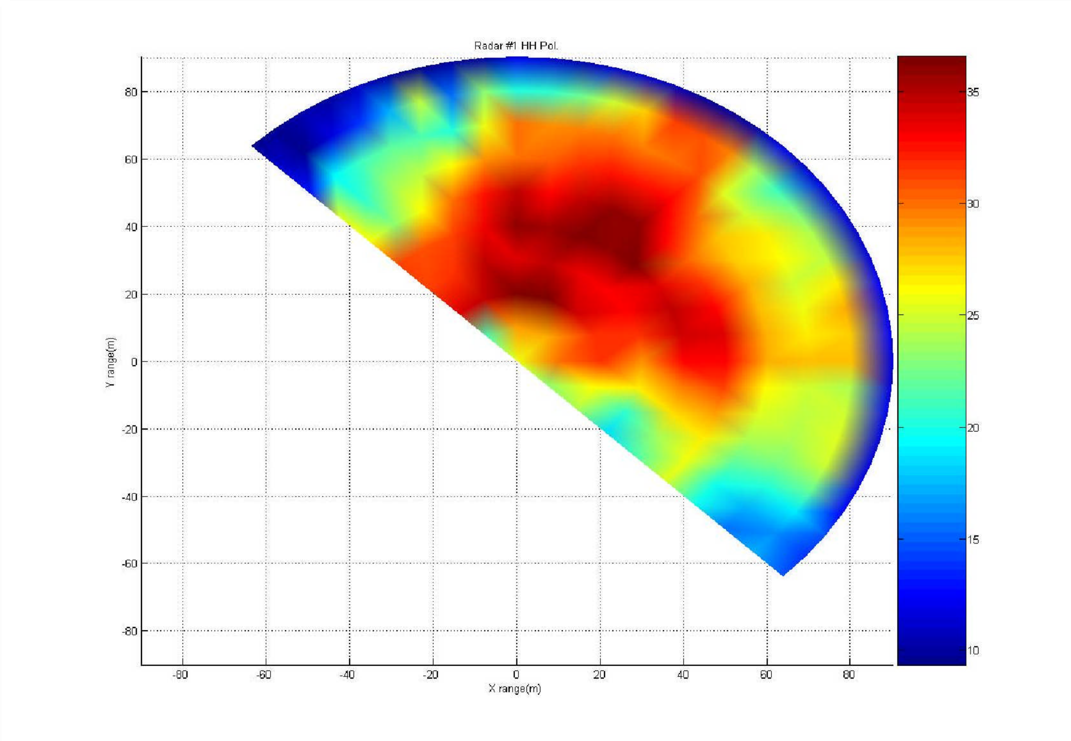

Figure 5: Radar #1 HH Polarization S/N Ratios

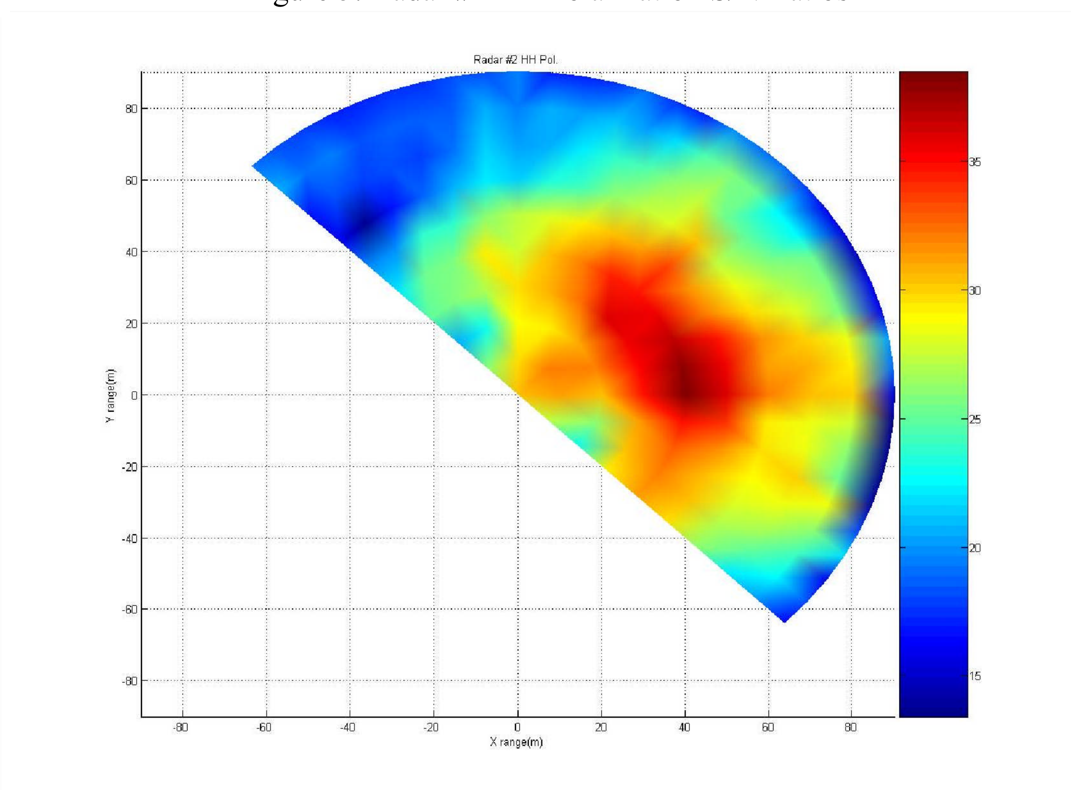

Figure 6: Radar #2 HH Polarization S/N Ratios

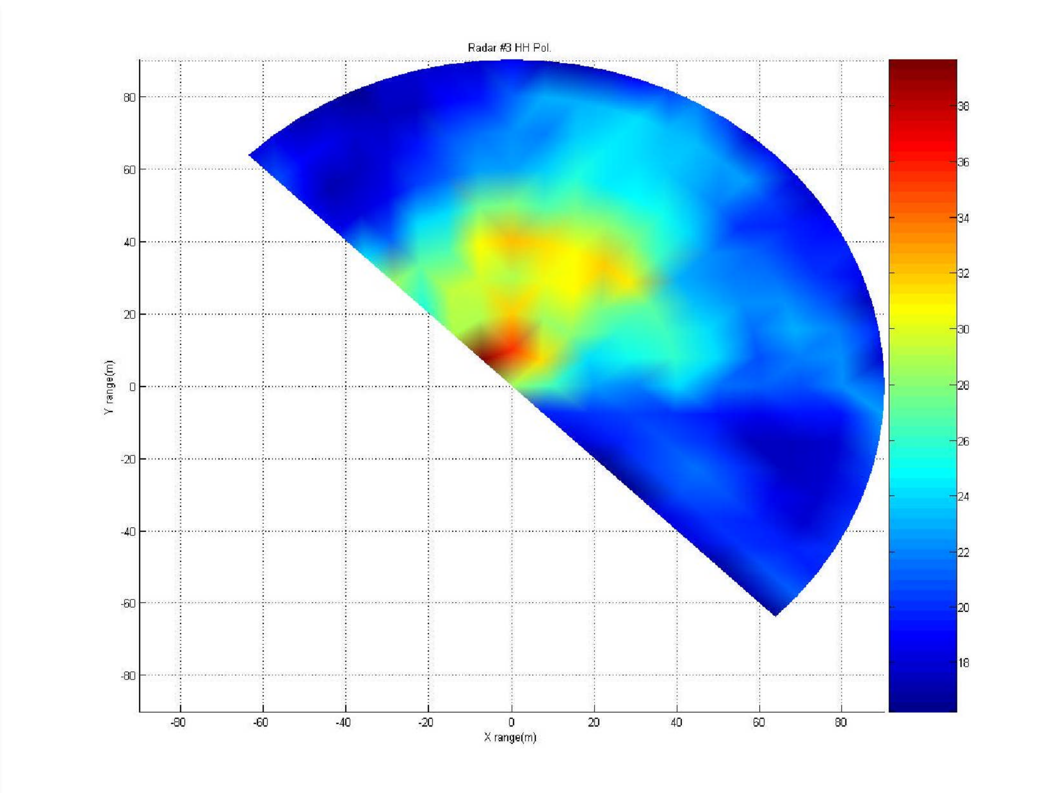

Figure 7: Radar #3 HH Polarization S/N Ratios

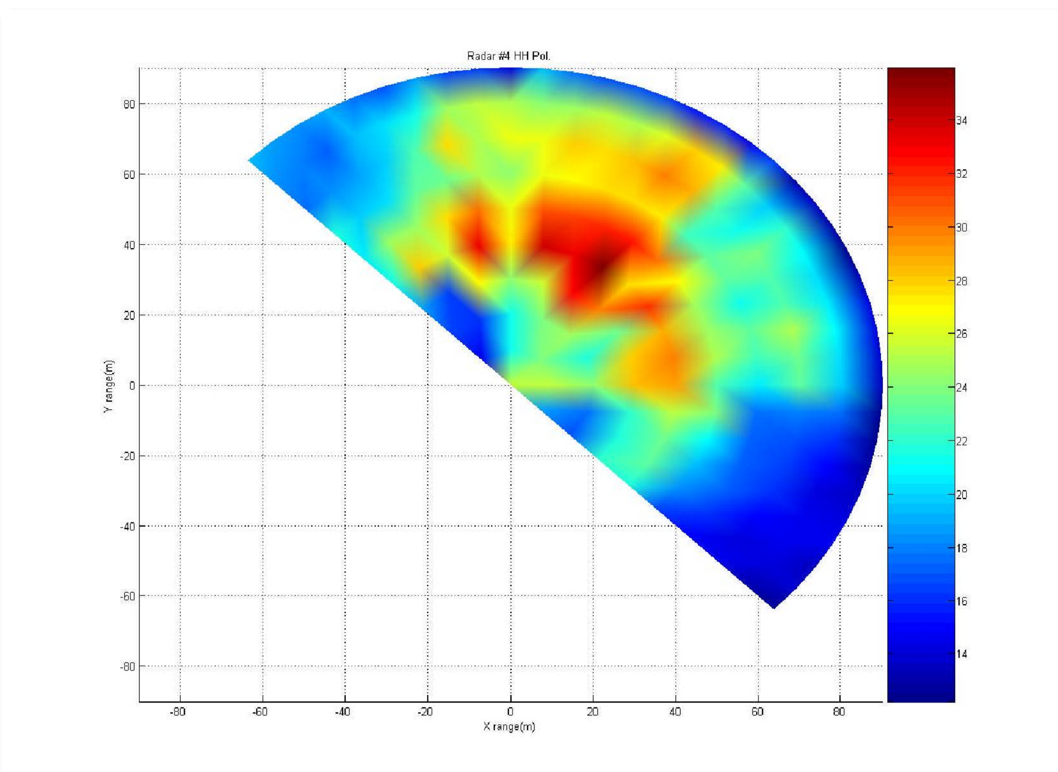

Figure 8: Radar #4 HH Polarization S/N Ratios

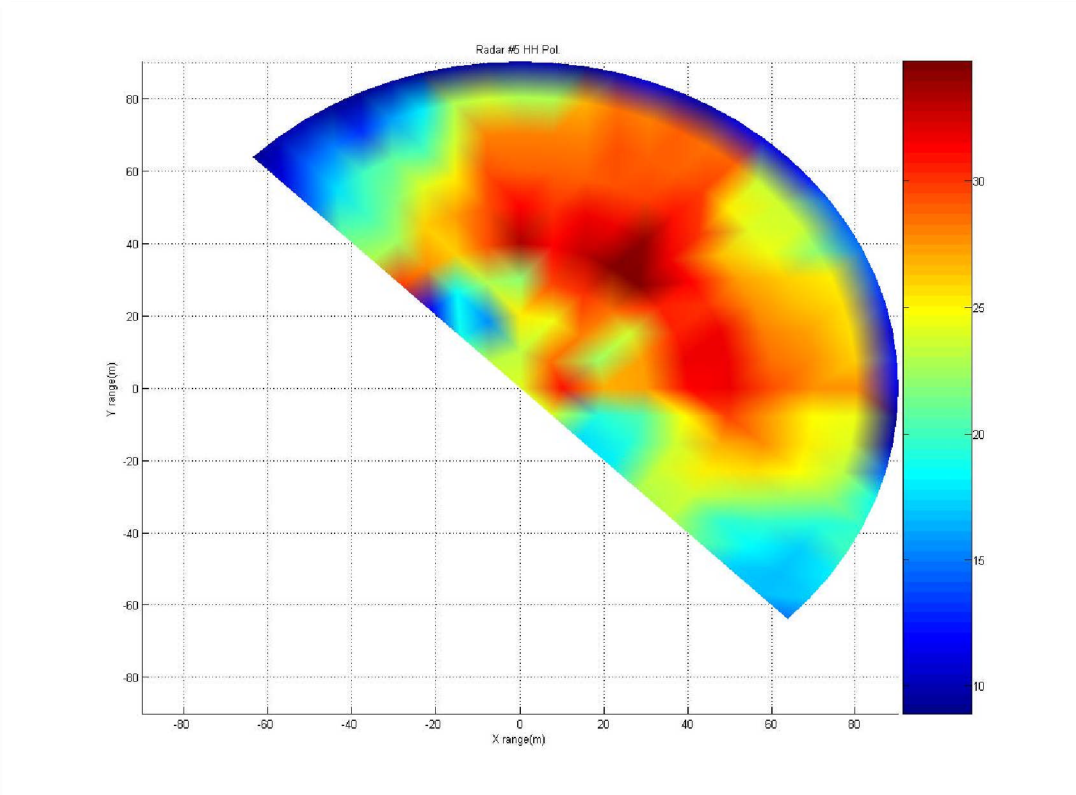

Figure 9: Radar #5 HH Polarization S/N Ratios

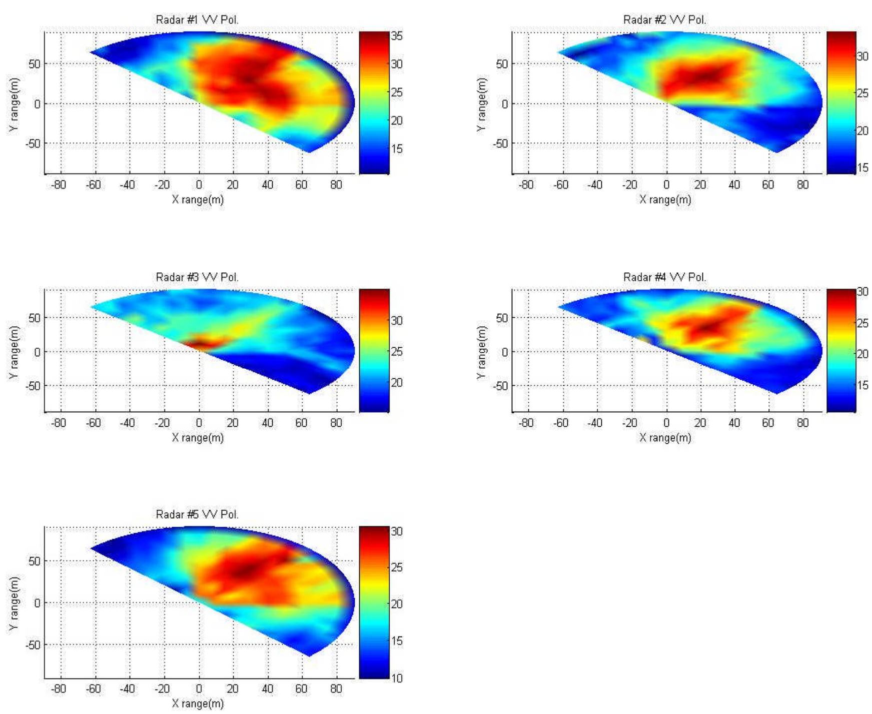

Figure 10: 180° View of Signal to Noise Ratios with VV Polarization

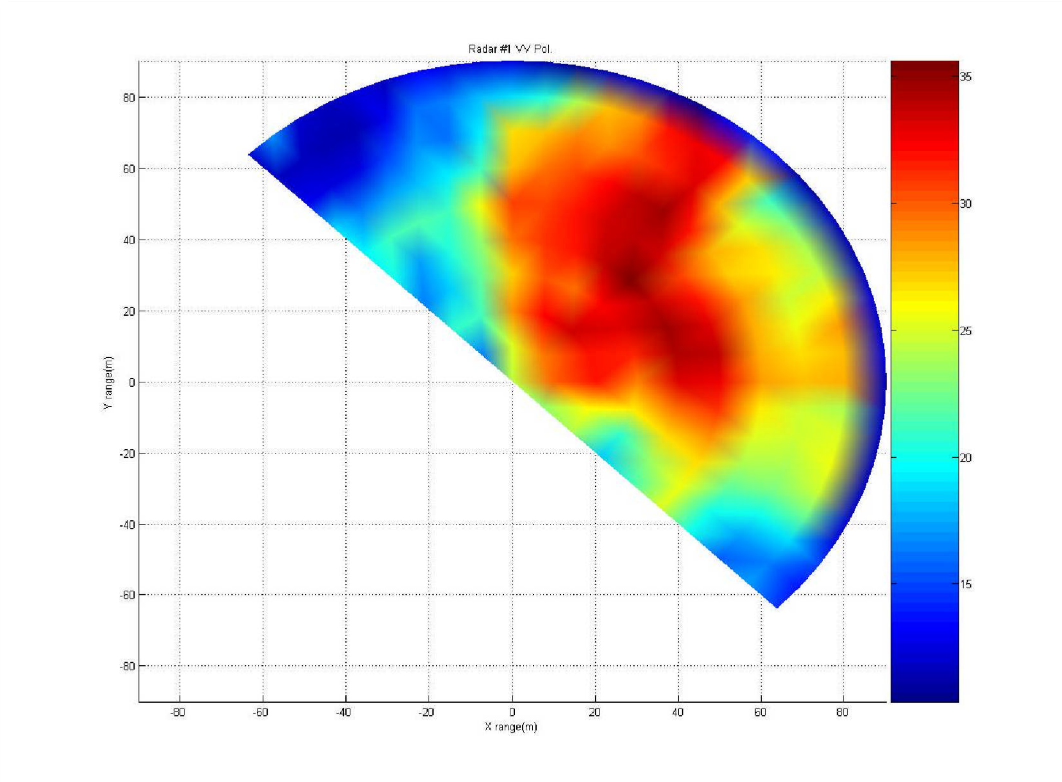

Figure 11: Radar #1 VV Polarization S/N Ratios

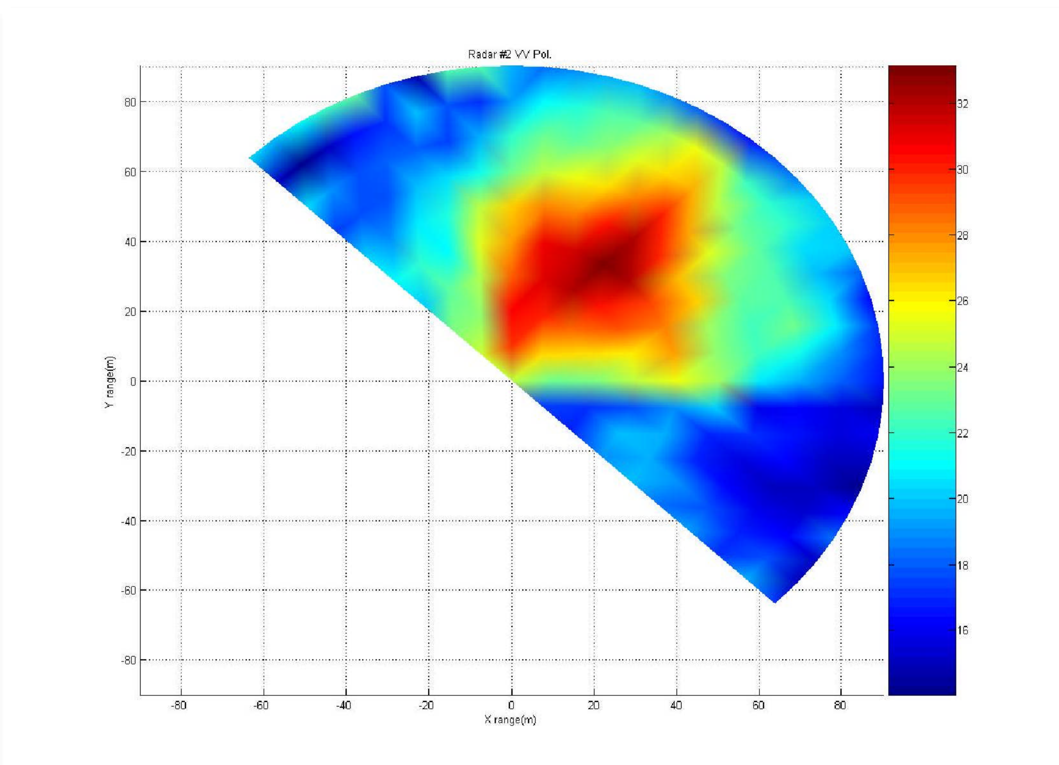

Figure 12: Radar #2 VV Polarization S/N Ratios

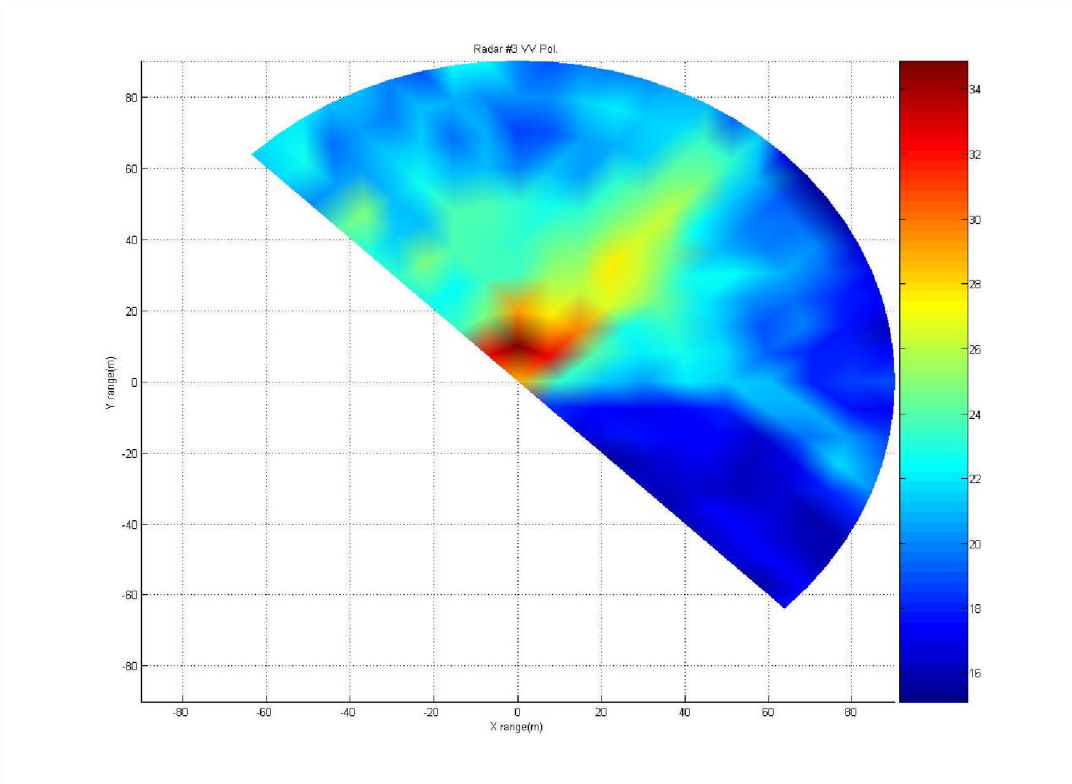

Figure 13: Radar #3 VV Polarization S/N Ratios

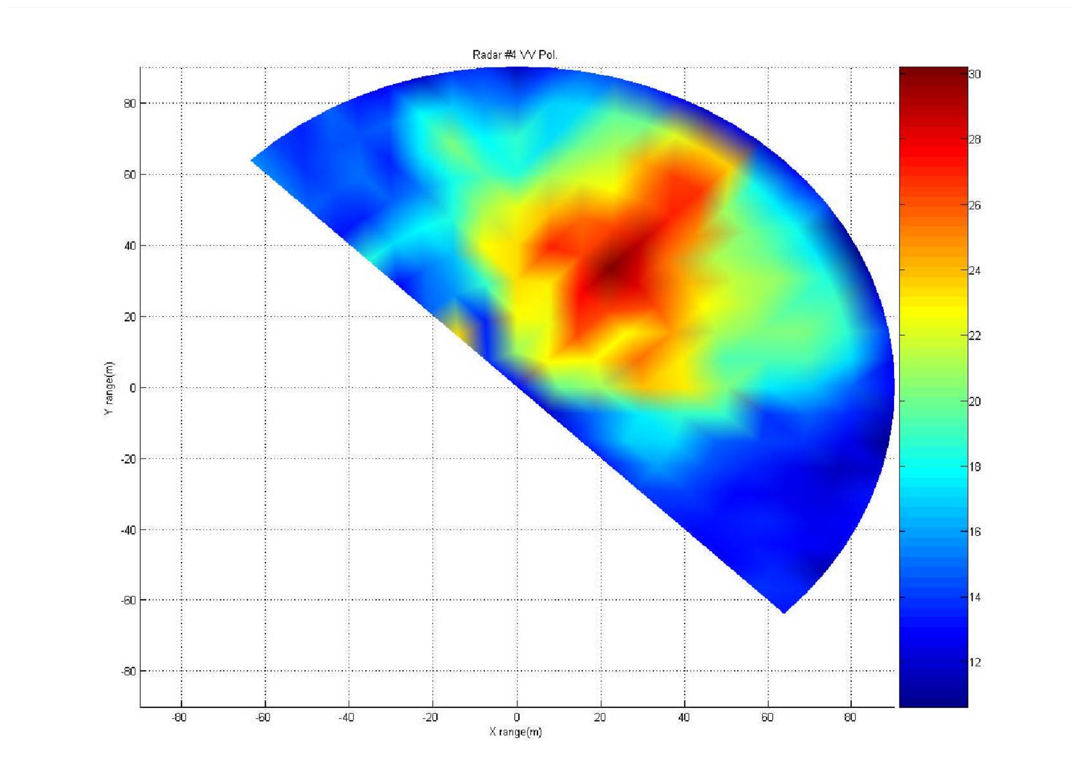

Figure 14: Radar #4 VV Polarization S/N Ratios

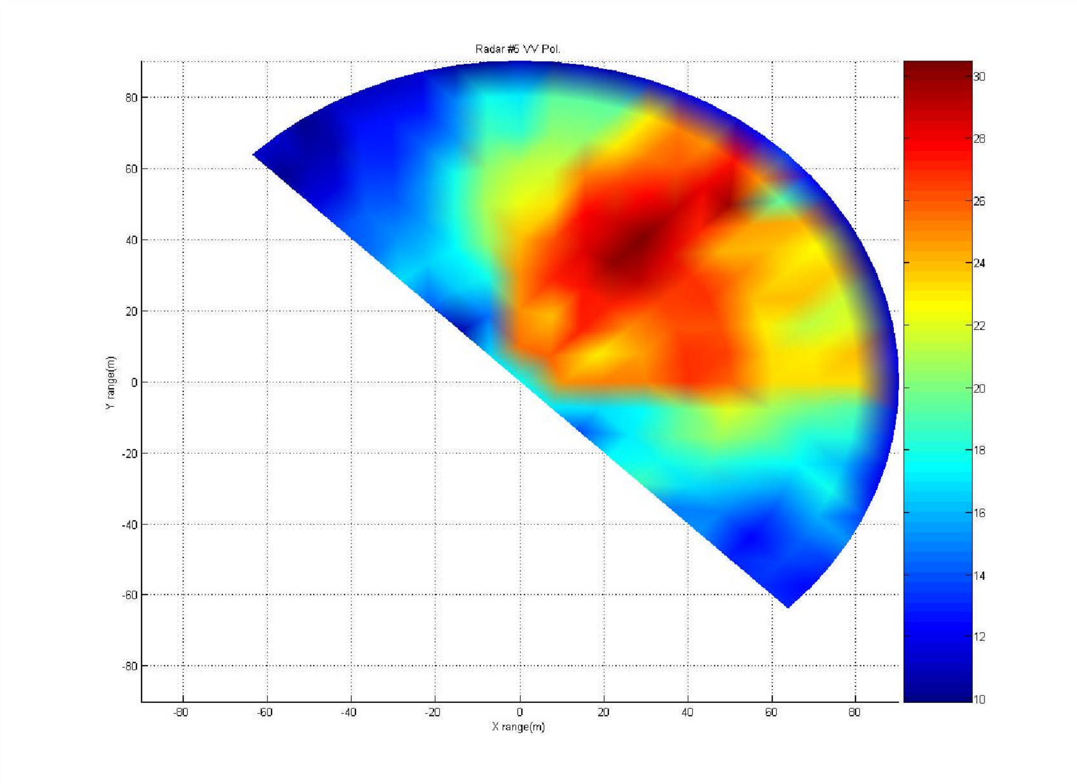

Figure 15: Radar #5 VV Polarization S/N Ratios

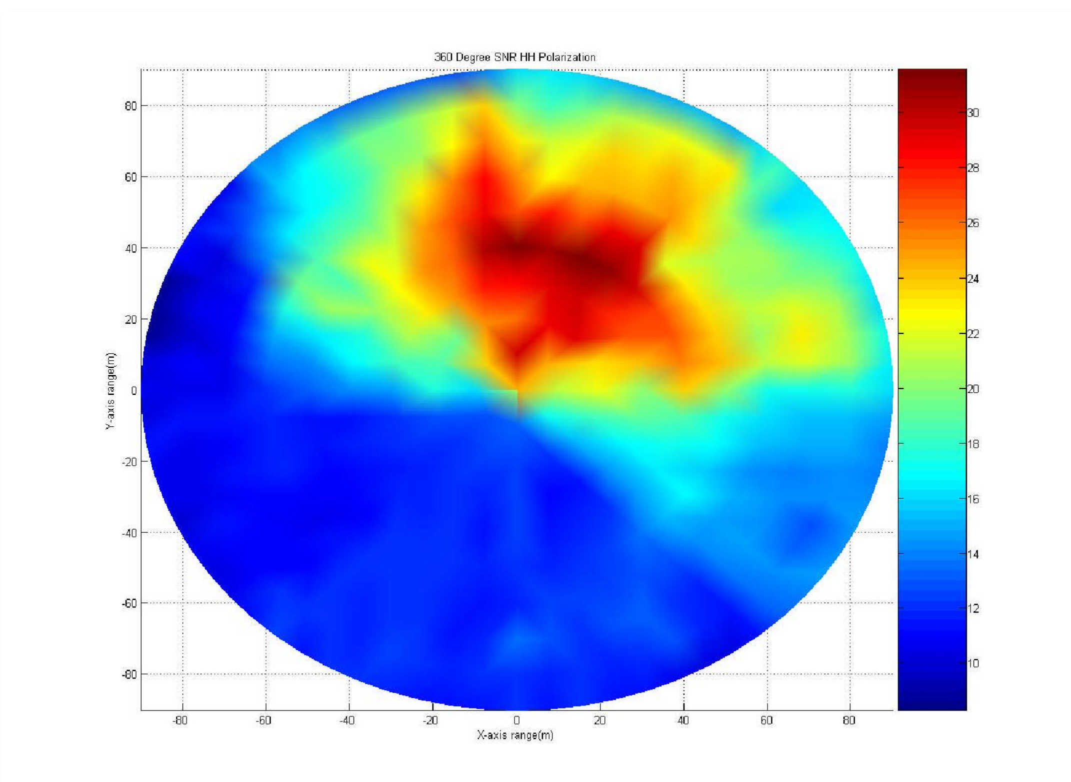

Figure 16: 360° View of Radar #3 HH Polarization

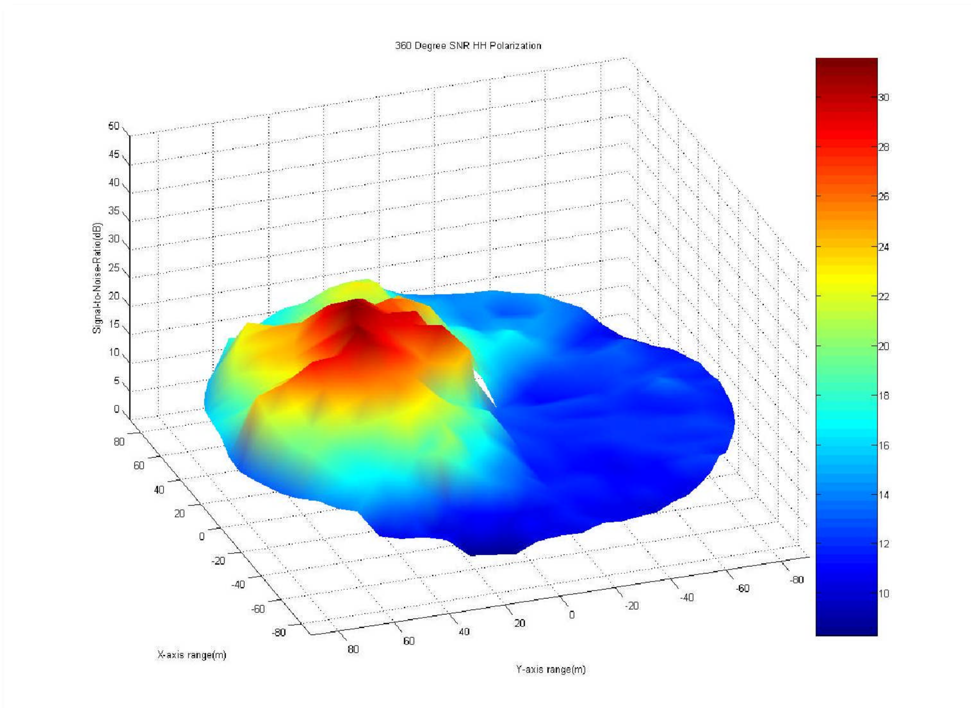

Figure 17: First 360° 3D View of Radar #3 HH Polarization

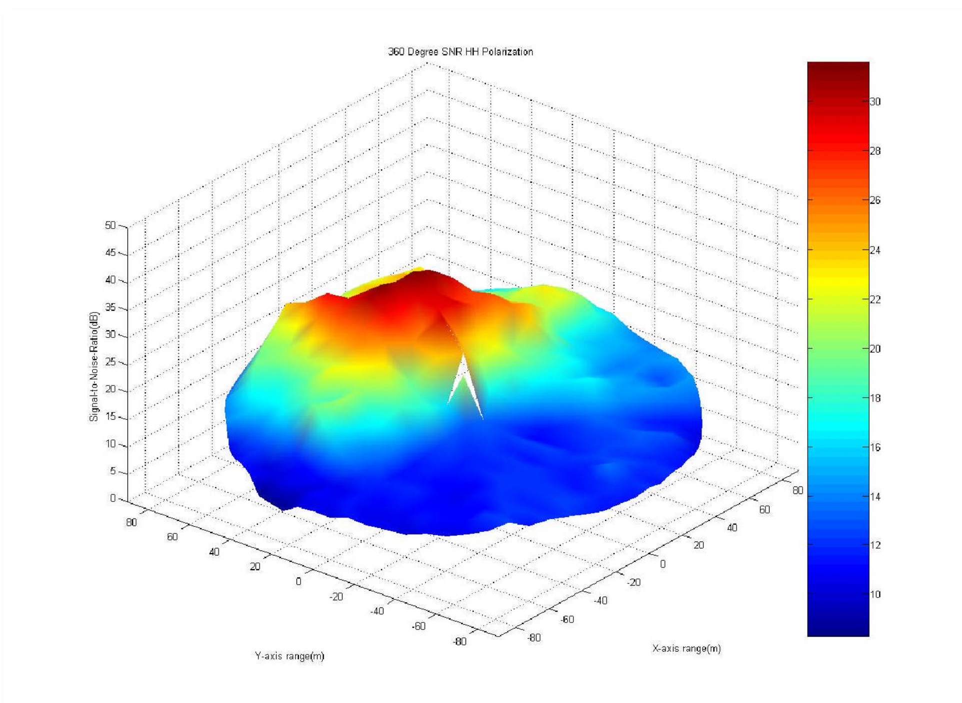

Figure 18: Second 360° 3D View of Radar #3 HH Polarization

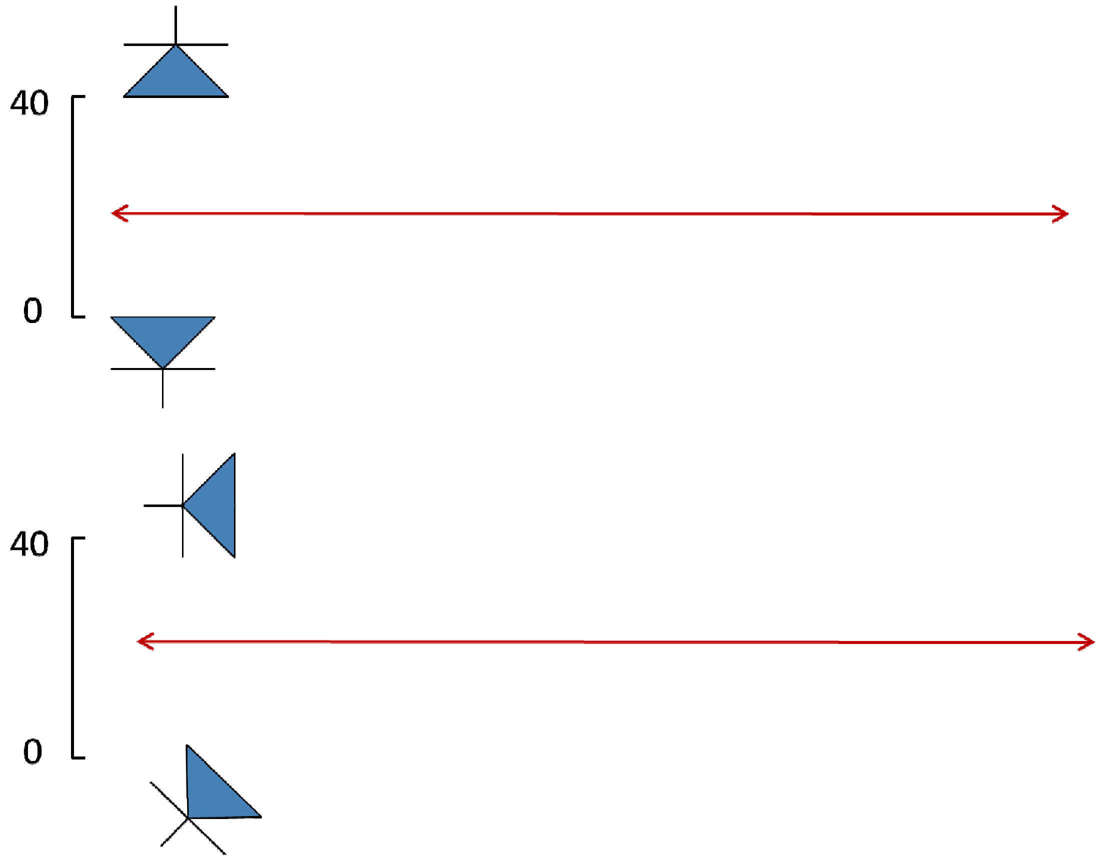

Figure 19: Setup for Interference Tests

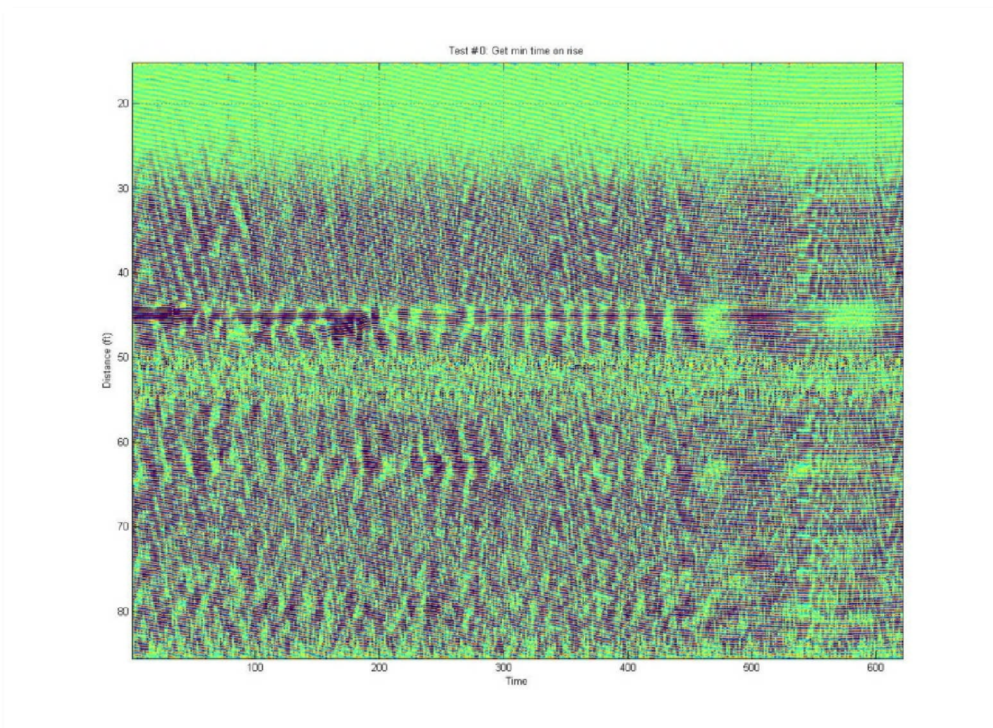

Figure 20: Radar #2, Interference Noise from both Radars in HH Polarization

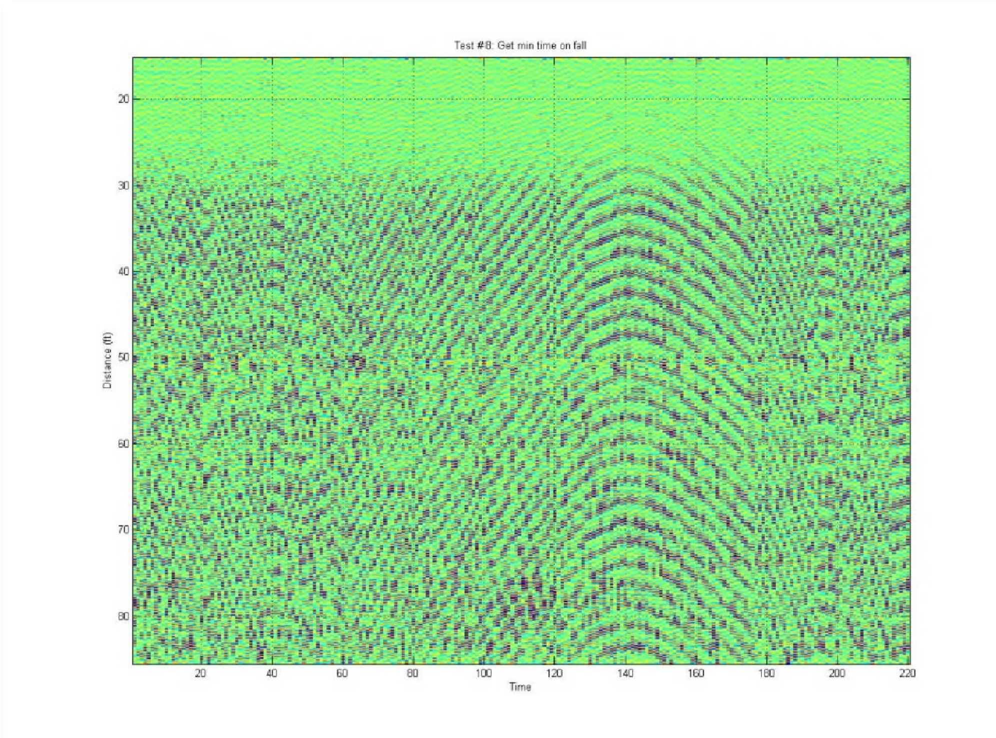

Figure 21: Radar #2, Interference Noise from both Radars in VV Polarization

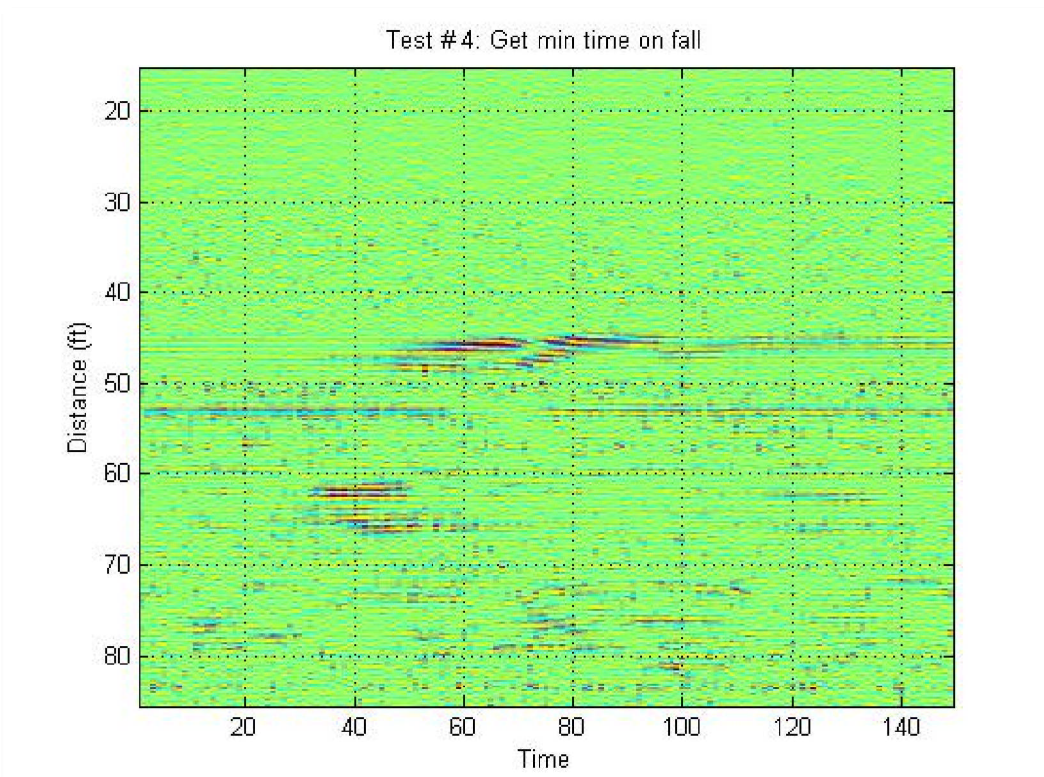

Figure 22: Radar #2, Interference Noise when one radar is HH, and the other is VV

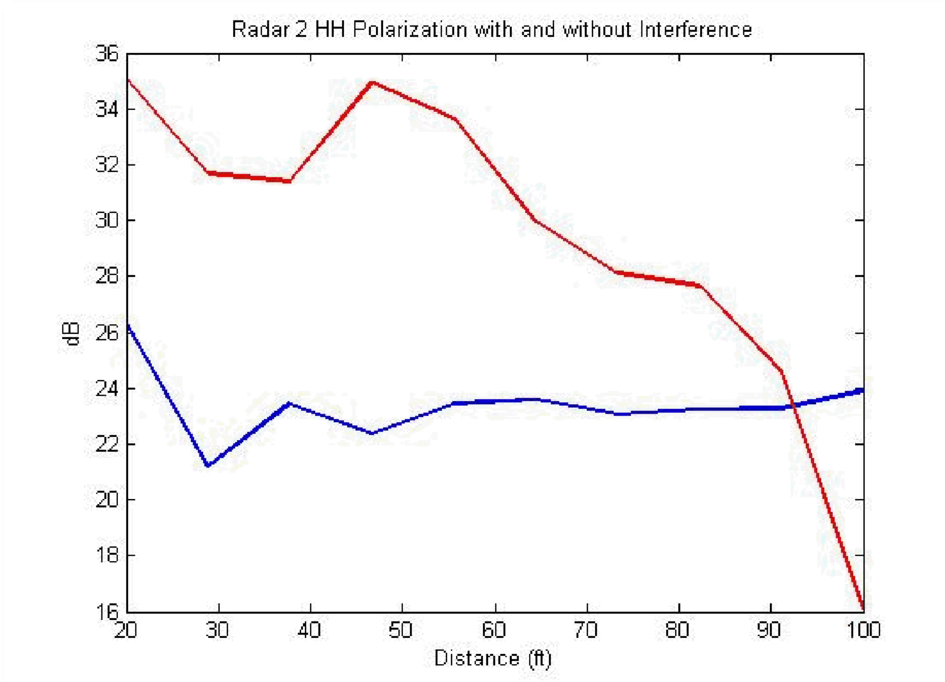

Figure 23: Effects of Interference on Radar #2 HH Polarization

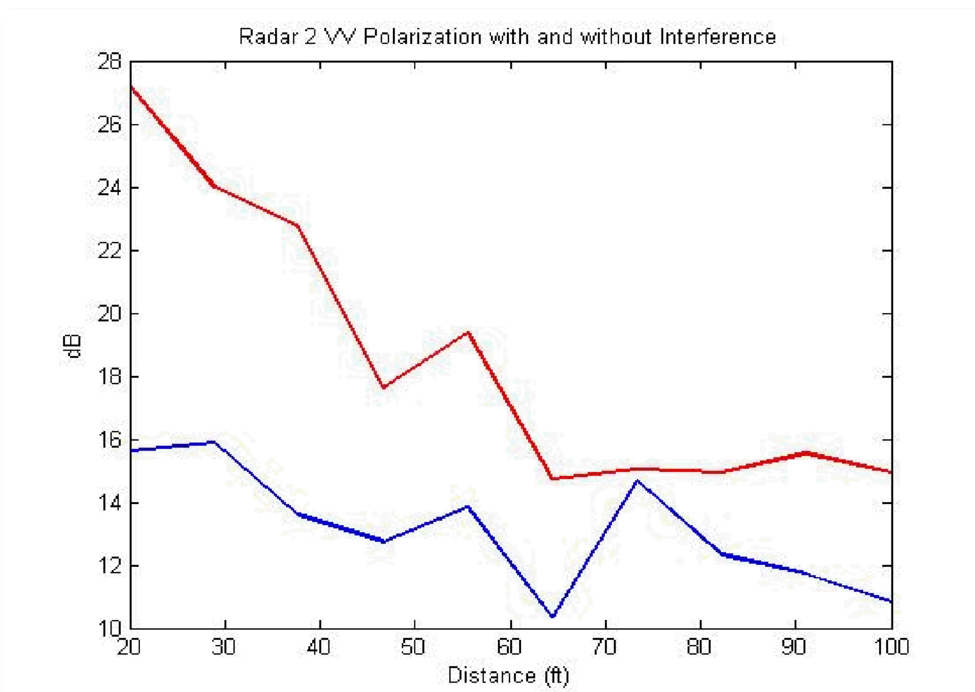

Figure 24: Effects of Interference on Radar #2 VV Polarization

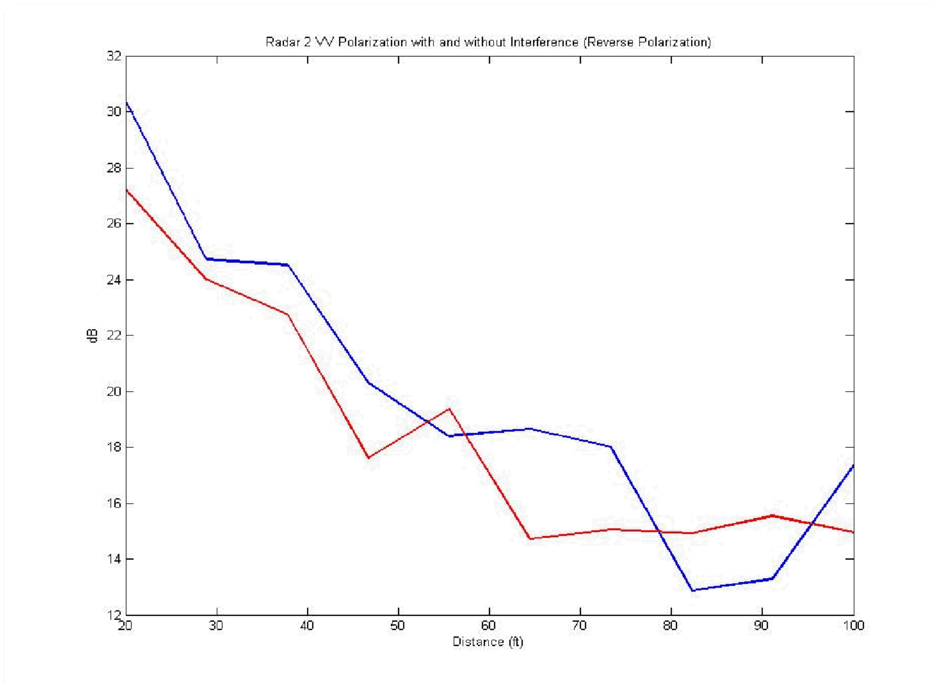

Figure 25: Effects of Interference on Radar #2 with Opposite Polarizations