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Initial Analysis and Calibration of the Fully Polarimetric Mode of the Templar Radar

by Kenneth Ranney and Tuan Ton

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Initial Analysis and Calibration of the Fully Polarimetric Mode of the Templar Radar

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1. Introduction

The Research and Technology Integration (RTI) Directorate within the US Army Combat Capabilities Development Command's (DEVCOM's) Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance (C5ISR) Center has recently upgraded the Templar radar from a dual-polarization (dual-pol) to a fully polarimetric system. That is, the new system can transmit and receive both horizontally and vertically polarized waveforms. This enhanced capability enables exploitation of polarization basis transformations to more fully understand and recognize specific target signature attributes.¹

Polarimetric signatures have been leveraged in the past to identify and exploit target symmetries,²⁻⁴ characterize clutter regions,⁵ and optimally detect targets.⁶ In each of these approaches, various combinations of polarization basis vectors often appear as part of the proposed polarimetric processing. For example, the Pauli decomposition represents a target response in terms of even-bounce and odd-bounce components, providing additional insight into the scattering behavior of specific targets.^{1,7} In order to fully utilize a basis transformation, however, the polarimetric channels must be calibrated relative to one another. Hence, in-scene canonical targets (e.g., dihedrals and trihedrals) are required to determine any necessary magnitude and phase adjustments.⁸

In this work, we document a simplified calibration procedure used by the Templar radar system⁹ to enable transformation between the measured linear polarization basis, comprising horizontal and vertical transmit and receive channels, and the Pauli basis, comprising even-bounce, odd-bounce, and cross-polarized (cross-pol) channels. In particular, we focus on estimating the relative phase and magnitude adjustments between the co-polarized (co-pol) horizontal (H) channel (H-transmit, H-receive) and the co-pol vertical (V) channel (V-transmit, V-receive) required to create the even-bounce and odd-bounce responses. We do not address a relative adjustment to the cross channel that may be necessary to transform between more general polarization bases. In Section 2, we describe the approach and define the canonical target set required to implement and test the proposed technique. In Section 3, we show experimental data that illustrates the effectiveness of the technique. As part of this analysis, we define a metric that quantifies the gain realized through implementation of the Pauli transformation. In the final section we summarize results and outline future experiments for developing algorithms to exploit the enhanced Templar capability.

2. Motivation and Approach

Researchers at the DEVCOM Army Research Laboratory (ARL) and C5ISR/RTI have collaborated in recent years to develop detection algorithms that operate on the dual-pol data produced by the ALARIC and initial Templar radar systems.³ Supporting data produced by ARL's high-fidelity electromagnetic models suggested that features based on even- and odd-bounce signatures could increase target-to-clutter ratios for certain targets. As a result, ARL and C5ISR/RTI have teamed to incorporate fully polarimetric data measurement, calibration, and processing into the Templar system. A simple transformation converts the measured Templar data from its native polarization basis to the Pauli basis.

The Templar radar records the following polarimetric data: transmit H, receive H (HH, co-pol); transmit V, receive V (VV, co-pol); transmit H receive V (HV, cross-pol); and transmit V receive H (VH, cross-pol). The Pauli basis can then be calculated from the linear basis according to

$$\begin{aligned} Even &= (HH - VV)/\sqrt{2} \\ Odd &= (HH + VV)/\sqrt{2} \\ Cross &= \sqrt{2} HV, \end{aligned} \tag{1}$$

where *Even* denotes the even-bounce response, *Odd* denotes the odd-bounce response, and *Cross* denotes the cross-pol response. It is clear from Eq. 1 that we can move easily from one basis to the next, and that appropriately selected magnitude and phase adjustments for *HH* and *VV* are all that we require. This suggests that an extremely straightforward calibration procedure may be applicable.

We begin by considering large canonical targets—a trihedral (odd-bounce target) and a horizontal dihedral (even-bounce target). We designate the trihedral as a calibration reference and use it to calculate calibration parameters. Data are recorded by moving the radar system along a straight path past the reference trihedral. Since both ultra-wideband (UWB) radar data and GPS data are recorded, we can examine both B-scan imagery and synthetic aperture radar (SAR) imagery. B-scan images comprise a collection of downrange radar measurements arranged sequentially to form a 2-D matrix (image). In this image, the target follows a well-defined trajectory as illustrated in Fig. 1. Synthetic aperture images are formed by focusing the data displayed in the B-scan image. Here, the target trajectories corresponding to each image pixel are identified within the B-scan data, and the corresponding data are coherently summed to obtain the SAR image pixel value. In all SAR imagery considered, the pixels are 2.5×2.5 cm. The SAR processing realizes additional gain in signal-to-noise ratio through its coherent processing. Figure 2 includes a SAR radar image of the trihedral as measured by the co-pol

channel. We consider two approaches: one designed to operate on B-scan images and a second to operate on SAR images.

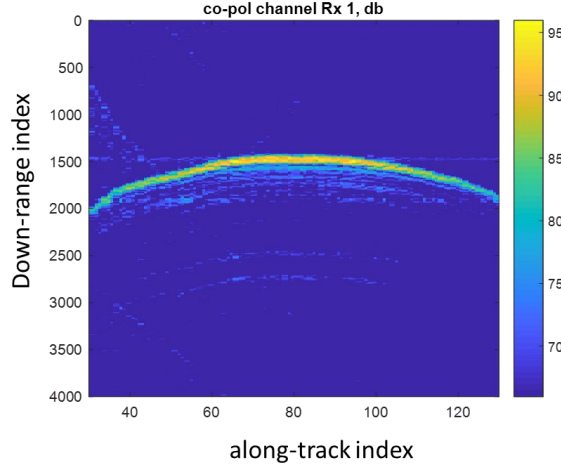


Fig. 1 B-scan example (logarithmic scale) of the co-pol trihedral response

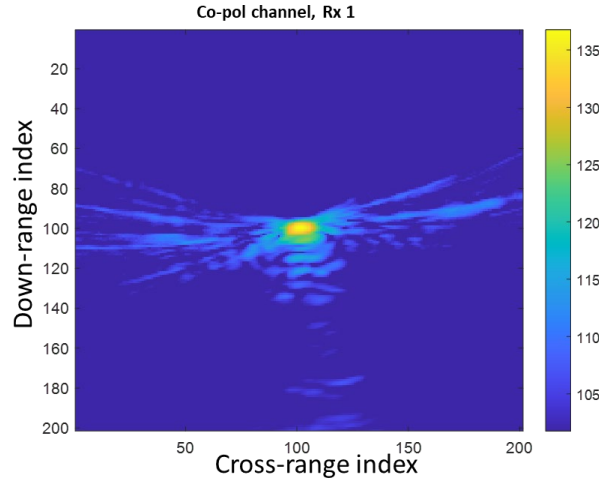


Fig. 2 SAR image example (logarithmic scale) of the co-pol trihedral response

2.1 B-Scan Approach

The first step in the B-scan polarimetric calibration procedure consists of selecting an along-track location that is closest to the reference trihedral (the canonical calibration target). The corresponding high-range resolution (HRR) co-pol signature should contain high-intensity samples in the vicinity of the calibration target. The peak of the interpolated HRR signature magnitude is identified in each of the co-pol channels (HH and VV), and the identified magnitudes and phases are extracted. The interpolated HRR signatures are calculated to ensure that the magnitude and phase estimates are as accurate as possible, as illustrated in Figs. 3 and 4. Next, the HH and VV channels located closest to one another are grouped

together to form a new “even/odd” channel. (See the Appendix for imagery of the Templar configuration.) One of the co-pol channels is selected as the reference, and the magnitude and phase of all samples in the other channel are adjusted so that the peak values are identical.

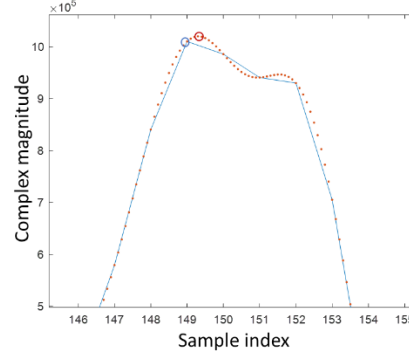


Fig. 3 Interpolated signature (red) vs. original signature (blue). Circles indicate magnitude estimates.

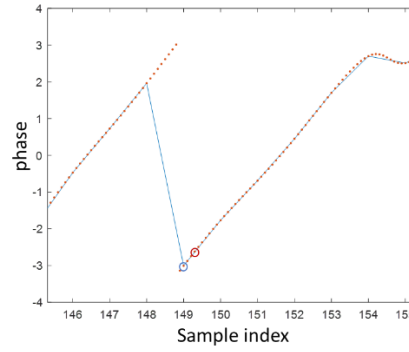


Fig. 4 Interpolated signature (red) vs. original signature (blue). Circles indicate phase estimates.

Matching the nonreference and reference channels ensures a maximum odd-channel response—as defined in Eq. 1—at the peak location. After the adjustments have been made, we examine the even-channel response of a double-bounce target. For this experiment we use the large horizontal dihedral shown in the Appendix.

2.2 SAR Image Approach

When analyzing even-bounce and odd-bounce signatures in SAR imagery, we make all necessary adjustments in the SAR image domain. That is, we identify the peak in the focused image of a canonical target in the reference SAR image and we adjust magnitudes and phases of all pixels in the nonreference image accordingly. As with the B-scan signatures, this ensures that the maximum pixel value for a trihedral in the odd-bounce image will occur at the selected peak location. We again

apply the calibration parameters to create the even-bounce image as described in Eq. 1, and we compare the results obtained for both odd-bounce and even-bounce targets (trihedrals and dihedrals, respectively).

3. Results

To determine the effectiveness of the simplified approach, we collected data using both the even-bounce and the odd-bounce canonical targets as described in Section 2. Since our objective was to determine the feasibility of the approach for the Templar system, we restricted our attention to large targets. This provided the highest likelihood of recording useable polarimetric responses.

3.1 B-Scan Experiments

The results obtained using B-scan data are summarized in the imagery in Figs. 5 and 6. We determined the calibration parameters for the HH and VV channels using the trihedral radar response along boresight, calculating relative magnitude and phase adjustments to maximize the odd-channel response defined by Eq. 1. Figure 5 illustrates the expected difference between the calibrated odd- and even-bounce (odd- and even-channel) responses for the trihedral, an odd-bounce target. That is, the main odd-bounce, calibrated trihedral response on boresight is 10–20 dB higher than the corresponding even-bounce trihedral response. The B-scan images of the trihedral in Fig. 6 illustrate that any improvement in odd-to-even ratio realized through incorporation of phase was negligible. The differences between the even and odd channels for the two calibration approaches differ by at most approximately 1 dB.

We observed similar behavior when these calibration parameters were applied to dihedral responses, and these results are summarized in the imagery of Figs. 7 and 8. Figure 7a depicts the calibrated even-channel response, while Fig. 7b depicts the calibrated odd-channel response. As expected, the main even-channel response—indicated by pixels within the red box—is larger than the corresponding odd-channel response. Figure 8 shows histograms of the even-to-odd ratio in decibels for the cases where 1) only a magnitude adjustment has been made and 2) both a magnitude and a phase adjustment have been made. Here, the ratios for the data calibrated using magnitude and phase adjustments have been manually decreased by 1 dB to maximize the overlap between histograms. In addition, when selecting pixels that contribute to the histogram, only those pixel locations with values that were within 30 dB of the peak value for both channels (even and odd) were considered. This was done to eliminate contributions from noise-like pixel values in either of the channels; the same approach was employed whenever histograms

were created. Based on these results, the magnitude plus phase approach yields approximately 1 dB of improvement.

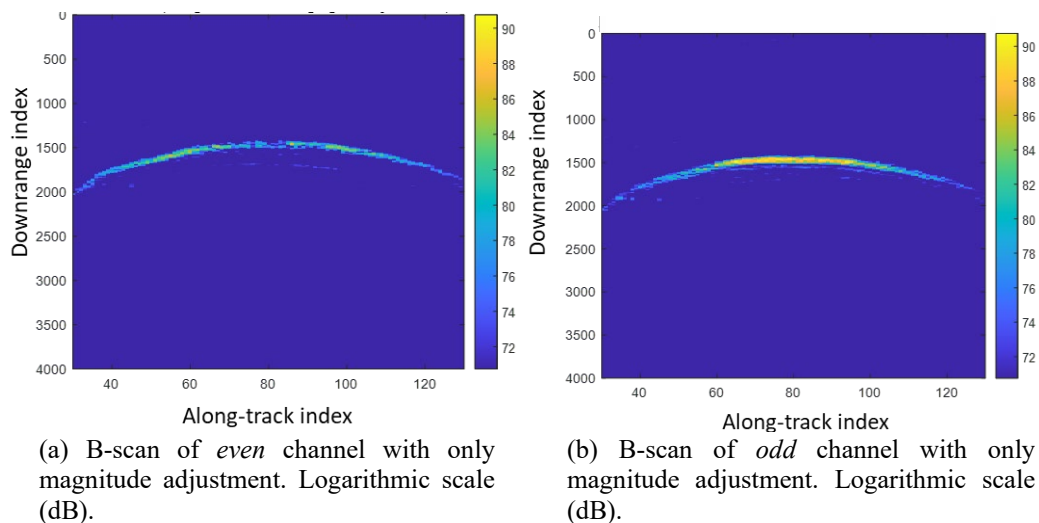


Fig. 5 Log-scale images of trihedral B-scans calibrated using magnitude adjustment only. Note the difference between even and odd responses near boresight (i.e., at closest range). (a) Even channel. (b) Odd channel.

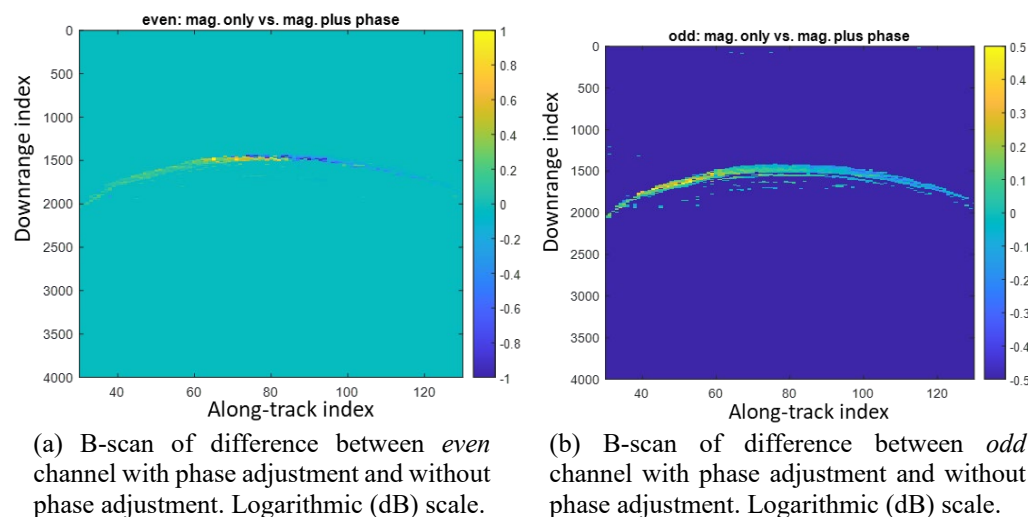


Fig. 6 Log-scale images of differences between B-scans for cases where only magnitude adjustments are made and both magnitude and phase adjustments are made. (a) Even channel. (b) Odd channel.

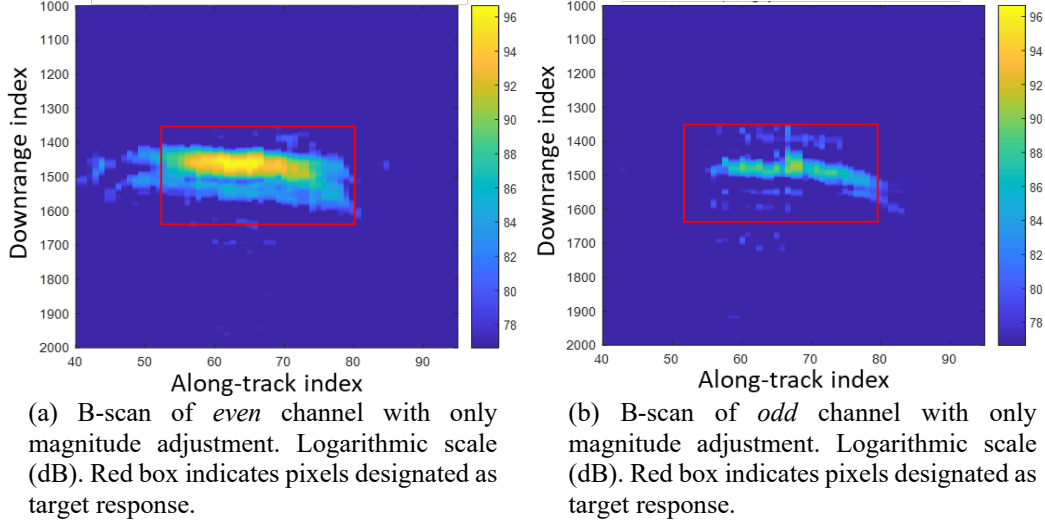


Fig. 7 Log-scale, B-scan images, calibrated using magnitude adjustment only. Note the difference between even and odd responses near boresight (i.e., at closest range). (a) Even channel. (b) Odd channel.

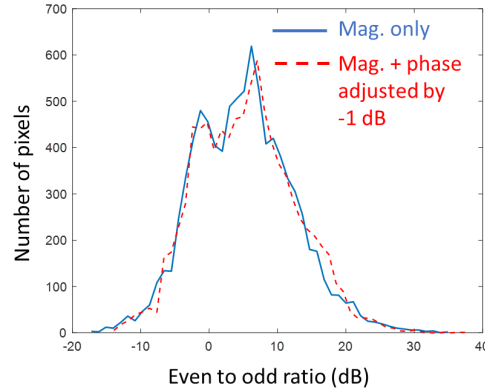
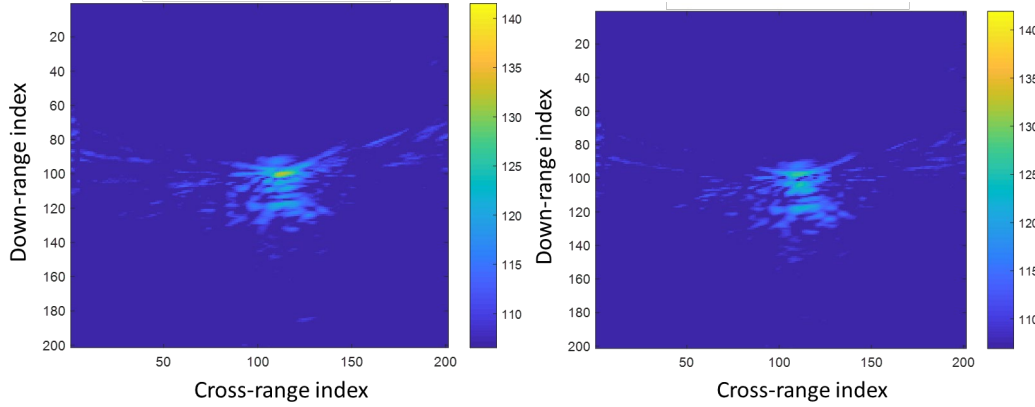


Fig. 8 Histograms of even-to-odd ratios for pixels within the red boxes in Fig. 7. Histogram overlap indicates that ~ 1 dB of improvement realized through implementation of both magnitude and phase adjustments.

3.2 SAR Experiments

We repeated the experiment for focused SAR imagery and noted that, unlike with B-scans, the inclusion of phase information significantly improved the peak even-to-odd ratio in the adjusted imagery. While the calibration target itself (the trihedral) produced a noticeable improvement in even- and odd-bounce separation, the dihedral target also produced similar amounts of improvement. Figure 9 shows the even-channel trihedral images for the cases where 1) only magnitude adjustments were made and 2) both magnitude and phase adjustments were made. The ratios of peak target values in the odd and even channels (i.e., peak-odd-to-

peak-even ratio) were 9.2 dB for magnitude-only adjustments and 16.1 dB for magnitude and phase adjustments. Hence, an improvement of nearly 7 dB was realized.



(a) SAR image of even channel with only magnitude adjustment. Logarithmic scale (dB). Peak value: 132.3 dB. (b) SAR image of even channel with both phase and magnitude adjustment. Logarithmic scale (dB). Peak value: 126.1 dB.

Fig. 9 Calibrated, even-bounce SAR imagery of calibration target (trihedral). (a) Magnitude-only adjustments to HH and VV. (b) Magnitude and phase adjustments to HH and VV. Peak-odd-to-peak-even ratios for target pixels: 9.2 dB for magnitude-only adjustments and 15.2 dB for magnitude-and-phase adjustments.

Histograms of the trihedral target region, included in Fig. 10, help to quantify the phenomenon observed in the imagery. The heavier tails on the histograms are a direct indication that a larger number of pixels exhibit larger odd-to-even ratios when both magnitude and phase adjustments are implemented. For example, 19.8% of the pixels exhibit odd-to-even ratios greater than 15 dB when both magnitude and phase corrections are applied. In contrast, only 9.7% of the pixels exhibit odd-to-even ratios greater than 15 dB when only a magnitude correction is applied. Pixel values extracted for the histogram calculations are indicated by the red box in the odd-bounce image of Fig. 10.

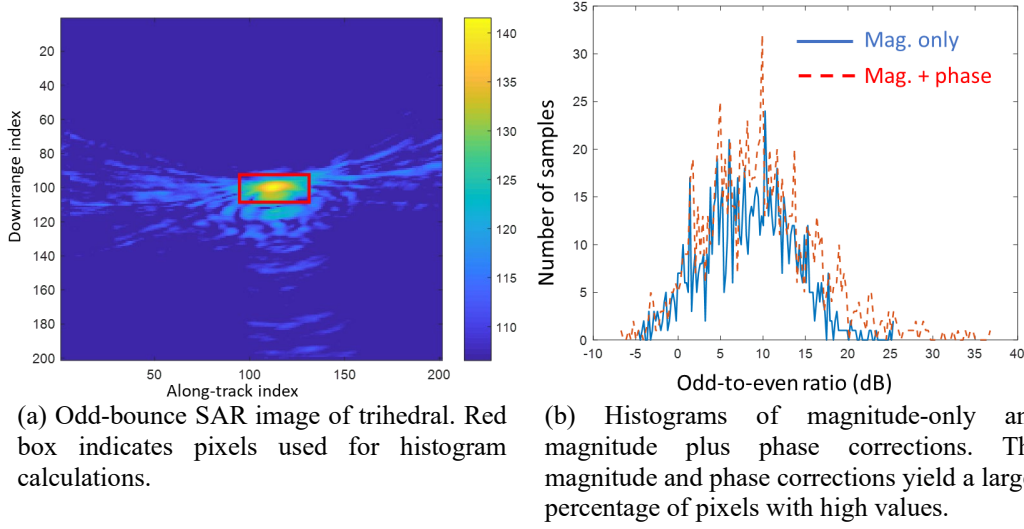


Fig. 10 Odd-bounce SAR image of calibration target (trihedral, magnitude-only adjustment) and histograms of pixelwise even-to-odd ratios. The red box designates pixels used for histogram calculations. The heavier tail on the red dashed plot is indicative of a larger number of samples with higher odd-to-even ratio.

Finally, we include SAR imagery of the dihedral in Fig. 11 to further illustrate the benefit of incorporating both magnitude and phase corrections. Here, we observe a peak-even-to-peak-odd ratio of 4.5 dB if only a magnitude correction is considered. Incorporation of both magnitude and phase adjustments, however, yields a peak-even-to-peak-odd ratio of 10.6 dB—an improvement of 6.1 dB over the magnitude-only approach.

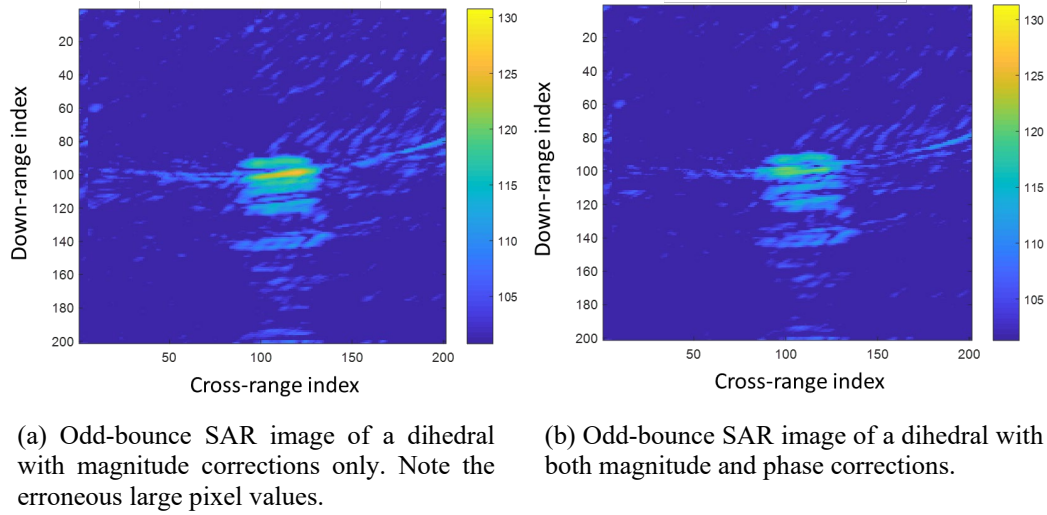


Fig. 11 Odd-bounce SAR image of the dihedral. (a) Magnitude adjustments only. (b) Both magnitude and phase adjustments.

3.3 Application of B-Scan Parameters to SAR Imagery

Comparison of the phase adjustments estimated using the B-scan and SAR approaches indicated a significant difference. When we applied the B-scan parameters to the dihedral SAR data, we observed the reduction in peak-even-to-peak-odd ratio of 4.6 dB, as illustrated, in part, by the odd-channel response in Fig. 12. The peak dihedral response in the even channel decreased and the peak dihedral response in the odd channel increased when the B-scan parameters were employed. When we applied the SAR phase adjustment to the B-scan data, however, the performance was similar to what we had observed using the B-scan parameters. There still was not a significant difference between results obtained using only magnitude adjustments and those obtained using both magnitude and phase adjustments.

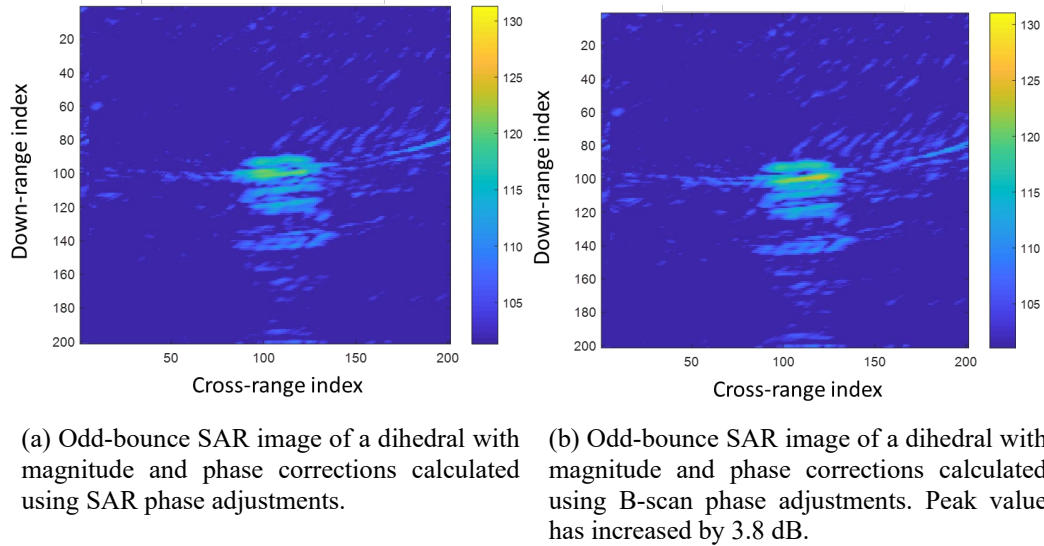


Fig. 12 Odd-bounce SAR image of the dihedral using different phase adjustments. (a) Phase adjustments calculated using SAR imagery. (b) Phase adjustments calculated using B-scan data. Since the even-bounce peak was 0.8 dB lower for magnitude-only corrections, this resulted in a total decrease of 4.6 dB in peak-even-to-peak-odd ratio when the B-scan parameters were used.

4. Summary and Future Work

Initial experiments suggest that only a magnitude adjustment may be necessary when generating even- and odd-bounce Pauli basis components using unfocused, B-scan data. If, however, further coherent processing is desired, then the experimental results suggest that inclusion of the phase adjustment would be beneficial. Specifically, phase parameters estimated from SAR imagery significantly enhanced the contrast between even and odd responses for canonical targets. When designing the experiment, we noted that a large trihedral provided a

concentrated, odd-bounce return that could be used to determine both magnitude and phase corrections. We also employed a large dihedral to verify the effectiveness of these estimated calibration parameters. Since this work was applicable to the Templar (low-frequency and UWB) system, we required large canonical targets. A horizontal dihedral was selected to enable easy target emplacement, with the horizontal side of the dihedral resting on the ground.

The initial data indicated that, for SAR imagery, an increase in the polarization response on the order of 7 dB could be realized through incorporation of both magnitude and phase corrections vice the incorporation of magnitude corrections alone. Regardless of the target considered, results indicated that improvement in the polarimetric SAR imagery could be realized via inclusion of the phase correction.

Future experiments will incorporate additional canonical targets as well as relevant tactical targets, and additional approaches will be considered to enhance the Templar polarimetric processing algorithm suite.

5. References

1. Lee J-S, Pottier E. Polarimetric radar imaging: from basics to applications. CRC Press; 2009. Ch. 6, section 6.5.
2. Touzi R, Charbonneau F. Characterization of target symmetric scattering using polarimetric SARs. *IEEE Trans Geosci Remote Sens.* 2002 Nov;40(11):2507–2516.
3. Ranney K, Wong D, Le C, Ton T. A polarimetric, multi-feature prescreener for vehicle-mounted, side-looking synthetic aperture radar. *Proceedings of the 63rd Annual Meeting of the MSS Tri-Service Radar Symposium*; 2017 July 18–21; Springfield, VA.
4. Nghiem SV, Yueh SH, Kwok R, Li FK. Symmetry properties in polarimetric remote sensing. *Radio Sci.* 1992 Sep–Oct; 27(5):693–711.
5. Lombardo P, Conte DI, Morelli A. Comparison of optimised processors for the detection and segmentation of oil slicks with polarimetric SAR images. *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium*; 2000 July 24–28. p. 2963–2965.
6. Novak L, Owirka G, Netishen C. Performance of a high-resolution polarimetric SAR automatic target recognition system. *Lincoln Lab J.* 1993;6(1):11–24.
7. Zhang L, Zhang J, Zou B, Zhang Y. Comparison of methods for target detection and applications using polarimetric SAR image. *PIERS Online.* 2008;4(1):140–145.
8. Van Zyl JJ. Calibration of polarimetric radar images using only image parameters and trihedral corner reflector responses. *IEEE Trans Geosci Remote Sens.* 1990 May;28(3):337–348.
9. Ton T, Wong D, Ranney K, Freeman S. The NVESD templar radar: results from the initial data collection. *Proc SPIE 11408, Radar Sensor Technology XXIV*; 2020 Apr 23. P. 1140816. doi: 10.1117/12.2566084.

Appendix. Templar Configuration

The ALARIC system is a low-frequency, ultra-wideband (UWB), impulse-based system operating in the band of 300 MHz–3 GHz. In its current configuration, the Templar’s pulse width is about 1 ns with a pulse repetition frequency of 1 MHz clocking rate. The average power across the bandwidth is about 5 mW, which minimizes the interference issues with other spectrum users in the test area. In this respect, the downrange resolution is derived from the bandwidth of the transmitted monocycle pulse and is about 5 cm. The range coverage for this implementation is designed to be around 20 m with an adjustable starting point forward of the radar.

In the transmitting portion of the RF chain, the impulse signals are fed to a commercial-of-the-shelf, quad-ridged antenna, AQR-530. It is a wide band antenna (i.e., 0.5–3 GHz) with dual linear polarization, which is suitable for UWB radar applications. Horizontal and vertical transmit polarizations are obtained by alternating between radiating elements of the antenna. In this way, the system produces a transmitted sequence of pulses in which an H-polarized pulse follows a V-polarized pulse. The backscattered energy from the downrange targets is captured by an array of four identical Vivaldi notch antennas placed closely together (in either polarization) and in a linear aperture that is approximately 0.5 m in length. The antenna polarizations are alternated to create a spatially alternating sequence of receive polarizations—H and V—as depicted in Fig. A-1. A picture of the data collection scenario for the is also included for the horizontal dihedral target.

For more details about the architecture and operation of Templar, we refer the reader to Ton et al.¹

¹ Ton T, Wong D, Ranney K, Freeman S. The NVESD templar radar: results from the initial data collection. Proc SPIE 11408, Radar Sensor Technology XXIV; 2020 Apr 23. p. 1140816. doi: 10.1117/12.2566084.



(a) Quad-ridge transmit and Vivaldi receive antennas. GPS data required for SAR image formation and in-scene calibration.

(b) Templar data collection scenario using a horizontal dihedral (even-bounce target).

Fig. A-1 Configuration of the Templar system. (a) GPS antenna, transmit antenna and receive array. (b) Templar system configured for data collection (using horizontal dihedral target).

List of Symbols, Abbreviations, and Acronyms

2-D	two-dimensional
ARL	Army Research Laboratory
C5ISR	Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance
co-pol	co-polarized
cross-pol	cross-polarized
DEVCOM	US Army Combat Capabilities Development Command
dual-pol	dual-polarization
GPS	global positioning system
H	horizontal
HRR	high-range resolution
RF	radio frequency
RTI	Research and Technology Integration Directorate
SAR	synthetic aperture radar
UWB	ultra-wideband
V	vertical

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