A prototype fully polarimetric 160-GHz bistatic ISAR compact radar range

A Prototype Fully-Polarimetric 160 GHz Bistatic ISAR Compact Radar Range

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ABSTRACT

We present a prototype bistatic compact radar range operating at 160 GHz and capable of collecting fully-polarimetric radar cross-section and electromagnetic scattering measurements in a true far-field facility. The bistatic ISAR system incorporates two 90-inch focal length, 27-inch-diameter diamond-turned mirrors fed by 160 GHz transmit and receive horns to establish the compact range. The prototype radar range with its modest sized quiet zone serves as a precursor to a fully developed compact radar range incorporating a larger quiet zone capable of collecting X-band bistatic RCS data and 3D imagery using 1/16th scale objects.

The millimeter-wave transmitter provides 20 GHz of swept bandwidth in the single linear (Horizontal/Vertical) polarization while the millimeter-wave receiver, that is sensitive to linear Horizontal and Vertical polarization, possesses a 7 dB noise figure. We present the design of the compact radar range and report on test results collected to validate the system’s performance.

Keywords: fully-polarimetric, bistatic, ISAR, millimeter-wave, compact range

1. INTRODUCTION

Radar remote sensing derives much of its value from the ability to operate as an all-weather sensor at very long stand-off ranges[1]. When compared to a monostatic radar, the bistatic modality has a somewhat more complex architecture, largely due to the difficulty in maintaining coherence between transmit and receive hardware systems that are physically separated over long baselines[2]. The requirement to coordinate pointing of the transmit and receive antenna beams at the scene of interest also poses additional challenges not faced by a monostatic system[2]. Technical challenges such as these are likely the reason why radar research has focused on monostatic radars over the past 60 years[3]. However, as the coherence of time and frequency standards continue to improve[4] and sophisticated bistatic antenna pointing designs are developed[5], it will become possible to further exploit the many inherent advantages of the bistatic operating modality.

Given the advances on such technical fronts, there is a large contingent of the radar community that is interested in the more general bistatic and multistatic modalities. Because these systems represent the more general case of the monostatic radar, they unlock additional free parameters that open up a diverse set of capabilities and applications. Given the breadth of these applications, the abundance of research into this field is not surprising. In fact, the applications are so diverse that entire texts are dedicated to the various facets of the subject[2]. Two radar applications which would immediately benefit from bistatic geometries are rough surface (clutter) characterization and target detection/classification.

1.1 Radar Clutter and Rough Surface Characterization

An accurate understanding of bistatic radar ground clutter and its relation to ground surface parameters and data collection geometry is crucial for developing the design of bistatic systems[6-10] and predicting target detectability within a scene [11,12]. In recognition of the need to further this knowledge, measurements and models (both numerical and analytical) have been produced to allow one to compute such clutter. However, the accuracy of these models are
such that they are not yet able to account for arbitrary surface roughness[3,13,14,15] and present weaknesses for near grazing angle geometries [11]. Studies have also shown that bistatic polarimeters provide further information that is intrinsic to the surface properties of terrain[14,15] and how they may be applied to study the dynamic behavior of an ocean’s sea state for altimetry applications[9,16,17,18]. Despite the wide span of models describing bistatic scattering of ground and sea surfaces, there is little experimental data to support focused studies of these models.

1.2 Target Detection and Classification

The extent to which radar may detect and classify difficult targets is a topic that is under constant advancement. When compared to a monostatic radar system, bistatic radars offer a variety of advantages in detecting and classifying targets. Specifically, slow moving targets within clutter may be more easily detected since the clutter’s Doppler spectrum may be tailored to reveal very slow ground movers in a bistatic modality[6,7]; they are also less susceptible to radar jamming [7]. Detecting targets in bistatic radar imagery is also more probable since the intensity of natural specular flash points is limited by bistatic scattering phenomenology [19]; a characteristic that improves the overall quality of a SAR image. Such specular scattering properties have also been exploited to develop more robust target classification algorithms based on bistatic scattering phenomenology [20,21,22]. While bistatic systems have been built and demonstrated, the focus of their results is limited in scope. Given this state of affairs, experimental data to test new algorithms for Ground Moving Target Indication (GMTI), Space-Time Adaptive Processing (STAP), and Automatic Target Recognition (ATR) is extremely limited relative to the parameter space offered by the bistatic and multistatic modalities.

1.3 Radar Scale Modeling and Development of Bistatic Radar Modalities

Because of their operating costs, versatility, and stability, physical scale model radar ranges are a very economical and efficient technique for collecting threat target signature intelligence which, in many cases, could not be feasibly managed in a full scale environment. In such systems, high fidelity scale-model targets are constructed and measured at the scaled radar wavelength to determine the radar scattering properties of the target at the full-scale wavelength[23,24]. In addition to dimensionally scaling the scene of investigation, it is necessary to match the electromagnetic properties of the components constituting the full-scale scene with those of the corresponding component of the scale model scene. The process of matching the electromagnetic properties is accomplished using dielectric scaling technology[25,26] and has been used to model ground planes and scenes having specified surface roughness and dielectric properties [27,28].

The radar scale modeling approach is a widely accepted technique for generating accurate target radar signatures. The technique is currently being used to collect monostatic radar signature data at UHF, C, X, Ku, Ka, and W-bands [27,29-31]. These systems have also been utilized to conduct focused studies of ship masts[32] and high resolution radar signatures for the Longbow radar[33] program. Data from X and W-band scale model radars[27,30,31,36] have also been used to support the Haystack Ultrawideband Imaging Radar (HUSIR) upgrade [34] and to develop atmospheric autofocusing algorithms for the new system[35].

The 160 GHz bistatic ISAR compact radar range system that we describe here is a variant of a previous system[36] that has been modified to incorporate a bistatic capability to conduct focused studies of bistatic and multistatic radar. The system possesses the ability to provide high-quality, accurate experimental bistatic radar data for which the target scene of interest is under complete control of the investigator. Similar to the HUSIR example, such a system may be used to study specific aspects of a notional bistatic system that may possess a variety of high risk performance uncertainties that are only addressed with experimental data. Such a system is also an invaluable source of data with which new bistatic GMTI, STAP or ATR algorithms may be leveraged to develop accuracy and precision metrics.
2. SYSTEM DESCRIPTION

2.1 Compact Radar Range Configuration

Figure 1 provides a graphical layout of the prototype 160 GHz bistatic compact radar range that was developed at STL. The millimeter-wave (MMW) transmitter and receiver sections are mounted on independent support girders, each with a dedicated 27” diameter compact range reflector that together provide a radar quiet zone diameter of approximately 8 inches. The receive girder is fixed to the supporting optical table while the transmit girder is rigidly coupled to the bistatic angle axis via the lever arm as indicated in Figure 1. Adjustment of the compact range’s bistatic angle is made possible by an air bearing that is pressurized during the adjustment to support the transmitter section. Presently, the adjustment is achieved by range personnel that first pressurize the bearing, then manually rotate the transmitter section, and finally depressurize the bearing so as to allow the transmitter to settle into place. This configuration supports bistatic angles between 10 and 80 degrees where the lower limit is dictated by the diameter of the mirrors and the bistatic lever arm and the upper limit by the extent of the optical table.

The bistatic radar’s quiet zone is represented by a nominal volume of intersection between the transmit and receive beams with depth determined by the bistatic angle (i.e. depth is near infinite at monostatic and minimum at 90 degrees).
Figure 2: Layout of radar data collection electronics within the CRR chamber. A portion of the backend electronics is installed below the MMW receiver section.

Figure 3: Layout of the backend radar data collection electronics exterior to the CRR chamber.
bistatic angle). Given this intersection volume and the relatively small size of the transmit and receive beams to a typical scale model target, it is important that the target staging have sufficient flexibility so as to maintain the target’s alignment with the quiet zone. To collect backscatter as a function of angular articulation, the target is mounted on a 2-axis angular positioner that supports posing in azimuth (0-360 degrees) and elevation (0-45 degrees) angle. Since elevation drive is conveyed to the target through a 2-foot-long target pylon, it can quickly shift out of the quiet zone as a function of elevation angle. To counteract this translation, the prototype target staging incorporates manually adjustable staging to maintain the target’s alignment with the footprint of the quiet zone.

Two independent pylons (target and calibration) are utilized to produce calibrated radar signature data. The target staging is manually fastened into place with retention locks that are removable to lift the target and associated staging off of the optical tables. The calibration pylon staging is outfitted with a hinge mechanism so that it may be easily lifted into a very repeatable orientation within the radar beam’s quiet zone for measurement of calibration data. The calibration pylon design is the standard Ogive type terminated with a LO-observable “football” design1. The football houses a calibration object axial rotation axis that is critical for alignment and fully-polarimetric bistatic radar calibration. This pylon also incorporates an azimuth rotation and tilt axis at the base to provide further object alignment for the radar data collection process.

2.2 Millimeter-wave Transceiver Electronics

The portion of the radar data collection electronics contained within the CRR chamber is shown in Figure 2. Because of the bistatic design of the system, it is necessary to relay the microwave drive signal to millimeter-wave (MMW) multiplier/transmitter section. To complete this connection, a microwave-over-fiber transceiver[37] is integrated into the prototype system to establish this connection from the location of the Tx synthesizer to the MMW transmitter. H and V polarized signals scattered by the target are harnessed by the MMW receiver section through the Rx feed horn where they are downconverted to the first IF (3.0 GHz). Subsequently, the H and V first IF signals are downconverted to the second IF (1 MHz) by the IF processor that in turn conveys them to the remainder of the backend electronics exterior to the CRR chamber.

The layout of the backend radar data collection electronics exterior to the CRR chamber is shown in Figure 3. The signals from the IF processor are detected by the lock-in amplifiers, then digitized by the backend ADCs, and finally stored on the data acquisition PC. These backend electronics also carry-out hardware interface functions that serve to configure the data collection process and control the target and calibration stages.

3. SYSTEM PERFORMANCE

3.1 Radar Quiet Zone

The expected size of the CRR quiet zone is approximately 8 inches in diameter as defined at the 3 dB points of the two-way beam. This expectation was developed based on a Gaussian optics analysis of the optical configuration presented in Figure 1. To verify its expected performance, a two axis XY scanning stage was installed to probe the CRR quiet zone (i.e. where the Tx/Rx beams intersect). The staging is aligned so as to scan in the plane that is orthogonal to the bisector of the bistatic angle in reference to Figure 1 and centered within the volume of intersection; this is the phase reference plane of the bistatic data collection geometry. The staging supported a 1 inch diameter probing sphere that was used to sample the amplitude and phase characteristics of the two-way beam by measuring the radar response of the sphere at various X(horiz)/Y(vert) positions.

1 The football’s RCS performance has only been evaluated for the monostatic case at 160 GHz. The efficacy of such an object for bistatic radar calibration has yet to be investigated.
From these quiet zone measurements, amplitude and phase, ripple and taper metrics were analyzed along the principle X and Y axes. These characteristics are calculated over the nominal 8 inch diameter of the quiet zone and are reported in Table 1 and Table 2 for VV polarization.

Table 1: Two-way VV beam amplitude characteristics measured over 8 inches in the principle X and Y axes.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>RMS Ripple (dB)</th>
<th>Taper (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X  \ Y</td>
<td>X  \ Y</td>
</tr>
<tr>
<td>152</td>
<td>0.4  0.3</td>
<td>2.3  3.2</td>
</tr>
<tr>
<td>161</td>
<td>0.5  0.5</td>
<td>2.3  3.4</td>
</tr>
<tr>
<td>170</td>
<td>0.5  0.4</td>
<td>2.7  4.1</td>
</tr>
</tbody>
</table>

Table 2: Two-way VV quiet zone phase characteristics measured over 8 inches in the principle X and Y axes.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>RMS Ripple (*)</th>
<th>Taper (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X  \ Y</td>
<td>X  \ Y</td>
</tr>
<tr>
<td>152</td>
<td>3.5  2.3</td>
<td>15.5 19.9</td>
</tr>
<tr>
<td>161</td>
<td>4.2  3.1</td>
<td>19.4 19.1</td>
</tr>
<tr>
<td>170</td>
<td>4.4  2.5</td>
<td>20.3 18.8</td>
</tr>
</tbody>
</table>

3.2 RCS Dynamic Range

In general, the dynamic range of the radar is determined by its maximum tolerable signal level at the frontend, as limited by non-linearity in the radar electronics, and its minimum detectable signal, as limited by noise in a specified lock-in amplifier time constant.

For the prototype bistatic CRR, the maximum tolerable signal is limited by the frontend MMW Sub-Harmonic Mixer (SHM); a variable IF attenuator is incorporated in the transceiver to enforce this condition. The SHM has a maximum tolerable input signal level of -10 dBm. This power level can be referred to an equivalent RCS through the compact range radar equation given the transmit power, frequency, feed gain, and the focal length of the compact range reflectors. The design parameters of the prototype bistatic CRR translate to a frontend-received-power-to-RCS relation of 41 dBm per dBsm at 160 GHz. Applying this relation to the SHM’s maximum input level of -10 dBm translates the power level to an equivalent RCS of 31 dBsm – the monostatic radar scattering equivalent of a 5.4 inch square flat plate at normal incidence at 160 GHz.

On the low side of the dynamic range spectrum, the radar’s minimum detectable signal or noise floor is determined by thermal noise performance of the radar frontend. The radar’s measured noise floor is -131 dBm in a 1.6 kHz receiver bandwidth. The observation is made after performing a background subtraction to suppress clutter in the radar range at the level of -120 dBm. The same power-to-RCS relation can be applied to relate the radar’s thermal noise floor to an equivalent RCS. In doing so, the resultant RCS noise floor is -90 dBsm at 160 GHz in a 1.6 kHz receiver bandwidth.

3.3 Linearity

As a test of the system’s linearity a series of calibration spheres and disc plates were measured to examine the RCS linearity of the radar. The selection of objects was such that they were within the dynamic range limits (-90 to +31 dBsm) outlined in section 3.2. Like the quiet zone characterization, the RCS measurements were conducted at a bistatic angle of 70 degrees. These frequency-averaged measurements, along with annotation of the exact objects, are plotted with the theoretical expectation in Figure 6. The standard deviation of the errors between the theoretical and measured RCS quantities is 1.3 dB.
In the case of a sphere, its theoretical RCS is taken simply as its projected area. While the sphere’s RCS is weakly dependent on the bistatic angle up to approximately 120 degrees, this simplification also ignores resonant scattering resonant phenomenon of the sphere. This effect is of order 1dB and only influences the two smallest spheres so it has been ignored in the theoretical curve generated in Figure 6.

In the case of the disc plates, their theoretical RCS takes the same functional form of the monostatic RCS of a plate at normal incidence but with a $\cos(\beta/2)^2$ term that solely describes the specular RCS dependence on the bistatic angle $\beta$.

![Plot of calibration object linearity](image)

Figure 4: Plot of the prototype bistatic CRR’s linearity demonstrated with an array of spheres and disc plates. The measurements were conducted at a bistatic angle of 70 degrees and discs were measured at normal incidence. The measured data points represent the frequency-averaged RCS.

### 3.4 RCS Validation

#### 3.4.1 Polarimetric RCS Accuracy and Cross-polarization Isolation

To perform and evaluate a fully-polarimetric calibration of the prototype bistatic CRR, a set of calibration objects including a flat plate and Dihedrons comprised the group of standards used to calibrate the system. The performance was evaluated at 15, 45, and 75 degree bistatic angles and each result yielded very similar results. In the interest of brevity, we only present the results obtained at 45 degrees bistatic angle.

A 3 dBsm flat plate was used as the absolute RCS and phase reference for the fully polarimetric calibration algorithm[38] and bistatic dihedrals were designed to yield the requisite polarization scattering matrices (PSM) for the optimal estimation of the system’s transmit and receive distortion matrices. Two additional dihedral objects were designed to evaluate the performance of the calibration independently of the objects utilized to estimate the distortion matrices. The nominal/normalized 45 degree bistatic angle PSM for each of the calibration and performance evaluation object is given by the following:

\[
\text{Calibration Objects:} \quad PSM_1 = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}, \quad PSM_2 = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}, \quad PSM_3 = \frac{1}{\sqrt{2}} \begin{bmatrix} -1 & 1 \\ 1 & 1 \end{bmatrix} \tag{1}
\]
Performance Evaluation Objects:

\[ PSM_4 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad PSM_5 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \]  \hspace{1cm} (2)

A photo of these objects is shown in Figure 5.

![Performance Evaluation Objects Image](image_url)

Figure 5: Photo of calibration and performance evaluation objects used for fully-polarimetric bistatic calibration and evaluation of the prototype bistatic CRR system. The diameter of each object is approximately 1 inch.

Raw radar data collected from observations of Calibration Objects 1, 2, and 3 were used to compute the transceiver’s polarimetric Transmit and Receive distortion matrices using the aforementioned calibration algorithm. These matrices were in turn used to calibrate subsequent raw data measurements of the Performance Evaluation Objects 4 and 5. Since Objects 4 and 5 were not used to compute the calibration distortion matrices, they provide an independent assessment of the transceiver’s calibrated performance. For each object, measurements were collected spanning the frequency band from 150 – 170 GHz. As a computational electromagnetic (CEM) basis to quantify the calibration accuracy and resultant cross-polarization performance of the prototype system, the polarization scattering matrices of each of the five objects shown in Figure 5 were computed using FEKO®’s MLFMM solver. Figures 6 – 10 report the calibrated measurements overlaid with the FEKO® computations. Since Objects 1, 2 and 5 theoretically do not exhibit any cross-polarized scattering; the level of cross-polarization content in the measured/calibrated results relative to the co-polar scattering yields the system’s cross-polarization isolation performance. Analysis of Figures 6-10 demonstrates that the accuracy of the calibrated RCS measurements is within 0.5 dB of the MLFMM prediction and that the system possesses approximately 50 dB of cross-polarization isolation.
Figure 6: Fully polarimetric, 45 degree bistatic angle RCS results for Calibration Object #1 – Flat Plate.

Figure 7: Fully polarimetric, 45 degree bistatic angle RCS results for Calibration Object #2 – Vertical Seam Dihedron.
Figure 8: Fully polarimetric, 45 degree bistatic angle RCS results for Calibration Object #3 – Split Co-to-Cross Polarization Dihedron; scattered power is split equally among all four channels.

Figure 9: Fully polarimetric, 45 degree bistatic angle RCS results for Performance Evaluation Object #4 – Co-to-Cross Polarization Dihedron. This object is designed to primarily produce scattering in the cross-pol channels. Note that scattering in the Co-pol channels originates from the circular perimeter/edge of the object and these levels are influenced by Co-pol scattering from the supporting pylon. The supporting pylon is not included in the CEM model. The cross-polarization channels are in excellent agreement.
To validate the prototype bistatic CRR with an object having size more comparable to that of the system’s quiet zone, a 1/16th scale model of the SLICY object was selected (Figure 11). The actual diameter of the SLICY object at its opposing corners is approximately 12 feet, a 1/16th scale model of which roughly fills in the 8-inch quiet zone size of the 160 GHz bistatic CRR. Xpatch® was used to compute the theoretical X-band (10 GHz) RCS of SLICY to provide a basis for the validation. The measurements of SLICY were carried out at 15, 45, and 75 degrees bistatic angle as a function of azimuth angle (0-360 degrees) at a fixed elevation angle of 15 degrees. The operating frequency range of the prototype bistatic CRR covers frequencies 150-170 GHz; at 1/16th scale these data model the RCS of SLICY from 9.375 – 10.625 GHz (X-band). Using its “Roll-Pitch-Yaw” capability, the Xpatch® simulation directly computed the X-band bistatic RCS of SLICY using the identical data collection geometry that was modeled by the prototype bistatic CRR measurement.

To avoid numerical instabilities in Xpatch®, the hollow cylinder and trihedral mounted on the top surface of SLICY were removed. Similar instabilities are observed in the Xpatch® cross-polarized data so the comparison presented here is strictly of co-polarized results. The source of these numerical instabilities, which may well be related to the setup of the Xpatch® simulation, are currently being investigated. The model of SLICY measured and modeled by Xpatch® is shown in Figure 11.

A representative plot of the measured and predicted total (frequency-averaged) radar cross section (TRCS) results at 45 degrees bistatic angle were overlaid and are reported in Figure 12. These TRCS data were correlated for each polarization and bistatic angle using standard signal processing correlation techniques on both linear and logarithmic bases of the TRCS results. The results of the correlation are reported in Table 3 and show that the measured and computed (Xpatch®) data are strongly correlated.
Figure 11: Photo of the modified 1/16th scale SLICY measured in the prototype 160 GHz bistatic CRR for comparison with Xpatch® computations of the 10 GHz TRCS of the full-scale modified SLICY model.

Figure 12: Scale-model measured and predicted 10 GHz Co-polarized TRCS signatures of the modified SLICY at 45 degree bistatic angle.
Table 3: Measured/Xpatch\textsuperscript{®} computed TRCS correlation performance

<table>
<thead>
<tr>
<th>Bistatic Angle</th>
<th>HH Polarization Channel</th>
<th>VV Polarization Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
<td>Logarithmic</td>
</tr>
<tr>
<td>15 degrees</td>
<td>93.5%</td>
<td>98.4%</td>
</tr>
<tr>
<td>45 degrees</td>
<td>89.9%</td>
<td>94.4%</td>
</tr>
<tr>
<td>75 degrees</td>
<td>88.7%</td>
<td>95.2%</td>
</tr>
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</table>

4. **1/35\textsuperscript{TH} SCALE INTERFEROMETRIC ISAR IMAGERY OF A TACTICAL SCENE**

As a small demonstration of the diverse capabilities of the prototype 160 GHz bistatic CRR, radar signature data were collected of a 1/35\textsuperscript{th} scale scene incorporating a T72 tank and rough surface ground plane modeling field soil at a bistatic angle of 75 degrees. A photo of this scene is shown in Figure 13. Data were collected over a full 360 degrees in azimuth angle with measurements at 15.0 and 15.3 degrees in elevation angle to support interferometric (IF) processing. The resultant data set physically scale models a C-band (4.5 GHz) radar signature collection with 570 MHz of radar bandwidth. These radar signature data were processed into ISAR imagery and subsequently into IFSAR 3D imagery by interfering the ISAR images produced at the two elevation angles for a given azimuth angle.

Fully polarimetric C-band ISAR imagery of the tactical scene is presented in Figure 14 at the azimuth pose angle of 23 degrees; a 12 degree processing aperture was utilized to generate this imagery. The imagery at 15.0 and 15.3 degrees cannot be distinguished based upon their magnitude alone so we present only those images at 15 degrees elevation in the interest of brevity. Using IFSAR processing techniques, the 15.0 and 15.3 degrees elevation angle ISAR imagery are interfered to derive a phase observable that represents an estimate of each image pixels height out of the ground plane. With this estimate of pixel height, the IFSAR processing allows the formations of front and side view imagery of the tactical scene above and beyond the top-down view provided by standard ISAR processing. In the interest of brevity, we only present 3D IFSAR imagery for the co-polarization channels.
Figure 14: Fully polarimetric C-band ISAR imagery produced from the T72 tactical scene at the same azimuth pose shown in Figure 13 (23 degrees) and at an elevation angle of 15 degrees. The bistatic angle in the radar signature collection was 75 degrees. Distinct shadows cast by the target in the direction of the transmitter and receiver are observed.
Figure 15: HH (top panel) and VV (bottom panel) 3D bistatic IFSAR imagery generated by interfering the C-band ISAR imagery of the T72 tactical scene at 15.0 and 15.3 degrees elevation angle. Imagery shown here are also at 23 degrees azimuth angle in keeping with the ISAR imagery shown in Figure 14.
5. SUMMARY AND NOVEL PROSPECTS

We have presented a novel approach for the acquisition of fully polarimetric bistatic radar signature data utilizing a compact radar range configuration in a physical scale model facility. The compact radar range ensures the data are of far-field quality and can support a plethora of operational, full-scale bistatic radar modalities and studies of bistatic scattering phenomena. The integrity of the far-field data are supported by the quiet zone characteristics reported in Table 1 and Table 2 as well as the SLICY validation results reported in section 3.4. While this optical arrangement has worked well as a test bed, it is not well-suited for larger 1/16th tactical scenes and hence can benefit from a larger set of focusing mirrors; we are actively seeking alternative sources of funding to support such an upgrade.

The accuracy of this prototype system also benefits from excellent dynamic range (120 dB) and linearity (1.3 dB 1-sigma variation over dynamic range), as reported on in sections 3.2 and 3.3, as well as a high performance fully-polarimetric calibration (0.5 dB accuracy with 50 dB cross-pol isolation) correction method. In these results, the dominant source of system error is attributed to the pylon (Figure 9) style utilized for measurement of all linearity test object sizes greater than the 0.5-inch sphere (Figure 4) and the calibration standards (Figures 5-10). Given the modest budget available to carry out this work, funds for the development of a custom pylon having LO bistatic radar signature were not supported. It is interesting to note that the calibration pylon design that was incorporated here was developed for monostatic RCS application and on-average, its bistatic RCS was ~10 dB greater than that in the monostatic case.

In section 4, we presented some of the imagery capabilities of the prototype bistatic CRR with a 3D IF SAR demonstration using a 1/35th tactical scene. The C-band bistatic ISAR imagery (Figure 14) alone revealed interesting scattering phenomenology. In these bistatic imagery, it is clear from the shadows cast onto the ground plane by the T72 that bistatic signatures of such scenes experience two shadows: one cast in the line-of-sight direction from the transmitter and the other in the line-of-sight direction to the receiver. The exposure of such a feature in this imagery demonstrates the potential for such a system to produce high quality bistatic radar signatures for ATR training and phenomenological studies.

To further enhance the utility of this prototype system, specifically for multistatic experimentation, we also plan to characterize and establish long term stability of the polarimetric distortion matrices as a function of bistatic angle. With suitable stability, these distortion matrices may be measured/calculated at a specified/optimal bistatic angle, after that time, the system may be reconfigured to collect radar signatures at any bistatic angle supported by the mechanical design. The capability is extremely attractive for multistatic SAR investigations. Such modalities possess the capability to extend the effective transmit bandwidth of a radar without electronics modification through careful design of the multistatic geometry alone. Such enhancements are highly desirable for classification of difficult targets as well as situational awareness in rapidly varying environments.

6. REFERENCES


