A 100 GHz Polarimetric Compact Radar Range for Scale-Model Radar Cross Section Measurements

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Abstract— **A fully polarimetric compact radar range operating at a center frequency of 100 GHz has been developed for obtaining radar cross section, inverse synthetic aperture radar imagery and high range resolution profiles on targets and structures of interest. The 100 GHz radar range provides scale-model RCS measurements for a variety of convenient scale factors including W-Band (1:1 scale), C-band (1:16 scale), and S-band (1:26 scale). An overview of the radar range is provided in this paper along with measurement examples of ISAR scale-model imaging, scale-model through-wall imaging, and preliminary kHz sweep-rate Doppler that demonstrate a few of the diverse and unique applications for this system. The 100 GHz transceiver consists of a fast-switching, stepped, CW microwave synthesizer driving dual-transmit and dual-receive frequency multiplier chains. The stepped resolution of the system's frequency sweep is sufficient for unambiguous resolution of the entire chamber. The compact range reflector is a CNC machined aluminum reflector edge-treated with FIRAM™-160 absorber serrations and fed from the side to produce a clean quiet zone. This range is the latest addition to a suite of compact radar ranges developed by the Submillimeter-Wave Technology Laboratory providing scale-model radar measurements at nearly all of the common radar bands.**

Keywords: Compact Radar Range, Doppler, Imagery, Instrumentation, ISAR, Millimeter-Wave, Radar, RCS Measurements, Scale-Modeling, Thru-Wall Imaging

I. INTRODUCTION

In order to effectively implement target recognition or RCS reduction, a detailed knowledge of how target features scatter radiation must be determined. Due to the complexity of acquiring radar signatures for many targets of interest (e.g. ground vehicles, sea vessels, airplanes) it is frequently costly or impractical to directly obtain the necessary signature information for a desired radar band. Thus the use of target models scaled in both physical size and dielectric constant, and illuminated with identically wavelength-scaled electromagnetic radiation, has become a proven and practical method of obtaining the radar signatures of full-size targets [1].

The use of submillimeter-wave radiation for scale model RCS measurements was reported in the late 1970s [2] but the concept dates back at least to the work of Sinclair in the 1940s [3]. Early systems were based upon the use of optically pumped narrow-band submillimeter-wave lasers, which are still typically used for generating frequencies above 700 GHz [4]. For frequencies below 700 GHz the use of solid-state multiplier chains (cascades of multipliers and amplifiers) is typically employed [5].

The University of Massachusetts Lowell Submillimeter-Wave Technology Laboratory, under contract with the US Army National Ground Intelligence Center, has devised a number of terahertz compact radar ranges for imaging applications, including RCS measurements, over the past 30 years [6]. Laser-based ranges have been developed to operate at frequencies as high as 1.56 THz [7] and solid-state ranges presently exist at 12 GHz [8], 160 GHz [9], 240 GHz [10] and 520 GHz [11].

The 100 GHz compact radar range is based upon a fully polarimetric transceiver consisting of a fast-switching, stepped, CW, X-band synthesizer driving dual X8 linearly-polarized transmit multiplier chains, and dual X8 local oscillator (receiver) multiplier chains. The low-noise 2-stage IF down-converter provides final 50-kHz signals input to DSP lockin amplifiers. The system measures a few thousand frequency points over 16 GHz of system bandwidth, allowing range resolution of the entire measurement chamber and, following identification of the appropriate target range bins, software range gating may be applied.

The following sections of this paper detail the 100 GHz transceiver including an overview of the compact range and transceiver layouts. An ISAR image of a complex target is presented as sample scale-model RCS data acquired with this system. Other unique applications of the system are presented including scale-model through-wall imaging and Doppler measurements of a rotating target.

II. COMPACT RANGE

The 100 GHz compact radar range, shown in Figure 1, consists of four functional components; the transceiver, the collimating reflector, the target and calibration positioning system, and the data acquisition system.

The transmit chains in the transceiver each produce approximately +12 dBm average transmit power over 16 GHz of bandwidth centered at 100 GHz. This radiation is coupled to the transmit horn as an 8.5 degree FWHM beam via an

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14. ABSTRACT

A fully polarimetric compact radar range operating at a center frequency of 100 GHz has been developed for obtaining radar cross section, inverse synthetic aperture radar imagery and high range resolution profiles on targets and structures of interest. The 100 GHz radar range provides scale-model RCS measurements for a variety of convenient scale factors including W-Band (1:1 scale), C-band (1:16 scale), and S-band (1:26 scale). An overview of the radar range is provided in this paper along with measurement examples of ISAR scale-model imaging, scale-model through-wall imaging, and preliminary kHz sweep-rate Doppler that demonstrate a few of the diverse and unique applications for this system. The 100 GHz transceiver consists of a fast-switching, stepped, CW microwave synthesizer driving dual-transmit and dual-receive frequency multiplier chains. The stepped resolution of the system?s frequency sweep is sufficient for unambiguous resolution of the entire chamber. The compact range reflector is a CNC machined aluminum reflector edge-treated with FIRAM?-160 absorber serrations and fed from the side to produce a clean quiet zone. This range is the latest addition to a suite of compact radar ranges developed by the Submillimeter-Wave Technology Laboratory providing scale-model radar measurements at nearly all of the common radar bands.

15. SUBJECT TERMS

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orthomode transducer. The beam propagates 6.3 meters to the primary (antenna) mirror which collimates the beam and allows it to propagate downrange to the target location 10 m from the antenna mirror. Backscattered radiation from the target retraces the transmit path to the receive horn which has an identical pattern as the transmit horn. The backscattered signal is down-converted through several stages to the final IF of 50 kHz where a DSP lockin amplifier measures the signal amplitude and phase. The combined transmit and receive patterns result in a 26 inch, 3 dB diameter quiet zone at the target. The receiver feed is located adjacent to the transmitter feed resulting in a 0.3 degree bi-static system configuration.

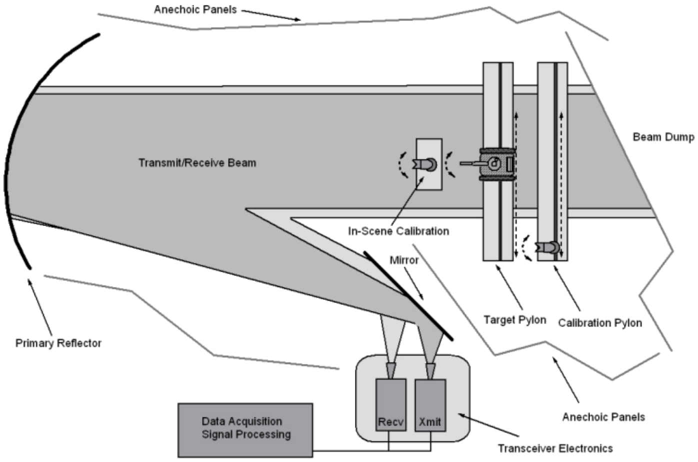

Figure 1. Top View of Compact Range

The compact radar range primary reflector (antenna mirror) is a 1.5 meter diameter, 6.3 meter focal length, CNC machined, hand polished, Aluminum mirror (See Figure 2). The mirror has an optical finish which greatly aids in the alignment of the system as well as testing of the antenna using optical techniques. The mirror is supported on an adjustable mount allowing fine changes in orientation for alignment purposes. The outer edge of the mirror is treated using serrated sections of custom designed FIRAM^{TM}-160 radar absorbing material (RAM) [12] in order to reduce edge scattering of the beam and associated quiet zone phase and amplitude ripple.

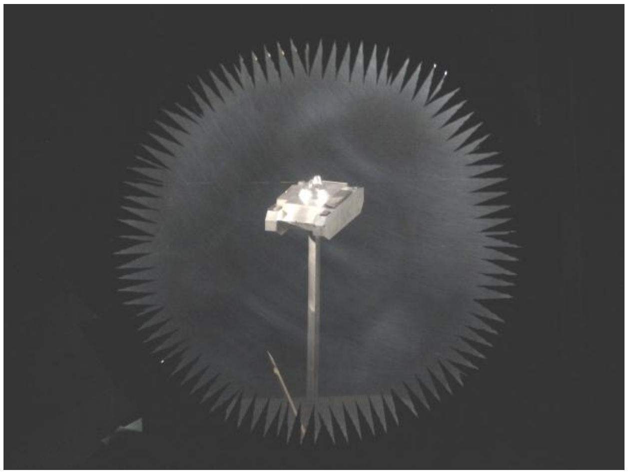

Figure 2. Primary (Antenna) Mirror in Compact Range with RAM Edge Treatment Showing the Reflection of the Complex Target Simulator and In-Scene Dihedron

The target positioning system automates the measurement and calibration operations (see Figure 3). The positioner allows for the translation of the calibration, target, and in-scene calibration object pylons into and out of the beam. The target pylon positions the target in azimuth and elevation. The calibration pylon is used to mount the ogive-terminated flat plate and dihedron calibration objects. The calibration dihedron can be rotated to any seam orientation via a high-resolution stepping motor equipped with an optical encoder. A second calibration pylon, called the in-scene pylon, is used to mount an ogive-terminated dihedron with the dihedron seam oriented to provide strong return signals in all four system channels for tracking and correcting of system phase deviations. A detailed description of the calibration algorithm that is applied to the acquired polarimetric data during post-processing is given in reference [13].

The entire compact radar range chamber is covered with a custom fabricated, wedge-style RAM designed at UMass STL [12]. The RAM is mounted onto large, movable panels which allow the angle of the absorber to be optimized to reduce backscatter, minimize target-chamber interactions, and deflect unwanted radiation to appropriate areas of the chamber (e.g. beam dumps).

All target positioning and transceiver operations are controlled via a PC-based data acquisition system. All data acquisition and processing software are written in National Instrument's LabVIEW® graphical programming software. Data processing allows acquired data to be presented as RCS plots, HRR profiles, and ISAR images.

Figure 3. Front-View of Target Positioning System with Calibration Pylon at the Rear (Left), Target Pylon with Adjustable Elevation and Target Azimuth (Center), and In-Scene Calibration Pylon with Dihedron (Lower-Left)

The transceiver consists of six modules: a frequency synthesizer, the transmit multiplier chains module, the receive multiplier chains module, the IF and reference frequency converter, I/Q demodulators (performed using lockin amplifiers), and data acquisition. A simplified diagram of these modules is presented in Figure 4.

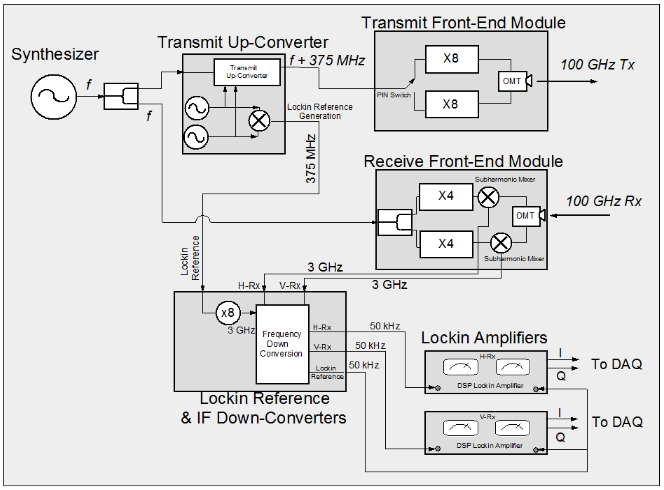

Figure 4. Block Diagram of the 100 GHz Transceiver

The Rx-drive synthesizer provides X-band RF power (11.125 GHz to 13.125 GHz) for the receiver front-end module, with one x4 frequency multiplier chain and sub-harmonic mixer for H-polarization receive and another set for V-polarization receive. The synthesizer also provides X-band RF power for the transmitter front-end module, after a frequency up-conversion of 375 MHz, with one x8 frequency multiplier chain providing H-polarization transmit and the other providing V-polarization transmit. The frequency difference between the transmit and receive millimeter-wave signals results in a 3 GHz intermediate frequency (IF) which is down-converted to 50 kHz for lockin-amplifier detection and data acquisition.

The 50 kHz reference signal for the lockin amplifiers is derived from oscillators common to the transmit frequency conversion electronics as well as those associated with the down-converter electronics. The outputs of two oscillators act as the LO input sources to each of the three separate 2-stage frequency down-converters in the system (e.g. V-Rx, H-Rx and Lockin Reference).

III. MEASUREMENTS

A. *ISAR Imaging*

The Complex Target Simulator (CTS), shown in Figure 5, is a complex model developed by STL in conjunction with the National Ground Intelligence Center (NGIC) and is used as a reference target during the development of various compact ranges. The CTS is a solid metal target which consists of several simple scattering centers positioned at strategic locations upon a tank-like silhouette. The scattering centers include dihedrons, trihedrons, frusta, and a cone-sphere, which each have well known scattering characteristics.

For this paper the CTS was mounted in a free-space configuration (on a pylon without a ground plane) and measured in the far-field. The system configuration was 16 GHz of bandwidth at a center frequency of 100 GHz and an angular azimuthal increment of 0.067 deg. This configuration corresponds to RCS modeling of the CTS (1:16 scale) at C-band for a center frequency of 6.25 GHz with 1 GHz of bandwidth and a range resolution of approximately 15 cm.

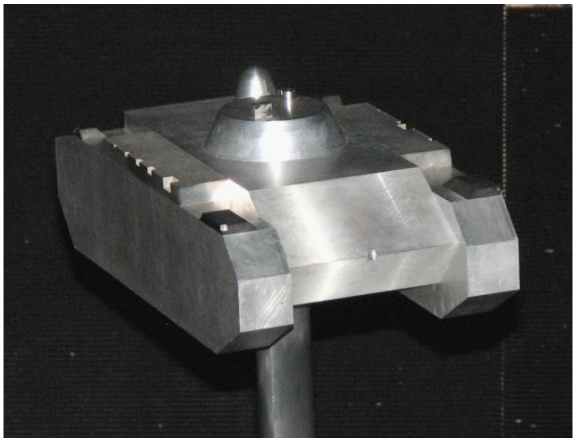

Figure 5. Complex Target Simulator (CTS)

An ISAR image of the CTS for HH (Co-Pol) with the target oriented at 240 deg Azimuth and 15 deg Elevation is included in Figure 6 (where the system transmit radiation is incident from the bottom of the figure). In the figure the ISAR image is overlaid with a CAD solid model of the CTS. The RCS values (in dBsm) are scaled to C-band (taking into account the 1:16 scale factor). The return from the corner reflectors along the lower edge of the CTS are easily visible demonstrating the excellent spatial resolution of the system. The RCS values presented by the scattering centers on the CTS vary from greater than 0 dBsm for the cone-sphere to below -30 dBsm for the rear corner reflector, while still being well above the noise floor of the system.

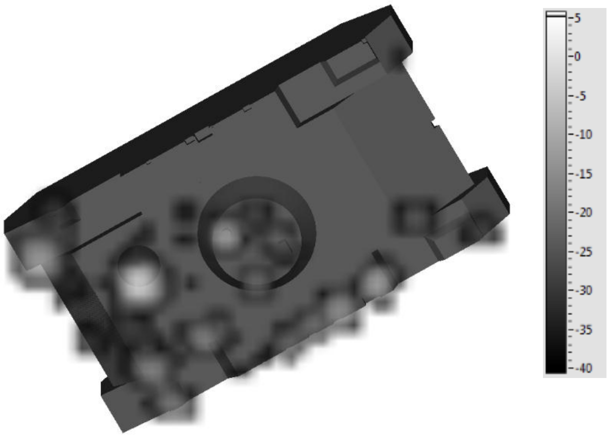

Figure 6. HH Channel C-Band (1:16 Scale) RCS (dBsm) ISAR Image of the CTS (240^o AZ, 15^o EL) Overlaid with CAD Solid Model of CTS

B. *Doppler of Rotating Target*

Doppler signature characterization of moving targets at millimeter-wave frequencies is a topic of great interest to the radar community [14-17]. The potential for Doppler motion characterization of moving targets using the 100 GHz compact radar range is demonstrated using the rotating target displayed in Figure 7. The system was configured to operate in a single-channel mode (HH) sweeping at a rate of 5.2 kHz with a range resolution of 0.2 meters.

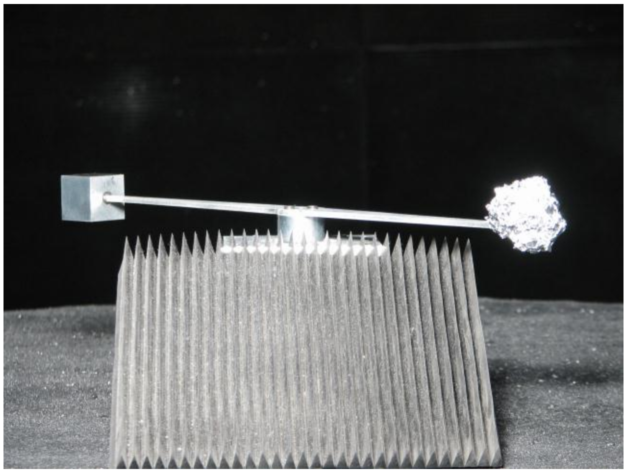

Figure 7. Rotating Target Consisting of Sphere Wrapped in Aluminum Foil and Metal Cube

In Figure 8 the acceleration of the target over time is easily captured by the system as well as the positive and negative Doppler frequency shifts associated with both the sphere and cube approaching and receding from the radar transceiver respectively. The peak return (*flashes*) arising from a given face of the cube when normal to the radar allows it to be easily distinguished from the sphere using a Short-Time Fourier Transform (STFT). The strong DC-Doppler return (0 Hz) as well as the constant-Doppler artifact at ~-1000 Hz will be removed in the future through a combination signal processing and shifting of the system final down-converted IF frequency.

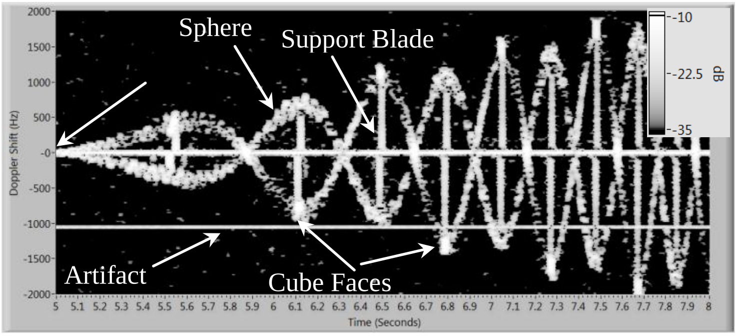

Figure 8. STFT-Processed Doppler versus Time of HH-Channel for Rotating Sphere and Cube (Normalized RCS)

C. *Scale-Model Through-Wall Imaging*

Another subject of interest to the military, disaster rescue, and homeland security communities is imaging through objects, particularly through-wall imaging [18-21]. Figure 9 provides an image of a scene used for demonstration of scale-model imaging through a 6” thick cinder block wall at 4.17 GHz. The scene consists of a scale-model cinder block wall (1:24 scale), with a variety of scale-model objects placed behind the wall, all mounted on a ground plane. The wall and miscellaneous objects within the scene (2 large metal drums, a bag of cement and a water jug) were created for other efforts at neighboring frequency bands but were used to provide reasonably accurate modeling of the relevant materials at 100 GHz for this preliminary demonstration. A 0.5” trihedron has also been located behind the wall, mounted in clay, as a reference object.

Figure 9. Scale-Model Scene for Preliminary Demonstration of Scale-Model Through-Wall Imaging

Figure 10 presents the results of ISAR imaging of the 1:24 scale model cinder block wall with plexi-glass mounting plate on a ground plane oriented at 344 deg azimuth and 5.05 degrees elevation for the VV channel (where the system transmit radiation is incident from the bottom of the figure).

For this baseline image there are no objects mounted behind the wall.

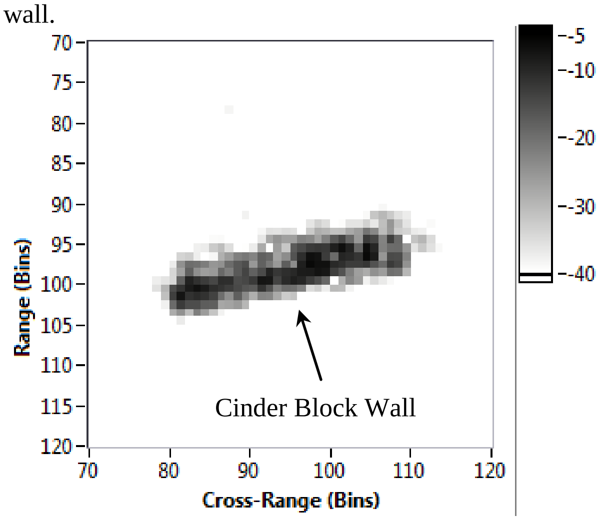

Figure 10. VV ISAR Image of 1:24 Scale Cinder Block Wall on Ground Plane (344 deg AZ, 5.05 deg EL; RCS in dBsm vs. Bins)

Figure 11 presents a sample result of ISAR imaging of the scale model cinder block wall with objects arranged behind the wall. For this orientation the two drums and trihedron are visible through the wall which confirms some potential for scale-model through-wall imaging. At various other azimuthal orientations of the wall the drums and other objects are at times difficult to image most likely due to a combination of multi-bounce, distortions of the wave-front through the cinder-block wall, and ground clutter. Future efforts to refine and improve this approach may include implementation of various signal processing techniques such as background subtraction and filtering [18-22], the potential use of Doppler information for moving targets [19, 20, 23] as well as the construction of other scale-model scenes of interest.

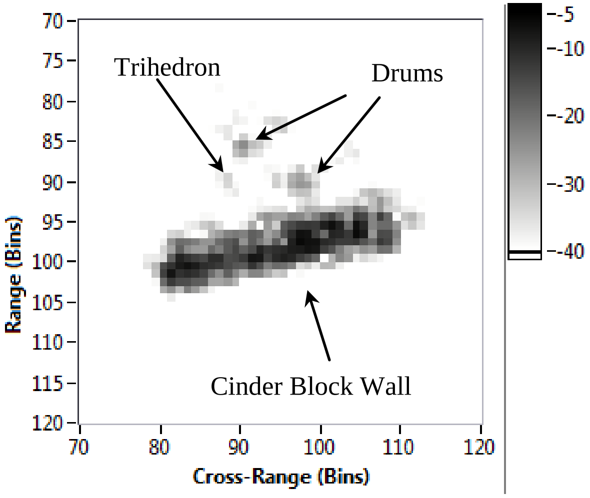

Figure 11. VV ISAR Image of 1:24 Scale Cinder Block Wall on Ground Plane with Scale Model Scene Behind Wall (344 deg AZ, 5.05 deg EL; RCS in dBsm vs. Bins)

IV. SUMMARY

In this paper we have presented an overview of a fully polarimetric compact radar range operating at a center frequency of 100 GHz, developed for obtaining radar cross section, inverse synthetic aperture radar imagery and high range resolution profiles on targets and structures of interest. The 100 GHz radar range provides scale-model RCS measurements for a variety of convenient scale factors including W-Band (1:1 scale), C-band (1:16 scale), and S-band (1:26 scale). Measurement examples of scale model ISAR imaging, scale-model through-wall imaging and preliminary kHz sweep-rate Doppler were presented in order to demonstrate a few of the diverse and unique applications for this system. This compact range is the latest addition to a suite of radar ranges developed by the Submillimeter-Wave Technology Laboratory providing scale-model radar measurements at nearly all of the common radar bands.

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