A Study of the X-Band Radar Signature Characteristics for Main Battle Tanks in Operational Environments

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ABSTRACT

An analysis of target separability has been performed under an OSD Target Management Initiative program entitled Radar Variations.(1,3,5,7) The program has concentrated on analyzing radar signatures from multiple main battle tanks(MBTs) in order to quantify the differences in Ka-band signatures of vehicles due to intraclass and interclass target variations. As a significant factor in the success of the Radar Variations program, U Mass Lowell's Submillimeter-Wave Technology Laboratory (STL) and U.S. Army National Ground Intelligence Center (NGIC) fabricated 1/16th scale "exact" replicas of the vehicles used in the Ka-band radar signature acquisition study directed by Simulation Technologies, Inc. (SimTech) and Targets Management Office (TMO). These replicas enabled NGIC to measure statistically significant amounts of high-fidelity signature data for a variety of target configurations with an indoor compact radar range. (3,7)

The metrics and model building procedures now provide the foundation for executing an analysis of target structures in operational environments. Multiple levels of operational environments can be modeled using modular assemblies of troop support hardware with the fine-scale replicas. To exemplify this capability, 4" resolution X-band signatures have been collected on precisely aligned test configured and operationally configured structures for comparative signature studies. Signature sets have been correlated to determine if, or which, in-scene target conditions produce changes in signature content that may confuse automated target recognition (ATR) algorithms. The signature-to-signature variability quantified is presented, along with a description and examples of the signature analysis techniques exploited. This signature data is available from NGIC on request for Government Agencies and Government Contractors with an established need-to-know.

Keywords: HRR, Ka-band, polarimetric, signature, ISAR, imagery, ATR

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1.0 INTRODUCTION

Pose-independent evaluative performance studies of high-value structures and conceptual radar systems for ATR applications are best served by signature libraries fashioned to encompass the complexity of the collection scenario.(2) Results reported on data sets of limited size tested in a laboratory environment typically see performance degrade when stressed with real-world target and environmental variability. To investigate signature requirements with target and environmental variability issues for stressing new ATR metrics, the U.S. Army's National Ground Intelligence Center (NGIC) and Targets Management Office (TMO) originated, sponsored, and directed a main battle tank (MBT) signature project plan to acquire multiple target full-polarimetric Ka-band radar signature data at Eglin AFB,(3) as well as its submillimeter-wave compact radar range equivalent using high-fidelity exact 1/16th scale replicas fabricated by the ERADS program.

To effectively understand signature reproduction requirements through the variability of multiple target RCS characteristics, TMO and NGIC sponsored researchers at U Mass Lowell's Submillimeter-Wave Technology Laboratory (STL) and Simulation Technologies (SimTech) to analyze the intra-class and inter-class variability of the full-scale turntable data. NGIC, TMO, STL and SimTech researchers then traveled to the location of the vehicles measured at Eglin AFB and conducted extensive documentation and mensuration on these vehicles. Using this information, the Expert Radar Signature Solutions (ERADS) program built high-fidelity, articulatable exact replicas for measurement in their compact radar ranges.

Figure 2. Shown is a $1/16^{th}$ scale replica of the T-72/M1 along side its full-scale equivalent (#940) at Eglin AFB.

Three-inch resolution X-band scaled signature data for this study was acquired on a precisely aligned test configured and operationally configured $1/16^{th}$ scale T-72/M1 using a 160 GHz Compact Range Radar. STL researchers measured these targets in several poses of increasing complexity by fixing the T-72 tank in the pose depicted in Figure 2 and then adding top-side modular assemblies of troop support hardware, to represent conditional changes, and placing the replica in the fortification berm, shown in Figure 3, to represent a change in environment. ISAR cross-correlation metrics were executed for analyzing the differences in signature content between the operational environments to determine if, or which, in-scene target conditions produced changes that might confuse automated target recognition (ATR) algorithms. Separability results establish the severity of RCS variability and enable ATR developers to insure command strike decisions on targets of interest not be compromised under varying operational conditions and environments.

Figure 3. Shown is a 1/16th scale T-72/M1 with top-side troop support hardware on open terrain and fortification berm.

2.0 THE SIGNATURE MEASUREMENTS AND TARGET DESCRIPTIONS

As described in the facility based documents like referenced(4), the X-band 1/16th scale signature data was collected at STL using a high-resolution full-polarimetric 160 GHz Compact Range Radar measurement facility. The critical system characteristics common to a full-scale equivalent target signature collection are listed in Table 1.

Table 1. The Operational Parameters of STL's X-band High Resolution Polarimetric Compact Range Radar

Parameter	Characteristic
Center Frequency	10 GHz
RF Agile Bandwidth	1.5 GHz
Frequency Step Size	5.88 Mhz at 256 steps
Polarization	full PSM linear
Aspect Resolution	0.04°

Test and operationally configured signature measurements were performed by STL researchers on the 1/16th scale T-72/M1 replica as well as a "generic" class representation of the T-80BV to explore signature-to-signature RCS variability issues. The top-side troop support hardware added as a conditional change to the T-72/M1 was two crew packs, three tool bags, six wooden ammunition crates, and four metal ammo boxes. To evaluate the impact of environmental changes, signatures were acquired of the 1/16th scale replicas configured on simulations of a flat rough terrain and an earth fortification berm. Detailed in Table 2 are the nine turntable signature sets measured for the entire spin of each vehicle/configuration at 10° elevation. Beyond the vehicle identification, characteristics recorded in table 2 are turntable configuration, top-side troop support hardware presence and archival file name.

Table 2. The sequence of MBT X-band scaled-signature data acquired using ERADS' 160 GHz Compact Range Facility.

Dataset	Vehicle	Turntable Configuration	Condition	filename
1	T-72/M1	Open Rough Terrain	No Top-Side Hardware	02C100XDAU.CLX
2	T-72/M1	Open Rough Terrain	With Troop Support Items	02C100XDAU.CLP
3	T-72/M1	Open Rough Terrain	With Troop Support Items	02C100XDBU.CLP
4	T-72/M1	with Fortification Berm	With Troop Support Items	02C100XDAT.CLP
5	T-72/M1	with Fortification Berm	With Troop Support Items	02C100XDBT.CLP
6	T-72/M1	with Fortification Berm	No Top-Side Hardware	02C100XDAT.CLX
7	T-72/M1	with Fortification Berm	No Top-Side Hardware	02C100XDBT.CLX
8	T-80BV	with Fortification Berm	With ERA	02D100XDAT.ASV
9	T-80BV	with Fortification Berm	With ERA	02D100XDBT.ASV

3.0 ANALYSIS OF THE SIGNATURE MEASUREMENTS

The comparative methodology used to quantify the signature-to-signature conditions and environments RCS variability was originally developed by STL researchers for evaluating (and establishing similitude between) MMW and scaled submillimeter-wave radar measurements[(5)]. To quantify the impact of these differences, independently measured images were cross-correlated using an averaged percent difference (APD) algorithm[(7)]. The APD algorithm was executed on high resolution ISAR at 1° aspect increments for the entire spin of the target (360 images). Since the target alignment between measurements was better than ±0.1° and the RCS signatures were calibrated using a simple shape calibration array, no adjustments in angular registration or RCS gain were necessary.

The front control panel of the Labview™-based software used to implement the cross-correlation algorithm has been shown in figures 4 and 5 for three typical signature combinations. Comprised in each of these panels are the last two ISAR images of a spin (as depicted in the top left and right of Figure 4's panel), the difference image (on the lower right), the APD value for each aspect (top graph on lower left), and the APD's probability density function(PDF) for the entire spin (bottom graph on the lower left). Also reflected in the panel are the average APD and standard deviation for the entire target spin. Figure 4 represents the cross-correlation of two independent measurements of the same target scene. Figure 5 contains the front panels for the change in target condition, on the left, and change in target environment, on the right.

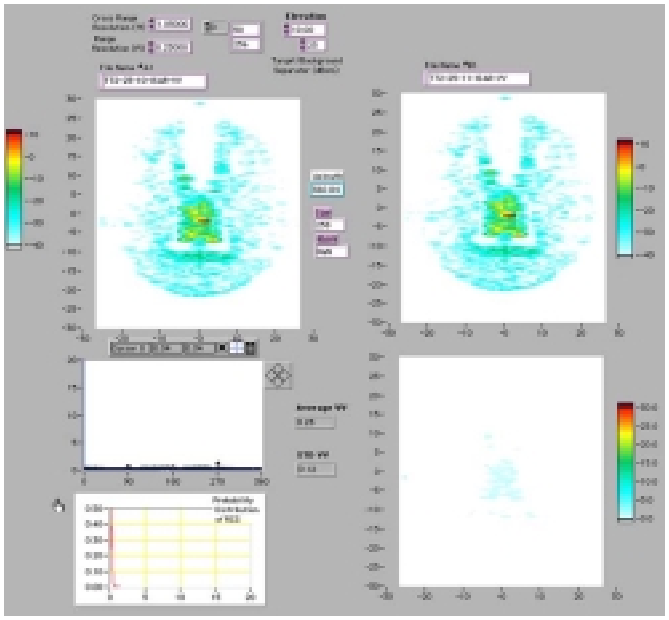

Figure 4. Shown is the cross-correlation of two independent spins of the T-72/M1 identically configured in the earth fortification berm. An APD value of 0.2% was achieved for the cross-correlation between the two imagery sets.

Using the spatial average of the percent difference between the 360 pairs of VV amplitude images (in units of dBsm), an APD value was calculated for twenty-nine cross-correlated combinations of scaled signatures to explore the RCS variability of changing operational conditions versus environments. See Table 3. As the probability density function (PDF) of this cross-correlation data, Figure 6 depicts the typical statistical spread in agreement between the paired conditional and environmental states for the VV ISAR imagery of the MBTs that has been documented in Table 3. Considered indicative of the system's measurement performance, there was satisfaction in observing that the cross-correlation values between any two independent measurements of a scaled vehicle/configuration are consistently the lowest tabulated values. Values for the independent measurements performed on the scaled T-72/M1 behind the earth fortification berm both with, and without, top-side hardware exhibited the highest correlation, 0.2% (lowest values in Table 3) just as for the T-80BV/ERA behind the earth berm. The spread in the correlation values of ±0.1% or less, as depicted by the blue PDF curves in Figure 6, provides further evidence of the signature's well behaved, reliably measurable, RCS content.

Considered indicative of the RCS variability in changing a target's operational conditions, the cross-correlation between the four open terrain measurements performed on the T-72/M1 with, and without, top-side hardware exhibited values of ≈3.0% while four similar measurements of the T-72/M1 behind the earth berm exhibited values of 3.8%. The ±1% spread in the correlations values exhibited by the PDF curves in Figure 6, depicted in red, provides evidence of the variability for a signature's RCS content strictly based on changing operational conditions.

The cross-correlation values of ≈12% between measurements of the T-72/M1 on open terrain versus behind the berm indicate there are significant differences in the signature content for targets between the operational environments. Further evidence is the ±4% rotationally (or pose) dependent spread in the APD values as observed in the right hand front panel of Figure 5. By graphing the PDF of typical examples spanning the condition and environment combinations, Figure 6 further illustrates the impact to X-band ISAR signature content for targets in differing conditions and environments.

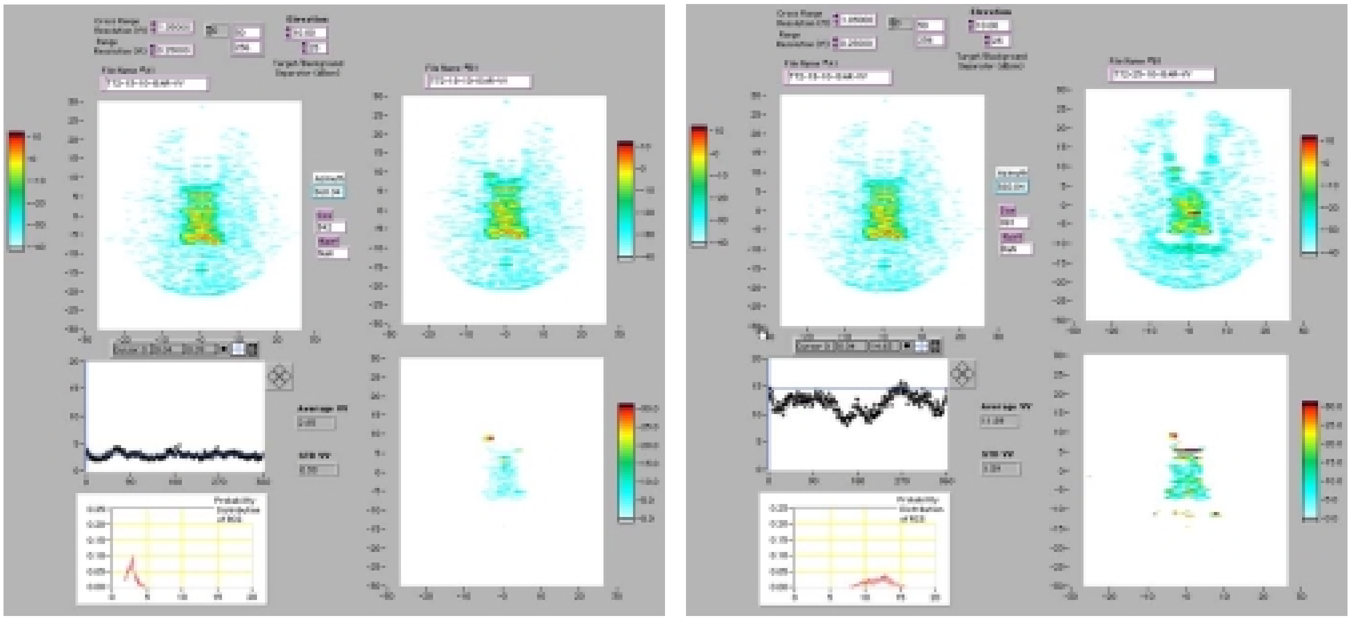

Figure 5. Shown is the cross-correlation of the T-72/M1 configured with, and without, top-side troop support hardware (left) along side the cross-correlation of the same vehicle in open terrain and a fortification berm.

Table 3. The VV ISAR APD Cross-Correlation of operational condition and environment X-band VV ISAR for a T-72/M1.

configuration	Open Terrain No Support	Open Terrain /Support 1	Open Terrain /Support 2	BERM /Support 1	BERM /Support 2	BERM No Support 1	BERM No Support 2	T-80BV/Berm /ERA
Open/Support 1	3.1							
Open/Support 2	2.9	1.2						
BERM/Support 1	11.9	11.8	11.7					
BERM/Support 2	11.9	11.8	11.7	0.2				
BERM/NoSupport 1	11.5	12.0	11.9	3.8	3.8			
BERM/NoSupport 1	11.5	12.0	11.9	3.8	3.8	0.2		
T-80BV/Berm	13.4	13.4	13.4	11.7	11.7	11.8	11.8	0.2

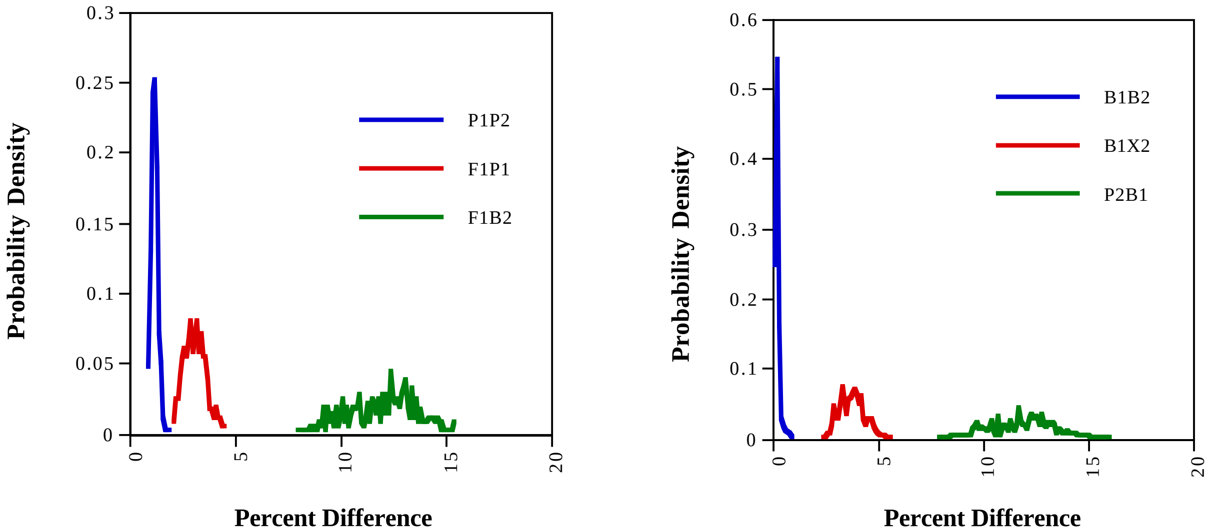

Figure 6. Displayed is the APD cross-correlation of operational condition and environment X-band VV ISAR of a T-72/M1.

Consistent with prior research on the RCS variability for signatures of multiple MBTs[7] are the average APD values for the cross-correlation between signature measurements of the T-80BV and T-72/M1. Within the context for RCS variability of changing operational conditions and environments, one observes that the T-80BV hidden behind the earth fortification berm correlates better with the T-72/M1 in the same environment than with the T-72/M1 in open terrain. One also observes no appreciable difference in the cross-correlation of these different MBTs regardless of the top-side troop support hardware changes made to the T-72. Critical to the observations between the T-72 and T-80, however, are the minimal difference between average APD values for the T-72 in open terrain when cross-correlated with the T-80, or itself, behind the fortification berm. Ultimately an ATR designed to search for an MBT in open terrain may be challenged to uniquely identify the same structure obscured in typical operational environments.

4.0 CONCLUSIONS

The cross-correlation of signatures for main battle tanks (MBTs) in operational conditions and environments have been explored through the use of 10° elevation high-resolution X-band ISAR. Confidence in the metrics and signature data exploited was quantified through ISAR cross-correlation values between independent measurements of individual scenes. While target separability seems easily achievable between MBTs in differing operational conditions using the X-band ISAR, the difficulty of exploiting signatures in different operational environments has been made evident.

With these results, an investigation of the RCS variability issues for targets in operational conditions and environments has been initiated using full-polarimetric X-band scaled radar signature data acquired at STL with ERADS' 160 GHz compact radar range. Enabling future ATR performance studies as a function of ground terrain clutter, ERADS' researchers are fabricating a variety of additional ground planes to expand this research. A data acquisition program designed to expand the archive of X, Ka and W-band signatures for structures posed in operational environments is under consideration. The signature data presented in this study is available from NGIC/TMO on request for Government Agencies and Government Contractors with an established need-to-know.

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