

Radar Cross Section Statistics of Ground Vehicles at Ku-band

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Three stylized stars in the top-left corner, one white and two red, with a 3D effect.

Outline

- **Problem Statement**
- **State-of-the-Art**
- **Military and Civilian Data Acquisition**
- **Distributions, Statistics, Swerling Target Number**
 - Vehicle Size
 - Vehicle Configuration
 - Vehicle Pose (azimuth and grazing)
 - Radar Resolution
 - Radar Polarization
 - Scene Clutter
 - Overall
- **Summary**



Problem & Motivation

- **Ground-moving target indication radar for ground vehicles in border, facility, and battlefield monitoring applications requires setting proper thresholds**
- **Detection requires an understanding of the distribution of vehicle RCS and general statistics**
- **Current literature is anemic at Ku-band, in which many GMTI radars operate, with most work based on models and simulations (e.g. Xpatch) or chamber measurements, or limited experimental data sets**
- **Radar measurements needed to corroborate the accuracy and suitability of simulations, controlled chamber experiments, and limited empirical results**



Data Set Acquisition

- **Sandia National Laboratories' Automatic Target Recognition Database**
 - **MSTAR**
 - **General Atomics Lynx Data Collects**
 - **Sandia Test-bed Radar Data Collects**
- **X-band and Ku-band Calibrated RCS Data**
- **Multiple vehicle chips with varying**
 - **Polarization (HH, HV, VV)**
 - **Vehicle Pose (0-360 degree AZ, 5-50 degree EL)**
 - **Resolution (4", 1', 1.5', & ability to coarsen)**
 - **Clutter**
- **Primarily large vehicle target types**



Data Set Target & Clutter Types

- **Military vehicles**

- Tanks
- Launchers
- Armored vehicles
- Fuelers
- Trucks
- Transporters

- **Civilian vehicles**

- Bulldozers
- Flat-bed trucks
- School buses
- Trailers
- Large pick-up trucks

- **Grass**

- **Asphalt**

- **Desert with Vegetation**

- **Fields**

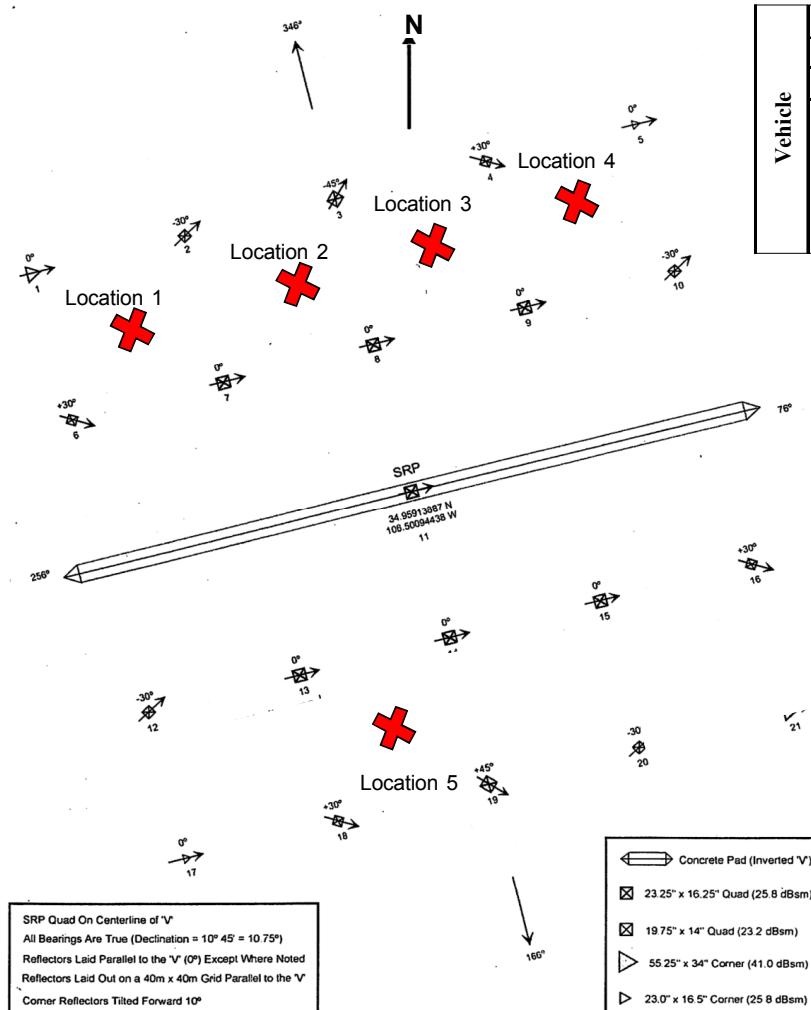
- **Clay**






- **Gravel**

- **Sand**

**CALIBRATED RCS OF VARIOUS LARGE VEHICLES AND CONFIGURATIONS
IN DIVERSE CLUTTER TYPES AND SCENES SETTINGS.**

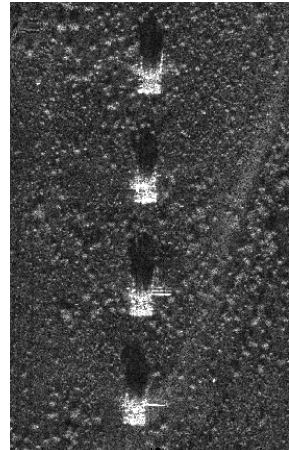
Personal Vehicle Experiment



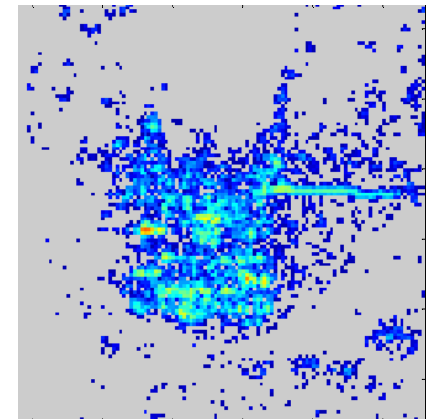
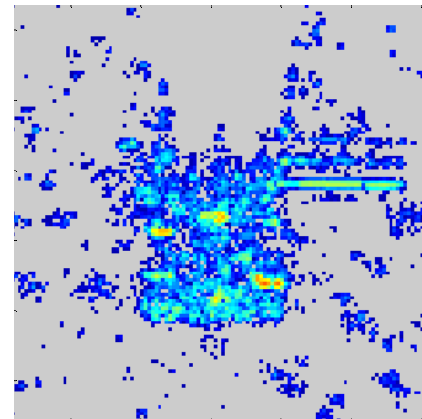
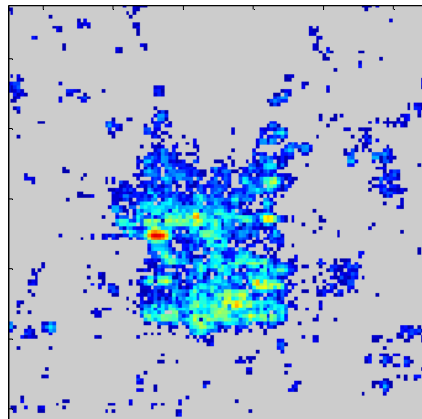
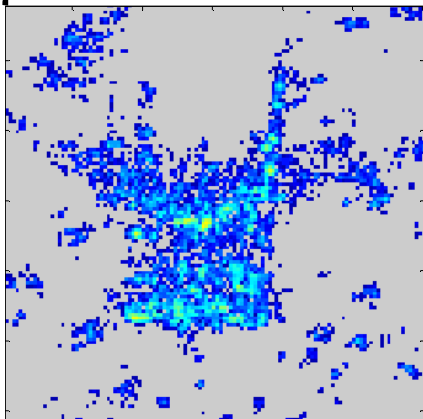
	Location 1	Location 2	Location 3	Location 4	Location 5
Vehicle	Chevrolet Express	Ford F350	Pontiac Grand Am	Dodge Caravan	Dodge Ram
	Large Van	Pick-up Truck	Mid-size Sedan	Mid-size Van	Pick-up Truck
					

- **TWO SPOTLIGHT CIRCLE PASSES EVERY 10 DEGREES IN AZIMUTH, 4" RESOLUTION, HORIZONTAL POLARIZATION, KU-BAND, AND DESERT CLUTTER WITH VEGETATION**
- **20 AND 30-DEGREE GRAZING ANGLES**
- **RADAR CALIBRATION SITE MULTIPLE QUAD AND SINGLE CORNERS IN SCENE FOR ABSOLUTE RCS.**
- **TWO VANS, TWO TRUCKS, 1 SEDAN**

Military Vehicle SAR Image Chip Example



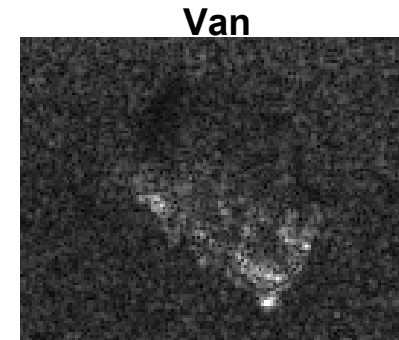
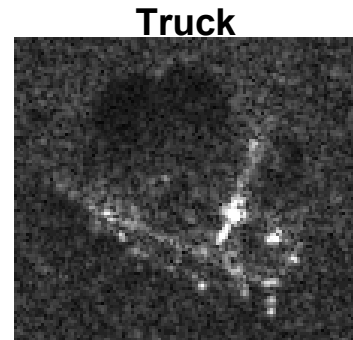
- Column of Derelict M-47 Tanks at 17.3 Grazing and 85.3 Squint.
- SAR Image Chips with Dynamic Range limited from -20 to 25dBsm.
- Chips consist of many scattering centers, with most exhibiting a dominant scatterer.



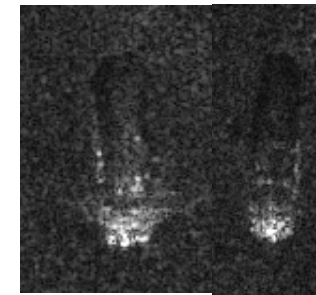
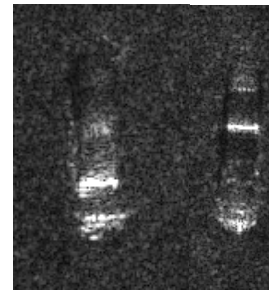
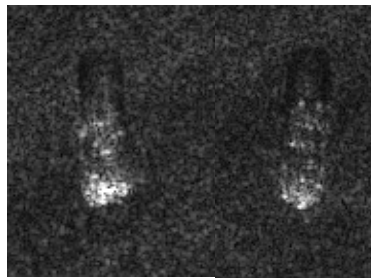
PEAK DETECTION USED FOR RCS DISTRIBUTIONS AND STATISTICS.

Civilian Vehicle SAR Image Chip Examples

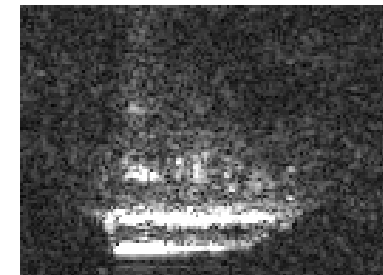
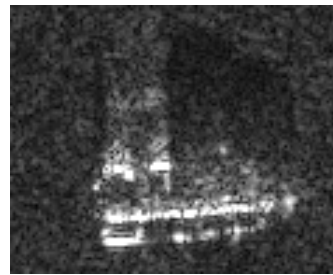
Side Oblique Angle



Back/Front Flash



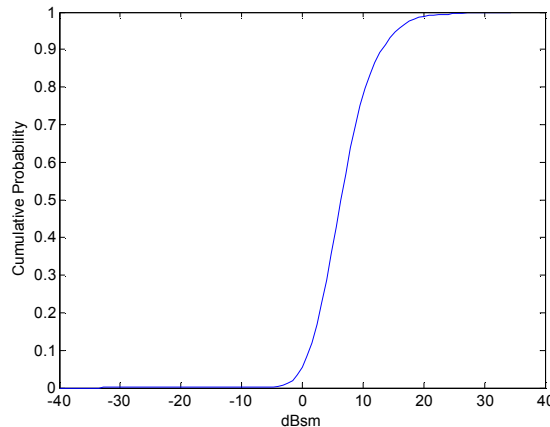
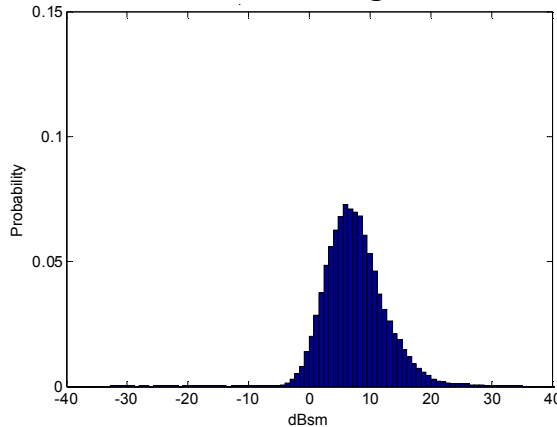
Side Flash



CHIPS CONSIST OF MANY SCATTERING CENTERS, WITH MOST EXHIBITING A DOMINANT SCATTERER.

RCS Variation with Polarization (X-Pol, Co-Pol)

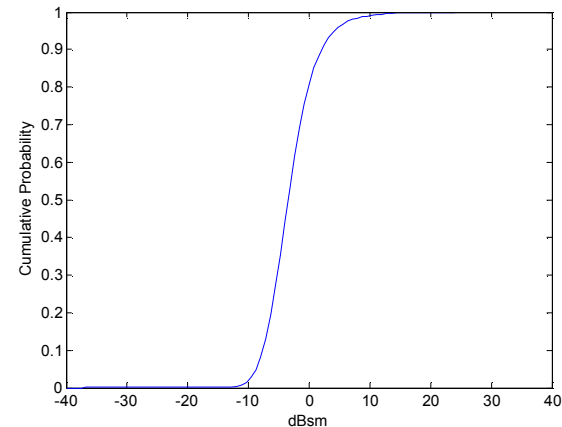
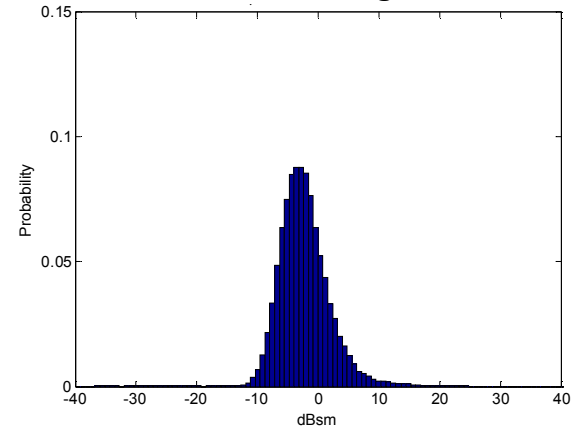
X-band, HH, 5 Grazing, 0.5m Res.



(6.2, 11.9, 7.6, 4.9)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

X-band, HV, 5 Grazing, 0.5m Res.

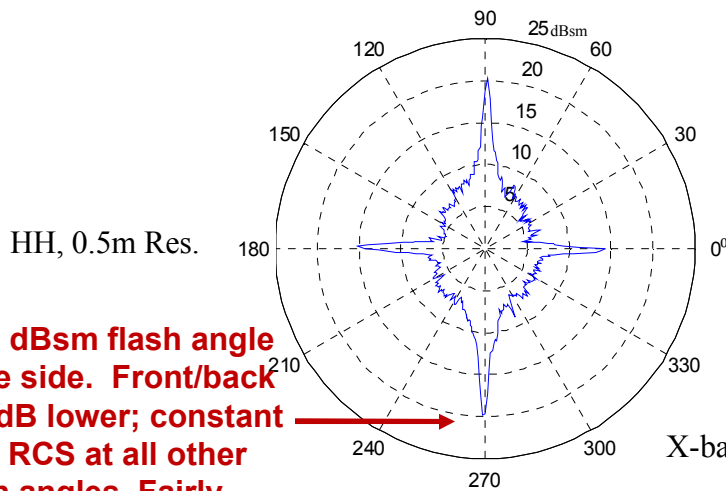


(-3.7, 0.7, -2.3, 4.1)

**RCS DISTRIBUTION AND STATISTICS ~10DB LOWER FOR X-POL VS. CO-POL.
CO-POL HH and VV SIMILAR ACCORDING TO THE LITERATURE.**

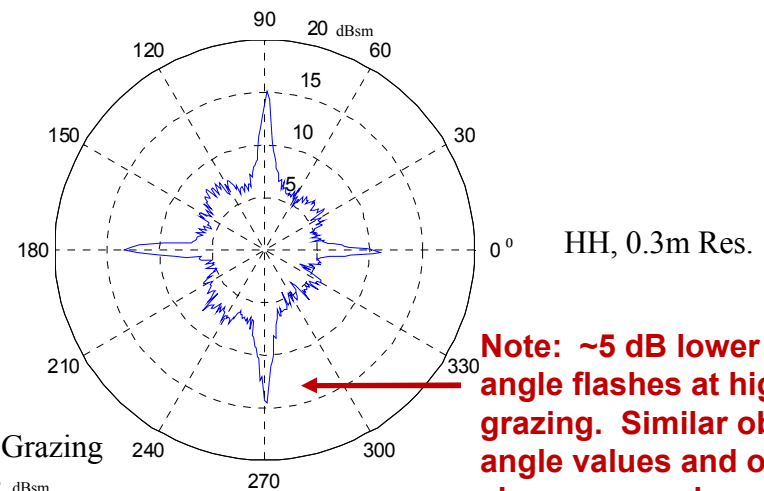
RCS Variation with Pose (Azimuth)

X-band, Low Grazing



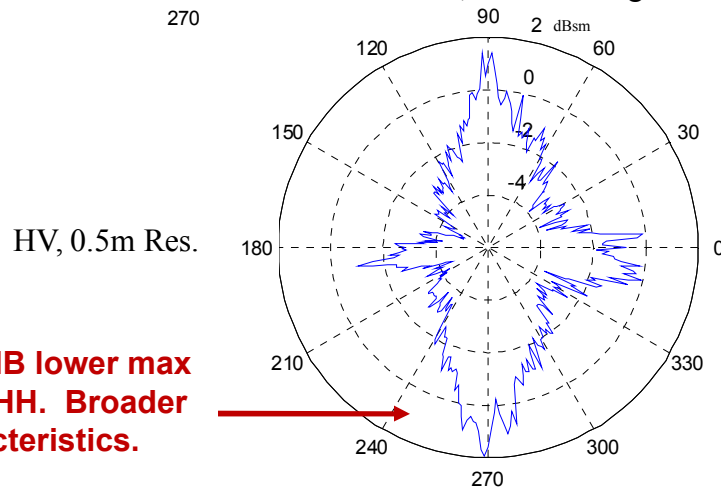
Note: 20 dBsm flash angle at vehicle side. Front/back flash ~5 dB lower; constant ~7 dBsm RCS at all other non-flash angles. Fairly symmetric shape.

X-band, High Grazing



Note: ~5 dB lower cardinal angle flashes at high grazing. Similar oblique angle values and overall shape versus low grazing.

X-band, Low Grazing

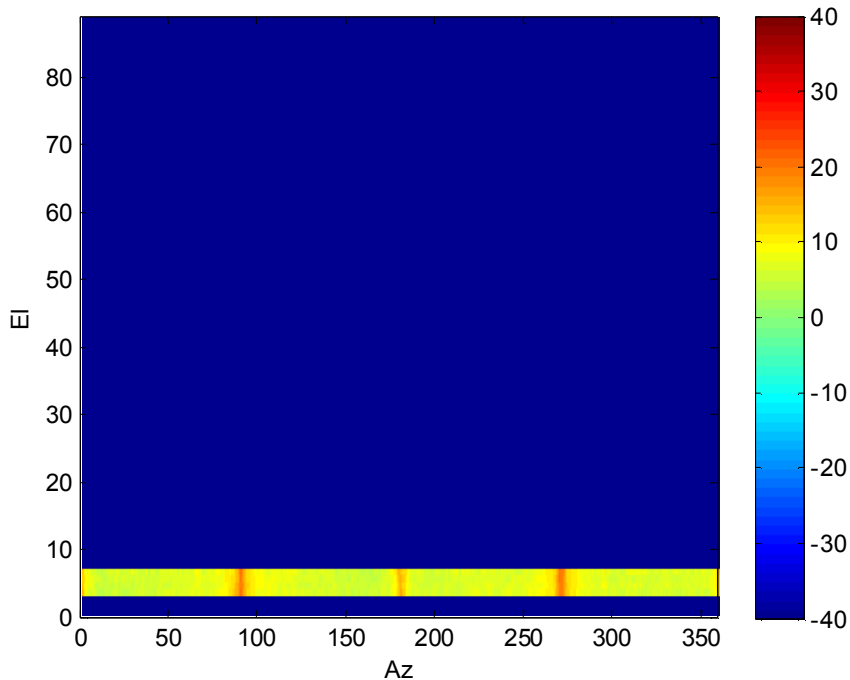


Note: ~18 dB lower max value from HH. Broader flash characteristics.

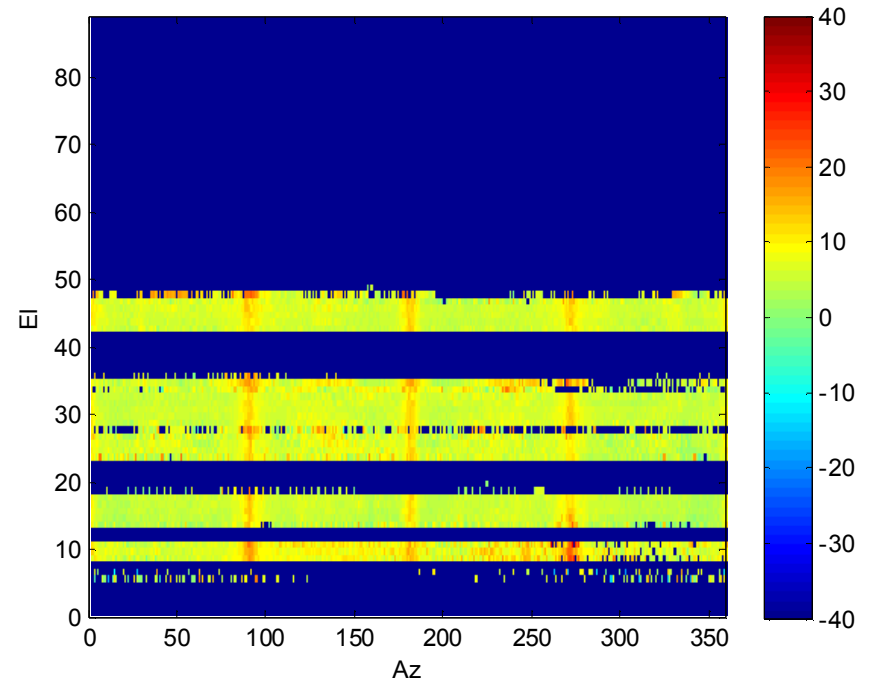
RCS VARIES WITH: X-POL AND CO-POL IN SHAPE AND MAGNITUDE; GRAZING IN MAGNITUDE AT CARDINAL ANGLES; AND OBLIQUE VERSUS CARDINAL ANGLES

RCS Variation with Pose (Grazing)

X-band, HH, Low Grazing, 0.5m Res.



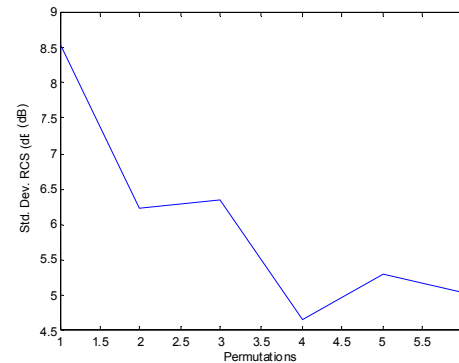
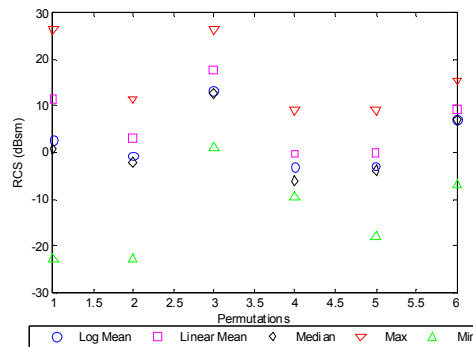
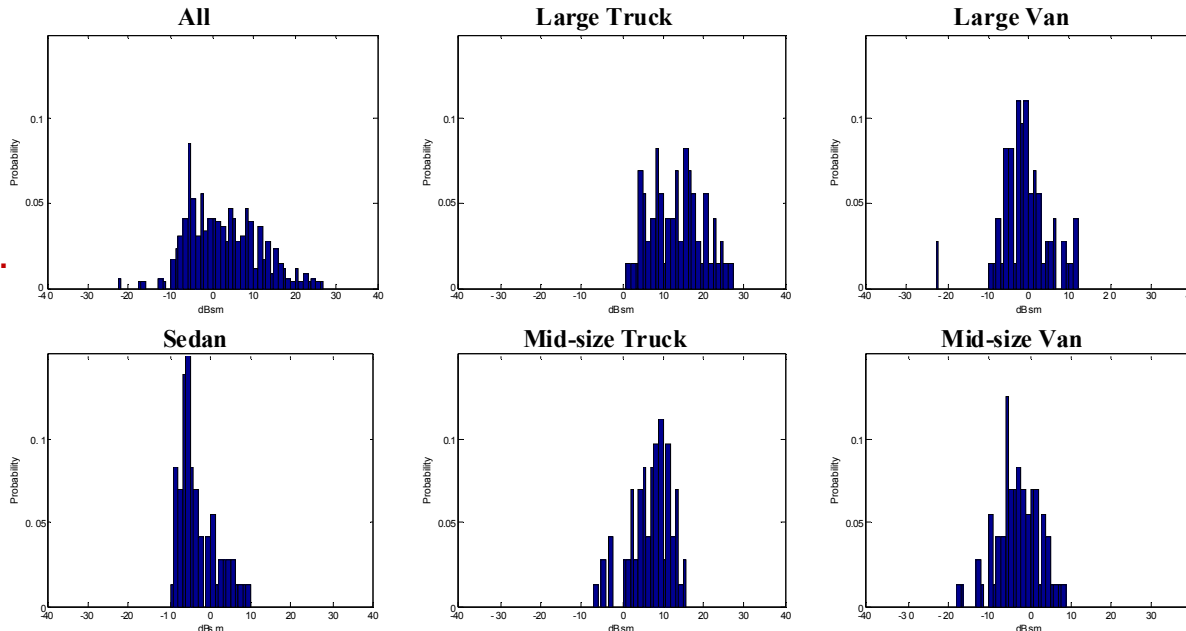
X-band, HH, High Grazing, 0.3m Res.



**RCS VARIES MINIMALLY WITH GRAZING ANGLE.
ALL OBLIQUE ANGLES CONSISTENT.
FLASH ANGLES (~5 DB LOWER AT WORST BETWEEN 5 AND 45).**

RCS Variation of Vehicle Type & Size

Note: Multi-vehicle distribution non-Gaussian and with large spread due to diverse individual vehicle distributions.



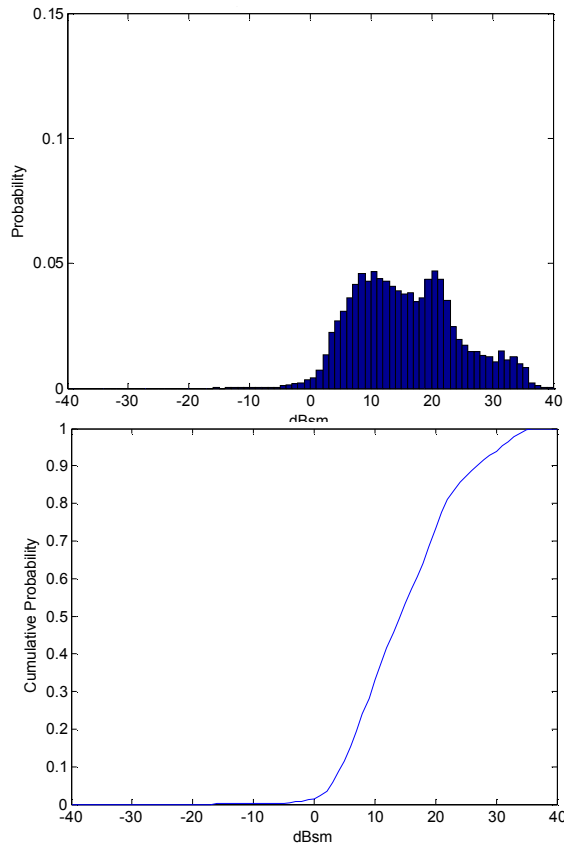
Note: Trucks have positive RCS range, whereas vans and sedans are between -10 to 10 dBsm due to strong trihedral and dihedral scattering from truck bed. Truck max RCS range related to size of truck.

Vehicle Type Permutations: 1. All, 2. Large Van, 3. Large Truck, 4. Sedan, 5. Mid-size Van, 6. Mid-size Truck

RCS DISTRIBUTION & STATISTICS SHIFT ~13 DB WITH VEHICLE SIZE & TYPE

RCS Variation of Vehicle Type & Size (cont'd)

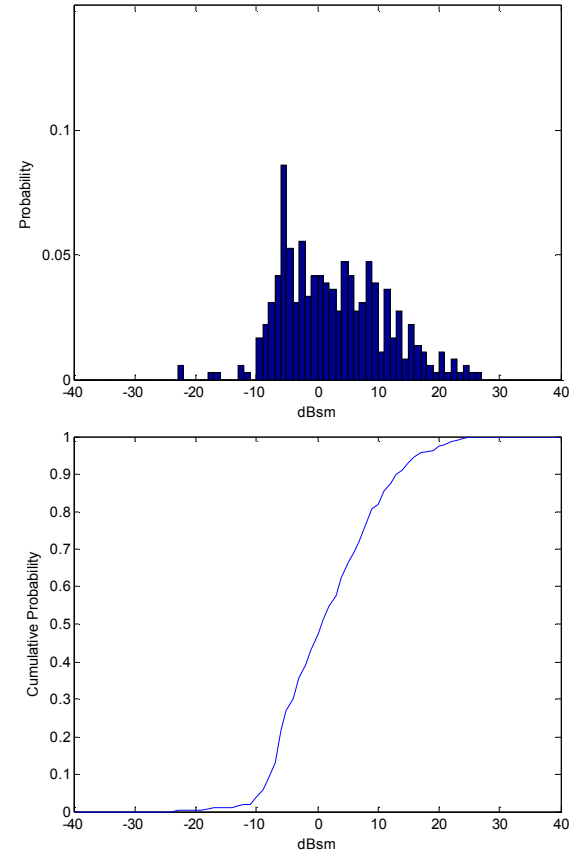
Ku-band, VV, Large Vehicles, 4''



(14.1, 23.9, 15.8, 8.4)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

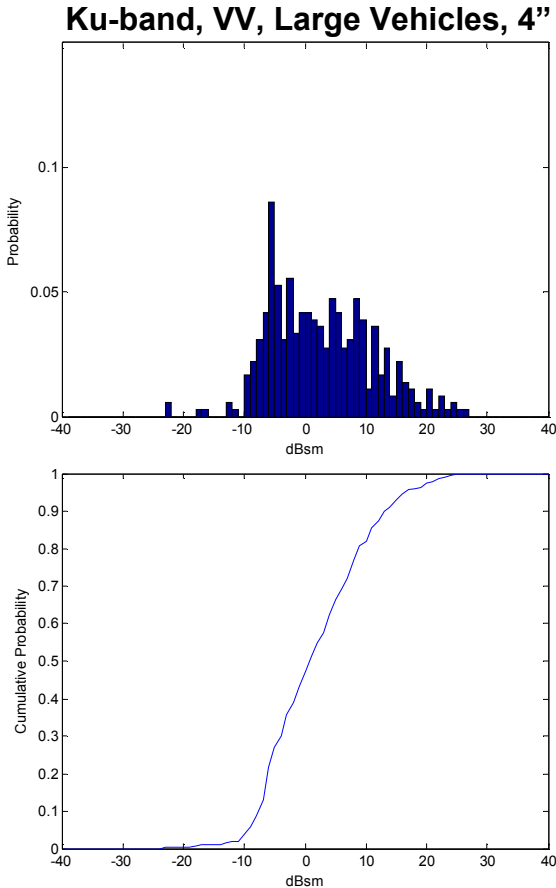
Ku-band, HH, Civilian Vehicles, 4''



(0.7, 11.4, 2.6, 8.5)

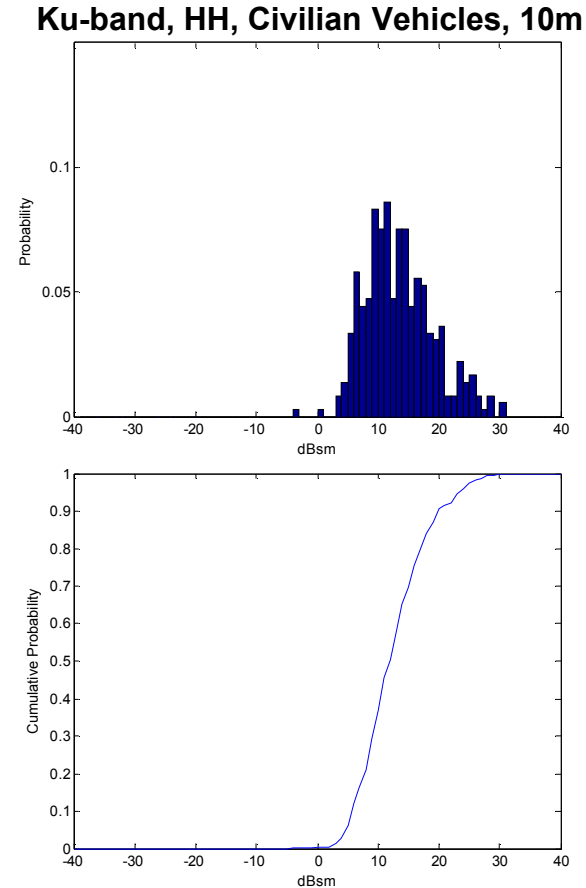
RCS DISTRIBUTION AND STATISTICS NON-GAUSSIAN DUE TO DIFFERENT TARGET TYPES.

RCS Variation with Resolution



(0.7, 11.4, 2.6, 8.5)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

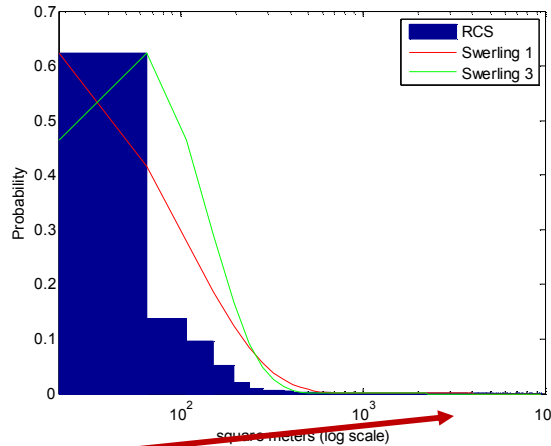


(11.9, 17.7, 13.5, 5.6)

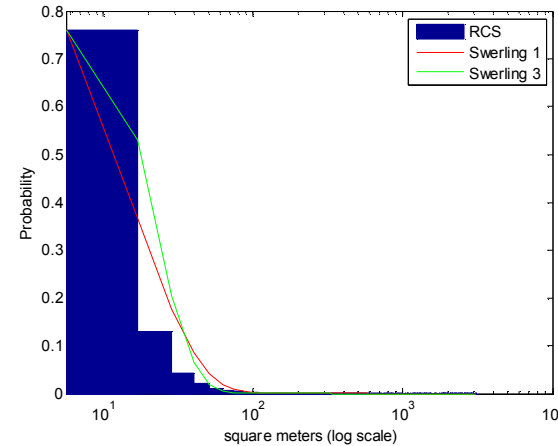
**RCS DIST. AND STATS 10 DB HIGHER FOR 10M RESOLUTION
--- TARGET IN SINGLE RESOLUTION CELL.**

Swerling Target Variation with Resolution

Ku-band, Overall, 4"

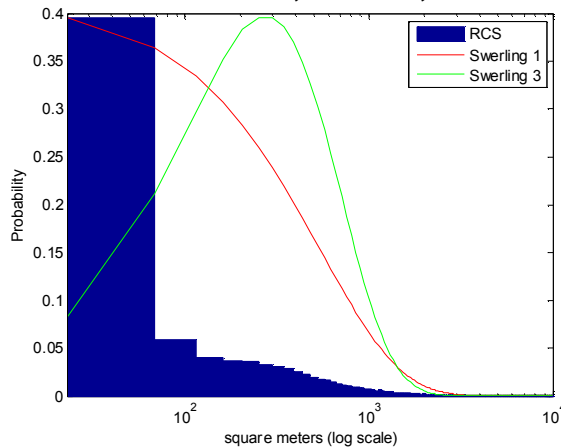


X-band, HH, Large Vehicles, 1.5-foot, All Samples

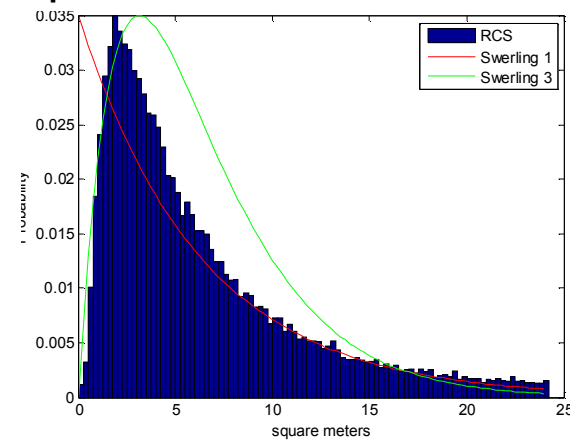


Note: Long tails in distribution due to cardinal angle flashes.

Ku-band, Overall, 10m

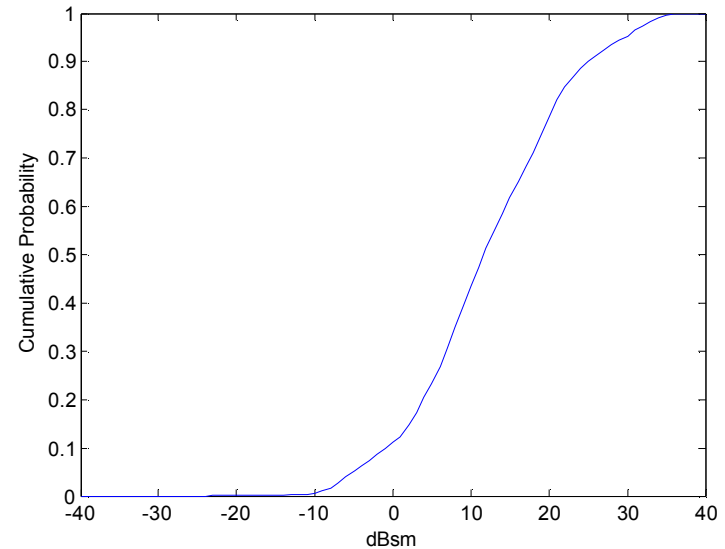
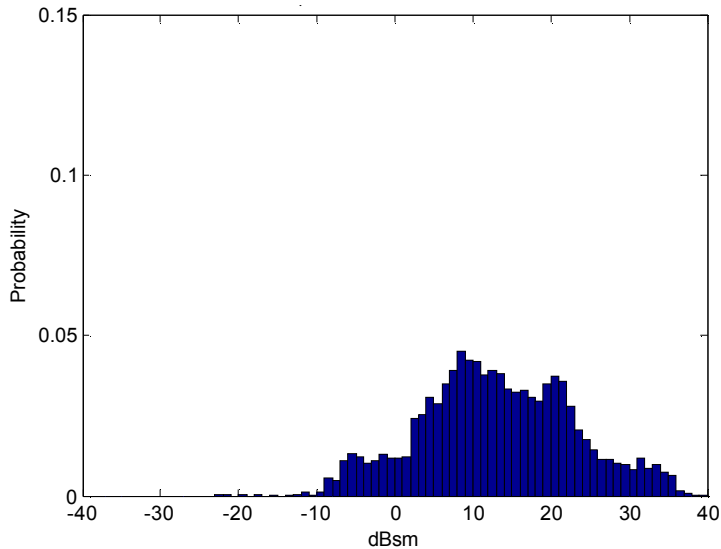


Samples Below 90% in CDF for Above Case



**SWERLING 1 CONSERVATIVE MODEL CHOICE FOR ALL DATA SETS.
SWERLING 3 POSSIBLE FOR SNR AND PD CONSIDERATIONS AT MOST ANGLES.**

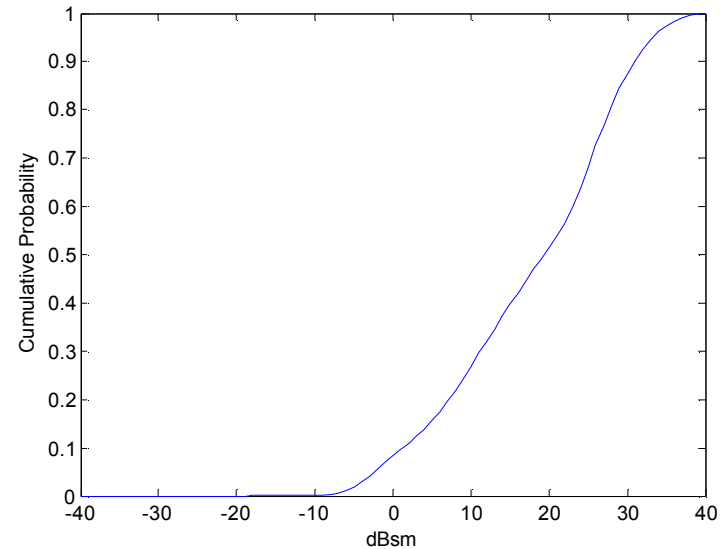
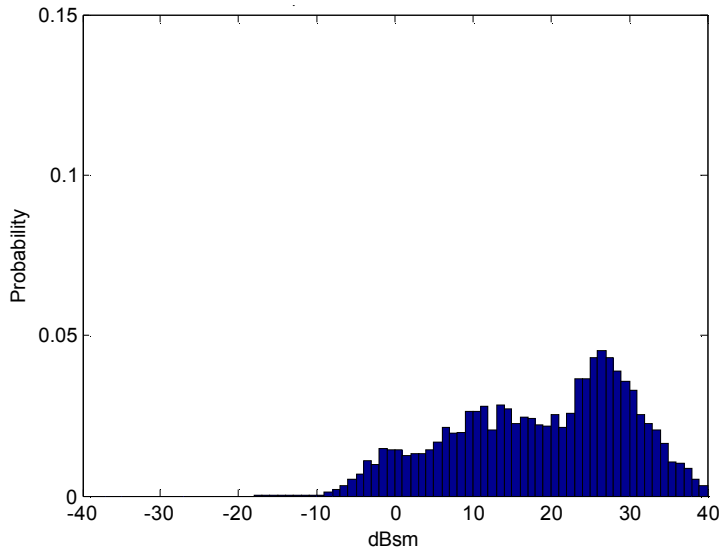
Overall 4" Resolution RCS Results



RCS Summary (All Experiments and Variations)	
Arithmetic Mean: 22.9 dBsm	Swerling Target: 1
Geometric Mean: 13 dBsm	90% P_d Threshold: 13.1 dBsm
Median: 11.7 dBsm	10% $P_{\text{exceeding}}$ Upper Limit: 26.5 dBsm
Std. Dev.: +/- 9.9 dB	Conclusions: Distribution & statistics generally vary across size, type, pose, and cross-polarization.
Range: -10 to 40 dBsm	

EXPERIMENTAL RCS CHARACTERISTICS --- VEHICLE IN MANY RESOLUTION CELLS

Overall 10m Resolution RCS Results



RCS Summary (All Experiments and Variations)	
Arithmetic Mean: 27.5 dBsm	Swerling Target: 1
Geometric Mean: 18.7 dBsm	90% P_d Threshold: 17.7 dBsm
Median: 19.4 dBsm	10% $P_{\text{exceeding}}$ Upper Limit: 31.1 dBsm
Std. Dev.: +/- 11.1 dB	Conclusions: Distribution & statistics generally vary across size, type, pose, and cross-polarization.
Range: -10 to 40 dBsm	

EXPERIMENTAL RCS CHARACTERISTICS --- VEHICLE IN SINGLE RESOLUTION CELL

Summary

- **Vehicles RCS Distributions and Statistics Vary with:**
 - Vehicle Size and Type (large/small or boxy/smooth)
 - Grazing Angle (minimally)
 - Azimuth Angle (large RCS at cardinal angles, fairly constant at oblique angles)
 - Radar Resolution (larger RCS at coarser resolutions)
 - Radar Polarization (X-Pol RCS drastically smaller and different azimuthal pattern, Co-Pol fairly similar)

4" Resolution	10m Resolution
Arithmetic Mean: 22.9 dBsm	Arithmetic Mean: 27.5 dBsm
Geometric Mean: 13 dBsm	Geometric Mean: 18.7 dBsm
Median: 11.7 dBsm	Median: 19.4 dBsm
Std. Dev.: +/- 9.9 dB	Std. Dev.: +/- 11.1 dB
Range (.1<P<.9): 13.1 to 26.5 dBsm	Range (.1<P<.9): 17.7 to 31.1 dBsm
Swerling Target: 1	Swerling Target: 1

- **Swerling 1 Target Model an overall conservative design choice (target number varies with azimuth angle and resolution)**
- **Observations in literature consistent**

References and Acknowledgements

References:

- W. E. Nixon, H. J. Neilson, G. N. Szatkowski, R. H. Giles, W. T. Kersey, L. C. Perkins, and J. Waldman, "A variability study of Ka-band HRR polarimetric signatures on eleven T-72 tanks," *Proceedings of the SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery V*, vol. 3370, pp. 369-382, Orlando, FL, 14 Apr. 1998
- R.H. Giles, W.T. Kersey, M.S. McFar1in, R. Fin1ey, H.J. Neilson, and W.E. Nixon, "A study of target variability and exact signature reproduction requirements for Ka-Band radar data," *Proceedings of the SPIE Conference on Signal Processing, Sensor Fusion, and Target Recognition X*, vol. 4380, pp. 117-126, Orlando, FL, 16 Apr. 2001.
- T. M. Goyette, J. C. Dickinson, C. Beaudoin, A. J. Gatesman, R. Giles, J. Waldman, and W. E. Nixon, "Acquisition of UHF and X-Band ISAR imagery using 1/35th scale-models," *Proceedings of the SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery XII*, vol. 5808, pp. 440-449, Orlando, FL, 28 Mar. 2005.
- G. Palubinskas and H. Runge, "Radar signatures of a passenger car," *IEEE Geoscience and Remote Sensing Letters*, vol. 4, no. 4, Oct. 2007.
- G. Palubinskas, H. Runge, and P. Reinartz, "Measurment of radar signatures of passenger cars: airborne SAR multi-frequency and polarimetric experiment," *IET Radar, Sonar, and Navigation*, vol. 1, no. 2, pp. 164-169, 2007.
- S. Papadopoulos and B. Mulgrew, "Scenario based RCS statistics of complex ground targets," *IEEE*, 2008.

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- *The ground team at Sandia for a civilian vehicle collect in 2011 with a Ku-band test-bed radar system*