



Radar Cross Section Measurement of a 50 Caliber Bullet at Ka-Band

by Thomas J. Pizzillo

ARL-TN-0296

October 2007

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Adelphi, MD 20783-1197

ARL-TN-2096

October 2007

Radar Cross Section Measurement of a 50 Caliber Bullet at Ka-Band

Thomas J. Pizzillo

Sensors and Electron Devices Directorate, ARL

Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) October 2007		2. REPORT TYPE Final		3. DATES COVERED (From - To) September 2003	
4. TITLE AND SUBTITLE Radar Cross Section Measurement of a 50 Caliber Bullet at Ka-Band				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Thomas J. Pizzillo				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRDL-ARL-SE-RM 2800 Powder Mill Road Adelphi, MD 20783-1128				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TN-0296	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1128				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Static radar cross-section (RCS) measurements of a pristine .50 caliber bullet at Ka-band are reported. Measurements are from 32.4-GHz to 35.6-GHz using a stepped frequency waveform with range resolution of 4.7-cm. The measurements are compared with model data and have good agreement. The data was collected during the summer of 2003 at the Army Research Laboratory's (ARL) millimeter wave anechoic chamber research facility located at the Adelphi Laboratory Center (ALC), Maryland.					
15. SUBJECT TERMS RCS Ka-band 50 caliber					
16. Security Classification of:			17. LIMITATION OF ABSTRACT U	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON Thomas J. Pizzilo
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (301) 394-3143

Contents

List of Figures	iii
Introduction	1
Target Description	1
Radar Description	2
Experiment Description	2
Data	2
Conclusions	5
Distribution	7

List of Figures

Figure 1. Three views of the bullet a) head-on, b) broadside, and c) from the rear. The upper scale is millimeters and the bottom scale is inches.....	1
Figure 2. HRR profiles for head-on orientation.....	3
Figure 3. HRR profiles for broadside orientation.	4
Figure 4. HRR profiles for backside orientation.....	4

INTENTIONALLY LEFT BLANK

Introduction

The Army Research Laboratory (ARL) has been studying Active Protection System (APS) schemes for defense against a variety of potential threat targets including rocket propelled grenades (RPG) and kinetic energy penetrators (KEP). Static RCS measurements of RPGs and KEPs at Ka-band are needed to better understand the scattering phenomenology associated with various targets.^{1,2} As a result, the ability to make Ka-band measurements in the Adelphi Laboratory Center's (ALC) anechoic chamber facility has been developed to make these static measurements. The details of the experimental setup and radar specifications are described fully in footnotes 1 and 2. During these measurement programs, whenever targets of interest were available, ARL took advantage of this new capability to build a database of Ka-band RCS values for various targets. This note documents the modeling and measurement of a .50 caliber bullet.

Target Description

The bullet is a copper-jacketed lead bullet 5.79 cm in length and 1.295 cm at the largest diameter. It is a pristine bullet meaning it has not been fired through a gun barrel so there are no lands or grooves along the length of the bullet. The tip is a nominal 0.286 cm diameter flattened, oblate hemisphere and the rear diameter is 0.885 cm. Figure 1 shows three photos of the bullet, head-on, broadside, and from the rear.



Figure 1. Three views of the bullet a) head-on, b) broadside, and c) from the rear. The upper scale is millimeters and the bottom scale is inches.

¹ Pizzillo, *High-Range Resolution Profiles and RCS Measurements of Five Kinetic Energy Penetrators at Ka-Band (U)* (SECRET); ARL-TR-3172; May 2004.

² Pizzillo, *High-Range Resolution Profiles and RCS Measurements of Three Canonical Shapes at Ka-Band* (UNCLASSIFIED); ARL-TR-2947; May 2003.

Radar Description

The radar used to collect the high-range-resolution (HRR) signature data was designed and developed at ARL and is reported in detail in footnote 2. The antenna is a fully polarimetric monopulse antenna. The radar data was collected using a pulsed stepped frequency waveform. The measurements were made at a range of 14 m.

Experiment Description

The bullet was suspended by the center-of-mass from the chamber ceiling using 0.15-mm diameter 40-lb test polyethylene fiber with a dielectric constant of 2.39 in the 2–18 GHz range. By looping the line around the bullet along the brass crimp groove, the smaller of the two grooves, the bullet was stable and remained level. The bullet did tend to rotate in the azimuth plane so two ceiling lines were necessary to secure the bullet in place. The azimuth angle was determined by aligning a laser along the bullet length and then used to point the bullet at the radar antenna. A digital level was used to set the elevation angle to zero. To ensure the accurate locating of the bullet, a piece of aluminum tape was affixed to the tip of the bullet and measured allowing for precise location of the bullet in subsequent measurements.

To correct errors in the radar and to scale the measurements to square meters, an 8.4 cm trihedral calibration reflector was measured suspended just as the bullet.

Data

Copolarization data for both vertical and horizontal polarizations was collected using a 250-KHz pulse repetition frequency (PRF). The transmitted waveform was stepped from 32.4 GHz to 35.6 GHz using 512, 6.25-MHz steps providing 4.7 cm resolution in range. Each dataset was transformed into a HRR profile using a complex Fourier transform applied to the data shaped with a 40-dB Hamming window. The measured data is compared with model data generated using TEMPUS,³ a high-order time-domain electromagnetic code. Model data was generated over the same bandwidth as the measurements for both polarizations using a computer-aided design (CAD) model created from the actual bullet. TEMPUS data sets were also generated for a 20-GHz bandwidth, from 20 GHz to 40 GHz, so the scattering centers could be readily identified. In each of the following plots the legend is as follows: HH20 and VV20 refer to the

³Kabakian, Adour V.; Shankar, Vijaya; Hall, William F. Unstructured Grid-Based Discontinuous Galerkin Method for Broadband Electromagnetic Simulations. *Journal of Scientific Computing* **June 2004**, 20 (3), 405–431.

20-GHz model data; HH3 and VV3 refer to the 3.4-GHz model data; HH and VV refer to the measured 3.4-GHz data. Figure 2 shows HRR profiles for the five, head-on, datasets with the CAD model superposed for reference.

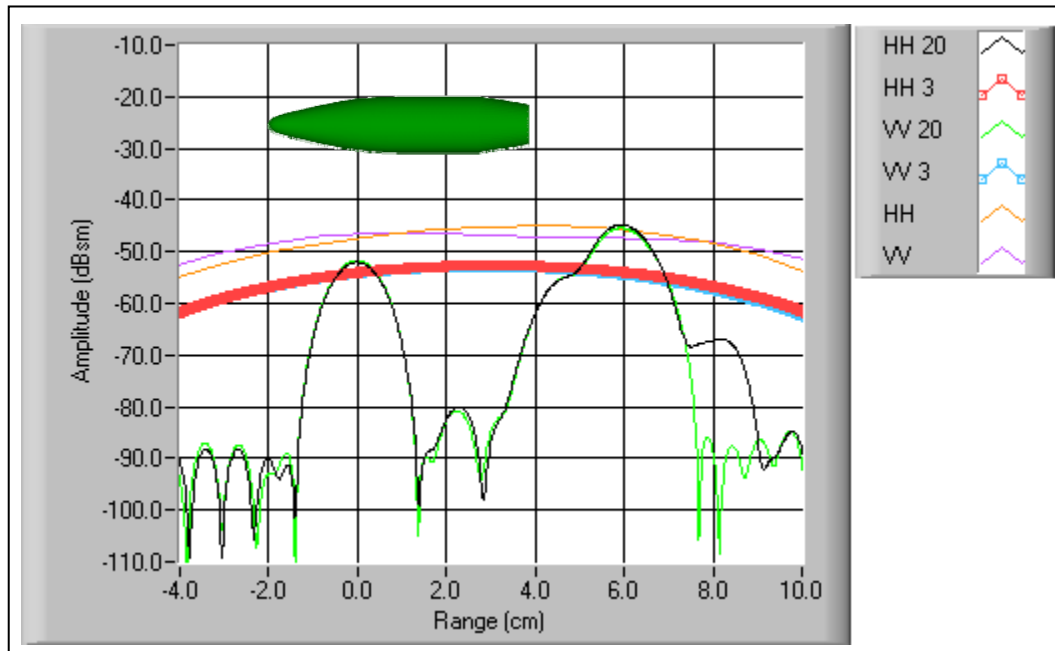


Figure 2. HRR profiles for head-on orientation.

Based on initial comparisons with the model data it had been determined that the measurements were not precisely head-on but with an approximately 2.5° elevation angle and an approximately 0.5° azimuth angle between the bullet axis and radar beam. This offset from head-on is the likely cause of the amplitude difference between the measured and modeled data shown in figure 2.

Figures 3 and 4 show HRR profiles for both vertical and horizontal copolarization data with CAD model image overlays of the bullet aligned as expected for the measured profiles.

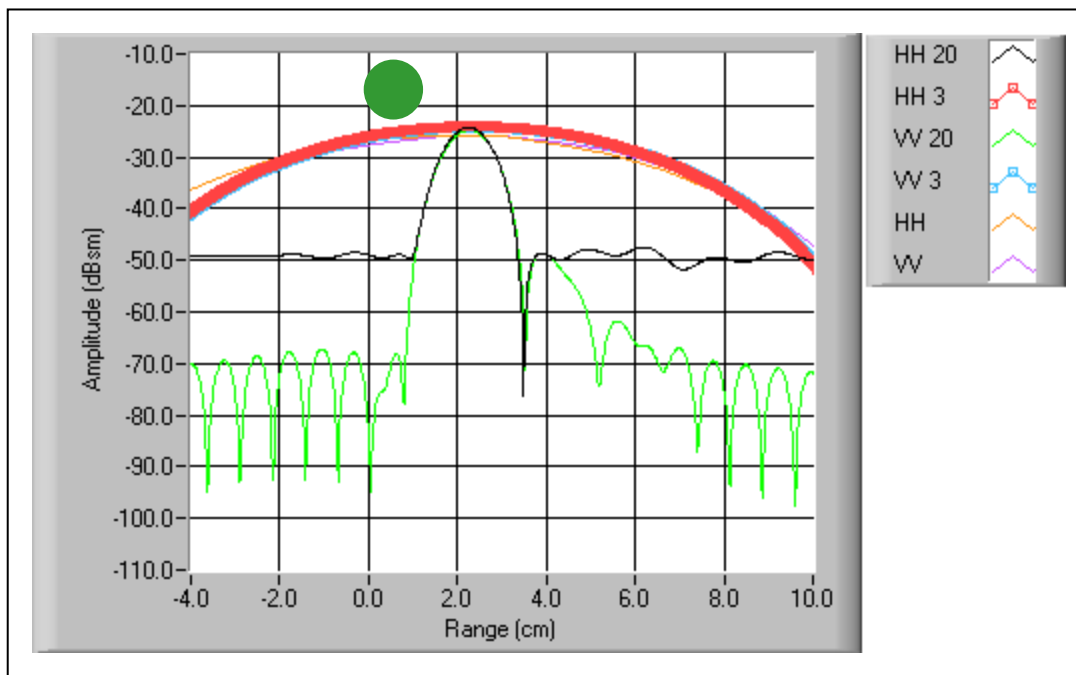


Figure 3. HRR profiles for broadside orientation.

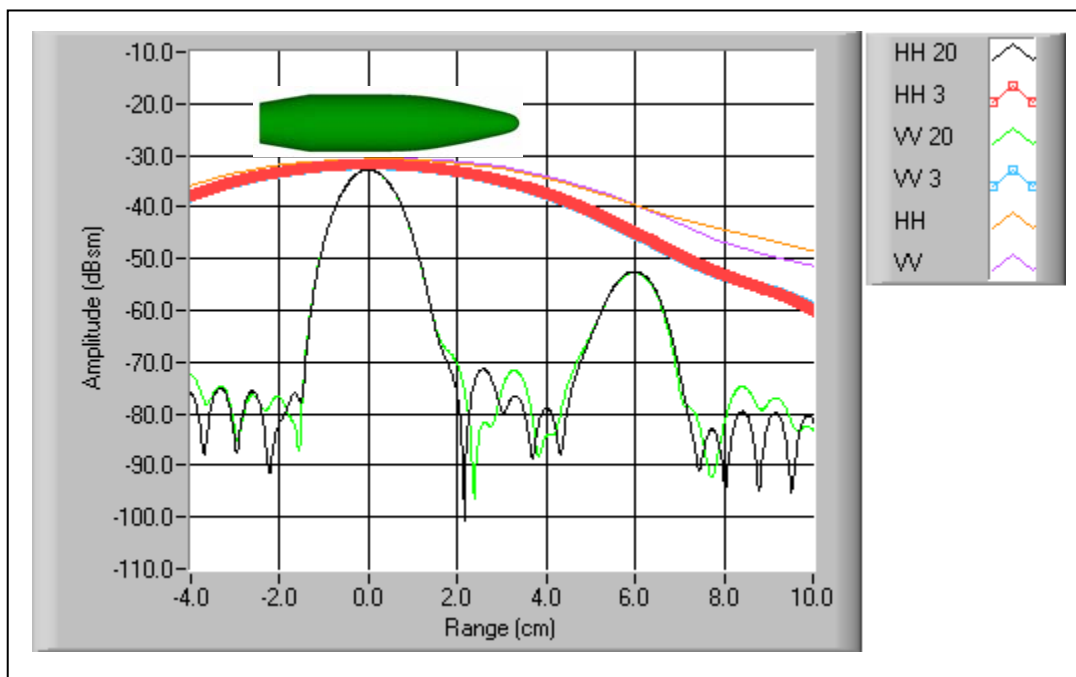


Figure 4. HRR profiles for backside orientation.

Conclusions

The co-polarization HRR profiles of a .50 caliber bullet were measured and compared with modeled results computed using a high-order time-domain electromagnetic code and very good agreement is found between these datasets. Co-polarization RCS sensitivity is shown to be responsible for as much as 6-dB differences between experimental and modeled data, though deviations from 0-deg azimuth angle may account for part of the reduction.

INTENTIONALLY LEFT BLANK

Distribution List

ADMNSTR
DEFNS TECHL INFO CTR
ATTN DTIC-OCP (ELECTRONIC COPY)
8725 JOHN J KINGMAN RD STE 0944
FT BELVOIR VA 22060-6218

US ARMY RSRCH LAB
ATTN AMSRD-ARL-CI-OK-TP TECHL LIB T LANDFRIED
BLDG 4600
ABERDEEN PROVING GROUND MD 21005-5066

US ARMY RSRCH LAB
ATTN AMSRD-ARL-SE-RM R BENDER
ATTN AMSRD-ARL-SE-RM S STRATTON
ABERDEEN PROVING GROUND MD 21005

US ARMY RSRCH LAB
ATTN AMSRD-ARL-SE-RM R TAN
ABERDEEN PROVING GROUND MD 21005-5066

US ARMY RSRCH LAB
ATTN AMSRD-ARL-CI-OK-T TECHL PUB (2 COPIES)
ATTN AMSRD-ARL-CI-OK-TL TECHL LIB (2 COPIES)
ATTN AMSRD-ARL-D J M MILLER
ATTN AMSRD-ARL-SE-RM D WIKNER
ATTN AMSRD-ARL-SE-RM E ADLER
ATTN AMSRD-ARL-SE-RM J CLARK
ATTN AMSRD-ARL-SE-RM J SILVIOUS
ATTN AMSRD-ARL-SE-RM T PIZZILLO
ATTN IMNE-ALC-IMS MAIL & RECORDS MGMT
ADELPHI MD 20783-1197

INTENTIONALLY LEFT BLANK