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**RCS Measurements and High-Range Resolution Profiles of
Three RPGs at Ka-Band**

by **Thomas J. Pizzillo**

ARL-TR-3511

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14. ABSTRACT Static radar cross section and high range resolution profile measurements of 3 rocket-propelled grenades (RPG) at Ka-band are reported. Measurements are from 32.4 to 35.6 GHz with vertically polarized transmit and receive stepped frequency waveforms providing 4.7 cm resolution in range for each of the following: Yugoslavian M57 grenade, Chinese Type 69 grenade, and a Romanian PG7M grenade. Measurements include azimuth aspect angles between -3° and +3° in 1° steps relative to head-on. The data were collected in December, 2003 at the U.S. Research, Development and Engineering Command, Army Research Laboratory (RDECOM-ARL) anechoic chamber research facility at the Adelphi Laboratory Center, Maryland.					
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Introduction

In December, 2003 the U.S. Army National Ground Intelligence Center had three rocket propelled grenades (RPGs) available for one week during which the millimeter wave branch was able to hang these targets in the anechoic chamber and make Ka-band measurements. These targets were made available in preparation for a future live-fire field test which was to be conducted at Aberdeen Proving Ground. It is necessary to know what the expected radar cross section (RCS) and high-range-resolution (HRR) profiles of these targets are to ensure that future dynamic radar measurements of these targets are successful. The data collected during these measurements may be used to properly design a radar for live-fire tests. The static positions were chosen to represent the extent of potential positions during flight. The following sections detail this one week measurement effort.

Radar Target Description

Figure 1 shows the three RPGs scaled in length relative to each other. The RPG at the top is a Chinese Type 69 grenade. It has an overall length of approximately 90 cm and a maximum diameter of approximately 9 cm. The diameter of the fuse cap is approximately 2.3 cm. The RPG in the middle is a Romanian PG7M grenade. It has an overall length of approximately 95 cm and a maximum diameter of approximately 7 cm. The diameter of the fuse cap is approximately 2.3 cm. The RPG at the bottom is a Yugoslavian M57 grenade. It has an overall length of approximately 57 cm and a maximum diameter of approximately 9 cm. The diameter of the fuse cap is approximately 4 cm. None of these targets had fuse caps in pristine condition; each had dents and minor damage. The worse case was the M57 which had a crease, approximately 1-cm deep across it. Unfortunately, this level of detail was not photographically documented.



Figure 1. Measured targets: Top, a Chinese Type 69; Middle, a Romanian PG7M; Bottom, a Yugoslavian M57.

Radar Description

The radar used to collect the HRR profile data was designed and developed at ARL. The antenna is a fully polarimetric monopulse antenna. The radar data was collected using a pulsed stepped frequency waveform. A detailed description of the radar is provided in ARL-TR-2947 “High-Range Resolution Profiles and RCS Measurements of Three Canonical Shapes at Ka-Band,” a summary of the radar specifications are shown in Table 1.

Table 1. ARL Ka-band radar system specifications.

Parameter	Value
Peak transmit power	1.6 watts
Frequency	32.4 to 35.6 GHz
Waveform Description	Stepped frequency, 512 steps, 3.2 GHz bandwidth
Receiver noise figure	5 dB
Losses	4 dB
IF bandwidth	80 MHz
Antenna diameter	6 inches
Antenna Gain	30 dBi
I/Q gain error	0.05
I/Q phase error	2 degrees
A/D voltage range	±1 volt
A/D sample rate	10 MHz
A/D bits	12 bits
Pulse width	35×10^{-9} sec
Pulse rise and fall time	2×10^{-9} sec
Gain in receiver	42 dB
Polarization	HH
TWT gain	42 dB
TWT noise figure	32 dB

Experiment Description

The radar was located on a platform outside the anechoic chamber and aligned at 0° elevation when pointed through the chamber aperture opening. This provided a 0.8-m diameter beam at the target location 1.9-m above the absorber-covered turntable in the quiet zone of the chamber. The RPGs were suspended by the center-of-mass from the chamber ceiling using 0.15-mm diameter 40-lb test monofilament fishing line. The grenades were hung so the rocket portion of the grenade was level with the lens of the radar. The grenade was then measured from -3° to +3° in 1° increments. These measurements were done twice, once with the tailfins vertical and horizontal relative to the incident radiation and once with the tail fins rotated approximately 45° relative to the incident radiation. An 11.7-cm trihedral was used to correct errors in the radar and to scale the measurements to square meters.

Data

The data was collected using a 250-KHz PRF providing 40-range gates with the target in the 1st gate. The transmitted waveform was swept, in 6.25 MHz steps, from 32.4–35.6 GHz using 512-frequency steps. This provides a range resolution of 4.7-cm. Only transmit vertical, receive vertical (VV) polarization data was collected. Each dataset was processed with a Hamming window. Table 2 provides a list of the target type, measurement angle relative to the incident radiation, and the average RCS for each measurement angle in dBsm. The last two rows give the average and standard deviation for each target column.

Table 2. Summary of RCS values for each target.

Angle (Degrees)	Type 69 (dBsm)	PG7M (dBsm)	M57 (dBsm)
-3	-12.63	-18.22	-22.08
-2	-11.54	-17.61	-19.75
-1	-10.76	-17.04	-17.28
0	-10.43	-16.93	-15.84
1	-10.47	-17.38	-17.30
2	-10.79	-17.60	-20.49
3	-11.40	-18.16	-23.29
Mean	-11.09	-17.54	-18.73
Standard Deviation	0.79	0.52	3.85

The largest RCS values occur at head-on (0°) for each target. The HRR profiles for this orientation are shown in Figure 2, Figure 3, and Figure 4 with vertical fin data in black and 45° fin data in red. There is little variation in the RCS of the peak scattering center for the different fin configurations. Variation in RCS of the scattering centers associated with the fins does occur for the Type 69 and PG7M; however, the peak response for each grenade is 10 to 15 dB higher and is unlikely the RCS will be significantly affected by fin position. Figure 5, Figure 6, and Figure 7 show the variation of the RCS for each target as a function of azimuth angle. Only the M57 has significant deviation from head-on and this may be due to the severely dented tip. Tip damage may also account for the 10-dB variation between the tips of the Type 69 and the PG7M given the fuse cap design is the same for both of these grenades. The overall larger peak associated with the type 69 is clearly due to the large edge exposed on the grenade body at the widest point as compared with the PG7M.

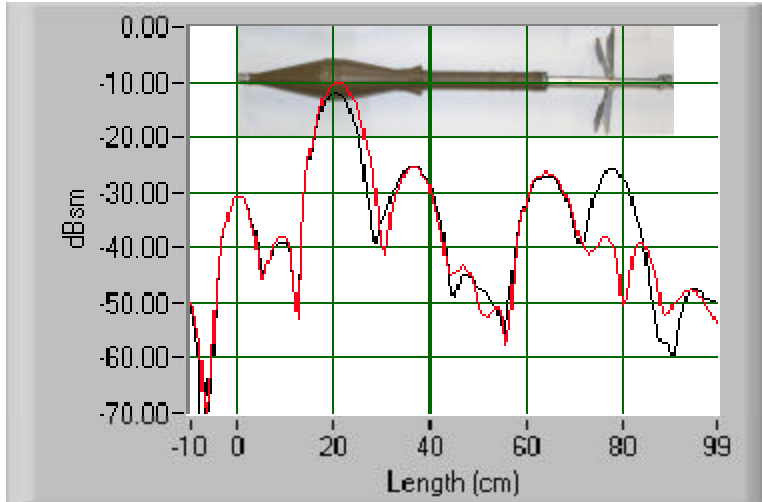


Figure 2. 0° azimuth, HRR profile for the Chinese Type 69 grenade.

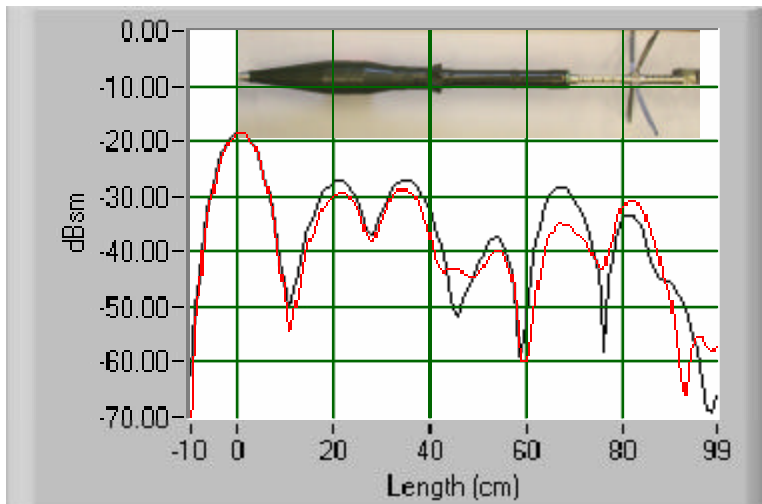


Figure 3. 0° azimuth, HRR profile for the Romanian PG7M grenade.

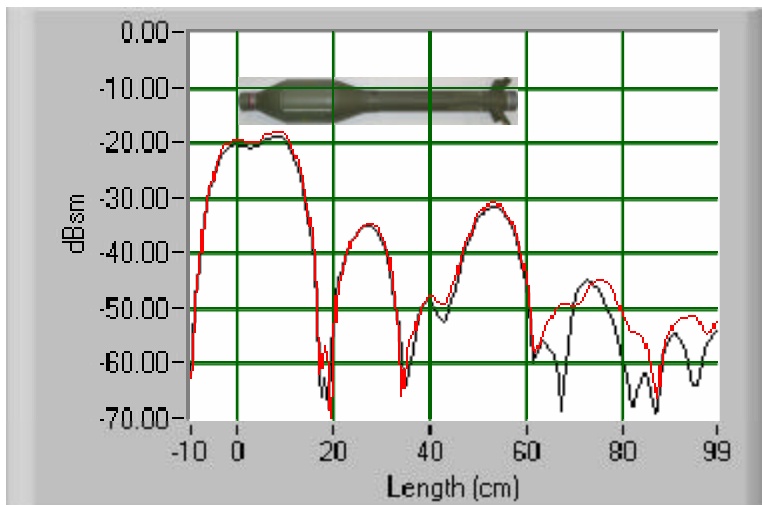


Figure 4. 0° azimuth, HRR profile for the Yugoslavian M57 grenade.

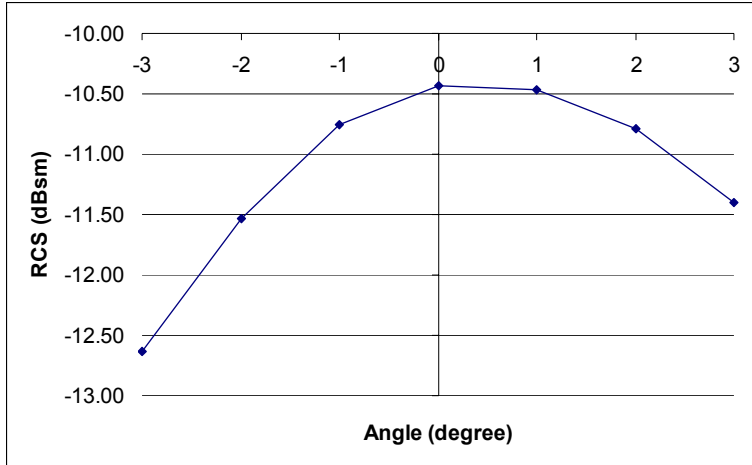


Figure 5. RCS versus angle for the Chinese Type 69 grenade.

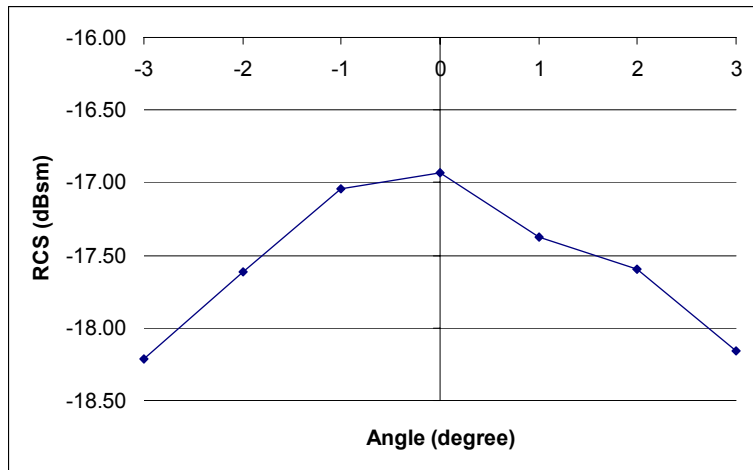


Figure 6. RCS versus angle for the Romanian PG7M grenade.

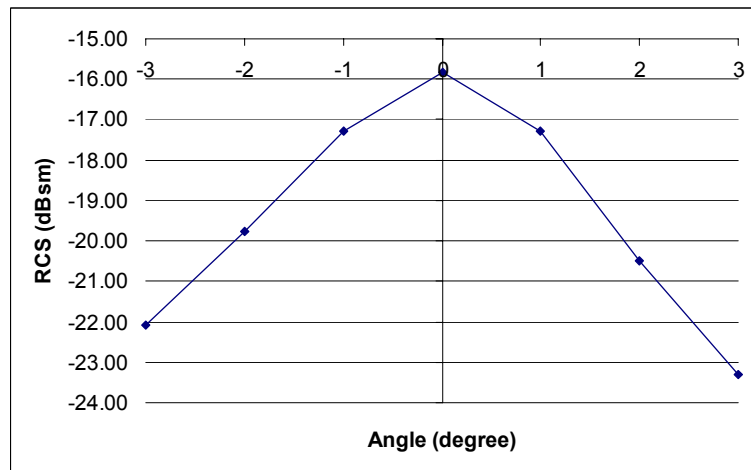


Figure 7. RCS versus angle for the Yugoslavian M57 grenade.

To determine the impact on the peak location due to reduced bandwidth, the original 3.2 GHz bandwidth data was reduced by half and one-quarter and then processed identically as the full bandwidth data. The results of this investigation are shown in Figure 8, Figure 9, and Figure 10. Four plots are included in each figure: The HRR profiles for each bandwidth and the corresponding frequency passbands. The colored arrows on the passband plots indicate which portion of the passband was processed to produce the corresponding colored-coded HRR profile shown adjacent to it. Hence, the top plots show the low frequency portions of the passband and the bottom plots show the high frequency portion. The 800 MHz data has a range resolution of approximately 20 cm. As the bandwidth is reduced, details in HRR profiles are lost, as expected, and the peak remains associated with the dominant scattering center. There does not appear to be a significant difference between the high and low frequency data sets, with the possible exception of the PG7M. Comparing the two 800 MHz, HRR profiles in figure 10, it is seen that the low frequency data does not have a pronounced peak, but rather a slow reduction along the grenade portion of the target.

Clearly, for very narrow bands, there are frequencies for each RPG which should be avoided and, conversely, frequencies which are optimal. Consider a 50-MHz band centered at 33.8 GHz. Both the Type 69 and PG7M could have RCS values significantly lower than reported, while the M57 may be within the reported deviation for the RCS value. The opposite situation occurs for a 50-MHz band centered at 35.15 GHz. Both the Type 69 and PG7M would be much closer to the reported RCS values, while the M57 would be significantly lower than the reported RCS value.

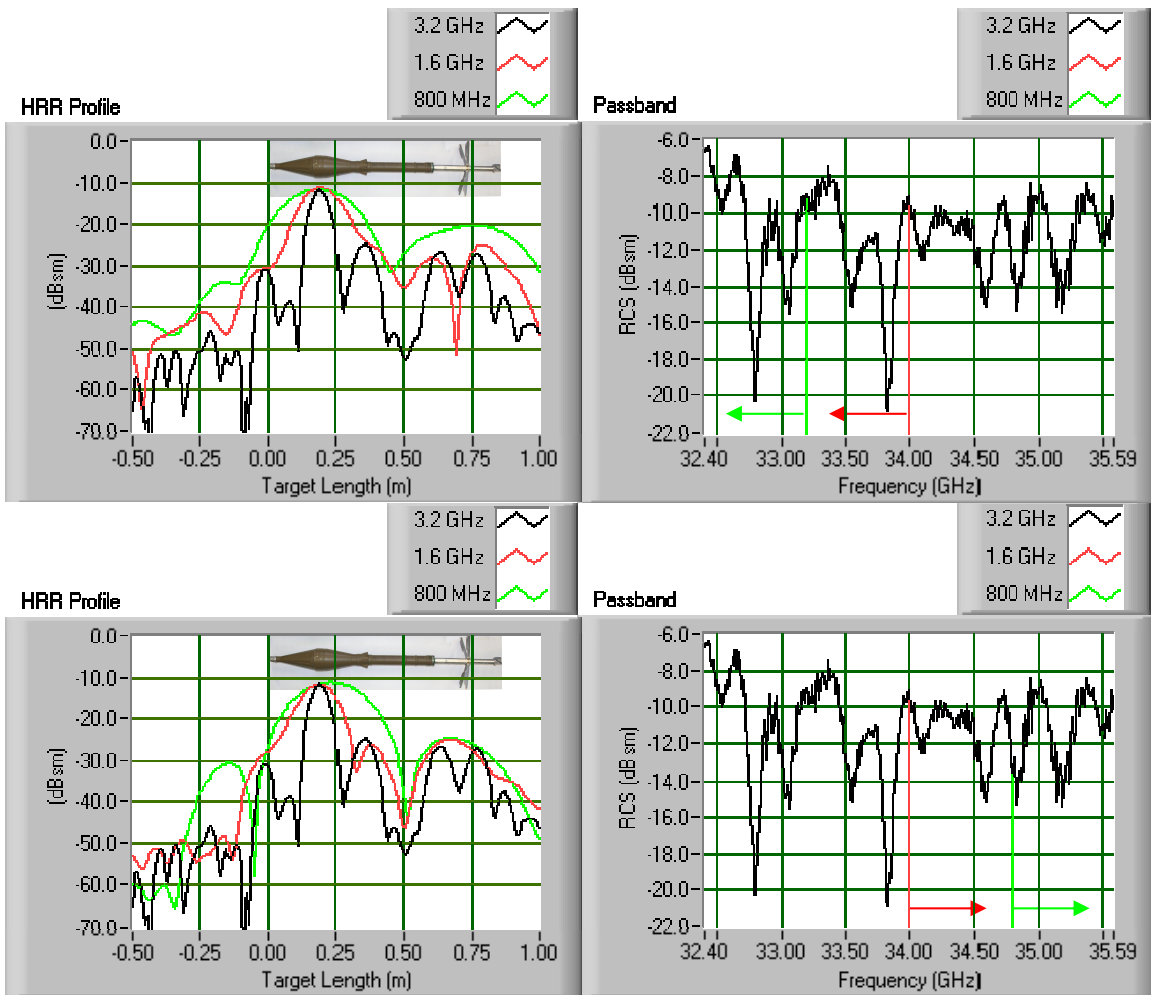


Figure 8. Comparison of reduced bandwidth HRR Profiles for the Type 69.

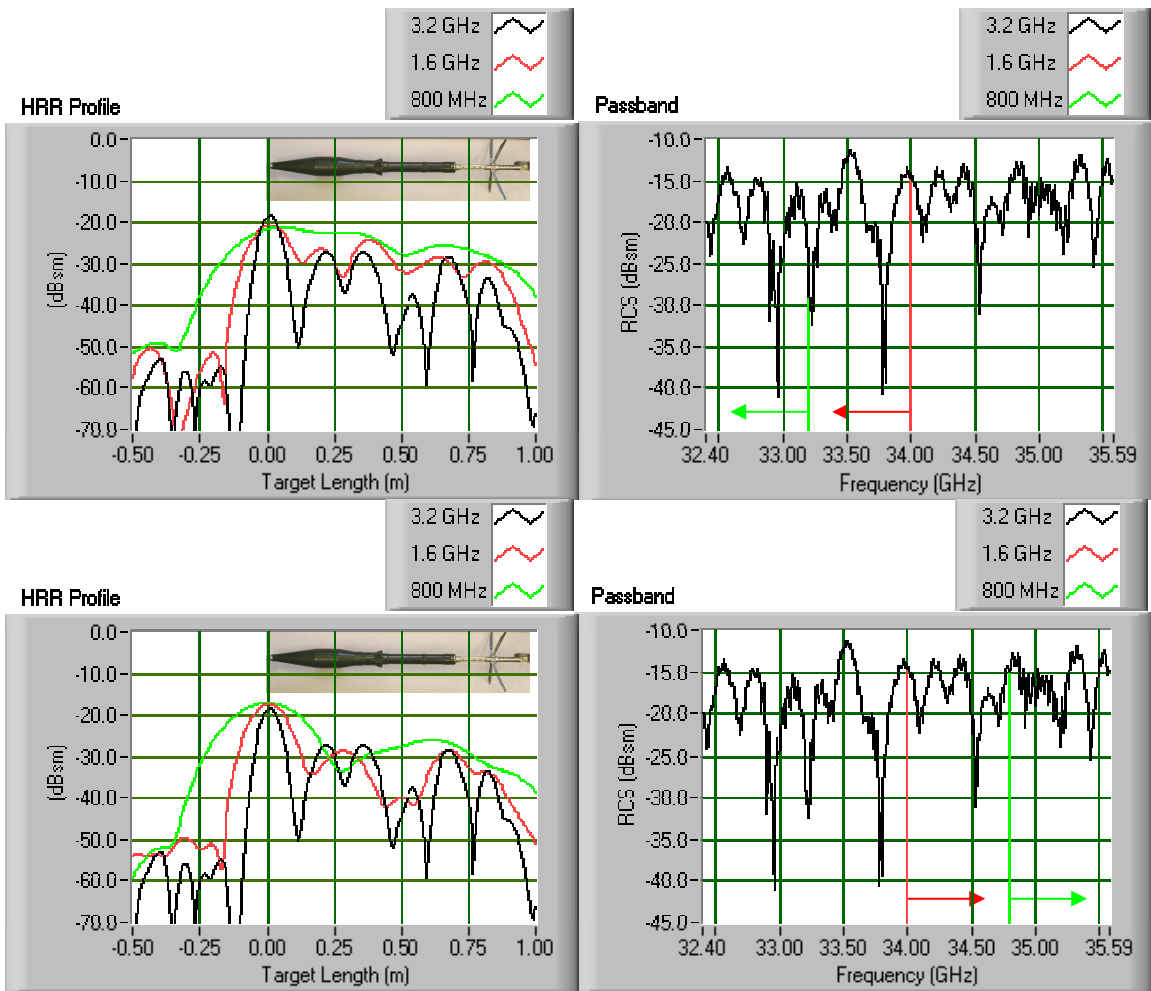


Figure 9. Comparison of reduced bandwidth HRR Profiles for the PG7M.

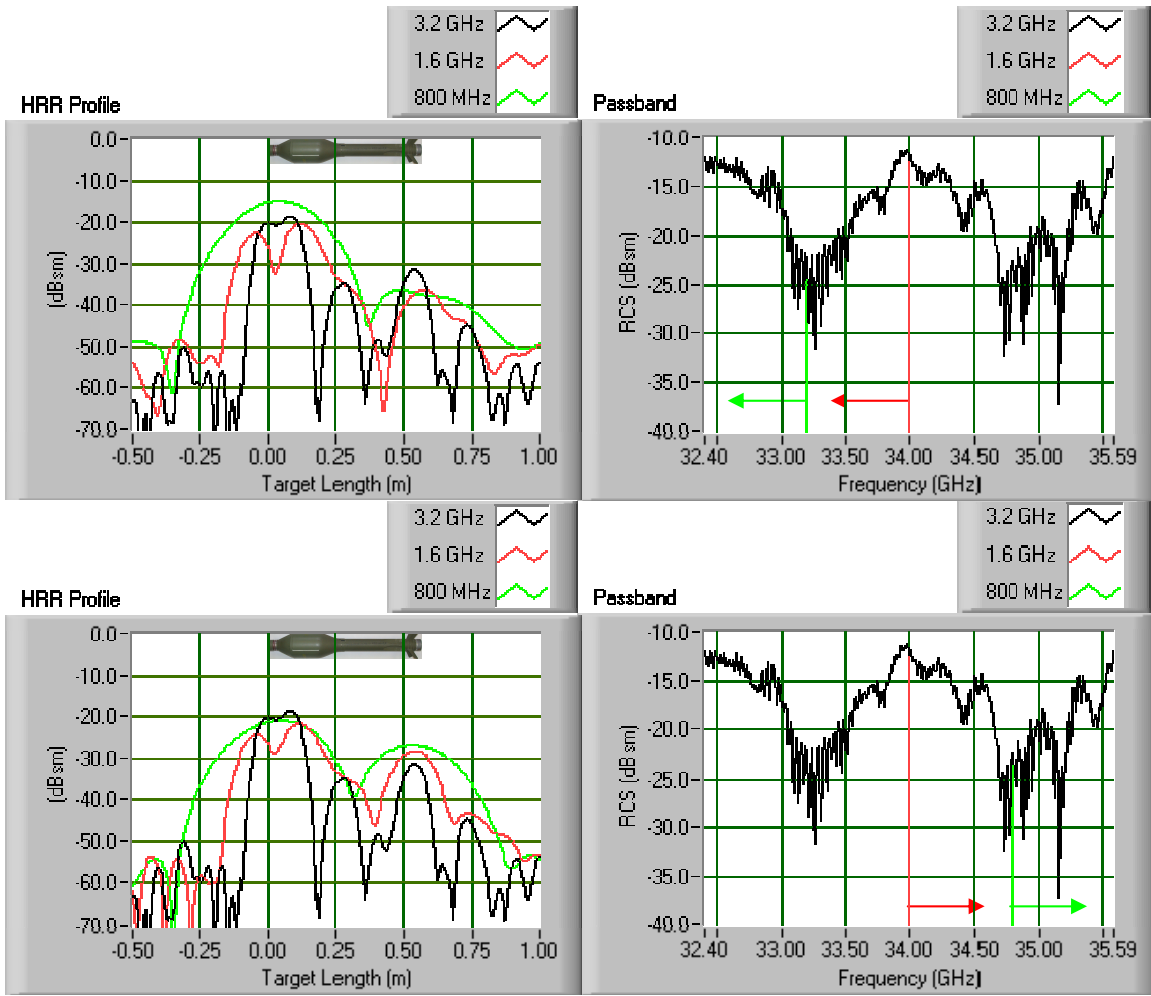


Figure 10. Comparison of reduced bandwidth HRR Profiles for the M57.

Conclusions

Static RCS and HRR profile measurements of 3 RPGs at Ka-band were presented. The data indicate that the RCS associated with these targets is a maximum for a head-on orientation and drops by as much as 3 dB with increasing azimuth angle. The average RCS between -3° and 3° for these targets are: Type 69, $-11.09 \text{ dBsm} \pm 0.79 \text{ dB}$; PG7M, $-17.54 \text{ dBsm} \pm 0.52 \text{ dB}$; M57 $-18.73 \text{ dBsm} \pm 3.85 \text{ dB}$. The scattering phenomenology is as expected with small variations due to the relative position of the tailfins. The effect of reduced bandwidth was considered and found to produce similar RCS values and peak scattering center response, with one exception noted for the PG7M and this exception depends upon which end of the passband is processed. However, for extremely narrow bandwidths, significant variation in RCS would be expected depending on the center frequency and which RPG was being considered. Hence, care should be exercised when designing very narrow band systems for applications to these targets.

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