

# Radar Signatures and Relations to Radar Cross Section

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## Abstract

This paper addresses a number of effects that are often responsible for considerable differences between measured radar signatures and numerically predicted radar signatures. Numerical predictions are used to illustrate the likely magnitudes of these effects using two complex test targets. The paper comments on the potential pitfalls that can occur when measurements are made to validate predicted data. The fundamental problem is that for true validation, the prediction and measurement scenarios must be exactly aligned.

The paper concludes that modern RCS prediction software is capable of generating reliable RCS data and that with care measurement procedures are possible that can generate suitable validation material.

## Introduction

Roke Manor Research Ltd. (RMRL) has previously reported on the many applications of its RCS prediction software [1]. During the same conference, the German Company - Forschungsinstitut Für Hochfrequenzphysic (FGAN) also reported on a number of validation exercises conducted with two other RCS prediction codes [2]. The large differences reported provided the basis for an interesting investigation. This paper reports on some of the hypotheses generated by RMRL to explain the large differences.

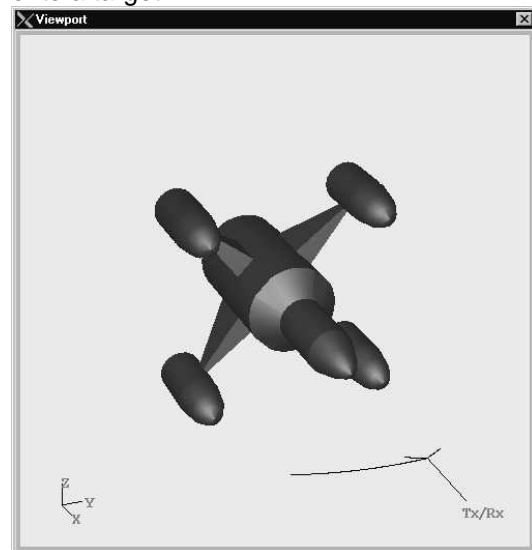
## Geometry Quality

The most obvious, but often missed issue, is that the CAD model used in the prediction must match very closely to the measured object. How close? As a starting point, the size and shape should have no areas that deviate from the object shape by more than one tenth of a wavelength at the highest prediction frequency. For predictions that

only use high frequency techniques such as Physical Optics, Physical Theory of Diffraction, and Multiple Scattering techniques this is a sufficient criteria so long as the object has not been specifically designed to have an extremely low RCS. For Low Observable (LO) objects, greater care must be taken in geometry preparation and resonant region scattering mechanisms need to be included in the prediction process as these will start to introduce significant scattering contributions.

## Angular Sampling

The selection of prediction parameters that provide sufficient sampling in angle is important. Numerical predictions have an inherently high precision in defining the angle of incidence of the illuminating wave onto a target.



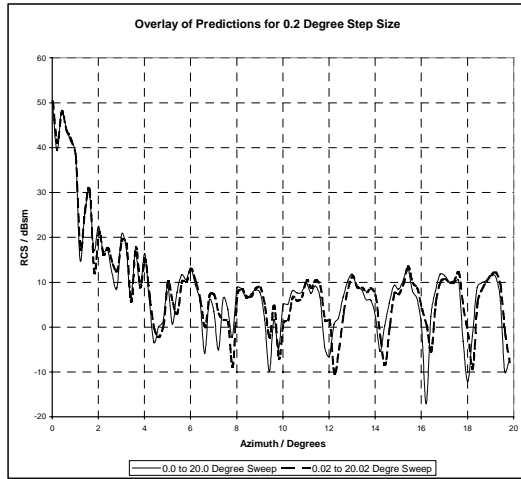
**Figure 1 Sample Complex Target Geometry.**

Knott et al. [3] suggests that for a flat plate aperture of dimension  $L$ , the approximate value of the Null to Null beamwidth in degrees will be given by Equation 1.

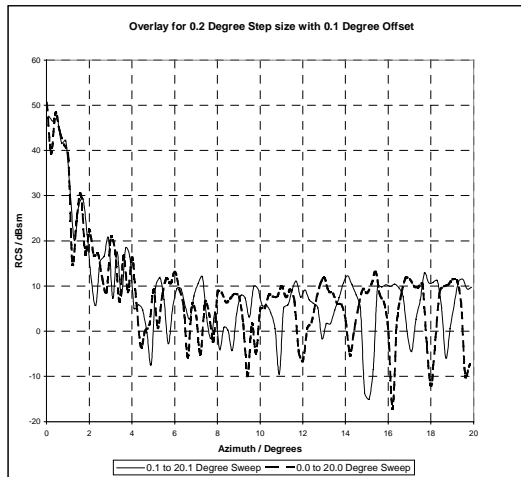
$$\theta_{(nul-to-nullbeamwidth)} = 57 \frac{\lambda}{L}$$

**Equation 1**

This criterion is for the main lobe width, whereas side lobes are generally half the main lobe angular width. To adequately sample a complex target an angle step size of the order of a sixth to an eighth of the value in Equation 1 will be needed.



**Figure 2 Closely spaced predictions.**



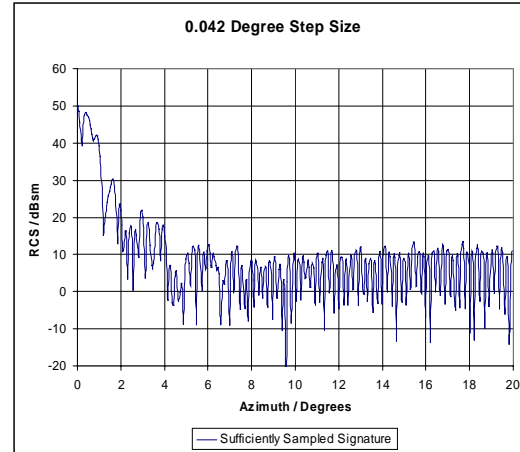
**Figure 3 Half stride offset predictions.**

To illustrate this the RCS of the object shown in Figure 1 was predicted at a range of angle step sizes. The target geometry is approximately ten meters wide and the predictions were performed at 5 GHz. From Equation 1 we see that the angular step size needs to be around 0.042 Degrees to give four samples per side lobe.

Figure 2 shows two predictions using a 0.2-Degree step size but offset from each other

by 0.02 Degrees. The correlation is good, and it is not immediately clear that the envelope is not sufficiently sampled.

Figure 3 Shows a similar overlay but with the offset set to 0.1-Degrees. Here we see the initial match is good, but between ten and twenty degrees the apparent envelope of the prediction is completely different.



**Figure 4 Sufficiently sampled prediction.**

Figure 4 shows the same prediction sampled at 0.042 Degree steps, inline with the previously derived sampling requirement. This example shows that the criteria derived from Equation 1 is valid for this target.

One interesting feature of the under-sampled data is the tendency to capture the peak values of the envelope of the RCS, in the 10-20 Degree region being around +10dBsm. This tendency is due to the fact that in general nulls tend to be narrow in angular extent and the peaks in the lobes are wide in comparison. This example shows that structure of RCS plots can be misleading unless the sampling is sufficient. It also demonstrates that comparison of under sampled data will generally contain large (up to 20dB) spot errors unless the angle sampling is controlled with great precision. If the object has significant multiple scattering interactions contributing to the signature then an even finer sampling in angle will generally be required to sufficiently capture the diffraction pattern. This is because the multiple scattering interactions generate an angular motion induced Doppler in excess of that expected from the physical extent of the target when imaged, which manifests as a larger effective equivalent aperture.

## Measurement Considerations

The previous section has shown that angular sampling and object alignment need to be precise for validation work. This is often not possible due to the mechanical limitations of the rotation apparatus. The quality of achievable rotator control and the effects of vibration from the environment can make fine sampling of angle resolution practically impossible for electrically large test objects.

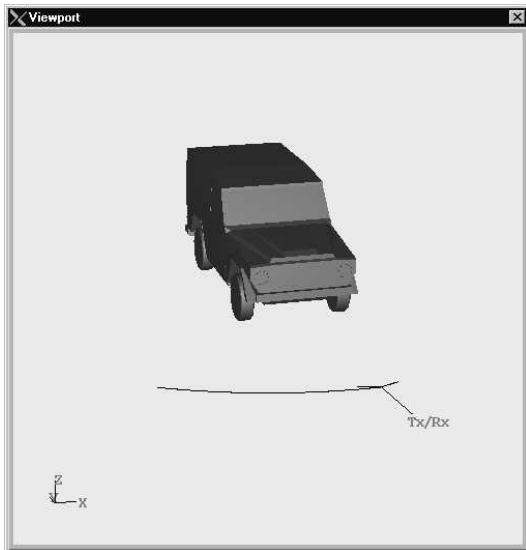
## Near Field Criteria

Knott et al. [3] provides a basic far field criteria for a target of principle dimension  $L$  and minimum range to the target  $R$  shown here in Equation 2.

$$R \geq 2 \frac{L^2}{\lambda} \quad \text{Equation 2}$$

It should be emphasised that this range criterion is derived from assumptions about a plane aperture that may not be valid for a complex target and will usually require a longer range.

For targets with discrete scattering centres, that in isolation meet suitable far field criteria, it can be argued that the composite signature only changes a little when measured in the near field.



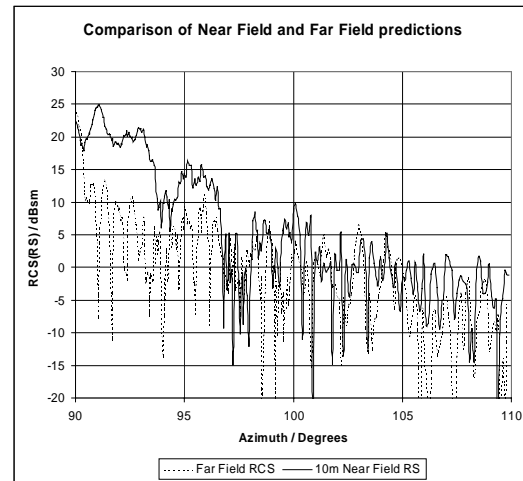
**Figure 5 Jeep Geometry**

Epsilon<sup>TM</sup> has the capability of predicting Radar Signatures (RS) by illuminating targets with a curved wave front as opposed to the RCS from standard plane wave. To illustrate the effects of wave curvature due

to near field effects we present the following predictions.

The target chosen for this is the jeep model that RMRL and FGAN have been working on. The object is about 2m wide and 4m long. The radar frequency for this example is 10GHz so the angle step size for this sweep is 0.05 Degrees. The far field criterion evaluates to approximately 1km.

The near field prediction was performed at ten meters range and a five degree look down angle in elevation is used.



**Figure 6 Overlay of comparison predictions.**

Figure 6 shows an overlay of the near field and far field predictions. Over the 90-95 Degree region the difference is very large. This is probably due to the front grill of the jeep acting as an extended reflector. Clearly differences of 10dB are possible from some classes of target structure. Over the remaining interval the near field signature is much the same as the far field one, supporting a discrete scattering centre hypothesis for the target at those angles.

## Wide Band Signatures

The use of Spread spectrum or wide bandwidth signals has come to dominate mobile communications technology. Its use is also becoming widespread in Radar and navigation systems. This has generated the need to characterise radar signatures over substantial fractional bandwidths. It is known that for short pulse radar systems that a true RCS signature is not possible unless the pulse duration is at least twice the physical extent of the object it is interacting with. For wide bandwidth signatures similar “steady

state” requirements exist if RCS is to be used directly in the radar design process.

### Prediction technique

Normal RCS prediction techniques evaluate the Bulk Signature at a spot frequency. If a number of evaluations are made at a series of spot frequencies then the frequency transfer function of the object can start to be approximated.

Typical examples of wide band signatures include Range Profiles, Short Pulse Signature and microwave images.

For the design of wide band radar systems it is important to know if predicted or measured bulk RCS figures are valid for link budget calculations. This will come down to the design of the radar waveform. In particular the transmitted bandwidth and the signal duration.

Taking a range profile signature as an example, the unambiguous range available from the waveform needs to be larger than twice the principle dimension of the target  $L$  to allow for late time returns from multiple scattering features. It is also known that the bandwidth  $BW$  of the signal will determine the achievable resolution. Let  $T$  be the time taken to transmit the full signal bandwidth once (for pulse compression radars this would be the duration of the pre-compressed signal). We define  $T_1$  to be the dwell time of a single or equivalent single frequency component, and require that

$$T_1 > \frac{2L}{c} \quad \text{Equation 3}$$

therefore

$$N = \frac{T}{T_1} < \frac{T \cdot c}{2L} \quad \text{Equation 4}$$

Where  $N$  is the equivalent number of steps of the frequency transfer function. To allow late time contributions to reach steady state and assuming that these will fall to a negligible level at twice the target length we require that the frequency step  $dF$  should satisfy

$$dF \leq \frac{c}{4L} \quad \text{Equation 5}$$

to provide sufficient unambiguous range. Therefore the bandwidth we transmit during time  $T$  should adhere to the following

relationship to ensure unambiguous sampling of the target object.

$$BW = NdF \leq \frac{Tc^2}{8L^2} \quad \text{Equation 6}$$

Generally care must be taken when using target bulk RCS figures for radar systems that break this relationship.

### Example

In this example the target geometry of Figure 1 has been used. The prediction parameters were for a 360-Degree azimuth sweep at 0 Degrees Elevation for a centre frequency of 5.5GHz and a 1GHz bandwidth.

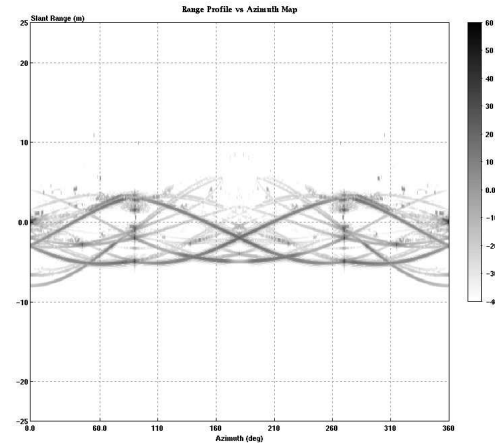
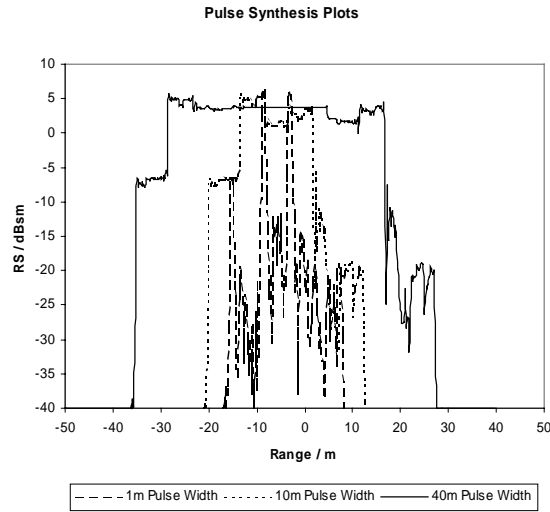


Figure 7 Range Profile vs Azimuth Map.

Figure 7 Shows a range profile map covering a full 360-Degree sweep of the target.

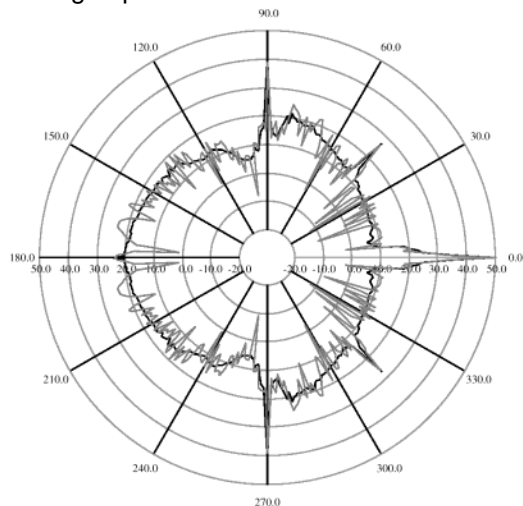
Figure 8 shows the transient Radar Signature (RS) synthesised for three different pulse lengths. For all the pulse widths there are a number of peak value transients in the signature. The 1m pulse never reaches steady state and generates a very Range Profile like plot. The 10m pulse also fails to reach a steady value. The 40m pulse has a long steady state region where the RS has converged to the Bulk RCS at the centre frequency of the sweep.

Figure 9 shows a full 360-Degree azimuth sweep for the example target. A frequency average over the whole bandwidth is compared with the bulk RCS at the centre frequency. Note how the averaging tends to reduce the signature side-lobe peaks and generates a smooth signature.



**Figure 8 Pulse Synthesis at 20-Degree Azimuth for three pulse widths.**

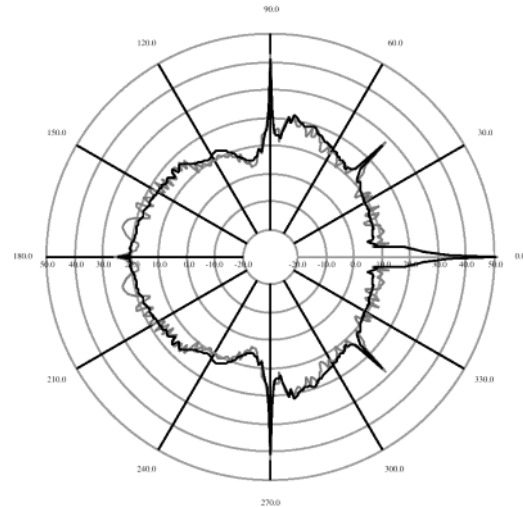
Figure 10 shows a comparison of the Frequency averaged data against a peak-detected signal for a 10-metre pulse length. Note how the peak-detected signal is generally higher than the frequency averaged plot.



**Figure 9 Frequency Average (dark) vs Centre Frequency Bulk signature (light) Polar Diagram.**

It is the intention of the author to extend the analysis capability to Epsilon<sup>TM</sup> to include integration under the received pulse, another common technique used in real radar systems.

In general, pulse integration detection will operate much like the peak detection scheme so long as the steady state RS exceeds all the transient peaks.



**Figure 10 Frequency Average (dark) vs Peak Detect Signature for 10m pulse length.**

## Conclusions

This paper has presented a number of ways to look at Radar Signatures and Radar Cross Section data for complex targets. Some of the pitfalls in comparing measured data to predicted data have been highlighted. In all cases the need to capture the data acquisition process, whether it be measurement or prediction is vital if comparisons are to be made.

A number of methods of viewing wide bandwidth signatures have been presented and a criterion for the capture of wide bandwidth data has been suggested.

## References

- [1] Simpson S H W, Galloway P E R, Harman M, 'Applications of Epsilon<sup>TM</sup> A Radar Signature Prediction and Analysis Tool', International Radar Symposium IRS 98, Munich, Germany, September 1998.
- [2] Biegel G., Essen H. at al., 'Validation of RCS Signature Simulations of Ground Targets at millimetre Wave Frequencies', Proceedings of IRS 98, Volume 1. pp413-420, Munich, September 1998.
- [3] Knott E F, Shaeffer J F, Tuley M T, 'Radar Cross Section', Second Edition, Artech House, 1993. ISBN 0-89006-618-3