MPD MICROWAVE PRODUCT DIGEST

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RCS Measurements in a Compact Range

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Introduction

The Radar Cross Section (RCS) of an object is defined as, "the area intercepting that amount of power which, when scattered isotropically, produces a return at the radar equal to that from the target." In simpler terms, RCS is the projected area of a sphere that has the same radar return as the target. The unit of measure for an object's RCS is "decibels per square meter," or dBsm. The power received by a radar for a target indicates how well the radar can detect or track that target. For this reason, much research and effort has been put into reducing the "signature" of various aircraft, ships and other objects. See Figure 1 for a schematic and definition of RCS.

The task of creating designs based upon theoretical modeling and simulation must be proven in the end. With RCS designs, this involves taking the object to an RCS measurement facility and measuring the radar return of the object. There are many types of RCS measurement techniques and RCS measurement range possibilities. Compact ranges are one of the most popular methods for measuring the RCS of various objects. Compact Ranges (CR) have the advantages of indoor testing in a controlled environment, direct whole-body measurements of the target and RF signal security if the compact range is in a shielded enclosure. See Figure 2 for a picture of a CR used for RCS measurements.

In short, a Compact Range consists of a large offset fed reflector and a feed to illuminate the reflector. Once properly aligned, a CR will produce a plane-wave zone with minimal phase taper, minimal amplitude ripple and approximately 0.5 to 1.0 dB amplitude taper over the designed plane-wave zone. For more information on the design and capabilities of compact ranges, the reader should consult the literature base regarding compact ranges. This article will focus instead on considerations involved for making good RCS measurements in a CR RCS measurement facility.

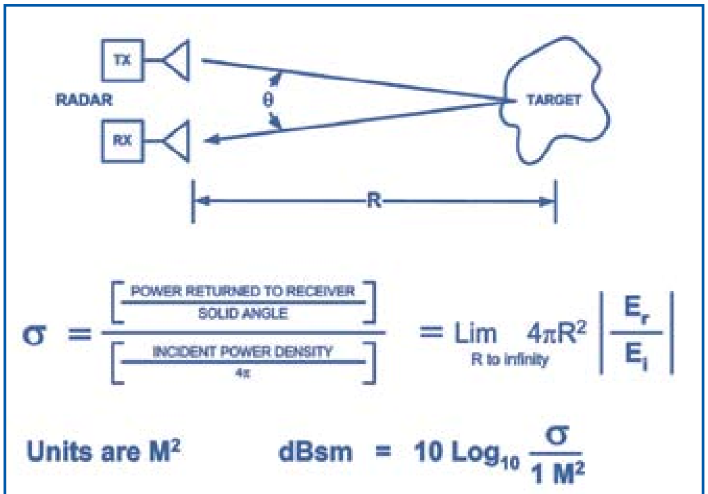

Figure 1: *The Definition of RCS.*

Figure 2: *Compact Range Reflector and Feed located at the Instituto Nacional de Tecnica Aeroespacial (INTA) in Spain. This CR is capable of testing the RCS of objects up to 5.5 meters wide by 5 meters tall.*

RF Measurement Considerations

There are many design challenges involved in RCS ranges that affect system performance.

Critical design factors include:

- **Clutter Rejection or Reduction–** Target response and returns from the range must be separated. These returns can include: objects in the range, such as walls and target mount; interaction of the target with these objects and any unwanted signals in the range itself. See Figure 3 for an illustration of clutter in a measurement.

• **Dynamic Range–** A receiver with high dynamic range (on the order of 85 to 90 db) is required to isolate large target responses from close smaller ones. This requirement is particularly true for whole body evaluations. Some complex targets can exhibit changes in RCS on this order over a few hundredths of a degree. See Figure 4 for a typical dynamic range measurement.

• **Frequency Coverage and Switching Speed–** An RCS instrumentation system usually requires a wide operating bandwidth. Many test frequencies may be required. A fast switching speed will greatly increase range throughput by allowing many frequencies to be collected in a single target rotation.

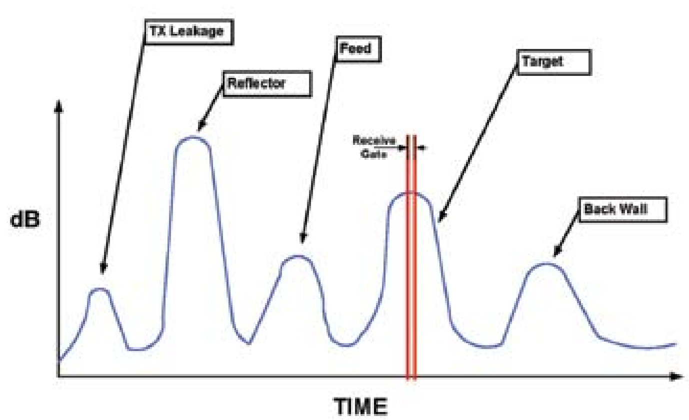

***Figure** 3: Illustration of Clutter and Leakage sources in a CR vs. time.*

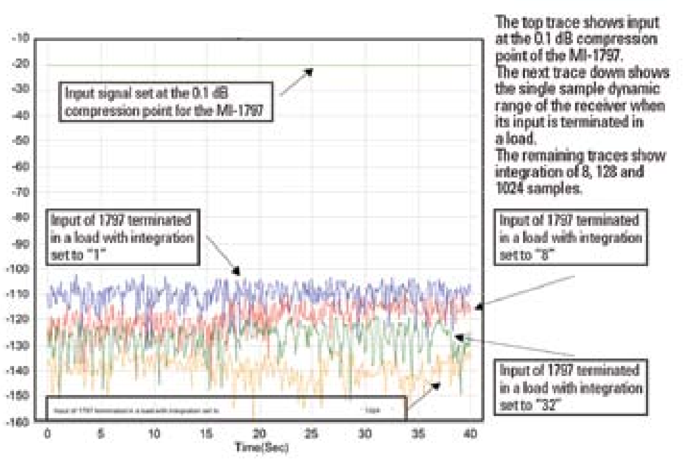

Figure 4: Dynamic Range Test data collected on the MI-1797 receiver at 10 GHz:

- *Input signal set at the .1 dB compression point for the MI-1797 (top trace)*
- *The other four traces are with the Transmit and Receive cables terminated in a load and averaging set at 1, 8, 32 and 1024 samples*

• **Measurement Capabilities–** A target's RCS is a function of target position, frequency, polarization and other factors. Some of the more common measurements are:

- RCS vs. Angle (See Figure 5)
- RCS vs. Cross Range (See Figure 6)
- RCS vs. angle vs. frequency (See Figure 7)
- RCS vs. Range Axis vs. Angle (See Figure 8)
- RCS imaging (See Figure 9)
- RCS Power Spectrum (Doppler measurements)
- Polarimetric measurements
- RCS vs. Bi-static angle

• **Ringdown-** Characterized by RF energy storage within the system, ringdown has significant impact upon overall measurement performance. The two most significant contributors to ringdown are related to the impulse response of the CR feeds and energy reflections between component connections due to impedance mismatch. When an energy pulse is transmitted to an antenna, the VSWR at the feed reflects some energy back to the transmitted output of the radar. The VSWR at that point will reflect some of the energy back to the feed. The cycle continues until all the energy is radiated or absorbed by the cable. See Figure 10 showing measured received power vs. time for an example of feed ringdown time. In the figure, note that between the 30 nsec and 180 nsec points, the reflection of the CR rises above the ringdown and VSWR.

• **Single vs. Dual Feeds–** The preferred technical approach implements a dual feed system in order to minimize RCS performance risk. Single feed systems have a somewhat lower complexity, but have notable technical drawbacks. With single feed systems, there are a limited amount of practical modifications to be made in order to reduce ringing. Primary reductions typically involve characterization of feed ringing performance, potentially leading to expensive and time consuming feed design changes. Also, feed ringing characterization in itself, is an involved and highly technical activity which must be factored into program risk. Dual feed systems, offer a significant increase in transmit to receive isolation at the expense of increased system complexity in controlling the receive gating pathway.

• **Sensitivity–** Typical Range specifications of -80 dBsm provide a challenging requirement and require significant attention to detail. A detailed RCS link budget for a compact range system utilizing the radar range equation is required. Subtle design implementations such as minimization of RF cable lengths, selection of appropriate RF cable type, utilization of receiver inte gration gain and prudent maximizing of duty cycle to minimize associated loss have to be considered. Individually each of these design elements may not seem critical, but when viewed in the composite they form a significant contribution to overall system sensitivity.

- **Isolation And Measurement Repeatability–** To meet a -80 dBsm requirement will require care in selecting RF components. Selecting a dual feed configuration with its better isolation combined with high component switch isolation provides for more robust system performance. MI Technologies' proven gating system cascades multiple elements to achieve significant improvement in isolation, up to 170 dB.

Attention to detail in thermal packaging and proximity placement of components is required. Background subtraction of artifacts and noise is only possible if consistent and repeatable measurements can be achieved. Focused design attention to thermal heat sinks and forced air cooling of active RF components as well as selection of ultra phase stable cables are significant keys to improving background subtraction.

- **Range Throughput & Human Factors –** Consideration for throughput and human factors are required to support both production and engineering development projects. Adequate consideration must be given to optimizing throughput of production antennas and ease of conversion between the Antenna-RCS configurations. High technical performance without consideration for the practical day-to-day use of the range is not acceptable. Several key aspects of the system architecture must be considered to ensure efficient configuration changes. A heavy-duty quick-change arbor mount design and man lift can be utilized to improve human factors.

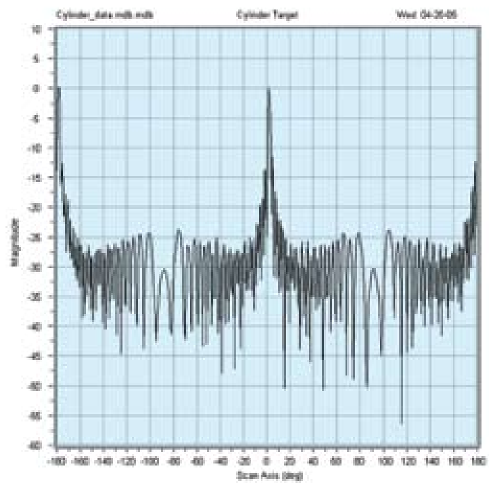

Figure 5: RCS vs. Angle

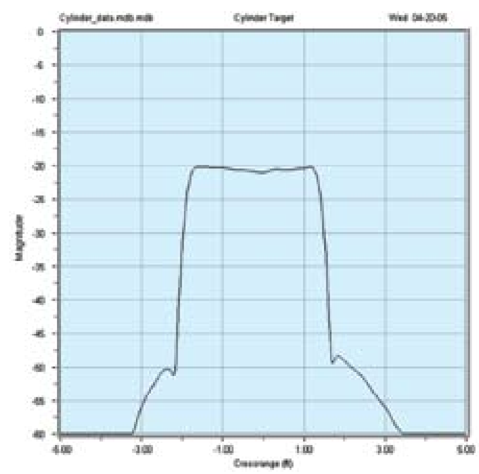

Figure 6: RCS vs. Cross Range

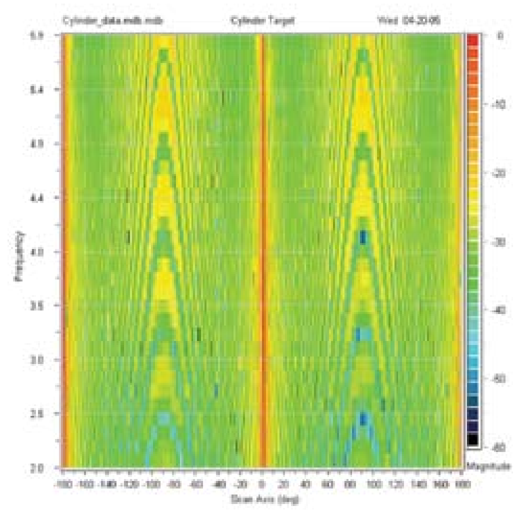

Figure 7: RCS vs. Frequency and Angle

Applicable RCS Link Budget Equation

In order to make high quality measurements with repeatable results, a careful examination of the expectation on received power must be made. This careful examination is made by reviewing the expected link budget of the RCS measurement range.

The link budgets are derived from the RCS range equation, which is shown below.

$$Pr = \frac{(Pt)(G^2)(\sigma)(\lambda^2)(N)}{(ktB)(Lt)(Lr)(Lg)(NF)(4\pi^3)(R^4)}$$

Where:
Pr = Receive power
Pt = Transmit power
G = Antenna gain
s = RCS
l = Wavelength
N = Integration Gain
ktB = Boltzman's Constant times Receiver Bandwidth
Lt = Losses between Transmitter and Feed
Lr = Losses between Feed and LNA
Lg = Gating Loss
NF = LNA Noise Figure
R = Range Length (Equal to CR Focal Length)

The radar range equation assumes that the potential error sources associated with the feed's isolation, ringdown and VSWR are inconsequential. The range equation also assumes that there are no residual reflections from other items in the chamber present within a measured pulse window. In a physically realizable RCS range, there are practical limitations to specific devices that can cause performance to be less than indicated by the RCS range equation.

Typical Equipment and the MI Solution

MI Technologies' approach for the range architecture is a gated CW system based upon a set of modular hardware and software which can be efficiently configured for RCS testing. Given that many RCS ranges are intended for both antenna and RCS testing, not only will the traditional system hardware be important, but the subtle, less obvious system design elements must also be balanced in order to meet various range requirements.

Figure 11 illustrates an RCS Measurement architecture. The system includes RF data acquisition, positioning and computing subsystems. The RCS hardware additions to a basic receiver subsystem include a dual feed cluster, pulse generator and utilization of a modular RCS RF subsystem which is located in close proximity behind the CR feeds. Software specific to RCS testing for post-processing analysis, display and reporting is added to complete the system.

The key RF measurement element of the system is the MI-1797 Microwave Receiver, providing RF data acquisition from .1- 20 GHz. A full description of the MI-1797 receiver can be found on the MI Technologies website (www.MI-Technologies.com). The MI-1797 coupled with the MI-3001 Data Acquisition and Analysis Workstation, enables the user to fully automate the measurement process.

At a high speed acquisition rate of 10,000 CW measurements per second (100 usec per sample) and single sample dynamic range of 85-90 dB over 0.1– 20 GHz, the MI-1797 provides significant performance advantages. Multi-frequency and multi-port measurements are supported with a high

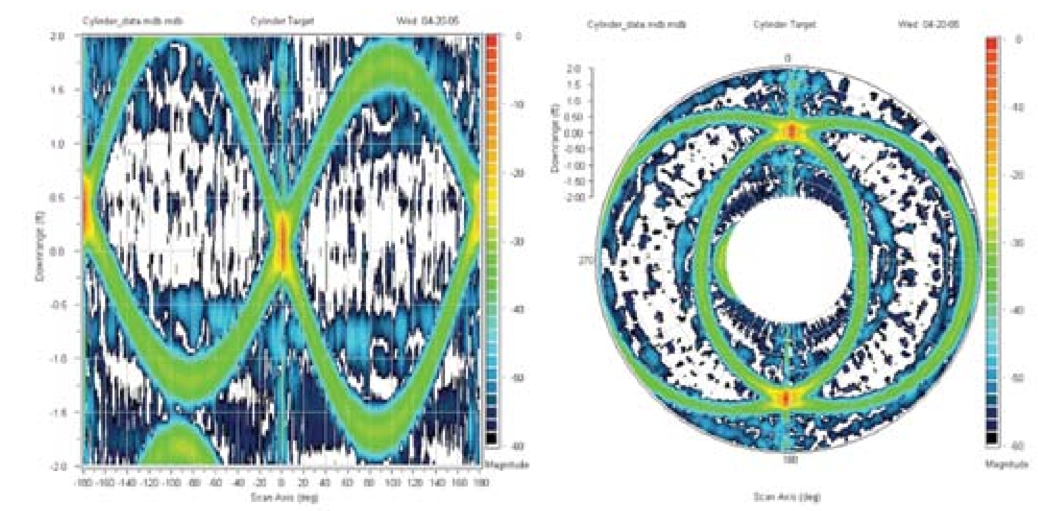

Figure 8: RCS vs. Range Axis vs. Angle. (a) Angular Scan Axis shown as X-Axis. (b) Angular Scan Axis shown along Polar Axis

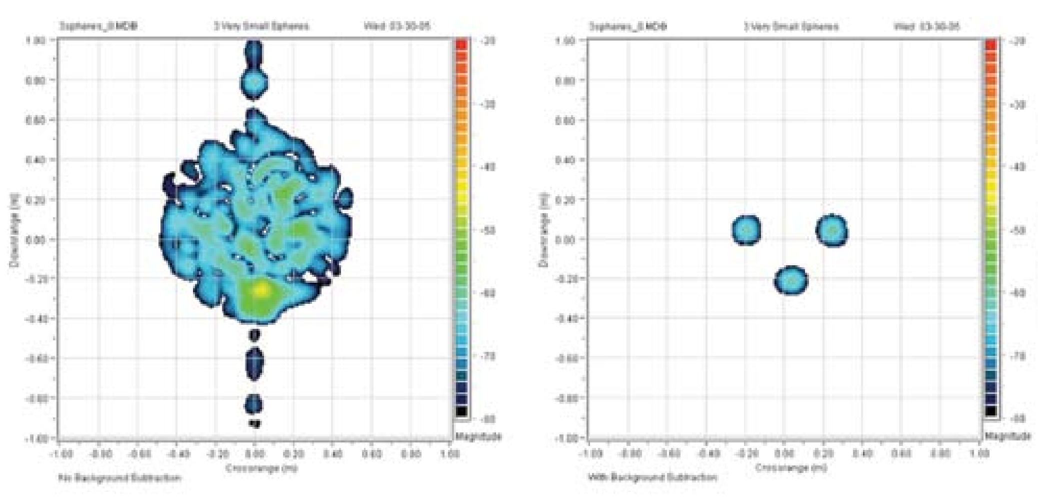

Figure 9: RCS of three spheres with an RCS of -60 dBsm on top of a foam column. (a) RCS of Spheres and Column. (b) RCS of the Spheres after using Background Subtraction to remove influence of the foam column.

speed frequency switching synthesizer and two-port multiplexers.

The key elements and subsystems of the measurement system are composed of:

- MI-1797 Microwave Receiver
- Two MI-3100 Series Synthesizers (LO and TX Source)
- RX Low Noise Amplifier
- LO Extender and Control
- Data Acquisition Co-Processor (DAC)
- TX & RX Mixers
- RF Couplers
- Two Port Multiplexers
- RF Range Cables including High Performance Phase Stable Cable
- RCS RF subsystem including Auxiliary Control and Power And Gating Control
- Pulse Generator Unit
- RCS Dual Feed Cluster (See Figure 12 for a photo of

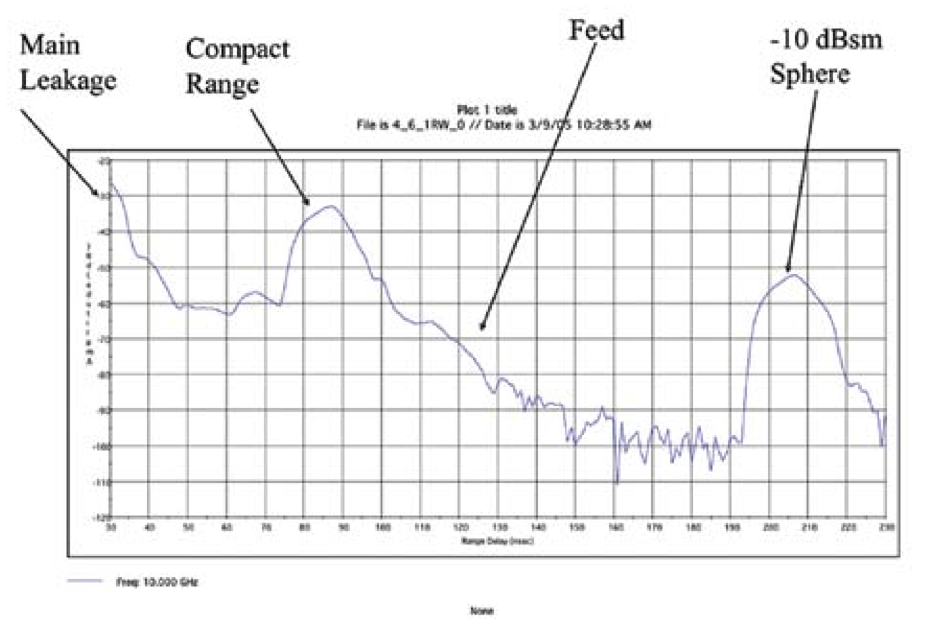

Figure 10: Plot of Received Power vs. Time showing system ring-down. The X-axis is range delay in nsec and the Y-axis is relative receive power. This plot was created by shifting the receive gate in time and plotting the received power.

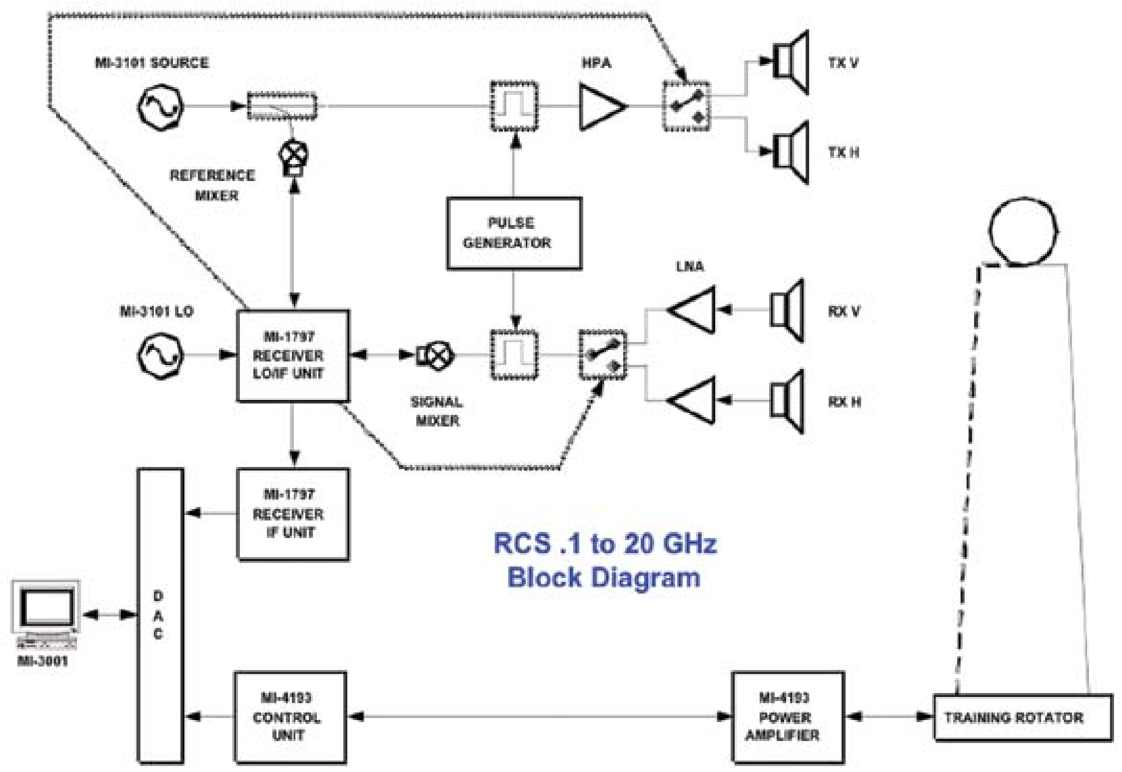

Figure 11: Block Diagram of Gated CW RCS Measurement System using an MI-1797 as the receiver.

a typical feed cluster

- RF Range Cables including High Performance Phase Stable Cable

Typical Performance

Baseline MI-1797 receiver dynamic range performance data is presented in **Figure 4**. The data illustrates the significant measurement capability of the MI-1797 receiver at a variety of measurement integration sample sizes. Even at low sample sizes, resulting in the fastest test times, the MI-1797 receiver shows outstanding signal measurement performance.

Using the RCS link budget equation from section 3.0, **Table 1** shows the typical sensitivity levels that can be achieved for a CR with a 24 ft focal length and a dual feed configuration.

Conclusion

The use of compact ranges to measure the RCS is a well proven method for testing a wide variety of targets. The close proximity in time of the radar feeds, the CR and target present significant design and measurement challenges. Care must be taken to ensure that the many sources of errors in the measurement are properly designed and accounted for to ensure a good measurement. Current generation of gated CW systems, such as the MI Technologies gated CW system presented in this white paper are capable of making very accurate measurements on well designed ranges.

The ability to make sensitive measurements twenty-four hours a day, seven days a week, in a secure facility using little real estate makes meeting the design challenges for this type of measurement system worthwhile. For more information, please call (800)854-3660 or visit www.mi-technologies.com

Figure 12: RCS Feed Cluster using wideband sinuous antennas as feeds. Each feed is dual linearly polarized.

7.3 meter Focal Length Duty Cycle 17% 10 ft Target, 40 nsec gate						
Parameter	2 GHz	10 GHz	18 GHz	26.5 GHz	40 GHz	
KTB (10khz)	-134	-134	-134	-134	-134	dBm
$(4\pi)^3$	33	33	33	33	33	dB
$(\text{Range})^4$	34.6	34.6	34.6	34.6	34.6	dB
TX Losses	2	2	2	2	2	dB
RX Losses	2	2	2	2	2	dB
LNA Noise Figure	3	3	3	4	4	dB
Power Transmitted	27	27	27	30	24	dBm
$(\text{Antenna Gain})^2$	16	20	28	20	28	dB
$(\text{Wavelength})^2$	-16.5	-30.5	-35.6	-38.92	-42.5	dB
Duty Cycle Loss	15.2	15.2	15.2	15.2	15.2	dB
Integration Gain	12	21	18	27	30	dB
Sensitivity	**-82.8**	**-81.7**	**-81.7**	**-81.4**	**-80.8**	**dBsm**

Table 1: Sensitivity Calculation