AN OVERVIEW OF PARAMETERS DETERMINING PRODUCTIVITY AND SENSITIVITY IN RCS MEASUREMENT FACILITIES

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ABSTRACT

A major objective in the design of an RCS measurement facility is to obtain the greatest possible productivity (overall measurement efficiency) while maintaining the accuracy and sensitivity necessary for low radar cross section targets. This paper will present parameters affecting the total throughput rates of an indoor facility including instrumentation, target handling, and band changes - one of the most time consuming activities in the measurement process. Sensitivity and accuracy issues to be discussed include radar capabilities, feeds and feed clustering, compact range, background levels, and diffraction control.

Keywords: Compact Range, RCS Sensitivity Productivity

1. BACKGROUND

The move toward widespread use of indoor anechoic chambers for Radar Cross Section Measurements is driven in part by some obvious advantages an indoor range has over an outdoor measurement system. Indoor facilities can be made much more secure than outdoor installations, where satellite flybys, physical security, day and night considerations and weather often severely impacted range time. The indoor compact range allows the target to be viewed in simulated far-field conditions, without requiring vast amounts of real estate and high power radar transmitters. The design of the compact range also avoids having to deal with ground plane considerations and its impact on bandwidth during imaging measurements. In addition, the EMI environment can be closely controlled, and such phenomenon as multiple-time-around returns from physical structures and land clutter are avoided with a compact range.

2. ELEMENTS OF THE COMPACT RANGE FACILITY

Figure 1 shows the four major elements of a compact range anechoic chamber for RCS Measurements.

Chamber
Compact Range and Feed
Target Positioning
Instrumentation

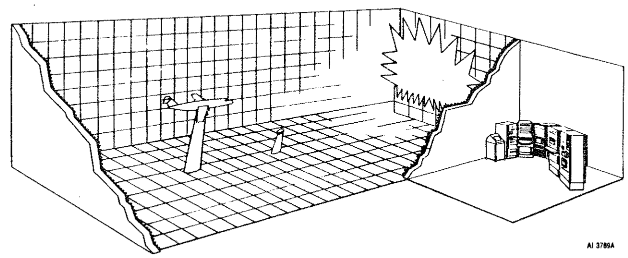

Figure 1: Typical Compact Range System for RCS Measurements

2.1 CHAMBER

The chamber's size and shape must accommodate the target and also be large enough to range gate out the target's coupling with ceiling, floor and walls. The anechoic treatment of the chamber should be of sufficient quality to maintain chamber background levels in the target range cell that are at least 20 dB below the target level. The shielding properties of the chamber should provide EMI protection from outside interference as well as security for the measurement radiation. The chamber should be environmentally controlled to maintain surface accuracies of the reflector, target and target positioning system.

2.2 COMPACT RANGE

The compact range's function is to produce a uniform field with acceptable polarization characteristics over the entire quiet zone space volume at all frequencies of operation.

The field taper outside the quiet zone should follow a smooth, fast roll-off to reduce the field illumination of the feed structure and chamber walls.

2.3 TARGET POSITIONING

The target positioning system must safely and accurately position the target to all the desired aspect angles for measurement and present to the measurement system a radar cross section lower than that of the target.

The target handling system should be capable of safely transporting the target from the staging area into the chamber without disturbing the RAM. This feature reduces the risk of chamber degradation and increases the operating life of the absorber material.

2.4 INSTRUMENTATION

The instrumentation system for the compact range facility is the functional composite of radar, system control, data collection and data reduction. To realize the full potential of the compact range facility, the instrumentation system should be capable of full polarization matrix operation with multi-frequency and multi-band operation during a single rotation of the target.

The instrumentation system must be accurate over a wide dynamic range and should not require frequent calibration to maintain accuracy.

Compact range geometries require very fast recovery for all elements of the system in order to receive low level target signals at the short range length. The compact range radar must utilize special packaging techniques to achieve this fast ringdown.

3. IMPLEMENTATION PROBLEMS FOR THE INDOOR COMPACT RANGE

Unfortunately, the expected gains in measurement productivity, accuracy and sensitivity by using indoor compact range systems have not been easy to achieve in practice.

Productivity gains resulting from the ability to work around the clock were offset by longer times to set up and take the measurement. For instance, feed bandwidths required up to 8 separate feeds to cover 1 to 18 GHz. As a result the feeds had to be changed either manually or through some kind of carrousel mechanism to complete the 1 to 18 GHz bandwidth. With each feed change, it was necessary to recalibrate the range, often requiring the dismounting of the target, calibrating, then remounting the target. Engineering had to work around the clock to achieve the productivity of an outdoor range!

The full potential of indoor range productivity was also restricted by RF switching speeds. The reduced target range length of the compact range geometry permitted much higher unambiguous pulse repetition rates which reduced the inter-pulse switching time for polarization and band switching. These higher PRF rates made possible with the indoor range geometry also required faster data throughput to realize this benefit.

While the indoor compact RCS range overcame many of the fundamental limitations of the outdoor ground plane range, it also presented sensitivity and accuracy limitations unique to its own geometry. Feed systems that had performed well for antenna measurement applications were not acceptable for pulsed RCS measurements. Waveguide structures used in the feeds were found to have high Q resonant modes which were excited by the transmitted pulse and continued to ring beyond the range of the target. This ringing energy coupled into the receiver and produced the equivalent of clutter in the range cell. Figure 2 shows a measurement of RCS vs range delay using a standard orthomode feed. Note that the ringdown to system noise levels takes about 300 nanoseconds. In some range geometries, the target path length is only 70 nanoseconds, so ringing energy would be present in the target range cell.

High level illumination of the feed support structure cross section resulted in unacceptable ripple in the quiet zone. Also the coupling between feeds support and reflector produced reverberations that appeared in the quiet zone. Shown in Figure 3 are ray paths that bounce off the feed and are diffracted into the target zone, and also ray paths that couple the feed directly with the reflector surface. These path lengths can result in unwanted energy in the target range cell.

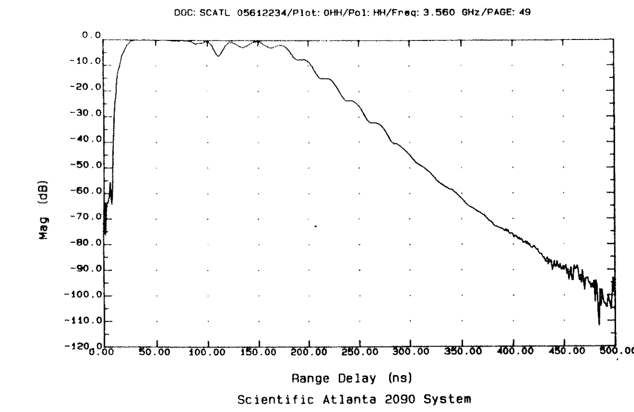

Figure 2: Ringdown Characteristic of Typical Standard Orthomode Feed

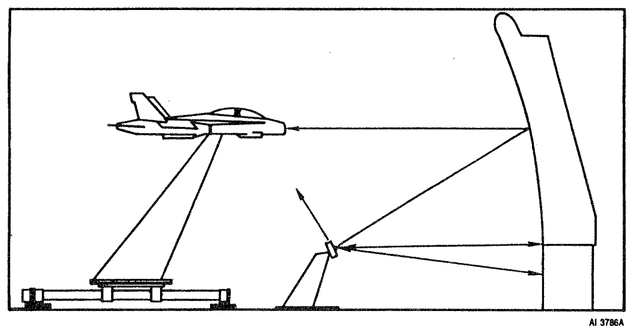

Figure 3: Feed Forward Scattering and Coupling

To minimize this problem, RF heads were kept out of the chamber, however, the longer transmission lines produced internal system ringdown. In the short geometries of the compact range, the RF pulse ringdown could also bleed into the target cell, increasing measurement error. In Figure 4 the ripple on the top of the pulse at the target range cell is shown to be caused by system ringdown.

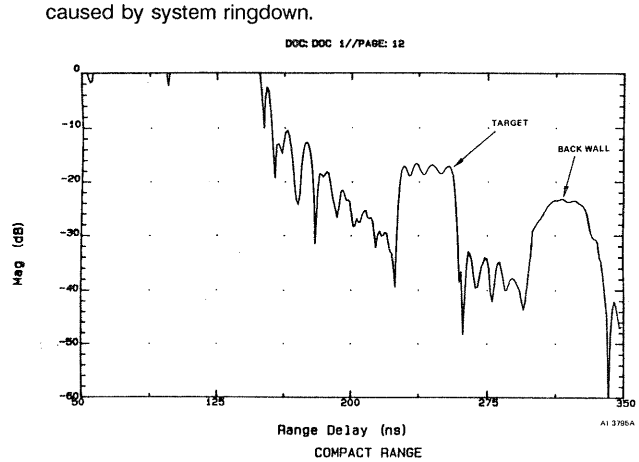

Figure 4: System Ringdown Depicting Impact of Ringing Energy on a Pulse

Radar absorber material used to treat chambers for antenna measurements were found to backscatter high levels into the range cell and limit the system sensitivity. Background subtraction helped in some cases; however, it was found that wedge type absorber in the quiet zone region performed much better for RCS ranges than pyramid.

4. SCIENTIFIC-ATLANTA APPROACH

Scientific-Atlanta has undertaken an extensive program to develop products that improve compact range productivity accuracy and sensitivity. Our R&D investments have addressed improved reflector designs, non-ringing feeds, feed clusters, and improved instrumentation radars.

4.1 REFLECTOR DESIGN

Figure 5 shows the current compact range configuration. Note the vertex is at the same height in the chamber as the feed, and is therefore not on the surface of the reflector. The problem of high level feed illumination has been solved by utilizing an offset vertex and improved serrated edge treatment. The feed-to-reflector coupling with the new design is now below discernable levels.

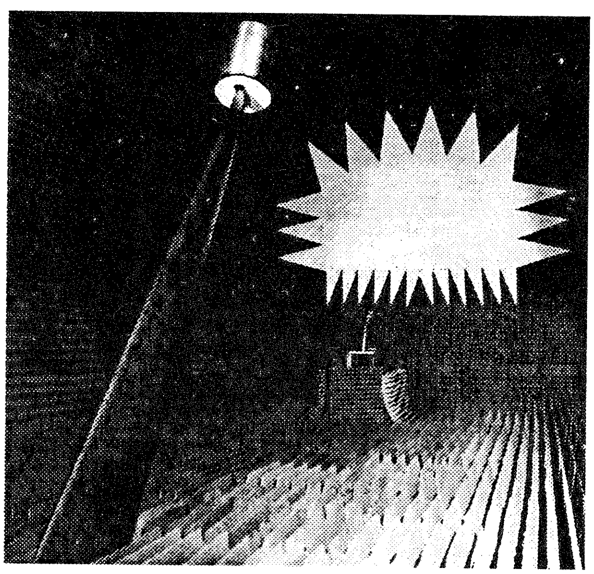

Figure 5: Scientific-Atlanta Compact Range

It was obvious that better analytical tools were needed and we therefore developed physical optics software programs to predict compact range performance with confidence. This analytic technique allows us to optimize compact range configurations to the customer's application needs. Figure 6 shows measured data superimposed on calculated data for a vertical amplitude cut on a Model 5704 Compact Range. Note the excellent agreement between calculated and measured data.

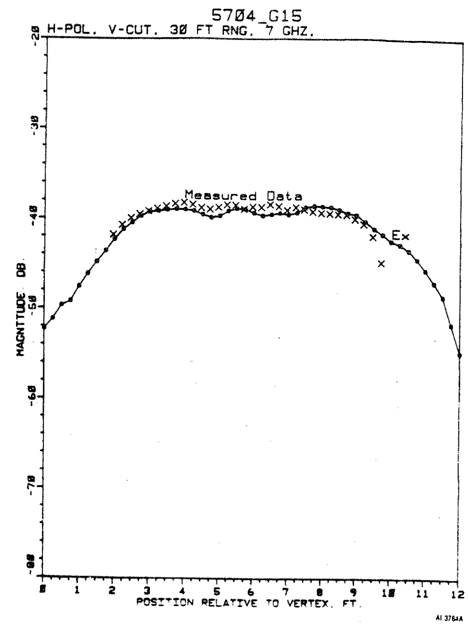

Figure 6: Calculated vs Measured Data
5704 Compact Range Vertical Amplitude Cut

4.2 FEED DESIGN

A major investment in resources and research was required to develop an acceptable compact range feed for RCS applications. The perfect feed would have 1-18 GHz bandwidth, dual linear polarization, acceptable gain and taper characteristics, and would not ring when energized with a high rise pulse. Unfortunately, this product does not exist. The new Scientific-Atlanta feed pictured in Figure 7 utilizes coaxial waveguide structures to avoid the inherent resonance modes in rectangular waveguides. It is available in range of 1-18 GHz, dual linear polarized, has excellent gain and taper characteristics, but has useful bandwidths less than an octave. It does not ring, as shown in Figure 8. Note the presence of no energy storage within the bandwidth of interest, 2-3.46 GHz.

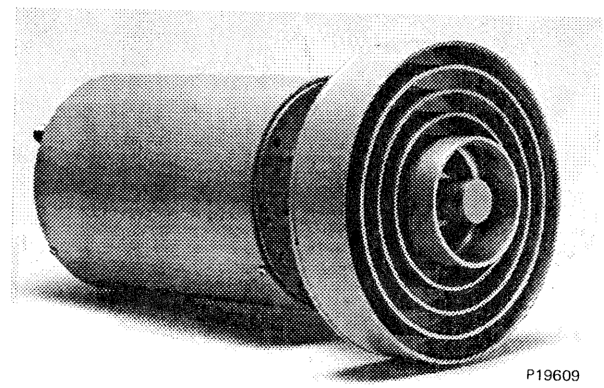

Figure 7: Scientific-Atlanta Non-Ringing Coaxial Feed
Model 32-2.6

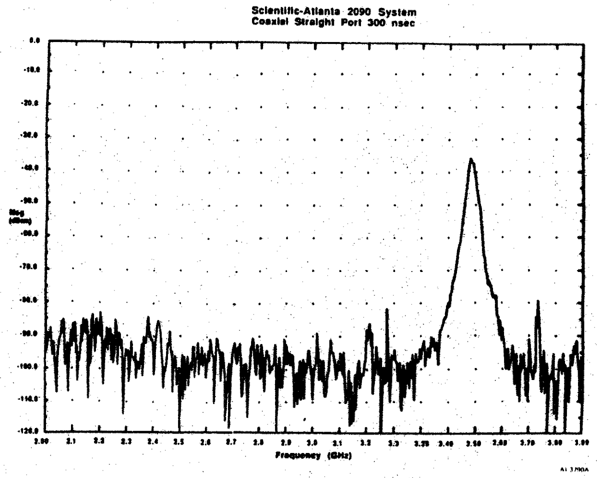

Figure 8: Amplitude vs Frequency for Non-Ringing Coaxial Feed

4.3 RF DESIGN

To complement non-ringing feed development, it was necessary to develop compact RF Units for both Gated CW and Pulse Radar Systems. This compact package by virtue of its small size can be placed in close proximity to the feed, and contains both transmit and receive modules. This combination of feeds and compact RF units exhibit excellent system ringdown characteristics, recovering to system noise in less than 70 nanoseconds, as shown in Figure 9. This is for a 5 nanosecond pulse with a 200 MHz bandwidth at 16 GHz.

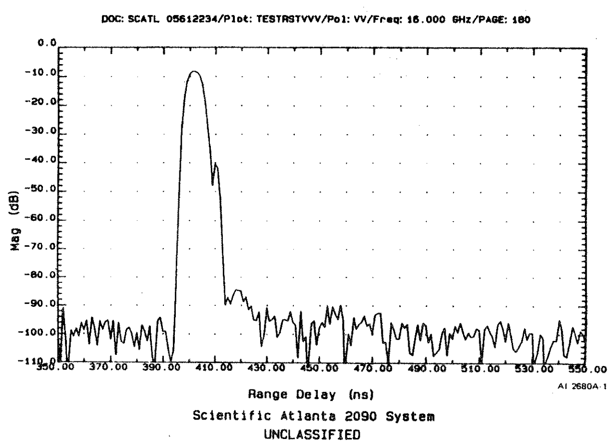

Figure 9: System Ringdown Performance of Scientific-Atlanta Pulse Radar Including RF Unit

4.4 FEED CLUSTER

To improve compact range productivity, Scientific-Atlanta has developed a feed cluster system along with RF unit packaging that allows multi-band operation without changing feeds. The cluster system utilized high speed RF switching that permits a single calibration of all bands and full polarization matrix measurements of multi-frequencies on multi-bands with a single target rotation.

This subject is treated in a paper by Marion Baggett and Dr. William Swarner of Scientific-Atlanta entitled "Use of Clustered Feeds in a Compact Range", presented at this AMTA session. A pictorial representation of the concept is seen in Figure 10. Note the ogive shaped feed support assembly to reduce feed support to reflector coupling.

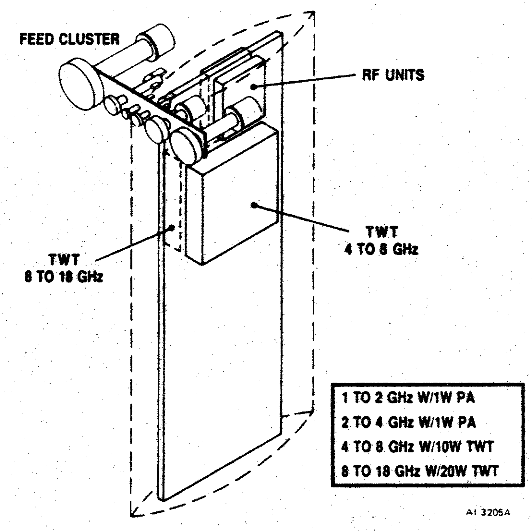

Figure 10: Conceptual Feed Cluster and RF Unit

4.5 RADAR DATA ACQUISITION AND PROCESSING SPEEDS

Another productivity opportunity applicable to both the outdoor application as well as compact ranges is to reduce the time required for the radar to collect data and then to process it. We have made considerable progress with recent improvements in radar hardware, controllers, and software to provide more efficient data collection and reduction rates.

The Model 2090 wideband pulse radar pictured in Figure 11, is now capable of changing frequencies, acquiring data and writing the data to disc at the rate of 8000 points per second. It can acquire full polarization data on all bands in a single rotation of the target. This allows either RCS vs aspect cuts or image data to be taken simultaneously. It has a dynamic range greater than 100 dB (with integration). The 2090 employs internal I & Q correction on a pulse-by-pulse basis and drift correction. This allows continued measurement testing without having to stop for re-calibrations due to temperature drift. A description of the Scientific-Atlanta 2090 Pulse Radar is included in the paper "RATSCAT Integrated Radar Measurement System" by Marvin Wolfenbarger of Scientific-Atlanta, presented at this session of the AMTA.

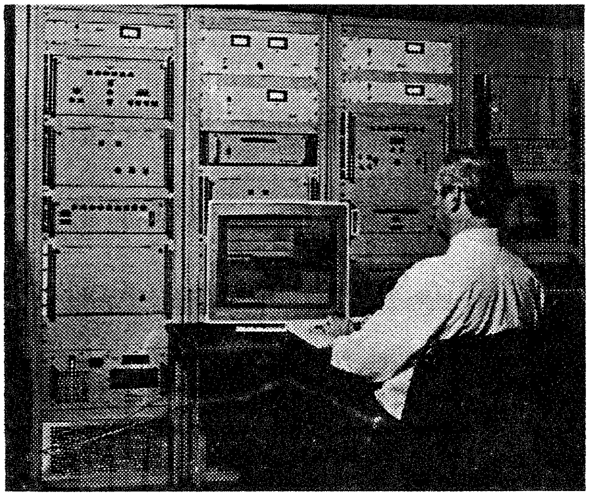

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Figure 11: Scientific-Atlanta 2090 Pulse Radar

The Model 2095 Gated CW Radar, pictured in Figure 12, can take data at the rate of 4750 measurements per second, a much faster rate than our previous technology up to 4 measurement channels are acquired simultaneously, to provide full polarization data. The 2095 System can achieve 84 dB dynamic range, and can transmit 5 nanosecond pulses with 2 nanosecond rise and fall times. For a fuller description, refer to the paper "Productivity Improvement in a Gated CW Radar" by J. B. Wilson of Scientific-Atlanta, presented at this AMTA session.

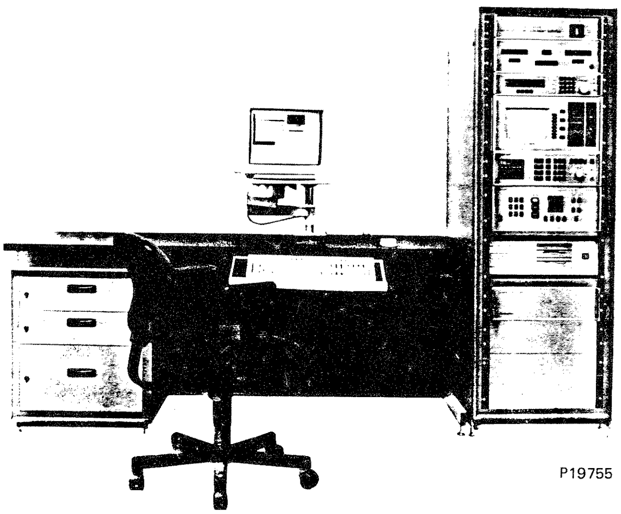

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Figure 12: Scientific-Atlanta Model 2095 Gated CW Radar

The impact of the data acquisition and processing improvements can significantly improve the time to take measurements and reduce them to images or plots. Because the Scientific-Atlanta automatic systems are multi-tasking, the range operator can set up the next measurement while the radar is acquiring and processing data for the current measurement. Figure 12 depicts data acquisition and processing rates for the Model 2095 Gated CW Radar and the Model 2090 Pulse Radar. Note that the acquisition times shown are limited by positioner and target rotational speeds. The actual acquisition time is a fraction of the times shown.

	MODEL 2095 GATED CW RADAR	MODEL 2090 PULSE RADAR
Raw Data Throughput Rate	4750 Frequencies	8000 Freq/Sec.
RCS VS ASPECT:		
Time to Acquire* 3600 Angles	< 2 Min	< 2 Min
Time to Process 3600 Angles	< 30 Sec	< 30 Sec
RCS IMAGE:		
Time to Acquire* 128 Angles, 128 Frequencies	< 2 Min	< 2 Min
Time to Process 128 Angles, 128 Frequencies	< 1 Min	1 Min
Time to Produce (128x128 contour plot	< 1 Min	< 10 Sec.
Rescale & Replot	< 1 Min	< 15 Sec
* Limited by Positioner and Target Rotation Speeds		

Figure 13: Scientific-Atlanta Data Acquisition and Processing Rates

4.6 THE PRODUCTIVITY ADVANTAGE

To determine compact range throughput improvements resulting from use of clustered feeds and instrumentation radars that have the speed characteristics mentioned above, consider a measurement set requiring aspect data at 0.1 degree increments on a target at 5, 7, 10 and 15 GHz. Also assume imaging data (128 x 128) at 4 aspects segments on the 4 bands for C, X, and Ku-bands. The calculations for time to mount target and feed, calibrate, and acquire the measurement, are shown in Figure 14. The first column is data for a radar system capable of 1000 data points/second, as is typical of many radars in the field today. The radar can only take data in one band, and only one feed can be illuminated at one time.

The second column illustrates the impact of a radar system that can take multiple band measurements in a single target rotation operating with a clustered feed arrangement. The target measurement time of ≈ 2 minutes is limited by target rotational speed. Also note that 4 bands of data are being taken during this time whereas only one band of data is acquired in the case of the former radar.

The impact of this approach is to reduce the time to make this measurement by a factor of more than 3 to 1.

Function	1000 Data Points/Sec with Single Feed Manual Change (Time)	8000 Data Points/Sec with Cluster Feed (Time)
Mount Calibration Target and Calibrated System	15 Min	15 Min
Mount Target	20 Min	20 Min
Measure Target	≈2 Min	≈ 2 Min
Dismount Target	20 Min	20 Min
Change Feed	5 Min	-
Mount Calibration Target and Calibrate System	15 Min	-
Mount Target	20 Min	-
Measure Target	≈2 Min	-
Dismount Target	20 Min	-
Change Feed	5 Min	-
Mount Calibration Target and Calibrate System	15 Min	-
Mount Target	20 Min	-
Measure Target	≈2 Min	-
Dismount Target	20 Min	-
Total	181 Min	57 Min

Figure 14: Productivity Comparison

5. CONCLUSION

Significant improvements have been made in sensitivity of compact range facilities with improved compact range reflectors, feeds, feed arrangements, and overall chamber design. Feeds that do not ring are especially important in reducing clutter in the range cell.

Productivity of compact range facilities can be significantly improved through the use of clustered feed assemblies for wide band frequency coverage. Productivity can also be improved through the use of instrumentation radars capable of fast data throughput and multiple frequency band data acquisitions in a single target rotation.

10. REFERENCES

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