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SCATTERING EXPERIMENTS AT THE IPSWICH ELECTROMAGNETIC MEASUREMENTS FACILITY: SWEPT BISTATIC ANGLE MEASUREMENT SYSTEM

Robert V. McGahan

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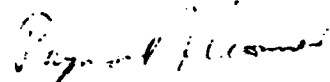
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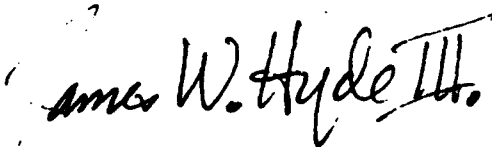

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REPORT DOCUMENTATION PAGE

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 of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 1991	3. REPORT TYPE AND DATES COVERED In-House Dec 1984 – Dec 1986

4. TITLE AND SUBTITLE

Scattering Experiments at the Ipswich Electromagnetic Measurements Facility: Swept Bistatic Angle Measurement System

6. AUTHOR(S)

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5. FUNDING NUMBERS

PE: 61102F
TR: 2305
TA: J4
WU: 04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Rome Laboratory (EECT)
Hanscom AFB, MA 01731-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

RL-TR-91-114

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A swept bistatic fixed aspect angle bistatic measurement system has been designed, built, and tested. The system is capable of measuring over bistatic angles from 10 degrees to 175 degrees, at frequencies from 2 GHz to 40 GHz, although target size is limited above approximately 15 GHz. Sample measurements on perfectly conducting spheres are presented. A preliminary test of automation was conducted and equipment procured for permanent automation. Suggestions for future modifications, including range gating and fixed swept aspect angle measurements, are discussed.

14. SUBJECT TERMS

Radar Cross Section
Measurements
Bistatic
Swept Angle

15. NUMBER OF PAGES 26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

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1. INTRODUCTION

The trend toward multistatic radars has created renewed interest in bistatic cross section solutions and measurements. In the past, serious doubt was cast on the feasibility of fielding practical bistatic radars[1], but progress in signal processing has alleviated many of these former concerns. In addition, there are some scenarios where a monostatic radar cannot do the job. As a result, bistatic radars have become more attractive to system designers and to the Air Force.

The data base of bistatic measurements is small. There are few ranges that can perform these measurements, and they are expensive to conduct. In addition, these ranges are extremely heavily utilized. There are also security issues involved. As an alternative, analytic and numerical solutions have been developed to make theoretical predictions on targets of interest. These predictive codes, when implemented on large mainframe computers, can calculate the scattering patterns of remarkably complicated shapes, but they must be validated by bistatic scattering measurements before the radar community can put unqualified trust in them.

For the reasons stated above, this validation process will not likely be done on outdoor ranges to any large extent. We have, therefore, devised a technique to perform bistatic scattering measurements on scaled targets. This bistatic measurement system is presently used in support of the laboratory surveillance program, and in-house scattering programs.

2. DESCRIPTION OF THE BISTATIC SYSTEM

The swept bistatic angle measurement system (SBMS) described herein is located at the Rome Laboratory Electromagnetic Measurements Facility in Ipswich, Massachusetts. In previous reports[2,3] a monostatic cross section measurement system was described, and measurements reported. The bistatic system is the logical outgrowth of that work and uses much of the same equipment. Preliminary results were reported in Reference 4.

2.1 Manual Bistatic Measurement System

The SBMS is located in a 20-ft wide by 20-ft high by 40-ft long anechoic chamber. The addition of 24-in pyramidal absorbers on the walls, floor, and ceiling reduces the usable dimensions to 16-ft by 16-ft by 36-ft. There is a section of the back wall of the chamber that is covered with 36-in absorber. This section of absorber is useful for reducing reflections from this wall when the chamber is used in a monostatic configuration, but is of no particular interest for bistatic operations.

The near wall of this chamber is constructed with nine removable ports. The measurement equipment is located behind this wall, and one or more of the ports is removed for antenna mounting or target alignment. Entry to the chamber is through one of two sets of double doors, allowing access to either end with minimum disruption of the absorber on the floor. Figure 1 shows the floor plan of the chamber.

The measurement system consists of a Scientific-Atlanta (SA) 2050 signal source and a SA 1770 phase-locked receiver. The signal source uses plug-in units to change frequency bands, and the master oscillator is synthesized to a stability of one part in 10^7 per 24-hours. Plug-ins up to 40 GHz are available, and the receiver has been modified to operate to 40 GHz; although due to the small size of the chamber, few measurements are foreseen at these higher frequencies.

[1] Skolnik, M. (1970) *Radar Handbook*, McGraw Hill Book Company, Inc., New York.

[2] McGahan, R.V. (1983) *Scattering Experiments at the Ipswich Electromagnetic Measurements Facility: Calibration With Perfectly Conducting Spheres*, RADC-TR-83-181, AD A138028.

[3] McGahan, R.V. (1985) *Scattering Experiments at the Ipswich Electromagnetic Measurements Facility: Backscatter From Metal Cubes*, RADC-TR-85-24, AD A157925.

[4] McGahan, R.V. (1985) Bistatic Scattering From Metal Cubes: Theory and Experiment. Paper presented at International URSI/APS Symposium, Vancouver, British Columbia, Canada.
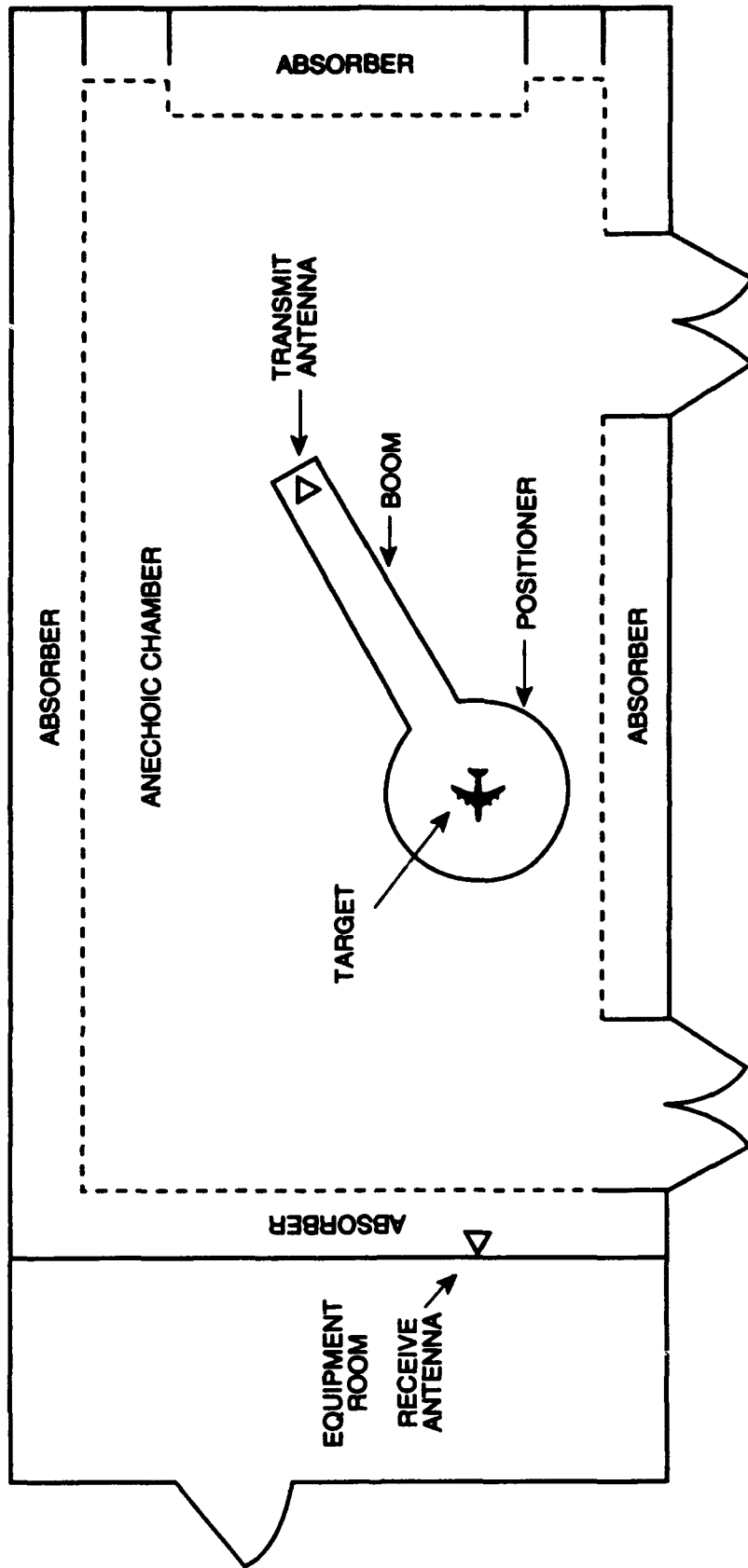
Figure 1. Floor Plan of Chamber and Equipment Room.

Targets are mounted on an SA 53150 positioner, controlled by a manual positioner controller. A wooden boom, attached to the turntable of the positioner, shown in Figure 2, is constructed so as to attain the highest possible degree of rigidity with the least possible weight penalty. The length of the boom is such that when the positioner turntable is rotated the boom sweeps out a circular arc, just missing grazing the sidewall of the chamber. As seen in Figure 1, the positioner is located off-center in the chamber to allow the maximum length boom to be used. As we will discuss later, this positioner location is a trade-off between boom length and proximity of target to the wall.

The transmitting antenna is mounted at the end of the boom, connected to the transmitter through either low loss coaxial cable or waveguide, depending on the frequency of operation. A rotary joint designed for operation over the frequency range 0 to 40 GHz couples the signal from the rotating boom to the stationary transmission medium on the floor of the chamber, under the absorber. These conductors run through the previously described wooden wall of the chamber, up to the equipment rack.

The receiving antenna is mounted on the wall of the chamber. The equipment rack is positioned directly behind the wall, and the antenna aimed through an open port. Once the antenna is properly aimed, the remainder of the port is closed up with absorber-lined panels, to eliminate stray energy from leaking into or out of the chamber.

Due to the location of the positioner, the propagation path from the receive antenna, mounted in the wall, to the target is longer than the path from the transmit antenna, at the end of the boom, to the target. This path length difference is not significant. However, due to the physical size of, and the absorber covering on, the transmit antenna, some occulting of the receive antenna by the transmit antenna occurs at small bistatic angles. This precludes making bistatic measurements with this system for bistatic angles less than 10 degrees.

The measuring system is similar to that in References 2 and 3. Figure 3 is a block diagram of this system. A typical measurement proceeds as follows. A target is selected, along with a range of bistatic angles over which measurements are desired. The boom is moved to the first bistatic angle of interest and the background signal is manually nulled out as described in Reference 2. A known calibration target is placed on the styrofoam pylon and the signal power $C_m(\beta)$ recorded. The calibration target is then removed and replaced by the target of interest. This power reading $U_m(\beta)$ is recorded, and finally the target is removed and the background level checked. If the background signal has drifted out of its null by an unacceptable amount, the system is re-nulled and the entire process repeated. When an acceptable measurement has been made, the boom is moved to the next bistatic angle and the process is repeated. At the completion of the series of measurements, the unknown target relative measurements are adjusted using the measurements on the known calibration target and the corresponding theoretical values. As noted in References 2 and 3, the adjustment, or calibration, is made according to the relationship

$$\sigma_T(\beta) = \frac{U_m(\beta)}{C_m(\beta)} \sigma_c \tag{1}$$

where σ_T is the radar cross section of the unknown target, σ_c is the theoretical value of the calibration target, and β is the bistatic angle.
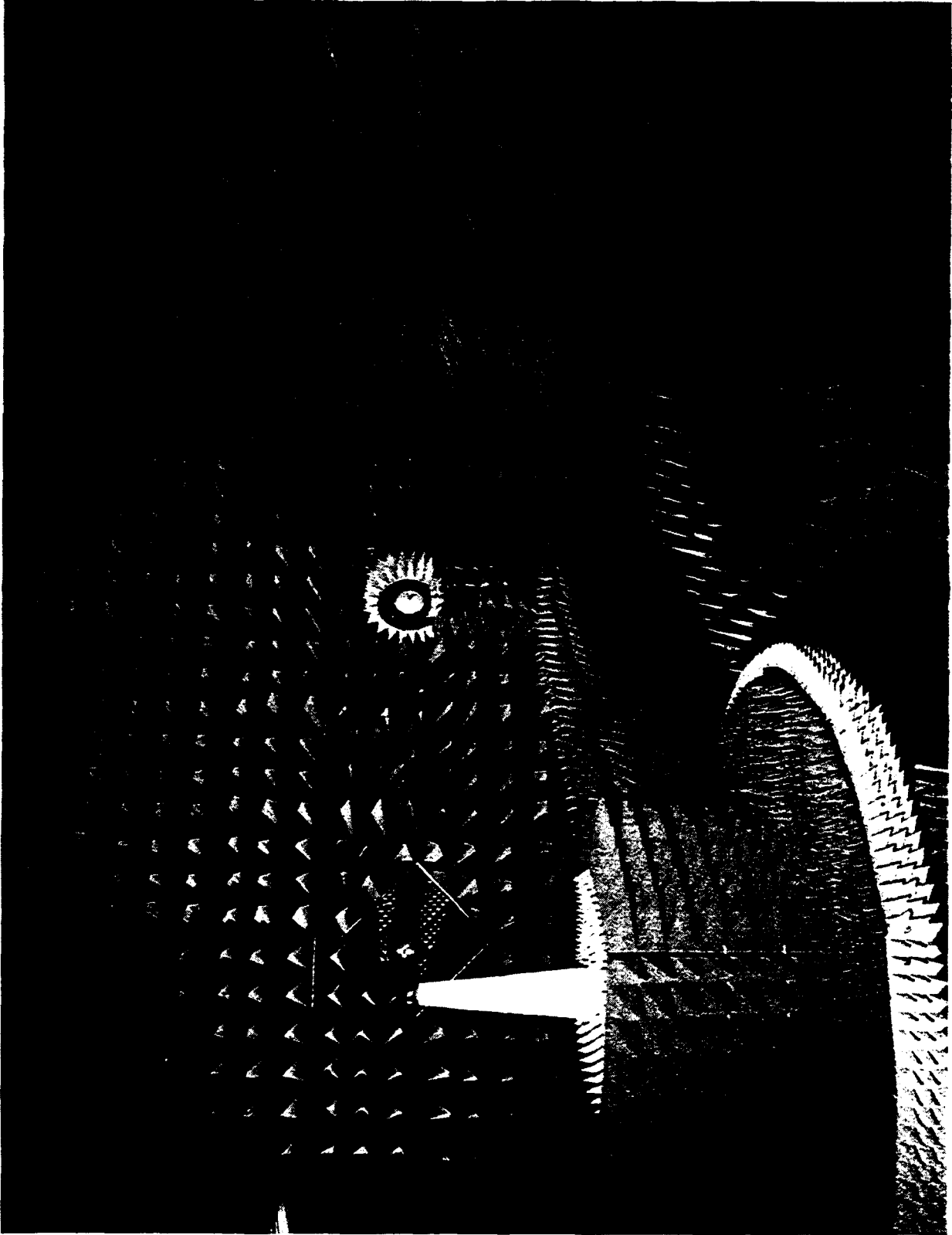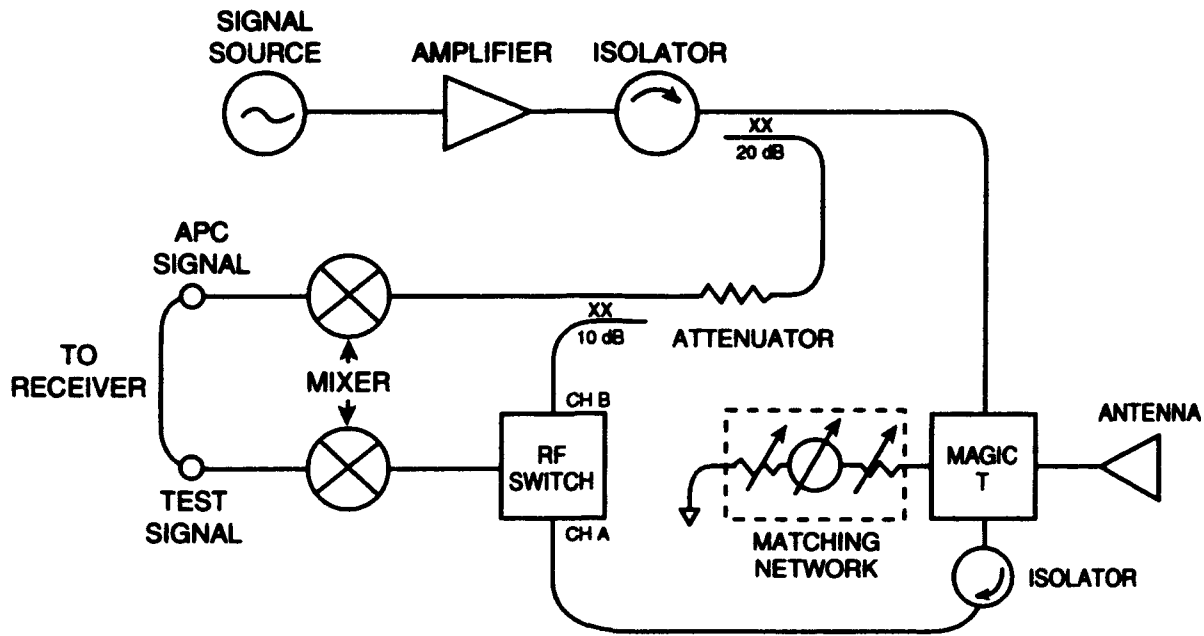
Figure 2. Picture of Positioner and Boom.

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Figure 3. Block Diagram of Measurement System.

The feature of the technique is that detailed knowledge of the measurement system character-istics is unnecessary. Since both the calibration target and the test target are measured by the same system at the same range, the power ration $U_m(\beta)/C_m(\beta)$ in Equation (1) cancels all measurement system quantities. Thus the target cross section is obtained directly in terms of the theoretical cross section of the calibration sphere.

This technique is somewhat tedious, particularly when measurements are required at a large number of bistatic angles, but generally yields high quality measurements.

There are two points to be made before reporting some typical measurements. The first concerns calibration. Since the bistatic scattering from a sphere is more or less oscillatory, depending on its size and the measurement frequency, there is often ambiguity involved in determining the exact bistatic calibration value to use when calibrating with a single sphere.

Figure 4 illustrates this problem. Since the scattering pattern of the chosen calibration sphere has a large derivative in the vicinity of the desired bistatic angle, and because there is some error in the positioner readout, one is not quite sure what value to use when calibrating the measure-ments. Depending on the size of the error in the position of the boom, there could be as much as 2 dB error in the final measurement. A way to eliminate this problem was devised. Instead of using only one sphere, three spheres of different sizes were used. The scattering patterns of three representative spheres are shown in Figure 5; all of these patterns are also oscillatory, but they have different periods. At a particular bistatic angle, there is a unique combination of RCS values for these three spheres. By measuring the three spheres repeatedly, moving the boom slightly between sets, it is fairly straightforward to determine when the boom is exactly at the desired bistatic angle.
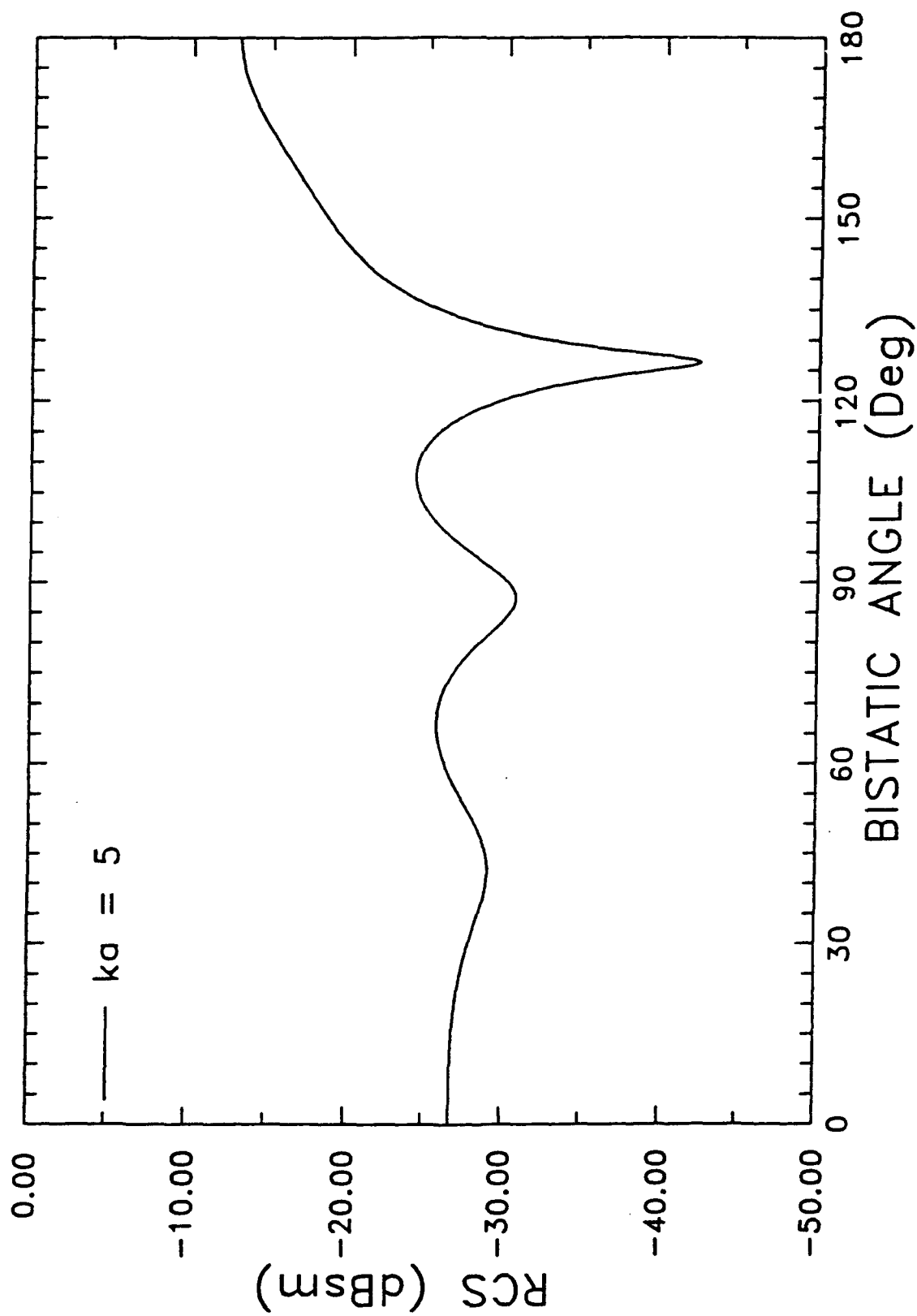
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Figure 4. Bistatic Scattering Pattern of One Metal Sphere, ka = 5.

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The second issue is a question of data collection. The system described here has been termed a swept-angle bistatic system (SBMS). It should be more properly called a swept bistatic, fixed aspect angle system, or SBFA. This is due to the manner of mounting the target on the positioner turntable. Since the styrofoam mounting column is placed directly on the turntable the target rotates along with the positioner. However, as described earlier, the boom and transmitting antenna are also mounted directly on the turntable and they also rotate as the positioner turns. The result of this is that a fixed aspect angle is maintained between the transmitted energy and the target. This could be represented equally well by holding the target and boom stationary and moving the receiving antenna (and in this case, the entire chamber).

This technique is different from the more common fixed bistatic swept aspect angle (FBSA) employed by most bistatic ranges. These ranges, usually outdoors, and much larger than our range, cannot use the swept bistatic technique with any degree of practicality, and the measurements provided by them are most often for a given bistatic angle, or series of bistatic angles, over 360 degrees of aspect angle. The range described herein can provide data in this format, by repeated measurements and manually varying the aspect angle, but this is impractical. A better solution will be discussed in the conclusions.

2.2 Preliminary Automation

To ascertain the feasibility of automating this type of measurement, we performed a simple experiment. For the purposes of this discussion, and the remainder of this report, the term automation is limited to the process of using a computer to set the source frequency, move the boom, and read and record the received signal. Of course, the tasks of placing and removing targets and changing polarization must be done manually.

A SA 2020 Automated Antenna Measurement System, located in an adjacent room, was available for a short time. We connected our 53150 positioner to the 2020 system and wrote a simple program to move the boom over a given range of bistatic angles and read the 2020 receiver. The uncalibrated measurements obtained were imperfect, but of high enough quality that a goal of permanent automation seemed reasonable. The 2020 system became unavailable and further tests of the automated system were postponed.

3. REPRESENTATIVE BISTATIC MEASUREMENTS

To test the range, bistatic measurements were made on metal spheres. Monostatic measurements on these same spheres were reported in Reference 2. The measurements were made at 10 GHz. The sizes of the spheres and their respective ka ($2\pi a/\lambda$) values are found in Table 1. Each sphere was measured over the bistatic angles from 10 to 175 degrees, at 10 degree increments.

The bistatic RCS for seven of these spheres are presented in Figures 6 – 12. The monostatic RCS for each sphere is also included. The measurements were made for both E- and H-plane cuts, (HH and VV) and the theoretical bistatic scattering patterns[5] for each of these cases are compared in the figures.

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[5] Dibeneditto, J.P. (1984) *Bistatic Scattering From Conducting Calibration Spheres*, RADC-TR-84-93, AD A154173.
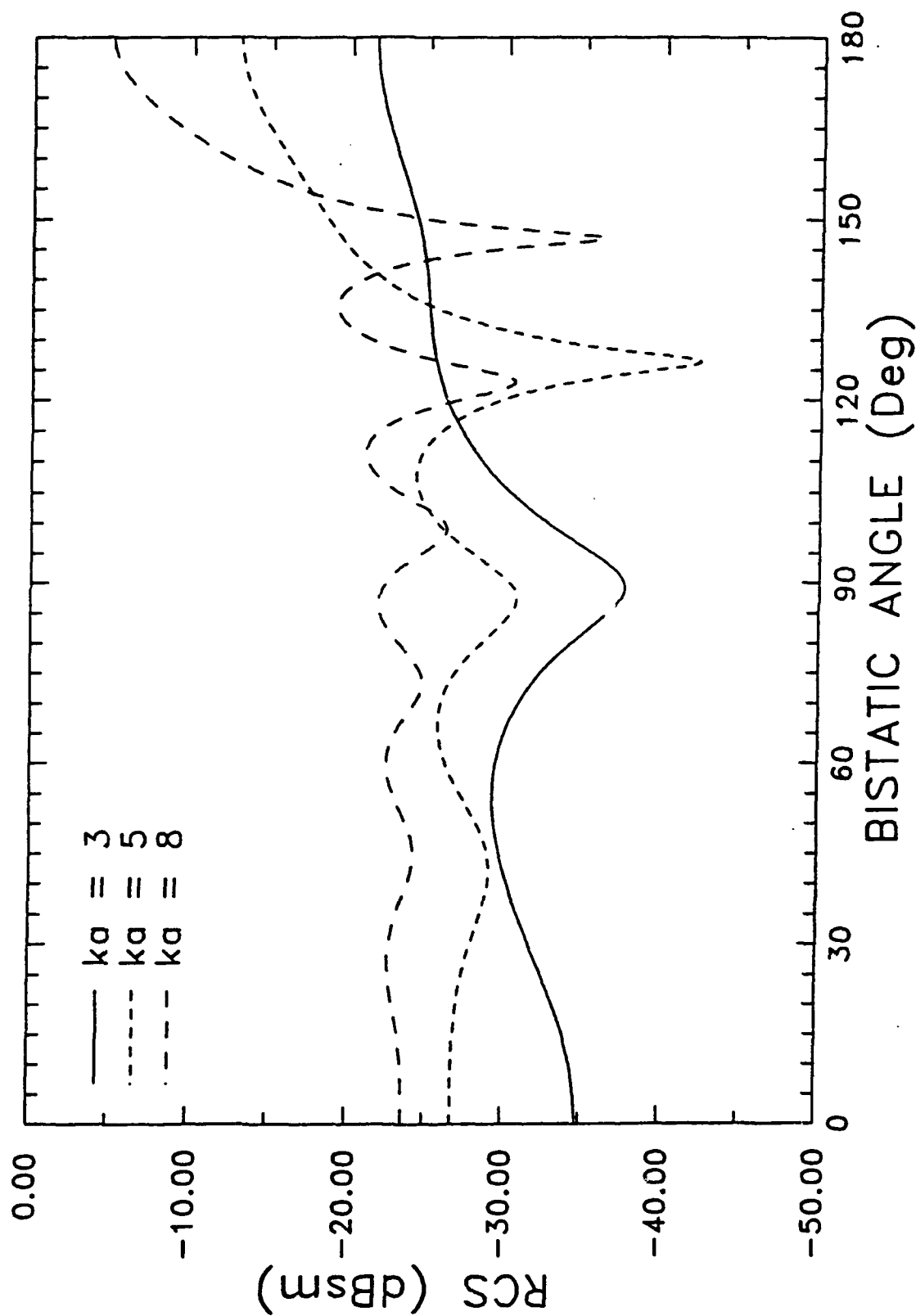
Figure 5. Bistatic Scattering Patterns of Three Metal Spheres, ka = 3, 5, 8.

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TABLE 1. DIAMETER AND ka AT 10 GHz FOR SEVEN METAL SPHERES	
Diameter (in.)	ka at 10 GHz
0.50	1.33
0.81	2.16
0.9	2.49
1.25	3.33
1.50	3.99
1.9	5.16
2.50	6.65

4. DISCUSSION

The system, as presently configured, shows promise for providing validation, or benchmark measurements on canonical shapes for which exact or iterative solutions are obtained, as well as for scale models of more realistic targets. The small size of the chamber precludes any measurements on full-sized targets.

In the course of building and shaking out this range certain problems arose and some changes suggested themselves. One such problem was alluded to in Section 2, namely that of locating the positioner. As stated earlier, the positioner location was a trade-off between boom length, which relates directly to target size, and proximity of the target to the chamber wall, which affects the multipath performance. A boom length of 12-feet allows one to measure a 9-inch target at 10 GHz, using the customary far field criterion of $R_{min} = 2D^2/\lambda$. Using a boom of this length places the target 4 feet from the chamber wall, a distance equal to 40λ at 10 GHz but only 8λ at 2 GHz, the lowest frequency at which bistatic measurements were envisioned. Eight wavelengths is not optimum. Ten would be better, but that would necessitate a shorter boom, making the maximum target size at 10 GHz unacceptable. As presently configured in the manual mode, accurate measurements can be made for both HH and VV polarizations with careful background nulling.

Another issue that arose was that of system sensitivity. As reported in Reference 2, a minimum RCS of -55 dBsm was measured, but this was not done with routine ease. Some way to improve the signal-to-noise ratio was required. This was done initially by adding a wide-band amplifier at the output of the synthesized source. This was a low-noise amplifier and strictly speaking would have been better employed at the output of the receive antenna, but we deliberately avoided placing it there in order not to overdrive the receive mixer, which can handle only 30 mW before damage occurs. A simple and less complicated way to increase the signal-to noise ratio would be to put the receive antenna on the end of the boom, and mount the transmit antenna on the wall of the chamber near the equipment. This would mean that the transmit antenna to target path would now be slightly longer than the receive antenna to target path, but the difference is insignificant. On the other hand, a tremendous advantage would be realized by
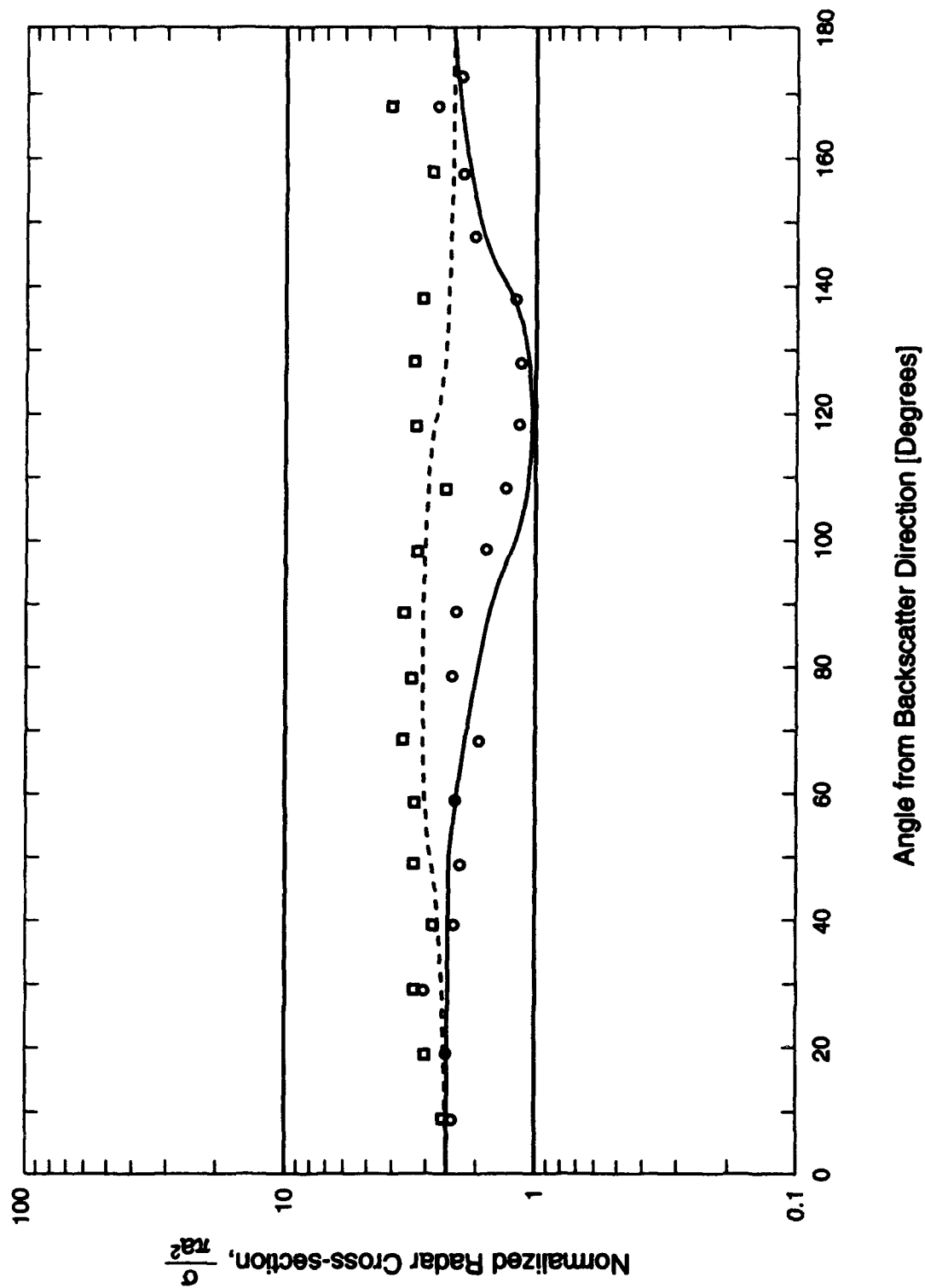
Figure 6. Bistatic Scattering Pattern of Metal Sphere, $ka = 1.33$; normalized RCS at 0° is 2.20 and at 180° it is 2.55; E-plane theory ———, measurements ooo ; H-plane theory · · · · , measurements □□□ .
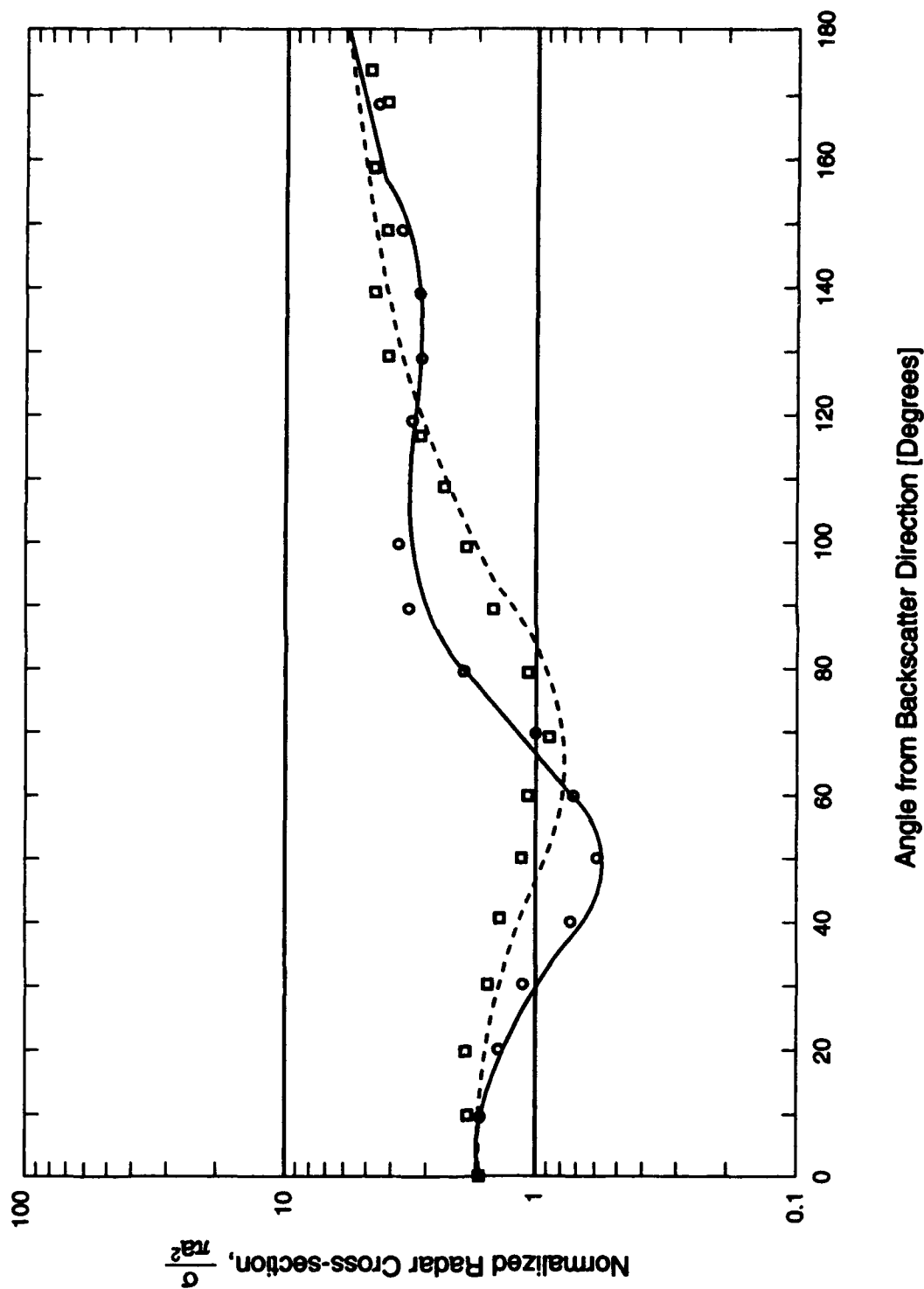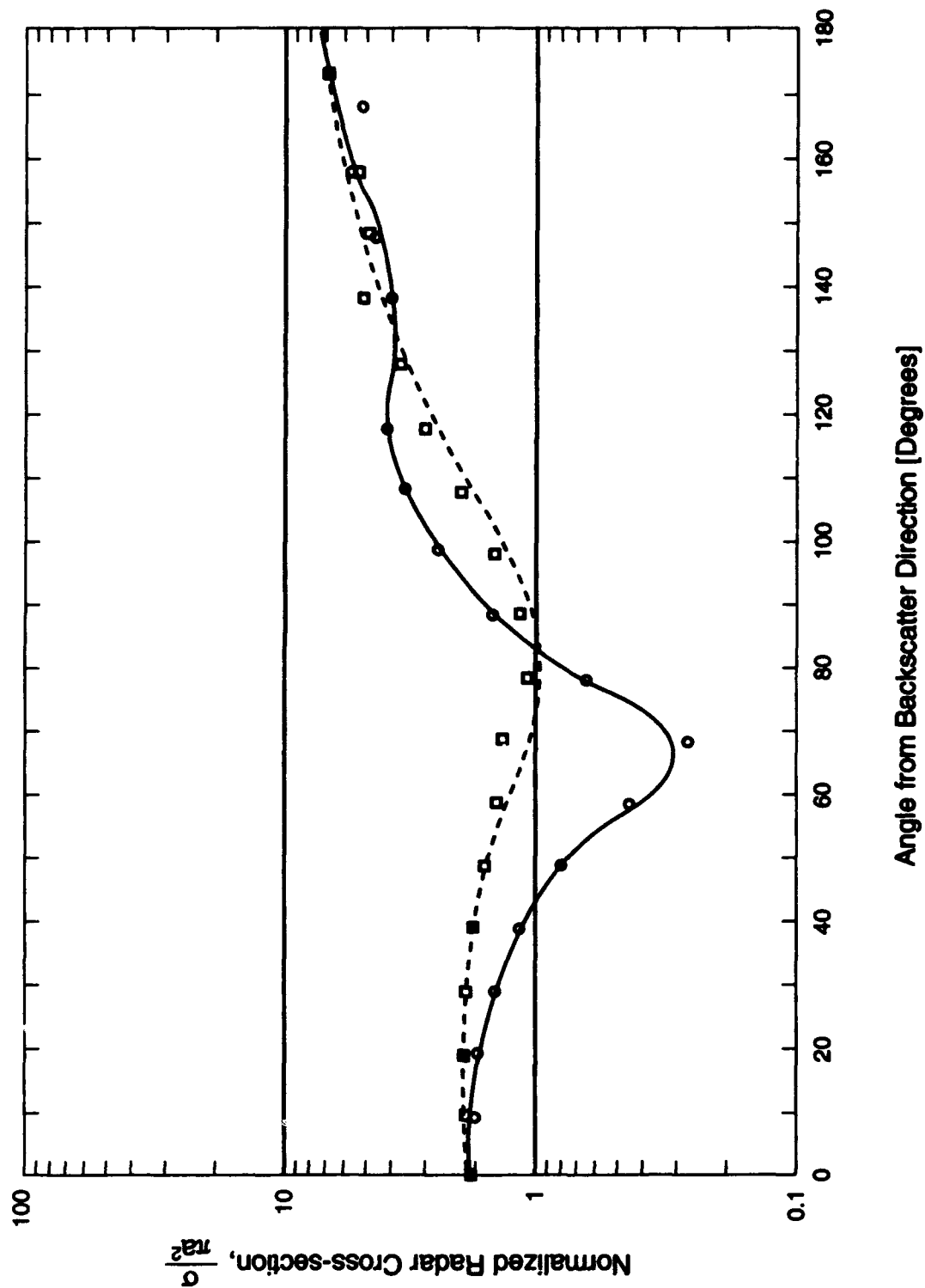
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Figure 7. Bistatic Scattering Pattern of Metal Sphere, ka = 2.16; normalized RCS at 0° is 1.7 and at 180° it is 6.00; E-plane theory ———, measurements ooo ; H-plane theory ····, measurements □□□ .

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Figure 8. Bistatic Scattering Pattern of Metal Sphere, ka = 2.49; normalized RCS at 0° is 1.74 and at 180° it is 7.5; E-plane theory ———— , measurements ⚪⚪⚪ ; H-plane theory - - - - , measurements ▢▢▢ .
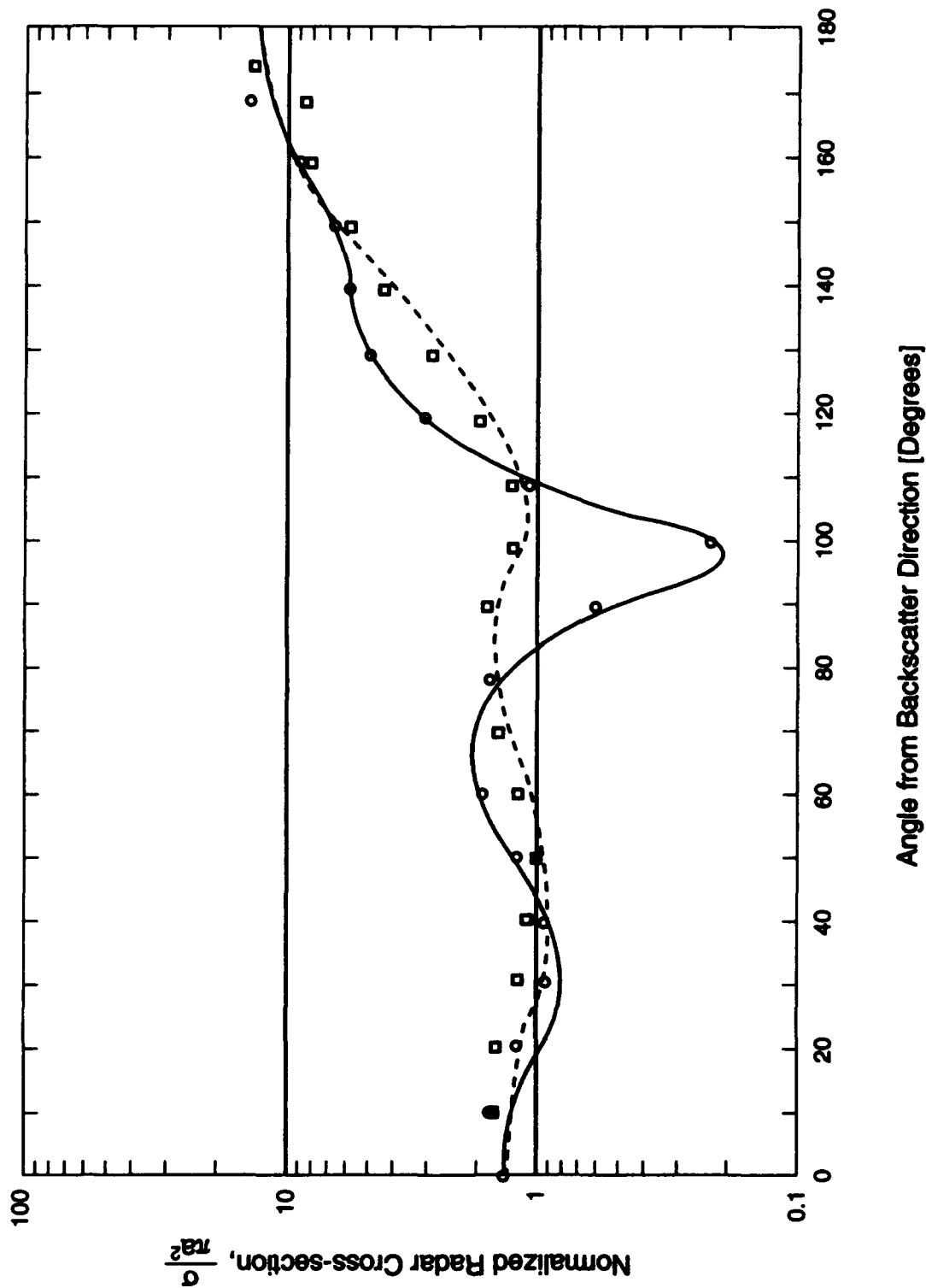
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Figure 9. Bistatic Scattering Pattern of Metal Sphere, ka = 3.33; normalized RCS at 0° is 1.26 and at 180° it is 13.01; E-plane theory ———, measurements ooo ; H-plane theory ----, measurements □□□ .

Figure 10. Bistatic Scattering Pattern of Metal Sphere, ka = 3.99; normalized RCS at 0° is 0.80 and at 180° it is 18.57; E-plane theory ———, measurements ooo ; H-plane theory · · · · , measurements □□□ .

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**Figure 11. Bistatic Scattering Pattern of Metal Sphere, ka = 5.16; normalized RCS at 0° is 0.90 and at 180° it is 29.76:
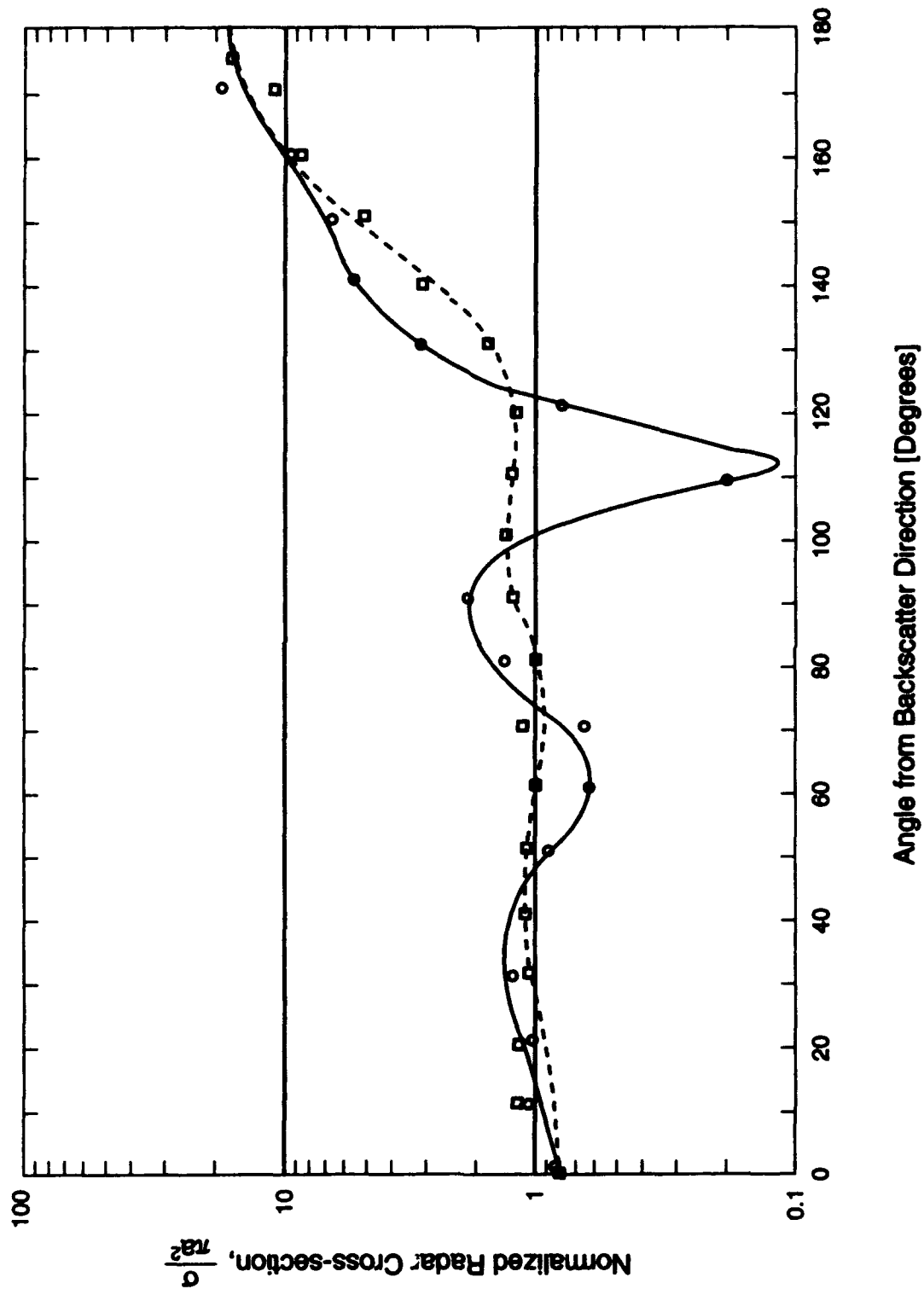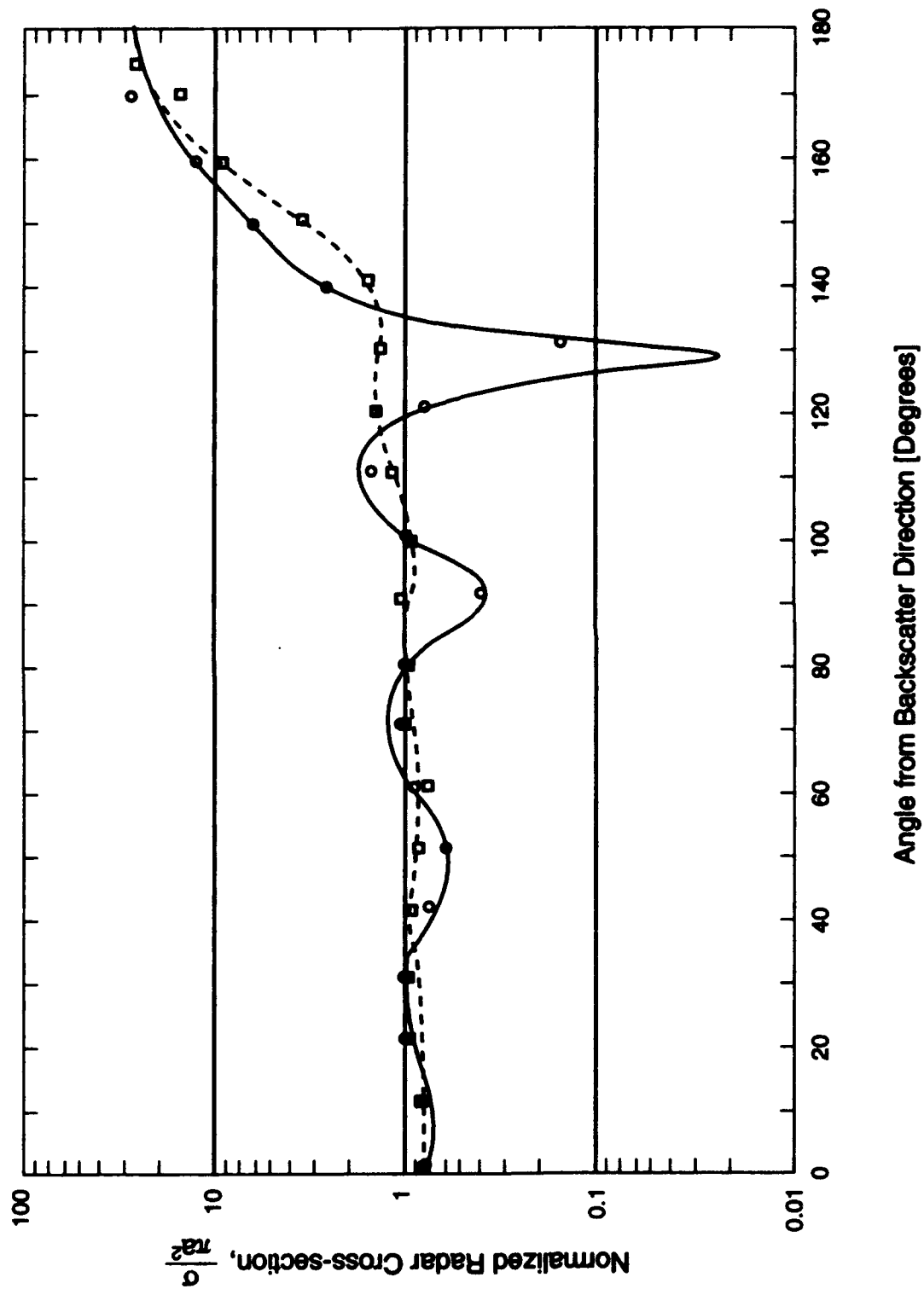E-plane theory ———— , measurements ○○○ ; H-plane theory · · · · , measurements □□□ .**

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Figure 12. Bistatic Scattering Pattern of Metal Sphere, ka = 6.65; normalized RCS at 0° is 0.80 and at 180° it is 48.37; E-plane theory ——, measurements ooo; E-plane theory ·····, measurements □□□.

eliminating the long transmission path under the absorber, through the (probably somewhat lossy) rotary joint, and out to the end of the boom. By putting the receive mixer and receive antenna at the end of the boom, only the IF signal will have to traverse the long path just described. This change is contemplated for future versions of this bistatic measurement system.

As noted previously in this report, this is a SBFA, or a swept bistatic fixed aspect angle system. As such, it is ideal for providing the types of bistatic measurements that are most useful for validating theoretical results on canonical shapes, namely the scattering behavior as the bistatic angle is varied. It cannot, however, easily obtain the types of measurements provided by most large, outdoor, full scale ranges, that is those at constant bistatic angle, swept aspect angle. To more easily do this, in order to compare measurements directly with those from other ranges, it would be desirable to add a FBSA mode. This could easily be done by mounting a second azimuth positioner above the center of rotation of the present SA 53150 positioner, in such a way that this second positioner remains stationary when the boom is moved. When the target is mounted on the second azimuth positioner, target and boom movements become independent.

This two-positioner arrangement would allow operating in the FBSA mode, by moving the boom to a given bistatic angle with positioner number one, and then using positioner number two to rotate the target in aspect angle. The addition of the second positioner would allow various measurements to be made at different aspect angles without entering the chamber. The utility of this mode would depend on the stability of the background, and may be impractical.

Another topic to be considered in future work is range gating. Although the manual nulling technique is accurate it is tedious and sometimes inexplicably balky. In addition, it depends upon the First Born Approximation criterion being satisfied, namely that the background fields in the chamber be essentially unchanged when the target is in place. For large targets it is not clear how well this criterion is satisfied. Due to the aforementioned unfortunate but necessary placement of the target relatively close to the chamber wall, it is highly likely that there are reflections from the walls with the target in place that are not there when the target is absent. Such reflections are not canceled by the nulling process, and may have undesired and unpredictable effects on the measurements. One way to eliminate this particular error is to place a range gate in the receiver so the energy coming from locations other than the target is rejected. This is a well-known technique and should be seriously considered.

The final and perhaps most obvious modification to this range is to permanently automate it. As noted in Section 2.2, the range was temporarily automated by borrowing the computer, receiver and positioner controller from the briefly available SA 2020 Antenna Measurement System. Some measurements were made, with results encouraging enough to plan to permanently automate. The problems that arouse during this test phase indicated that although automating would eliminate some problems, others would be introduced that will require careful attention.

For example, automating will eliminate the need to null the background, since the background signal can be measured and recorded on some storage media, to be vectorially subtracted later from the target plus background measurement. However, due to the maximum sampling rate of the receiver a finite and considerable length of time is required to sweep the boom over the desired range of bistatic angles. By the time one has performed the last of the background, unknown, and calibration runs, the background may well be quite different from what it was at the start. Special techniques may have to be developed to handle this.

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Other issues that must be addressed include positioner repeatability from sweep to sweep, receiver sampling times, possible boom vibration, and data storage. Nevertheless, automation showed enough promise that equipment to do so was procured, a Hewlett-Packard 9860 computer, a SA 1870 programmable receiver, and an Interface Engineering 538-1 positioner controller. It is expected that range automation with this equipment is the next logical step.

In summary, a swept bistatic fixed aspect angle bistatic measurement system has been designed, built, and tested. The system is capable of measuring over bistatic angles from 10 degrees to 175 degrees, at frequencies from 2 GHz to 40 GHz, although target size is limited above approximately 15 GHz. Sample measurements on perfectly conducting spheres were presented. A preliminary test of automation was conducted and equipment procured for permanent automation. Suggestions for future modifications including range gating and fixed bistatic swept aspect angle measurements were discussed.

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1. Skolnik, M. (1970) *Radar Handbook*, McGraw Hill Book Company, Inc., New York.

2. McGahan, R.V. (1983) *Scattering Experiments at the Ipswich Electromagnetic Measurements Facility: Calibration With Perfectly Conducting Spheres*, RADC-TR-83-181, AD A138028.

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