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# Description and Operation of a Microwave Reflectance Measurement System

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## DESCRIPTION AND OPERATION OF A MICROWAVE REFLECTANCE MEASUREMENT SYSTEM

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### ABSTRACT

A recent effort at the NASA Lewis Research Center (LeRC), Microwave Systems Laboratory has been to develop the capability to perform farfield reflectance measurements. This effort has resulted, to date, in a system that can perform X-Band, monostatic, measurements of test objects. This report describes the system and the measurement procedure. Data is presented which assists in the evaluation of the quality of the measurements obtained with the system.

### INTRODUCTION

A recent effort at the NASA Lewis Research Center (LeRC), Microwave Systems Laboratory has been to develop the capability to perform farfield reflectance measurements at X-Band. To accomplish this goal, a compact range measurement system has been developed for use within the Near-Field Facility. The purpose of this report is to describe the system and its use. This system utilizes an offset fed, parabolic reflector in conjunction with a specially designed corrugated horn feed (refs. 1 and 2). The reflector system produces a quiet zone which is roughly circular in cross section, with a diameter that is on the order of 30 cm (-1 dB amplitude taper criterion). The amplitude ripple within this quiet zone is on the order of a few tenths of a dB. The small quiet zone (5 percent of the aperture area), and the ripple levels are the result of under illumination of the reflector to reduce edge diffraction. The size, however, is sufficient to meet the requirements of this particular system. Measured data, using standard targets, will be compared to theoretical predictions in order to demonstrate the performance of the system.

The Near-Field Facility is primarily a facility for antenna testing (ref. 3). The system being reported here represents an experimental arrangement that can be set up within the facility. Therefore, a secondary objective of this report is to document the hardware configuration and to describe the experimental procedure that has been developed for the system. This will assist in the future when the Near-Field Facility is reconfigured for reflectance testing.

### SYSTEM DESCRIPTION

A photograph of the Near-Field Facility, in the reflectance measurement configuration, is shown in figure 1. The reflector and feed are mounted on the antenna test pedestal of the near-field range. The mount is an azimuth

over elevation type of pedestal and it can be used to provide accurate alignment of the reflector system. Target support is provided by the white, polystyrene foam column shown in the photograph. The column is placed on top of a turntable which provides azimuth rotation as well as adjustments for leveling the column. Rotation of the turntable is produced by a Klinger Scientific Corporation, RT 120 PP rotational stage with a stepping motor drive. The rotational stage allows targets to be positioned with a resolution of  $0.01^\circ$ . To accommodate reflectance testing, the near-field probe has been removed from the probe cart assembly. The probe is replaced by a shelf which holds the target support system. This arrangement allows the near-field scanner assembly to set the horizontal and vertical position of the target. When combined with the laser positioning system of the scanner (ref. 3), precise placement of the target, within the quiet zone, can be achieved. When in position, the top of the target support column is approximately 25 ft above the floor. Therefore, targets are put in place either by lowering the scanner or by climbing a mobile platform that can be rolled into the test area.

A schematic of the instrumentation used for the reflectance testing is shown in figure 2. The system uses as a receiver, the HP8510B Network Analyzer that is being implemented in the Near-Field Facility receiver upgrade (ref. 4). The system uses the HP8340B synthesizer as the RF source and the HP8511A test set. To keep the RF transmission lines as short as possible, the synthesizer and the test set are placed in the test chamber near the feed horn. The reflector support truss provides ample space to hold this equipment. All RF lines use 0.141 in. semi-rigid cable except for the line connecting the coupler to the feed. This is a 6-ft length of low loss flexible cable. Because of the distance between the reflector and the control room, the test set IF interconnect is an HP08510-60104 which is 40 ft in length. The connections between the network analyzer and the synthesizer use 50-ft sections of RG-58 while the connection between the HP-IB extenders use a 50-ft length of RG-59.

The measurement is controlled by an HP9000 236 computer which is located in the control room. The computer commands the HP8510B over the HP-IB interface bus. The HP8510B then directs the other instruments over the 8510 interconnect. The computer also commands the Klinger CC1.1 Stepping Motor Controller over the bus. The computer is also used to process and store the measured data. Data can be plotted through the HP8510B to the HP7475A plotter.

#### PROGRAM DESCRIPTION

RADAR7 is the current version of the program that was written to operate the reflectance measurement system. The program was written in HP BASIC version 3.0. The binary files that are required by the program, which are loaded in when the computer is booted, are listed in table I.

TABLE I. - BINARY FILES REQUIRED BY RADAR7

| Filename | Version | Description               |
|----------|---------|---------------------------|
| GRAPH    | 3.0     | Graphics                  |
| GRAPHX   | 3.0     | Graphics Extensions       |
| IO       | 3.0     | I/O                       |
| MAT      | 3.0     | Matric Statements         |
| PDEV     | 3.0     | Program Development       |
| KBD      | 3.0     | Keyboard Extensions       |
| CLOCK    | 3.0     | Clock                     |
| MS       | 3.0     | Mass Storage              |
| ERR      | 3.0     | Error Messages            |
| HPIB     | 3.0     | HPIB Interface Driver     |
| GPIO     | 3.0     | GPIO Interface Driver     |
| DCOMM    | 3.0     | Datacomm Interface Driver |
| CRTB     | 3.0     | Bit-mapped CRT Driver     |
| CRTA     | 3.0     | Alpha CRT Driver          |

The program enables the measurement system operator to control the equipment through a series of soft key menus. After execution of the program has begun, the Main Menu appears on the screen as shown in table II.

TABLE II. - RADAR7 - MAIN MENU

|            |         |      |         |      |
|------------|---------|------|---------|------|
| POSITIONER | MEASURE | DATA | PROCESS | PLOT |
|            |         |      |         | QUIT |

These are the current soft key labels. Each label represents another menu which allows the operator to control the measurement equipment or the data. Each menu is accessed by pushing the corresponding soft key on the keyboard. The Positioner Menu controls the setting and adjustment of the Klinger controller and the turntable. The Measure Menu permits the setting of the various parameters for the measurement and initiates the measurements. The Data Menu is for storage and transfer of each data set. The Process Menu performs various types of processing of the data sets and the Plot Menu plots the data on the screen of the computer. Quit exits the program. A detailed description of each menu and each key in the menus is given below.

A view of the screen when the Positioner Menu appears is shown in table III. POSITION allows the operator to set the position of the turntable. When the key is pressed, the operator is prompted for the target position. Once the position is entered, the positioner controller moves the turntable to that position. After the motion is completed, program control returns to the Positioner Menu. MAX SEARCH has not been implemented at this time, but it is intended to automate the search for a scattering maximum. This would assist

TABLE III. - RADAR7 - POSITIONER MENU

|           |            |       |       |            |
|-----------|------------|-------|-------|------------|
| POSITION  | MAX SEARCH | + JOG | - JOG | SET ORIGIN |
| TO ORIGIN | READ RCVR  |       |       | MAIN MENU  |

in the alignment of targets. The + JOG key rotates the turntable in the forward direction by a small increment. Currently the increment is set to  $0.01^{\circ}$ . The - JOG key rotates the turntable in the negative direction. The SET ORIGIN key allows the current position of the turntable to be reset to  $0.00^{\circ}$ . TO ORIGIN returns the turntable to the origin ( $0.00^{\circ}$ ) from the current position. READ RCVR reads the receiver to obtain the scattering of the target at the center frequency (10 GHz) and it reads the positioner controller to obtain the current aspect angle. The angle (in deg), the amplitude (in dB) and the phase (in deg) are displayed on the screen. This option is valuable for aligning targets. MAIN MENU returns control to the Main Menu.

When the MEASURE key is pressed from the Main Menu, the Measure Menu appears as shown in table IV.

TABLE IV. - RADAR7 - MEASURE MENU

|        |              |              |            |              |
|--------|--------------|--------------|------------|--------------|
| SET CW | SET FR. SCAN | SET AZ. SCAN | FREQ. SCAN | AZIMUTH SCAN |
|        |              |              |            | MAIN MENU    |

When the SET CW key is pressed the operator is prompted to enter the frequency for CW operation. After the operator enters the frequency in GHz, the program sets the measurement system for CW operation at that frequency. This key is used mainly for target alignment. The SET FR. SCAN key asks the user to supply the frequency range for the measurement. The operator is prompted for the start frequency, stop frequency and the number of measured points to be taken in that interval. Note this information must be given for both frequency scan measurements and for azimuth scan measurements. It must be given before the initial measurement but is not necessary to enter this information for each measurement if the frequency range and number of points is kept the same. The SET AZ. SCAN key allows the operator to set the starting angle, ending angle and angle increment for an azimuth scan measurement. The operator is prompted for each. The FREQ SCAN key performs the swept frequency measurement and the AZIMUTH SCAN key performs the azimuth scan measurement. After each key in the menu has completed its particular function, control of the program returns to the Measure Menu. The MAIN MENU key returns control to the Main Menu.

The Data Menu is accessed from the Main Menu by pressing the DATA key. The menu appears on the screen as shown in table V. After a measurement, the program reads the network analyzer and stores the data in an internal array.

TABLE V. - RADAR7 - DATA MENU

|            |               |              |             |            |
|------------|---------------|--------------|-------------|------------|
| Store data | Write freq.   | Read freq.   | Send data   | Read exact |
|            | Write azimuth | Read azimuth | Write Ascii | MAIN MENU  |

The data remains in the array until another measurement is taken at which time the data is lost. To save the data, it must be stored to another internal array or written to permanent storage. The Store data key allows the data to be stored to another array, mainly so that the data can be processed once the complete measurement set has been taken. After the Store data key is pressed, the menu shown in table VI appears. Pressing a key will write the current measured data to an internal array corresponding to the key label. REFERENCE is the

TABLE VI. - RADAR7 - STORE DATA MENU

|           |           |        |           |  |
|-----------|-----------|--------|-----------|--|
| REFERENCE | REF. BKG. | TARGET | TAR. BKD. |  |
|           |           |        |           |  |

array for a measurement of a reference target. REF. BKG. is the background measurement of the reference. TARGET is the measured data of the target and TAR. BKG. is the background of the target. After a key is pressed and the data stored, control returns to the DATA Menu.

Returning to the description of the Data Menu, the Write freq key writes the data from a frequency scan to the floppy disk drive 0, which is the drive on the right-hand side of the machine. The computer prompts the user for a filename under which to store the data. After the file is written, control returns to the Data Menu. The Read Freq. key reads a frequency scan file from the disk in drive 0. A list of the files contained on the disk is presented and the user is prompted for the name of the file that is to be read. This data is read into the same array that is used for current data. Therefore it must be stored elsewhere if it is to be used for later processing in the program. The Send Data key converts processed data into a format compatible to the network analyzer. The program then sends the data back to the network analyzer. Operation of this key allows the time gating and plotting features of the HP8510B to be used on data that has been processed. The Read Exact key allows the operator to read into the program a file containing the theoretical scattering data of a reference target. The screen displays the files on the disk in drive 0 and then prompts the operator for the desired filename. The file is read and stored in array that is used exclusively for the exact data information. The Write azimuth key writes the data from an azimuth scan to the disk in drive 0. The user is prompted for a filename. Read azimuth displays the directory information for the disk in the drive 0 and prompts the user for the azimuth scan file to be read. The data is stored internally in the current data array. The Write Ascii key writes the data from the current array to the disk drive 0 using the Ascii format. The users is prompted for the filename to be used. This option is included in the program to enable the data to be sent to other computers. Finally, the Main Menu key returns program control to the Main Menu.

The Process key on the Main Menu presents the operator with the Process Menu. The Process Menu appears as shown in table VII. The purpose of the Process Menu is to allow certain mathematical processing of the data that has been stored in the arrays via the Store Data key in the Data Menu. For each

TABLE VII. - RADAR7 - PROCESS MENU

|          |            |      |  |           |
|----------|------------|------|--|-----------|
| SUBTRACT | REL TO REF | DBSM |  |           |
|          |            |      |  | MAIN MENU |

option in the Process Menu, after the processing is complete, the processed data is stored in an new array that is different than the raw data array. The SUBTRACT key presents the operator with the screen shown in table VIII.

TABLE VIII. - RADAR7 - SUBTRACT MENU

|             |          |  |  |  |
|-------------|----------|--|--|--|
| TAR-TAR_BCK | REF-REFB |  |  |  |
|             |          |  |  |  |

The TAR-TAR\_BCK key performs the operation,

$$\text{target data} - \text{target background data} \quad (1)$$

while the REF-REFB key produces,

$$\text{reference data} - \text{reference background data.} \quad (2)$$

After this processing is completed, program control returns to the Process Menu. The REL TO REF key performs the operation,

$$\frac{\text{target data} - \text{target background data}}{\text{reference data} - \text{reference background data}} \quad (3)$$

The operation produces the scattering levels of the target relative to the reference. The DBSM key generates,

$$\frac{\text{target data} - \text{target background data}}{\text{reference data} - \text{reference background data}} * \text{exact data.} \quad (4)$$

which gives the scattering of the target in same units as the exact data. Generally, these units are in dB relative to a square meter (dBsm). A target that scatters 0 dBsm, implies that the target reflects an amount of energy, to the antenna, that is equivalent to the energy contained in a one square meter cross section of the incident field. The MAIN MENU key returns program control to the Main Menu.

The PLOT key in the Main Menu gives the operator access to the Plot Menu which is shown in table IX.

TABLE IX. - RADAR7 - PLOT MENU

|          |          |  |  |           |
|----------|----------|--|--|-----------|
| AZ. SCAN | FR. SCAN |  |  |           |
|          |          |  |  | MAIN MENU |

The AZ. SCAN key displays the azimuth scan pattern of the target, at the center frequency, on the screen. The FQ. SCAN key plots the processed data from a frequency scan measurement of the target, on the screen. The MAIN MENU key returns program control to the Main Menu.

#### MEASUREMENT PROCEDURE AND EXAMPLES

In general, the Near-Field Facility is in the antenna testing configuration. This is advantageous to reflectance testing for it allows the quiet zone of the reflector system to be probed prior to the change over to the reflectance test configuration. Such probing ensures that the antenna is operating appropriately and that it is pointed in the proper direction. Probing also identifies the quiet zone location with respect to the laser positioning system. Correct alignment of the reflector is determined by observing the near-field phase of the antenna. The phase pattern from a centerline horizontal or vertical scan should be examined for flatness. If the phase pattern of the antenna has a slope to it, then the position of the antenna needs to be corrected. The relationship between the slope of the phase pattern and the pointing error is given by,

$$\sin(\theta) = \frac{m\lambda}{360^\circ} \quad (5)$$

where  $m$  is the slope in deg/m,  $\lambda$  is the wavelength in meters, and  $\theta$  is the angle by which the reflector must be rotated. The horizontal scan phase pattern indicates the azimuth alignment of the reflector. The vertical scan is used for elevation alignment. Examination of the phase patterns should alternate between a vertical and horizontal scans until the phase patterns for each become flat. This will ensure that the correct pointing of the antenna is converged upon.

Once the reflector antenna has been aligned, the boresight and hence the center of the quiet zone can be determined. The boresight is found by examining the amplitude patterns of the reflector, again from horizontal and vertical scans of the near-field. Ideally, the center of the quiet zone would be at the point of maximum amplitude in each pattern plane. However, at some frequencies, the patterns do not have well defined maximums. Therefore, a more reliable technique is to choose some level below the maximum, such as -2 dB. Then find the location of that point on each side of the maximum and define the center to be the average of the two positions. Once the center has been defined in one plane, the scanner should be set to that position and the other plane scanned. The combination of the two centers define the location of the quiet zone and the displays of the laser positioning system should be read and recorded. During the reflectance measurements, the targets will be positioned in the center of the quiet zone using the near-field scanner.



The next step is to reconfigure the Near-Field Facility for reflectance testing. The equipment is to be arranged as indicated in figure 2. The scanner is sent to the "home" position for easy access to the probe. To prepare the target area, the near-field probe is removed from the probe cart and replaced with the target shelf. The turntable pedestal is centered on the shelf and leveled using the leveling screws. Then, the polystyrene column is fastened to the turntable using double-coated tape. The top of the column should be checked to be sure that it is level. Adjustments can be made with the leveling screws.

With the target support column in place, the scanner is moved to place the target area in the center of the quiet zone. The horizontal position of the scanner remains at the position that was read before from the laser display. The vertical position must take into account the height of the pedestal. For example, with the 4-ft column and the offset of the target shelf, the top of the column is 1566.66 mm above the location that the probe was at during the near-field test. Therefore, if the vertical position of the quiet zone center was defined to be 2500 mm, then the cart must be placed at 933.40 mm to position the top of the column. Further lowering of the cart must be done to account for the height of a particular target. The placement and alignment of the target occurs after the correct position for the scanner and support column has been established.

To determine the radar cross section (RCS) of a particular target, four measurements are required. They are measurements of the target, target background, reference target, and the background for the reference target. Two backgrounds are required because generally, the fixtures to hold the target and the reference are different. After each measurement, the data from the measurement is saved to a disk and stored internally to the proper data array. Following completion of the final measurement, the exact file for the reference target is read and stored in the exact array. Then, from the Process Menu, the DBSM operation is performed. The processed data is sent to the network analyzer in order to take advantage of the time domain options of the HP8510B. These options allow the operator to set up a software gate around the response of the target in the time domain. The gate is a software filter that allows signals outside of the gate to be removed while preserving those inside the gate. Turning the gate on suppresses the unwanted clutter and greatly improves the accuracy of the measurement. The gated response is then viewed in the frequency domain and can be plotted to paper using the copy menu on the network analyzer.

As an example of this measurement process, consider figure 3. This plot compares the measured and exact radar cross section of a 3.187-in. diameter sphere. In the measured data, the time gating and background subtraction have been employed. A 6-in. diameter sphere was used as a reference target. The gated and ungated time domain response of the 3.187-in. sphere are shown in figure 4. The figure shows the clutter suppression enabled by the gate. The gate span and center are indicated by the markers in the figure. The advantage of using the gating and removing the clutter is shown in figure 5. This figure compares the gated and ungated RCS of the sphere. The figure makes apparent the advantages of using the gating capabilities of the network analyzer.

The theoretical and experimental results for another target are shown in figure 6. In this case, a flat metal plate was tested. The dimensions of the plate were 5 in. high by 8 in. wide. The theoretical results were computed by using a method of moments technique. As shown in the figure, the agreement between the experimental and theoretical is within 1 dB. Although this is good agreement, the comparison is not as good as that which was demonstrated in the case of the sphere. The reason is that the plate is a larger target and the experimental results are beginning to show the effect of the amplitude taper in the quiet zone. This consideration must be kept in mind when viewing measured results of targets. The estimated size of the quiet zone of this system is given in reference 2.

The other type of scattering measurement that can be performed with this system is an azimuth scan. This scan is the scattering of a target as the target is being rotated. This measurement also takes advantage of the time domain gating capabilities of the network analyzer. However, in order to avoid excessive acquisition time, the network analyzer is operated in the ramp sweep mode instead of the step sweep mode. The HP8510 manuals can be consulted for a discussion of the step mode and the ramp mode. After the target has been set in place and aligned, the operator obtains local control of the network analyzer and views the target response in the time domain. The time domain gate is set to the center of the target, The span is set to be wide enough to encompass the response of the target at all intended azimuth angles. The gate is then turned on.

As the azimuth scan begins, the computer directs the pedestal to rotate the target to the starting angle. The network analyzer is commanded to take the ramp mode measurement. After the measurement is complete, the computer waits a few seconds for the network analyzer to complete the gating operation. Once the operation has been completed, the computer reads and stores the gated data in an array. The pedestal is then directed to the next azimuth angle and the measurement at that point is taken. The process continues until the measurement is completed at the final azimuth angle. The target is returned to  $0^\circ$  and the data from the scan is written to the disk. At the present time, the scattering at 21 frequencies within the band is written for each azimuth point.

An example of an azimuth scan measurement is shown in figure 7. The target was an  $90^\circ$  dihedral corner reflector composed of two 8-in. wide by 12-in. high plates. The frequency for the data shown in the figure is 10 GHz. The pattern exhibits the envelope that is characteristic of this type of corner reflector. The lobes which appear at  $0$  and  $90^\circ$  are the returns of the individual faces of the corner reflector. The broad lobe in the middle results from the interaction of the two faces. Here, the incident energy is reflected twice, once from each face. Note that the peak of the broad lobe is approximately 3 dB higher than the peaks of lobes from the individual faces as expected.

#### CONCLUSION

This report has described a system for performing reflectance measurements in the Near-Field Facility at the Lewis Research Center. The components of the system were identified along with a brief description of the software

that controls the system. The procedures used for performing both frequency scans and pattern measurements were given. Experimental agreement with theoretical, can be achieved to within to a few tenths of a dB on smaller targets. The amplitude taper in the quiet zone produces lower RCS levels on the larger targets, however agreement with theoretical is still within 1 dB. Techniques used by the system also produce realistic pattern measurements. Thus it can be concluded that the system can provide accurate measurements of targets that fit within the specified quiet zone size.

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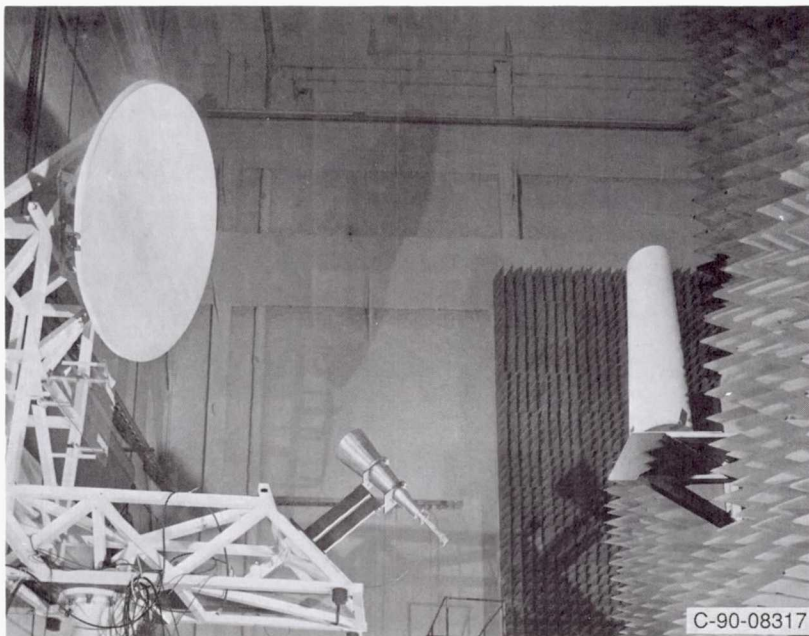


Figure 1.—The Near-Field Facility in the reflectance measurement configuration.

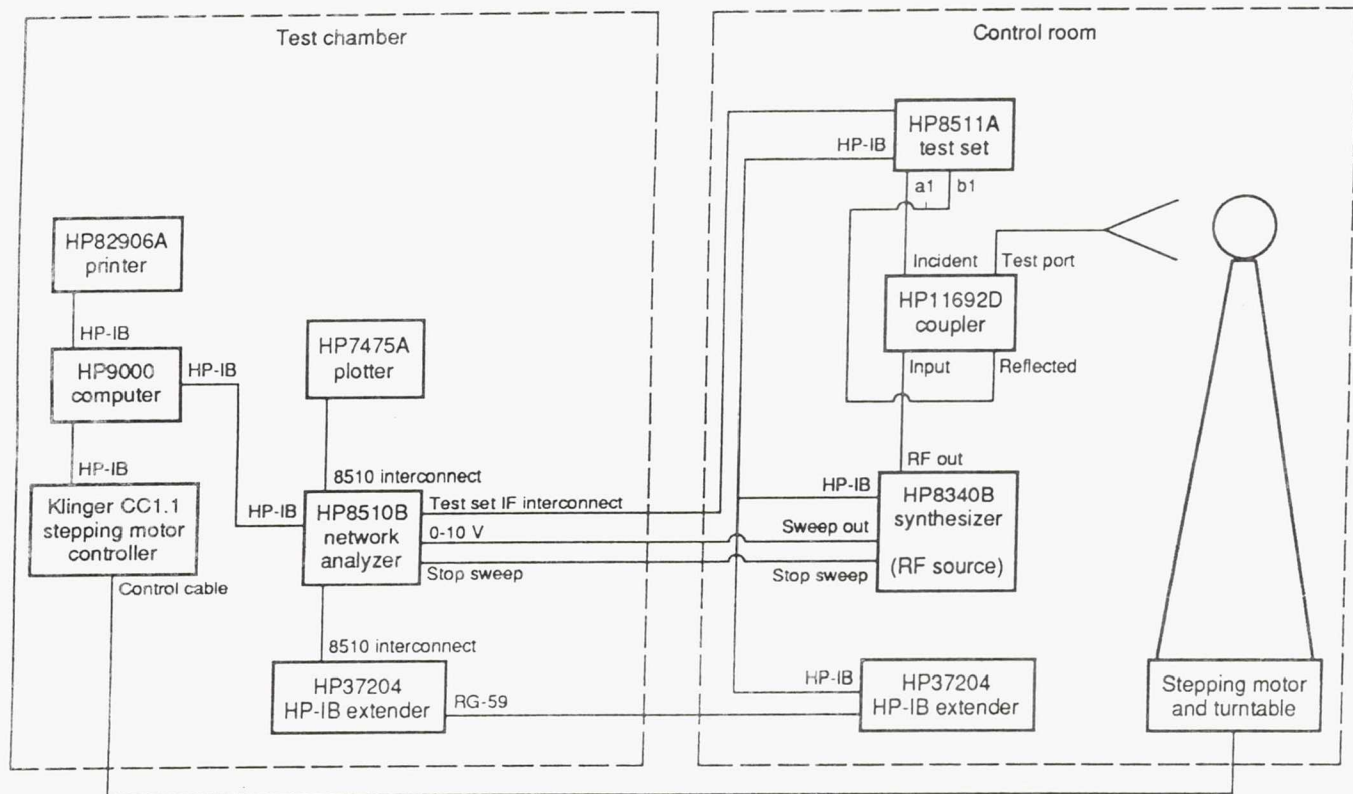


Figure 2.—Block diagram of the reflectance measurement system.

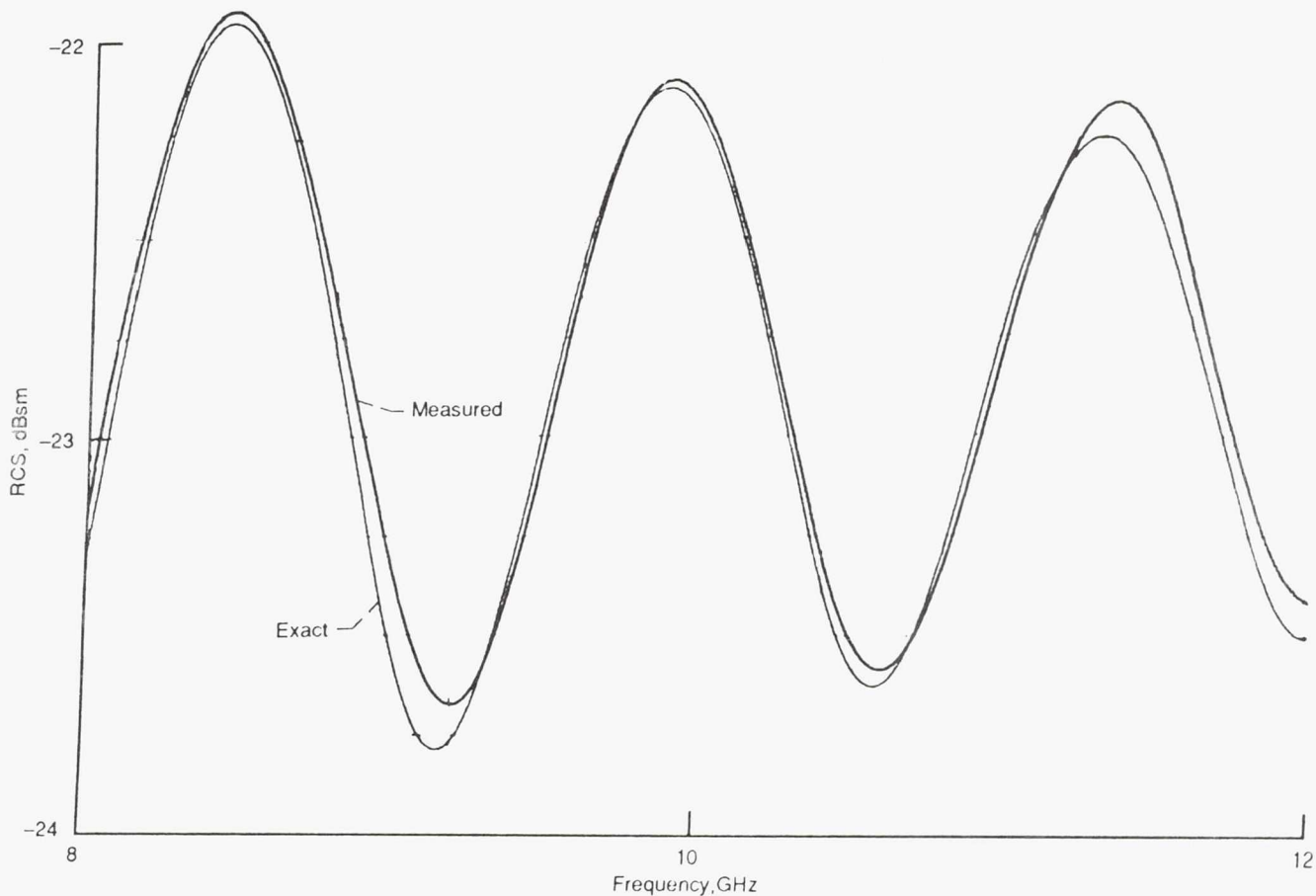


Figure 3.—Experimental and exact RCS of a 3.187 in. diameter sphere.

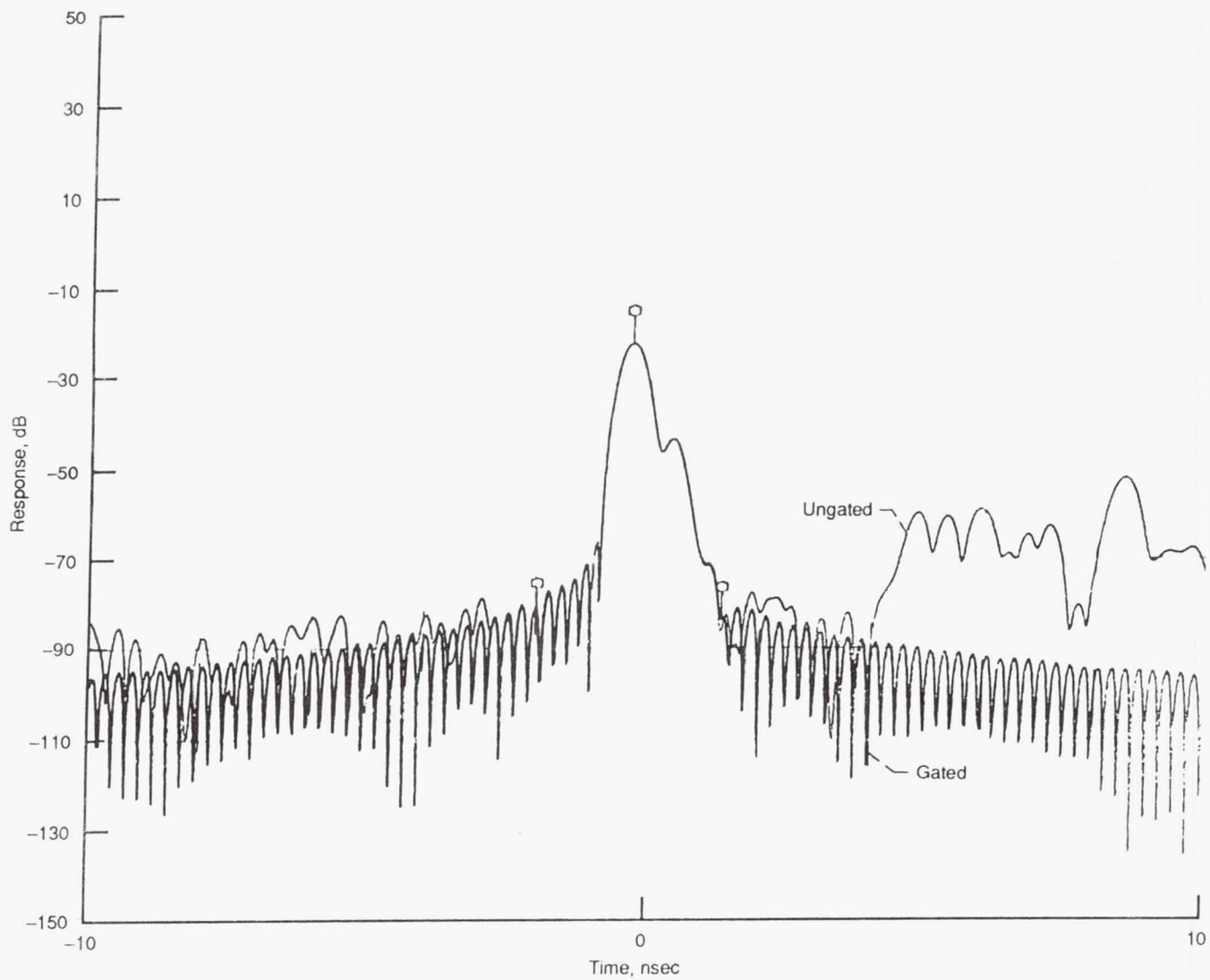


Figure 4.—Experimental time domain response of a 3.187 in. diameter sphere, with and without gating applied.

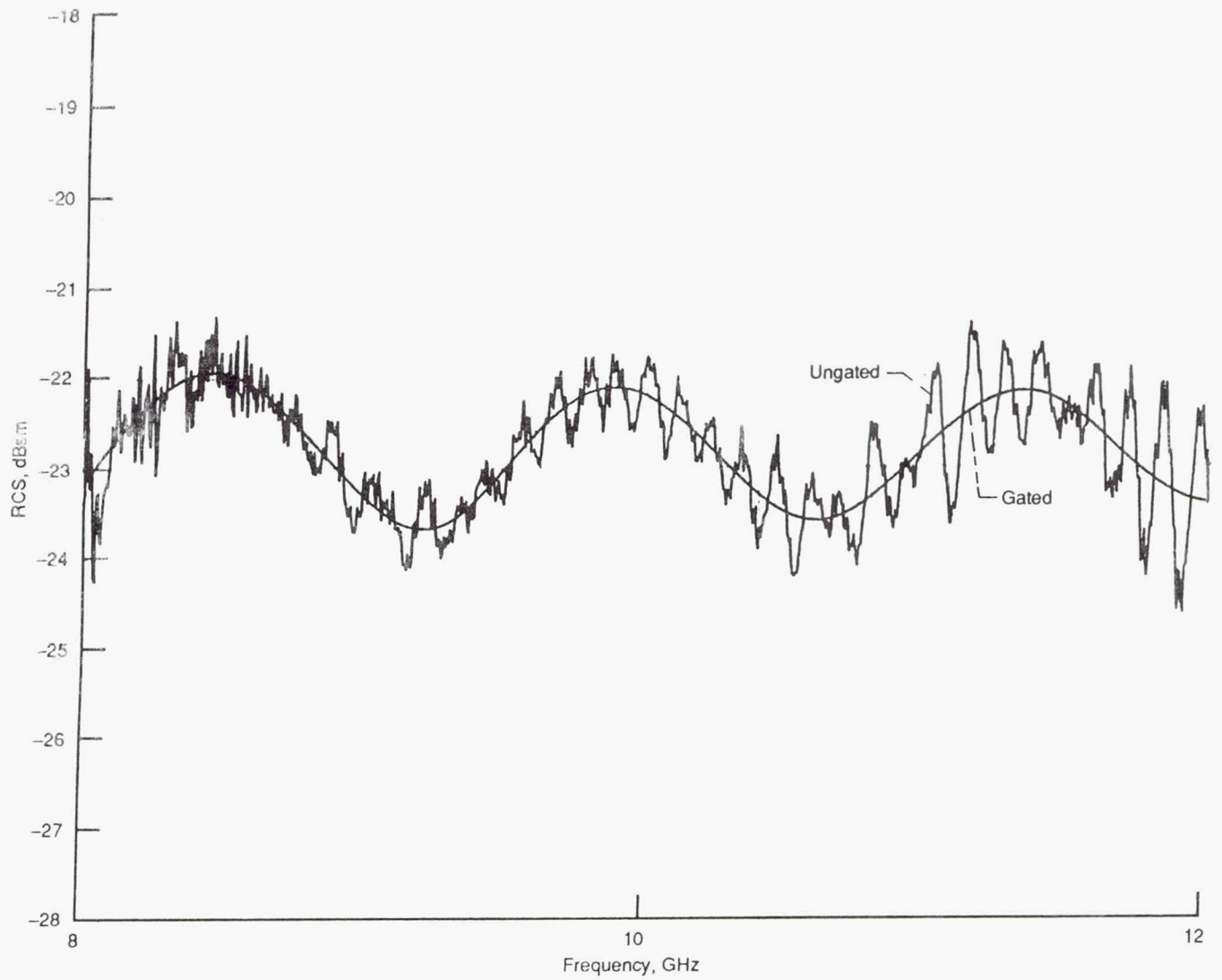


Figure 5.—Experimental RCS of a 3.187 in. diameter sphere, with and without gating applied.

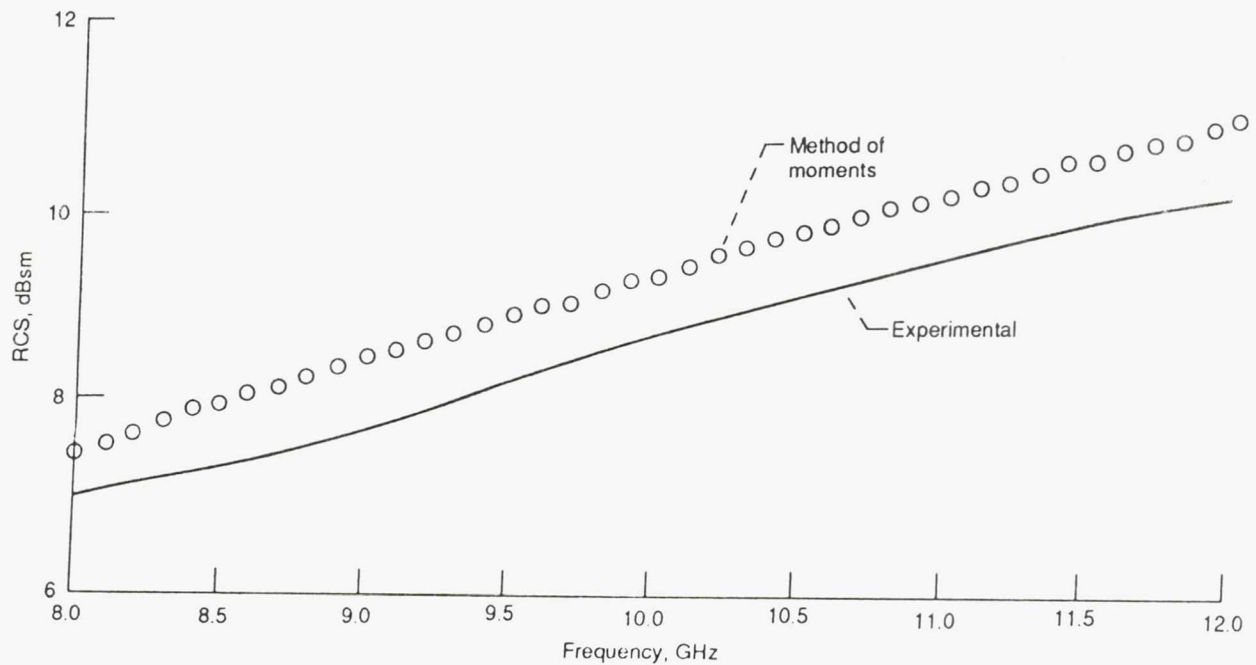


Figure 6.—Experimental and theoretical RCS of a metal plate, 5 in. high by 8 in. wide. Vertical polarization.

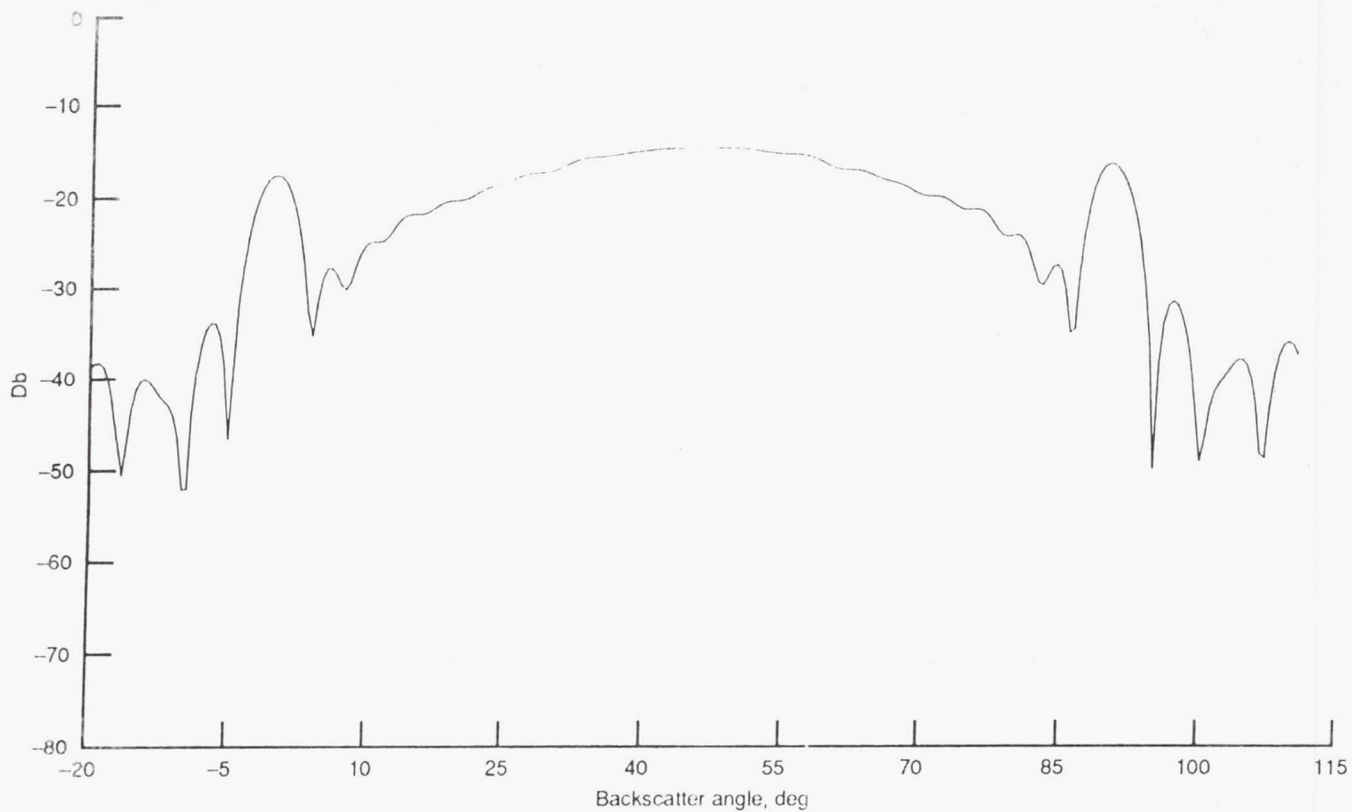


Figure 7.—Relative RCS pattern, measured at 10 GHz, of a 90°, dihedral corner reflector, with faces 8 in. wide by 12 in. high.

|  |  |  |   |   |                   |
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| 16. Abstract<br>A recent effort at the NASA Lewis Research Center (LeRC), Microwave Systems Laboratory has been to develop the capability to perform farfield reflectance measurements. This effort has resulted, to date, in a system that can perform X-Band, monostatic, measurements of test objects. This report describes the system and the measurement procedure. Data is presented which assists in the evaluation of the quality of the measurements obtained with the system. |  |  |   |   |                   |
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