NASA Technical Memorandum 83785

Characteristics and Capabilities of the NASA Lewis Research Center High Precision 6.7- by 6.7-m Planar Near-Field Scanner

G. R. Sharp, R. J. Zakrajsek, R. R. Kunath,
C. A. Raquet, and R. E. Alexovich
Lewis Research Center
Cleveland, Ohio

Prepared for the
Meeting of the Antenna Measurement Techniques Association
San Diego, California, October 2-4, 1984

NASA

CHARACTERISTICS AND CAPABILITIES OF THE LEWIS RESEARCH CENTER HIGH PRECISION 6.7- BY 6.7-m PLANAR NEAR-FIELD SCANNER

G. R. Sharp, R. J. Zakrajsek, R. R. Kunath, C. A. Raquet, and R. E. Alexovich
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-2281

INTRODUCTION

The development of advanced spacecraft communication antenna systems is an essential part of NASA's satellite communications base research and technology program. The direction of future antenna technology will be toward antennas which are large, both physically and electrically; which will operate at frequencies to 60 GHz and above; and which are nonreciprocal and complex, implementing multiple beam and scanning beam concepts that use monolithic semiconductor device technology. The acquisition of accurate antenna performance measurements is a critical part of the advanced antenna research program and represents a substantial antenna measurement technology challenge, considering the special characteristics of future spacecraft communications antennas.

Recognizing the limitations of the conventional far-field approach for testing large, high frequency communications antennas, the Lewis Research Center has built a very precise 6.7 m by 6.7 m planar near-field scanner. This paper describes the characteristics and capabilities of this scanner.

NEAR-FIELD TESTING DESCRIPTION

Although the far-field technique is older and better known, the near-field technique has now become an established testing approach. The near-field technique is a mature technology based on the work over a 20 yr period by several institutions, notably the National Bureau of Standards (Boulder, Colorado) and the Georgia Institute of Technology (Atlanta, Georgia).

In the far-field technique, direct measurements are made of the test antenna response in far-field conditions. However, in the near-field technique, far-field antenna parameters are calculated from phase and amplitude measurements made over a well-defined grid of points in the near-field.

Figure 1 illustrates a planar near-field scanner where phase and amplitude values are measured over a planar N by N grid with a small test probe and recorded. Complete far-field pattern information is calculated for the principal and cross polarized components from the near-field data by a procedure which basically involves performing a discrete Fourier transform of the near-field data for each polarization. Corrections for probe pattern and polarization characteristics can be implemented at this time. The planar near-field data acquisition constraints are that the scanned area must intercept essentially all of the antenna radiation and the scanned area (as described by the motion of the probe tip) must be flat to within a small fraction of a wavelength. Because all measurements are made in the near-field, the antenna and the measurement system can both be located in a controlled indoor environment.

SCANNER DESIGN APPROACH

The near-field antenna testing approach is simplified if the probe moves in a precisely known, controlled, repeatable path. This is especially true in making near-field antenna measurements at extremely high frequencies. Thus, the scanner structure and guide rails need to be very rigid and dimensionally stable over long periods. For a planar near-field scanner, the plane described by the motion of the probe tip must be kept very flat over the test period in order to minimize phase error. An extremely rigid structural/mechanical design constructed from a stable material (steel) was chosen in order to minimize the Z-axis (boresight) electrical phase corrections that would otherwise be required. Simple differential screw adjustments are used for alignment of the rails on which the moving components of the scanner are mounted. Much care had to be exercised regarding phase distortion during hard-line transmission of both the source RF signal and the received RF signal. All RF transmission lines and sources had to be adequately shielded in order to prevent phase and amplitude errors caused by RF power leaks. Laser interferometer systems are used both for X-Y RF probe positioning and for measuring the straightness of the horizontal and vertical guide rails.

SCANNER CHARACTERISTICS

The scanner is presently configured with the RF probe in a receive only arrangement. However, a reciprocal arrangement with the probe as a transmitter is planned for the future and will be used when necessary. The scanner configuration and components and their various degrees of freedom are illustrated on a photograph of a 1/24th scale model (fig. 2). An offset fed reflector antenna is shown in the figure for illustrative purposes. Figure 3 shows the actual scanner testing a 30 GHz experimental multiple beam communications antenna.

Before testing begins, it is generally desirable to position the antenna boresight perpendicular to the vertical scan plane so that the near-field data can be used for antenna diagnostics. The antenna does not have to be moved during the scans. The maximum size of the vertical scan plane (as described by the probe tip motion) is 6.7 m by 6.7 m (22 ft by 22 ft). The probe tip motion describes a plane flat to within 0.005 cm (0.002 in.) rms. This accuracy allows the test frequency to be varied from 0.8 to 60 GHz+ without first order corrections for out of plane errors. Thus, the scanner is capable of scaled antenna testing for antennas having an aperture diameter to wavelength ratios, D/λ, to 1100 for antenna apertures to 5.5 m (217 in.) diameter. These and other scanner characteristics are summarized in Table I.

SCANNER RF SYSTEM

The RF System (see fig. 4 for block diagram) for the near-field scanner is comprised of a signal source near the test antenna, the RF probe, and a dual channel phase lock receiver.

The signal source is located in a shielded box attached to the cart supporting the test antenna positioner; in this manner, most of the RF connections to the test antennas can be made with waveguide.

An RF sample is extracted from the source signal near the output of the shielded RF signal source box and converted down to the reference channel's IF Frequency. The down converted signal is then routed to the receiver via co-ax cable. The RF signal is routed from the RF signal source box to the antenna under test where it is radiated toward the scan plane. The radiated signal is received by a probe of known receiving characteristics on the scanner probe cart. The received signal is then down converted on the cart, routed to the control room via co-ax cable that is attached to a large RF arm (with three rotary joints) and becomes the Signal channel IF signal to the receiver. The receiver then down converts the Signal channel IF and the reference channel IF signal to the frequency needed by the ratiometer and phase meters. These meters convert the amplitude ratio and phase differences to values that are then sent to the computer for processing and recording. This process is done continually while the probe cart is moving for each data point on the scanned grid.

DATA ACQUISITION AND PROCESSING SYSTEMS

The near-field data set is a square matrix of complex field values or equivalently, an amplitude matrix and a phase matrix. The matrix size varies depending upon frequency and the characteristics of the antenna under test, the probe, and the transmitter and receiver. The entire data collection operation is under the control of a Perkin-Elmer 8/32 minicomputer which coordinates the activities of three separate instruments: a Scientific Atlanta (S/A) model 2012 positioner programmer, a S/A model 1823 Phase Display, and a S/A model 1833 Logarithmic Ratiometer.

The method of scanning the planar surface is to perform a raster scan under the control of the minicomputer. At the beginning of each test, parameters such as total scan length, data point spacing, scan speed, and other variables are calculated, and positioning instructions are downloaded to the positioner programmer. When the initialization is complete, the positioner programmer stations the scanner to begin data acquisition. To achieve the accuracy needed in positioning the probe, the positioner programmer is given position information from an HP5526A laser measurement subsystem. This subsystem yields microinch resolution of position by essentially counting interference fringes of helium-neon laser light. The positioner programmer has the ability to scan either vertically or horizontally. Normally, complete data scans are scanned vertically and stepped horizontally while calibration scans are scanned horizontally and stepped vertically. To minimize test times, dual direction scanning is used. However, single direction scanning is an option.

The data acquisition sequence involves coordination of the positioner programmer and of the amplitude and phase meters. The positioner programmer is responsible for moving the probe and outputting record pulses at positions corresponding to data point spacings. The minicomputer monitors the positioner programmer pulses and in response reads the phase and amplitude meters and writes this data to a permanent disk file. Additional information such as testing conditions and test parameters are also written to a permanent disk file. When the scanning is finished, a complete set of amplitude and phase data is available on the permanent disk file for subsequent processing.

Before running a complete two-dimensional test, preliminary centerline scans are acquired. These consist of data from single line scans through the center of the scan plane. From these data, a one-dimensional Fourier Transform is obtained which is representative of the far-field pattern of the antenna under test with the given test parameters. These centerline tests are made and processed to determine the optimum testing parameters for the complete two-dimensional test. The phase measurements in these centerline scans can also be used to align the electrical boresight of the antenna relative to the scanning plane. Any single scan line of a complete two-dimensional test can also be processed using the centerline scan test processing method. All single line processing is done in the facility by the minicomputer.

A complete test consists of two near-field scans, each scan over the full scan plane. Each of these scans is taken with one of two orthogonal polarizations. A discrete Fourier transform is then performed on the data set of each scan. The results, along with the appropriate receiving probe far-field characteristics, are processed to yield full three-dimensional far-field pattern information for each polarization. These two-dimensional data sets are processed by an IBM 370 in Lewis' Research Analysis Center due to the large volume of data and the large arrays required to correct the data for probe characteristics.

SCANNER MECHANICAL SYSTEM

Scanner Structures and Mechanical Adjustments

The flatness of the scan plane as described by the out-of-plane motion (Z-axis - fig. 2) of the RF probe tip is of primary importance. Scan out-of-plane errors will result in proportional phase measurement errors of the transmitted or received wave. The scanning plane flatness goal was to have the plane flat within 0.005 cm (0.002 in.) rms. This is equivalent to a phase error of $\lambda/100$ or 3.6° at 60 GHz.

A structurally very stiff, rigid design was chosen in order to meet this flatness requirement. However, structurally stiff and accurate machines can be extremely heavy and expensive if that accuracy is gained through precision machining. While such accuracy can be gained by a shimming adjustment of the guide rails from a less accurate but very rigid structure, shimming was felt to be very labor intensive and also very demanding of the technicians involved. After considerable study, a rigid structural design was developed in which the rails could be adjusted via multiple differential screws that adjust the rail support brackets.

The resulting rail support structure, horizontal precision rails and horizontal platform are shown in Fig. 5. Figure 6 shows the Thomson V-mounting block roller bearing which supports the scanner platform on the longer of the platform horizontal rails (fig. 5). The rail, rail support bracket and the differential screw arrangement for adjusting the rail are also shown.

Scanner Drive System

The requirements of the scanner drive systems are to:

1. Operate over the full velocity range (table I). Nearly constant velocity is chosen during scanning in order to preclude small errors in the distance over which each data point is taken (each data point is measured over a fixed time period, currently 10 m sec).

2. Stop accurately and hold position during scanning along the perpendicular axis.

3. Start and stop smoothly so as not to excite the vibration resonances of the scanner during test. (For example, a cantilever vibration of the probe tip causes its exact X-Y position to be in error during scanning.

A drive system was needed that had minimal backlash and minimal adverse dynamic excitation of the probe tip. The system chosen had synchronous cogged drive belts (figs. 7 and 8) that were used to reduce the dc motor speed by the selected ratio. These belts had no "dead-band" and nearly zero backlash.

Both the horizontal and the vertical carts were driven via continuous chains. The largest drive sprocket available for the selected chain size was used in order to minimize the cogging effect of the chain as it comes off each tooth of the sprocket (figs. 7 and 8).

Antenna Interfaces and Antenna Positioning System

In addition to controlling the X-Y motion of the scanning probe, the Scientific Atlanta (SA) model 2012 positioner programmer can be used to position the test antenna boresight perpendicular to the scanning plane prior to scan initiation. For small antennas, the test antenna is supported on a SA model tower which is mounted to a SA azimuth over elevation antenna positioner. If large antennas are to be tested, the model tower is removed and the antenna is mounted to the positioner via an antenna interface fixture. The bolt pattern of the antenna positioner is shown on figure 9. Figures 9, 10 and 11 show the facility space available for antenna testing.

RF Arm System

The RF probe (figs. 2 and 3) receives the RF energy transmitted by the test antenna. The RF energy must be down converted to an IF signal and routed from the probe and probe cart to the remote receiver. During this transmission, care must be taken to avoid introducing unknown phase changes into the IF signal. Any such unknown phase changes add to phase errors resulting from probe Z-axis positioning errors and errors in the phase measurement instrumentation. Unknown phase shifts or changes can be caused by flexure of the co-axial cable that carries the IF signal from the mixer on the probe cart to the receiver on the ground. In order to avoid this, a hinged RF arm system (figs. 2 and 3) was erected to conduct the IF signal from the probe cart to the ground. A rotary RF joint is centered at each hinge point. (Previous tests of the phase sensitivity of these rotary joints had shown less than 1° of phase shift during a full rotation.) Co-axial cable is attached to the hinged arms and connected to the rotary joints so that the cable is not flexed during operation thus avoiding phase errors that could be caused by cable flexing.

Without compensation, the RF Arm exerts a considerable side load on the probe cart extension to which it is attached (fig. 2). The magnitude of the side load is a function of the probe cart position in the scanning plane. This side load laterally flexes the probe cart structure and results in an X-axis error in actual probe position. To prevent this, a spring loaded overhead line was attached from the upper elbow joint of the RF arm via a series of motion reduction pulleys to a spring array. The rate of the spring array was then adjusted to exactly counterbalance the side load exerted by the arm.

SCANNER ENVIRONMENTAL REQUIREMENTS AND DESIGN APPROACH

RF Absorber

It is imperative that no reflective surfaces face into the RF energy transmitted by the antenna under test since this energy could be reflected back to the receiving probe and result in erroneous data. This can be prevented by designing the scanner so that all metallic surfaces seen by the test antenna are completely covered with RF absorbing material (fig. 3). The RF absorber used to cover both the scanner and the walls behind and beside the scanner was 0.46 m (18 in.) thick pointed carbon impregnated urethane foam (Emerson and Cuming Eccosorb VHP-18-NRL). This absorber has a minimum reflective performance of -50 dB at 5 GHz and above for directly incident RF energy.

Temperature Control

If (1) the shape of an antenna reflector is altered or (2) the near-field scan plane is distorted or (3) the length of any of the waveguides or co-ax cables is changed, errors will result in the amplitude and phase data. Small amplitude errors will have little effect on the far-field pattern. However, even small dimensional changes will result in large phase errors with resulting significant errors in the calculated far-field antenna pattern. All of the above physical distortions to the antenna or the scanner can be caused by either temperature or humidity changes or combinations of these. Temperature and humidity control during testing is therefore of great importance. As an example, a 3° F temperature change in a 7.62 m (25 ft) long aluminum waveguide will result in an 11° phase error at 30 GHz. Also, when carbon/epoxy matrix antenna structures are exposed to high humidity, they absorb moisture and distort which can result in an erroneous antenna pattern.

The test chamber thermal control design approach was to control air leaks into the test area by extending the RF absorber walls upward toward the ceiling, reducing any other large openings, and installing an airtight seal over a large roll-up entrance door. A 18 000 kg (20 ton) heating/air conditioning unit was installed with the outlets discharging horizontally above the test area (above the RF wall) and down the outside wall. Care had to be taken that these air movements did not unduly disturb the test area because strong air currents will interrupt the laser beams and distort very light weight antenna reflectors. Temperatures are recorded periodically in eight locations in the test area. These, along with humidity and barometric pressure readings, become part of the permanent test record.

RESULTS

Scan Accuracy Results

A Hewlett-Packard type 5526 laser straightness measuring system was used to align the longer of the horizontal rails (fig. 5). The results of that alignment are shown in Figs. 12 and 13 where the rail misalignment has been plotted as deviation from a least squares straight line fit through the data. The rms deviation from the least squares straight line fit was 12.1 μm (477 μin.) for the vertical (fig. 12) and 11.7 μm (461 μin.) for the horizontal alignment (fig. 13). The shorter rear rail (fig. 5) was then aligned to the front rail by means of an electronic level and dial indicators. The rails on the vertical tower had been optically aligned using jig transits and a precise level before the tower was erected. A realignment of all rails is planned when higher test frequencies require the greater accuracy. At that time, the laser straightness system will also be used on the vertical tower rails in order to achieve the higher overall accuracy required.

When rail alignment was completed, the flatness of the plane defined by the probe tip Z-axis motion was measured using a jig transit. A least squares fit plane was fit through these data. These results are shown in figures 14 to 16 for successively smaller planes. The rms deviation of the data from the least squares fit plane is 0.091 mm (0.00358 in.) for the 5.54 m by 6.04 m (218 in. by 238 in.) measurement plane (fig. 14). This improves to 0.061 mm (0.0024 in.) for the smaller 2.42 m by 2.42 m (96 in. by 96 in.) plane at the center of the scanned area (fig. 16). Thus, the $\lambda/100$ rms plane deviation criteria will presently allow measurements to at least 30 GHz for the full scan plane and to 50 GHz for the central 96 in. by 96 in. scan plane without the need for phase corrections to the near-field data set. It can be implied from the present accuracy that the scanner has the structural rigidity and dimensional repeatability to support measurements to 100 GHz. In the future, a phase correction algorithm can be implemented or an active open loop Z-axis probe positioner installed in order to extend operation to higher frequencies than achievable by alignment alone.

ANTENNA MEASUREMENT RESULTS

Given an accurate scan plane, the accuracy of the measurements that can be obtained from a Near-Field Antenna Measurement Facility can be demonstrated by an examination of the noise level in the unprocessed near-field amplitude data and by the day to day repeatability of the antenna patterns. Figure 17 is a near-field plot of amplitude in dB versus the vertical position of the receive probe. The antenna tested was the TRW proof of concept 30 GHz multiple beam antenna [1]. Here, the near-field amplitude data noise level is below 60 dB. Figures 18 and 19 are approximate far-field antenna patterns based on single line scans (typical of fig. 17) that were taken one day apart. A comparison of figures 18 and 19 demonstrate repeatability within one dB of variation at the -40 dB level. Figure 20 is a typical far-field elevation cut through the peak of one of the fixed beams of the TRW multibeam antenna. This pattern is based on a full two-dimensional near-field data set. These figures are representative of results obtained on the TRW antenna and demonstrate the capabilities of the scanner to measure complex high gain multibeam antennas.

FUTURE IMPROVEMENTS

As the demand increases for more performance from communications systems, transmission frequencies will become higher and antenna operation and design will grow more complex. Greater performance will also be demanded of the antenna test facilities. It is therefore necessary to plan for upgrading this test facility on a continual basis.

Several improvements are being evaluated for the drive and control systems. These include: (1) implementation of a multiple axis drive control system; (2) incorporation of a linear drive motor located to pull through the center of mass of the scanner for the horizontal drive system and; (3) measuring the scanning plane flatness and then making probe out of plane (Z-axis) corrections either analytically or with an open loop probe drive system.

The rate of data acquisition could be improved by: (1) the implementation of faster electronics systems (data acquisition and recording equipment); (2) coordination and use of multiple probes with data multiplexing; and (3) design and implementation of dual polarization probes.

The design philosophy used for the scanner was to construct a system wherein changes can be readily made. Consequently, any of the improvements listed above can be implemented without major construction or interruption.

REFERENCES

1. NASA Report CR-174643, 30/20 GHz "Multiple Beam Antenna for Space Communication Satellites," TRW final report. (Contract No. NAS3-22499).

TABLE I. - SCANNER CHARACTERISTICS

Antenna orientation	Boresight horizontal
Mounting support considerations	Antenna not moved during test
Scanning plane	Vertical, 6.7 m by 6.7 m overall
Scanning plane flatness	0.005 cm rms
Frequency of operation	0.8 - 60 GHz + (without corrections)
Maximum antenna aperture	5.5 m diameter
Scaled testing	To D/λ = 1100 +
Probe positioning	Probe position on gantry truss rails (vertical axis) and base platform position on horizontal rails (horizontal axis) determined by laser interferometer
Mechanical alignment	Laser straightness measuring devices, precise optical level, and jig transits
Horizontal drive	Chain driven by computer-controlled dc motors with precision tachometers through a synchronous belt reduction drive, speed range: 17.7 to 0.012 cm/sec
Vertical drive	Essentially identical to horizontal drive, speed range: 35.4 to 0.012 cm/sec
Computer	Pretests and data acquisition: Perkin Elmer 832 (located in N-F facility control room) data processing: IBM 370 (located in laboratory central computing facility)
RF absorber	0.46 m (18 in.) loaded urethane foam (Emerson and Cuming Eccosorb)

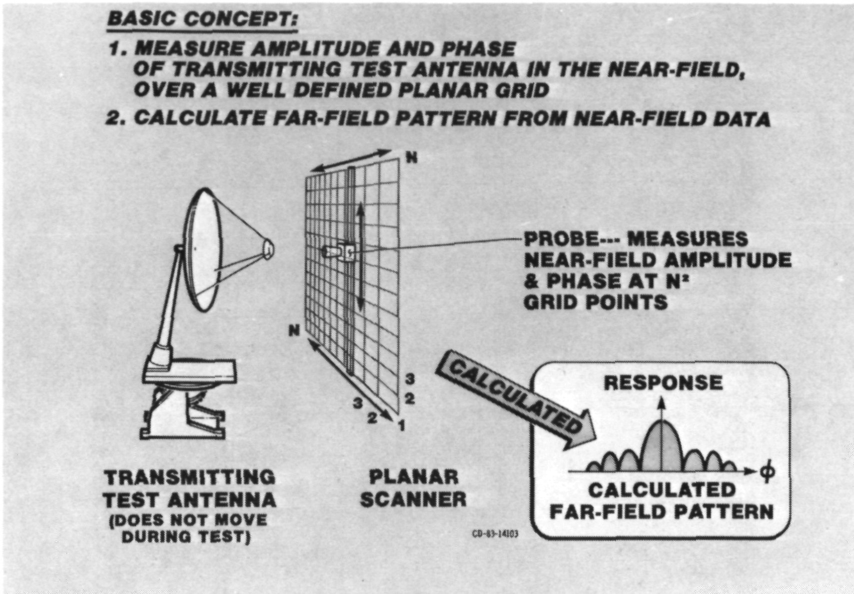

Figure 1. - Near-field antenna measurements (planar system).

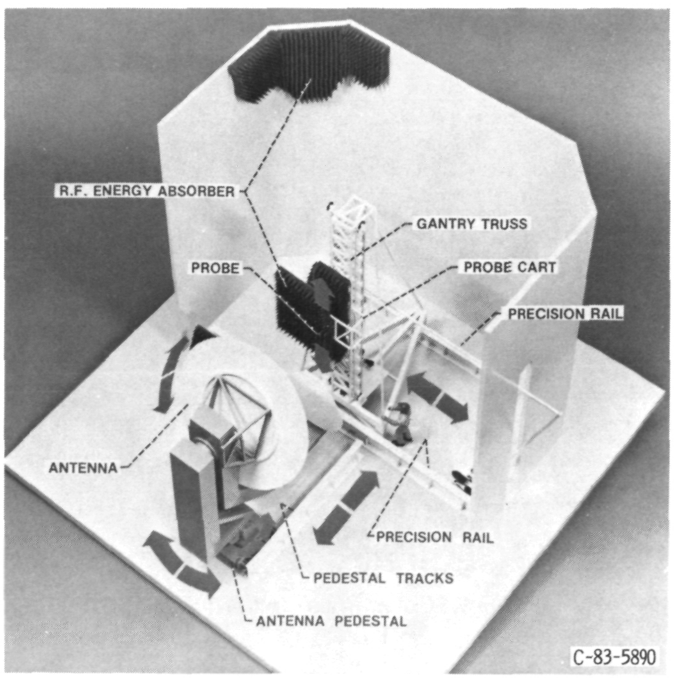

Figure 2. - Near-field antenna measurements (planar system).

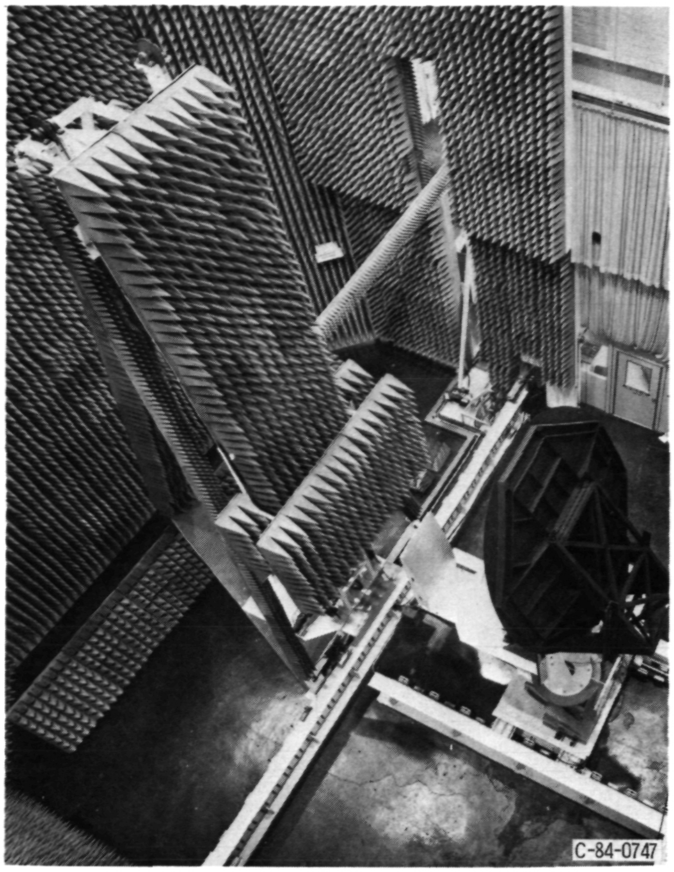

Figure 3. - 6.7 m X 6.7 m planar near-field scanner.

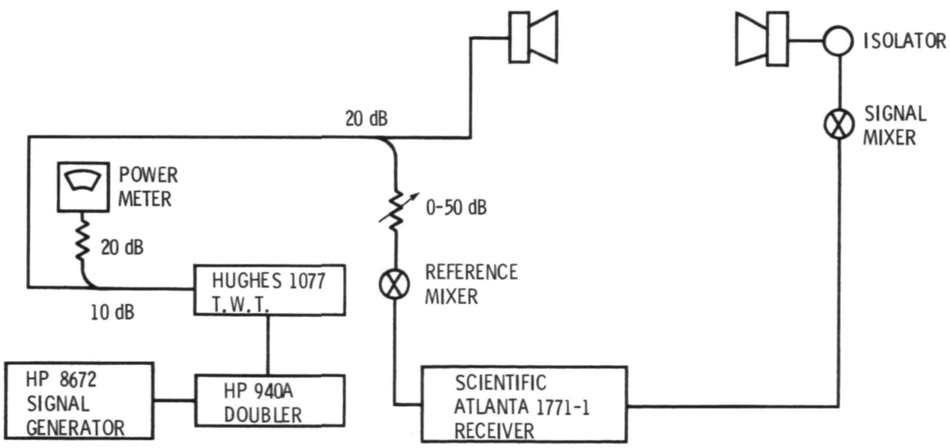

Figure 4. - Current system configuration.

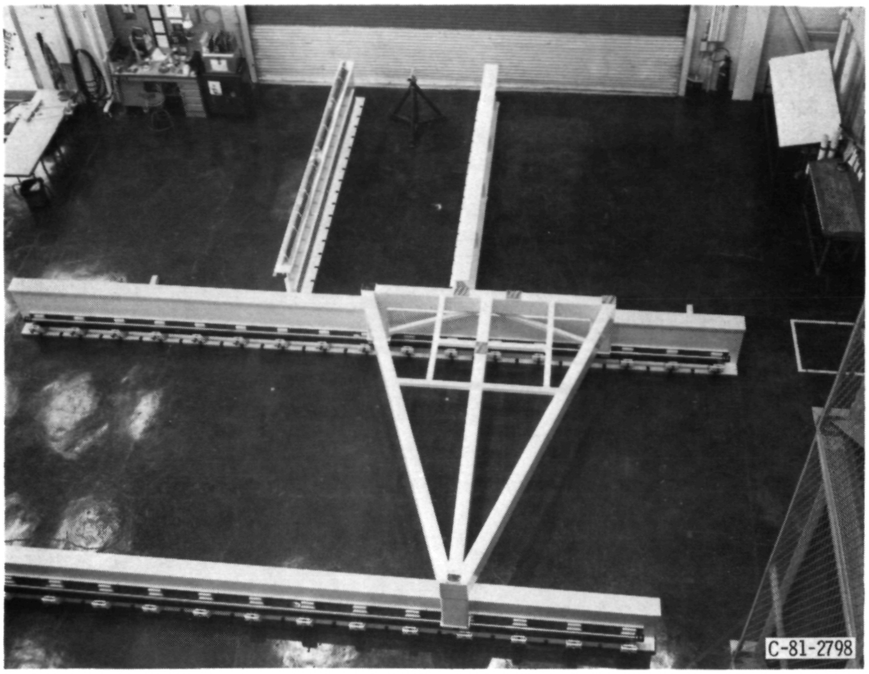

Figure 5. - Plan view; support rails and scanner platform (6/5/81).

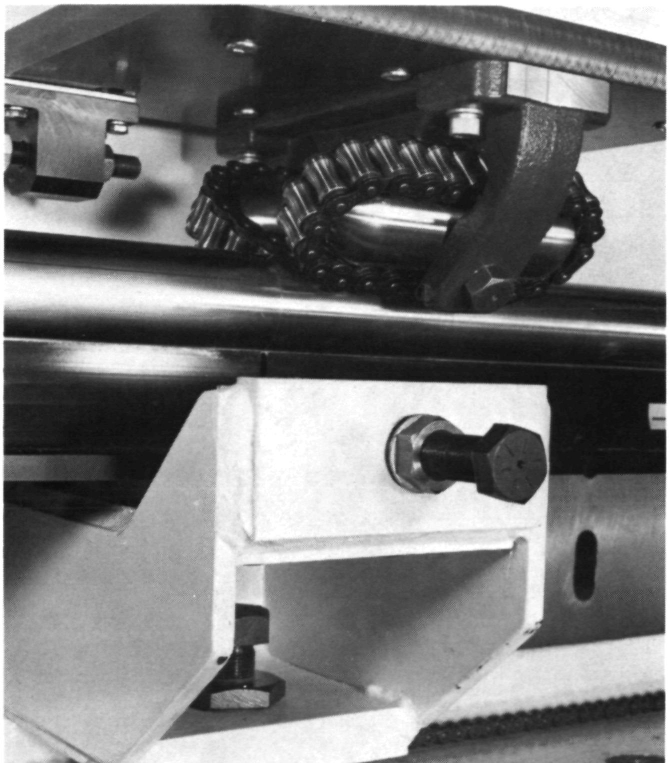

Figure 6. - Horizontal rail-detail assembly.

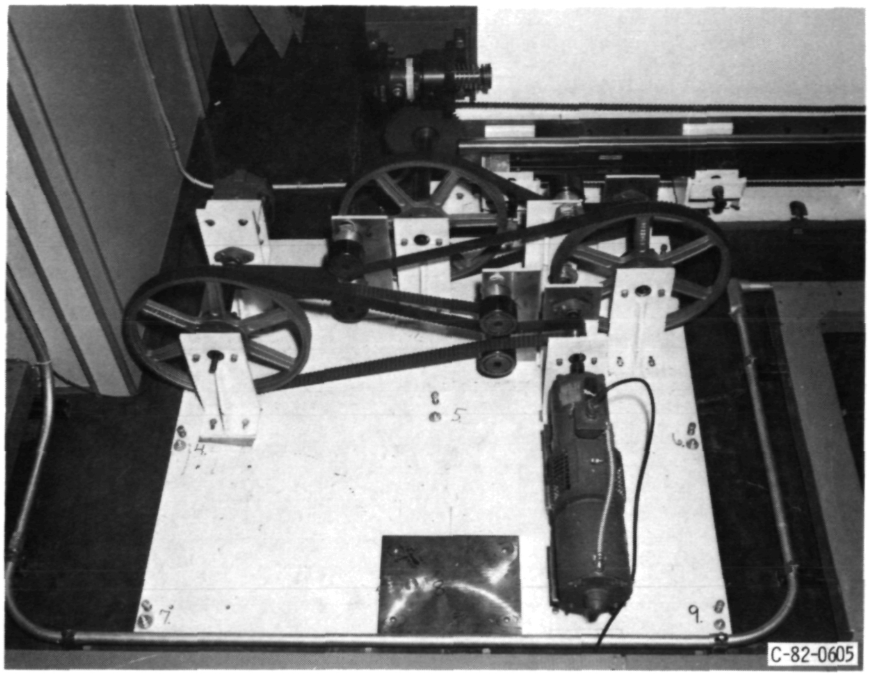

Figure 7. - Horizontal drive gear train.

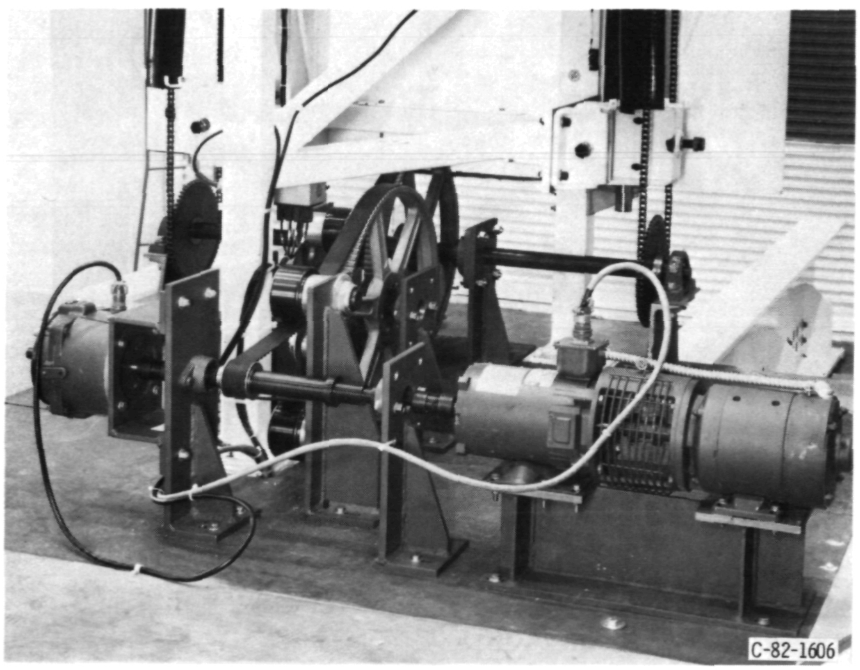

Figure 8. - Vertical tower drive system.

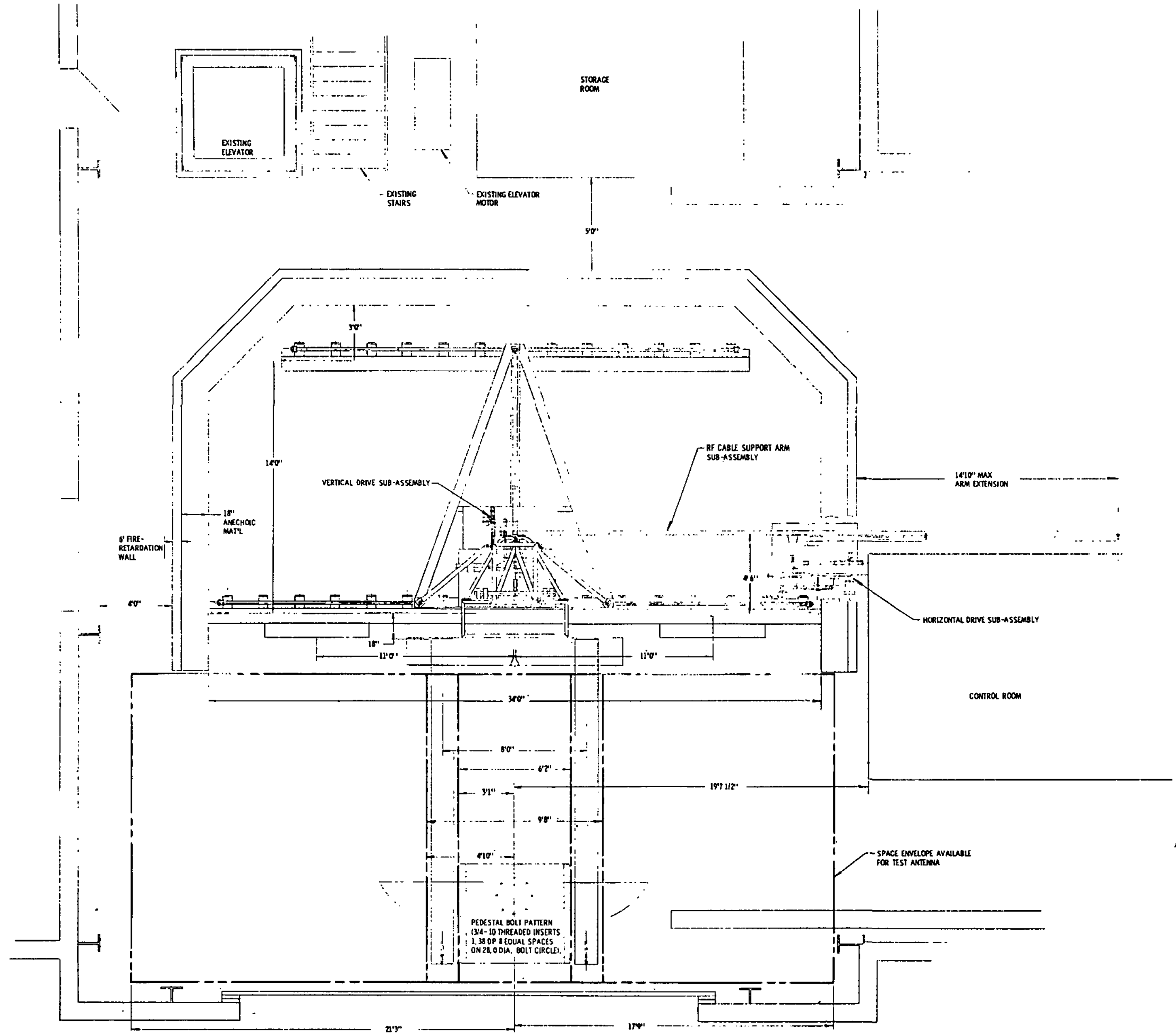

Figure 9. - Near field antenna scanner (plan view) installation. Antenna envelope.

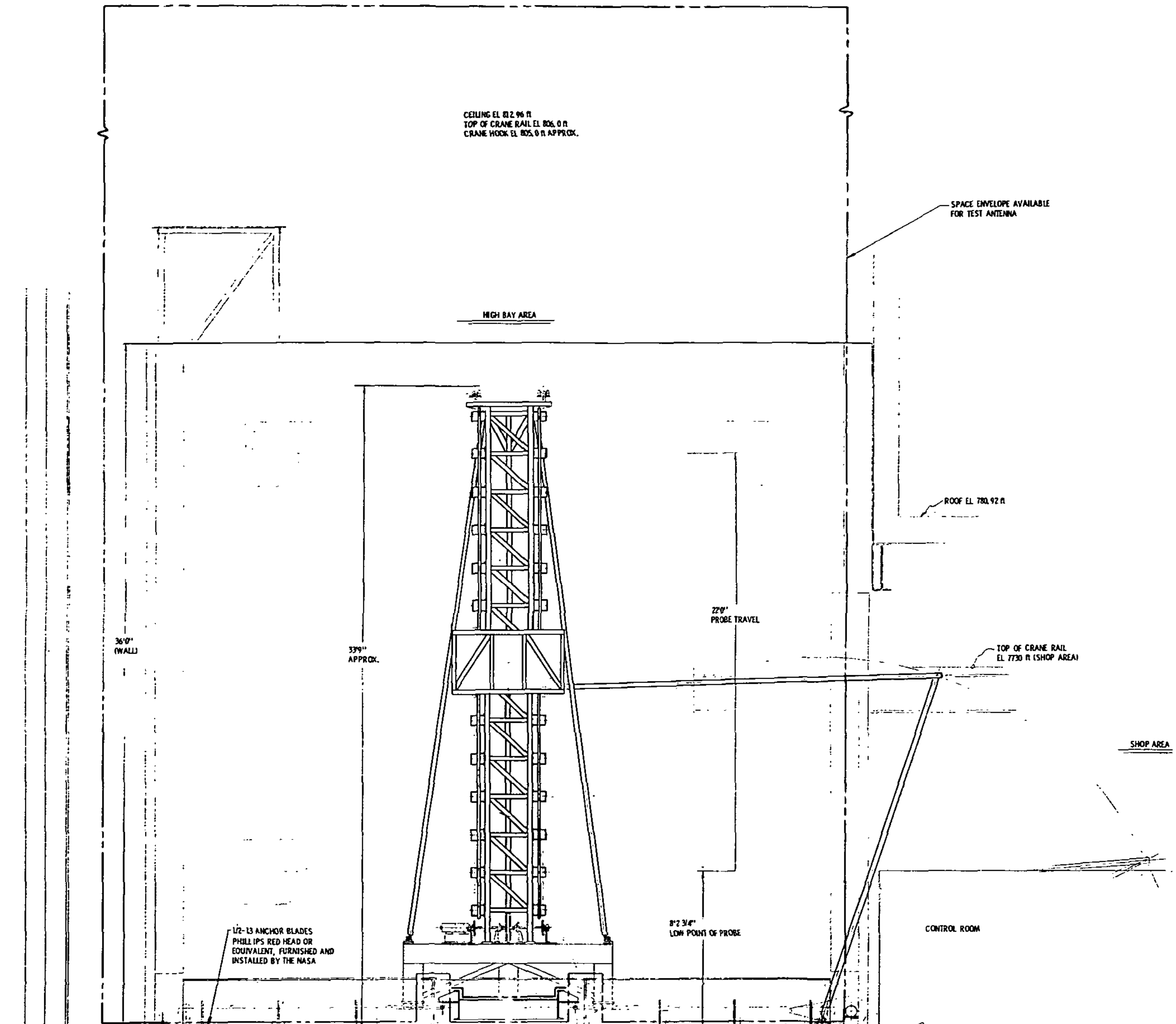

Figure 10. - Near field antenna scanner (front elevation) installation. Antenna envelope.

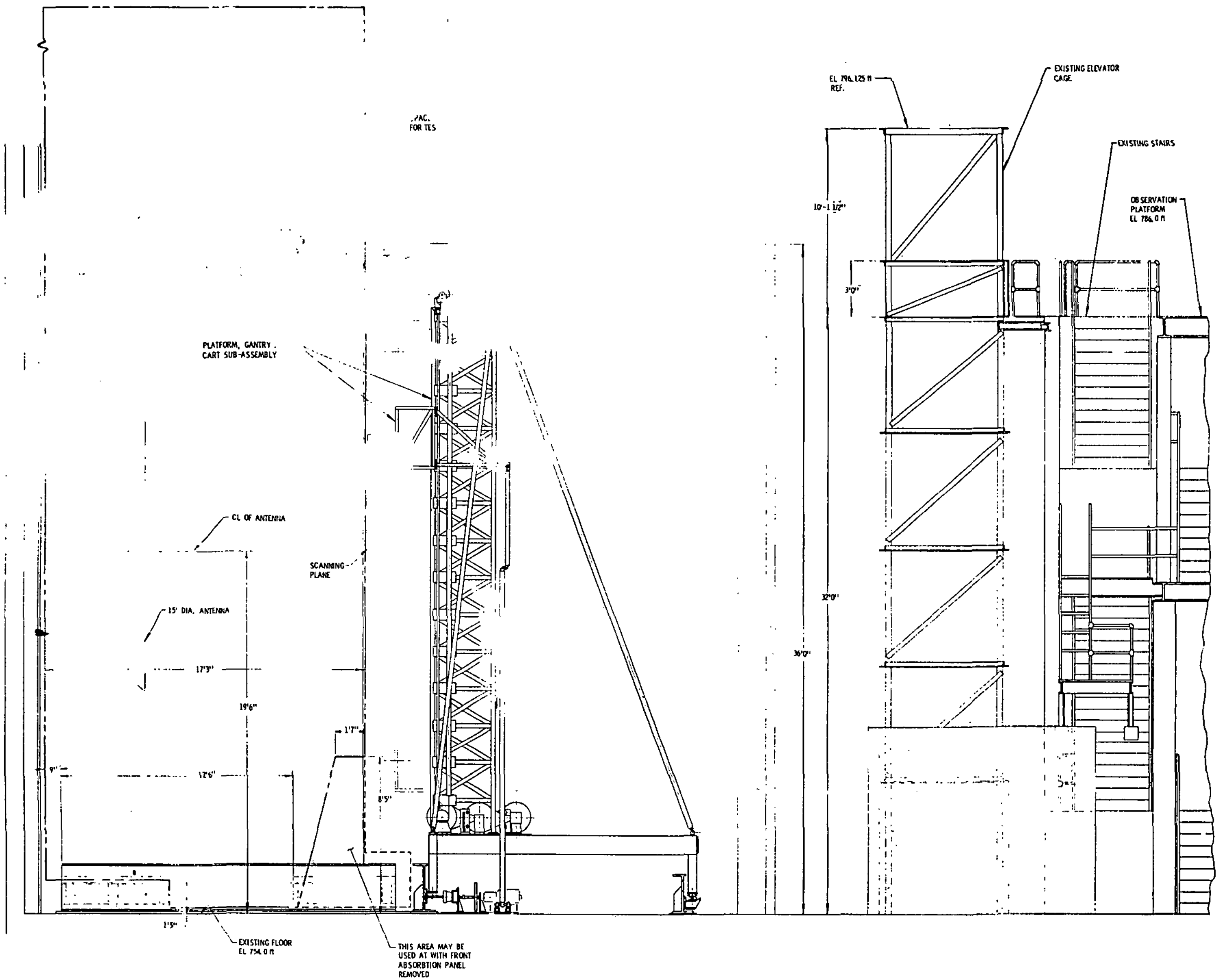

Figure 11. - Near field antenna scanner (side elevation) installation. Antenna envelope.

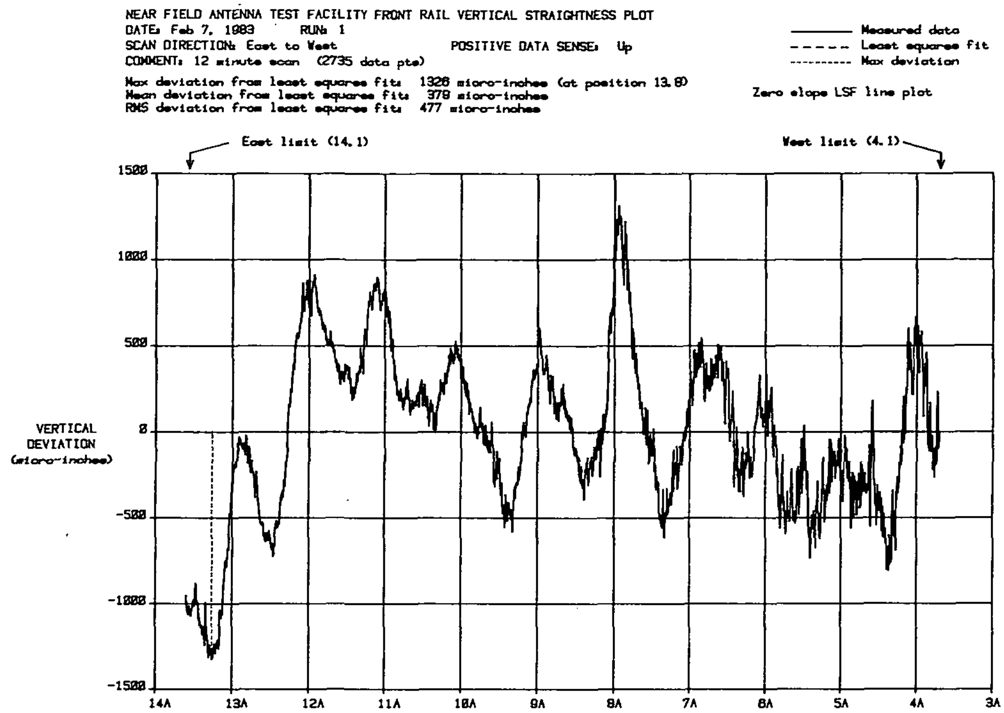

Figure 12. - Horizontal position of straightness interferometer (front center of tower platform) (rail support number - 2 foot spacing).

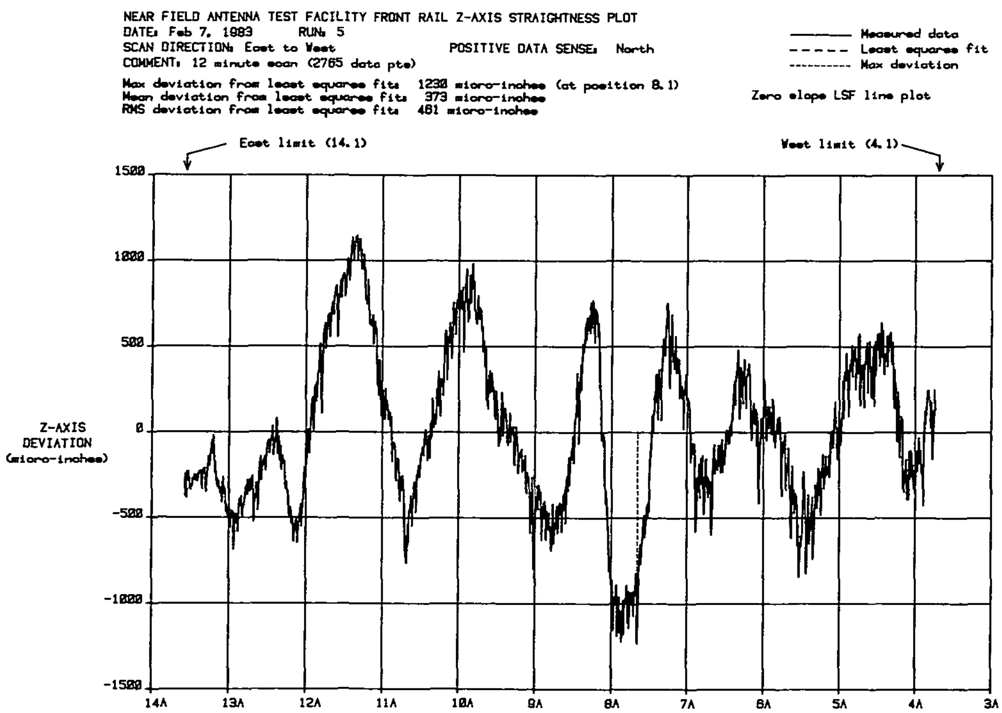

Figure 13. - Horizontal position of straightness interferometer (front center of tower platform) (rail support number - 2 foot spacing).

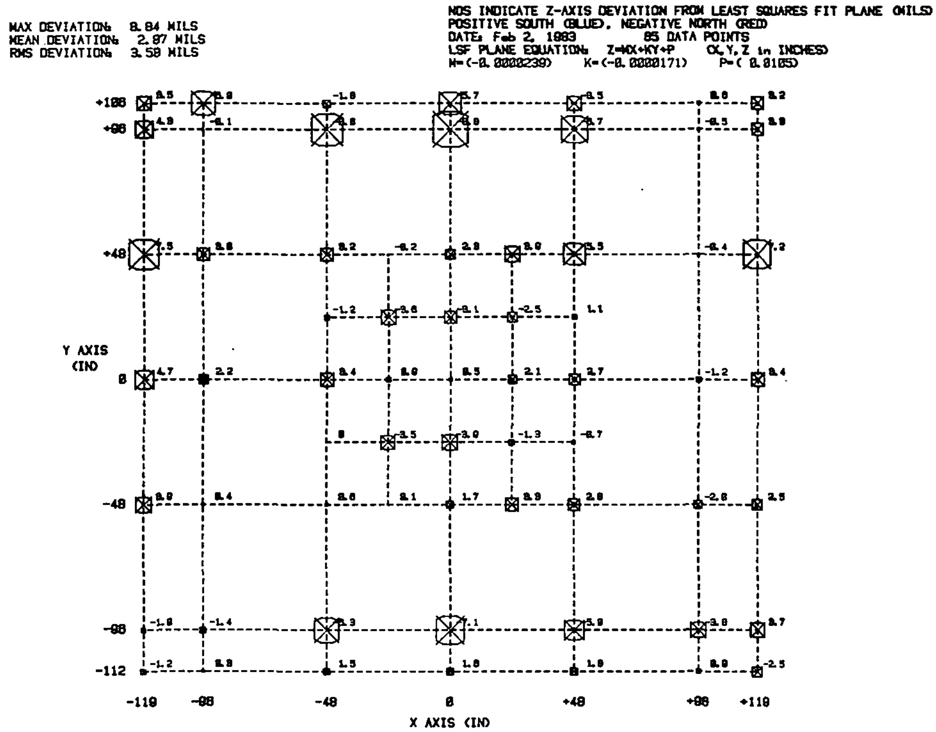

Figure 14. - Near field ATF Z-axis planarity.

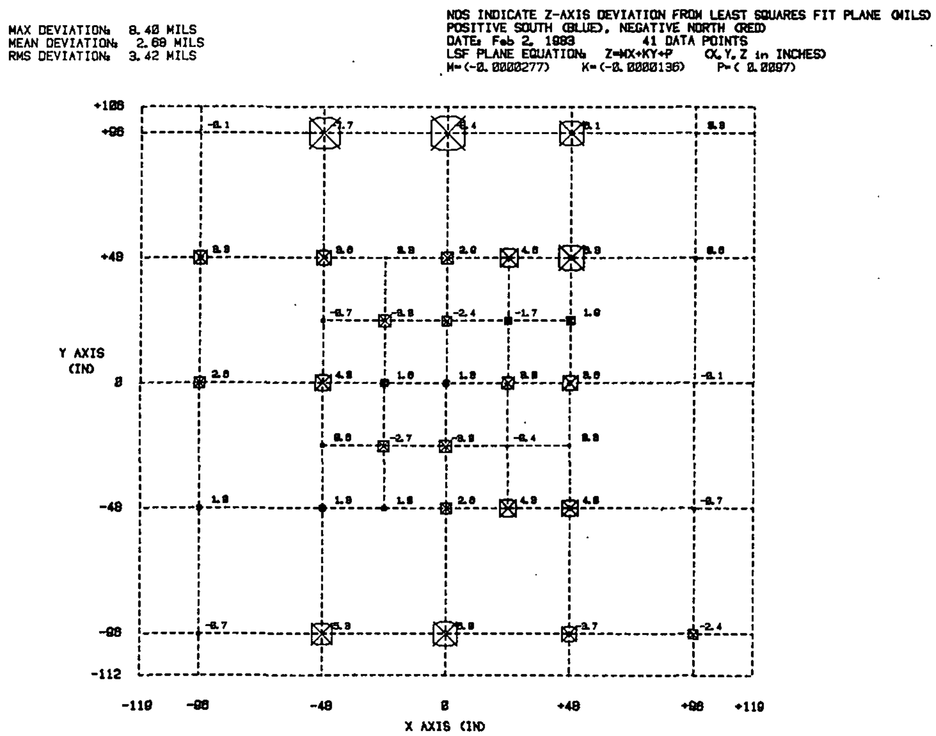

Figure 15. - Near field ATF Z-axis planarity.

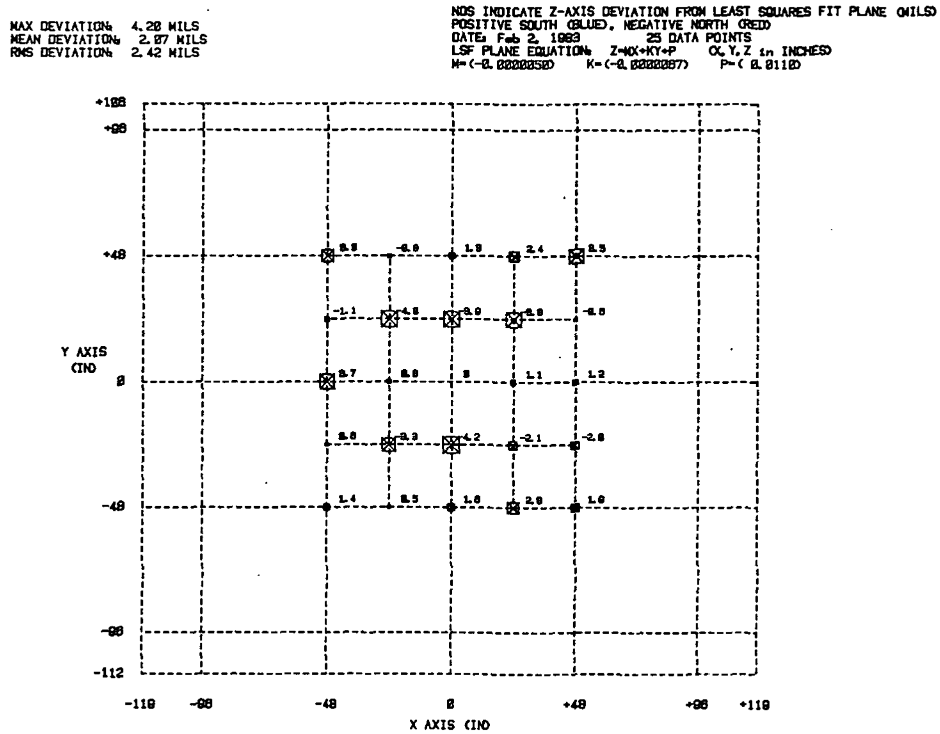

Figure 16. - Near field ATF Z-axis planarity.

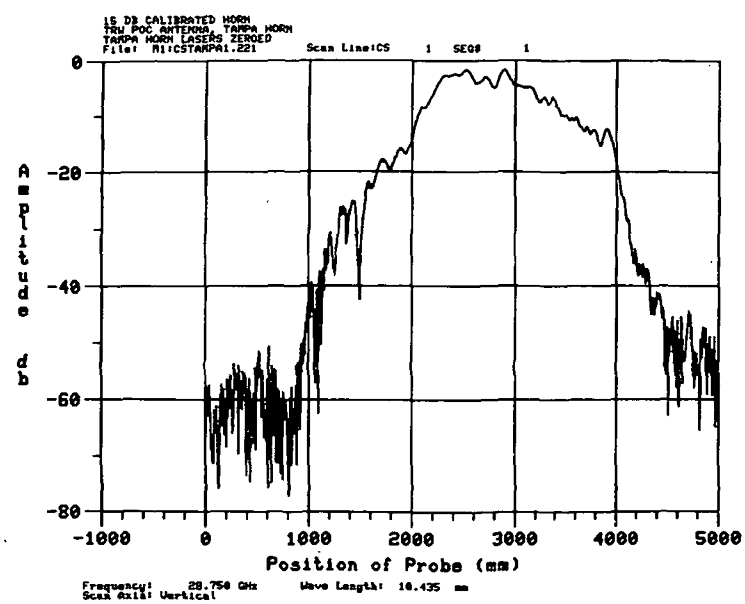

Figure 17. - Near-field amplitude pattern.

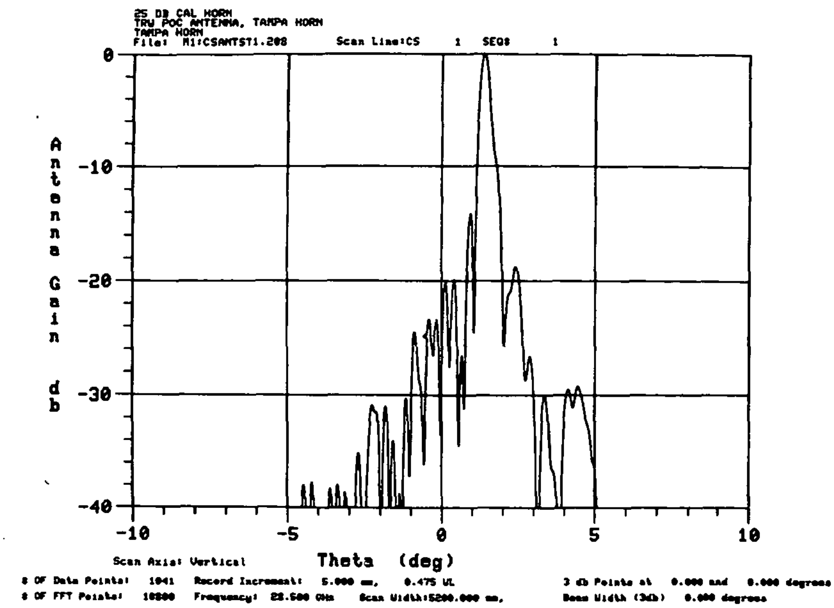

Figure 18. - Composite far-field antenna pattern.

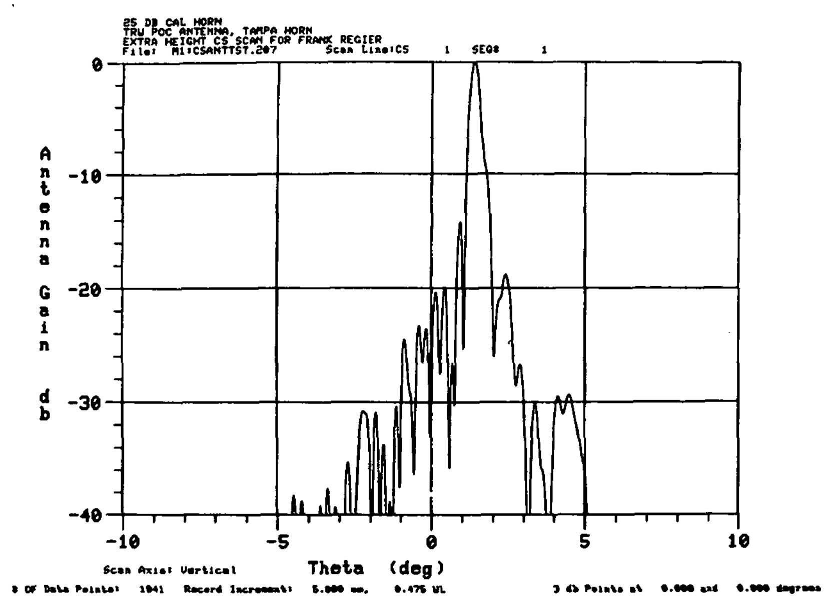

Figure 19. - Composite far-field antenna pattern.

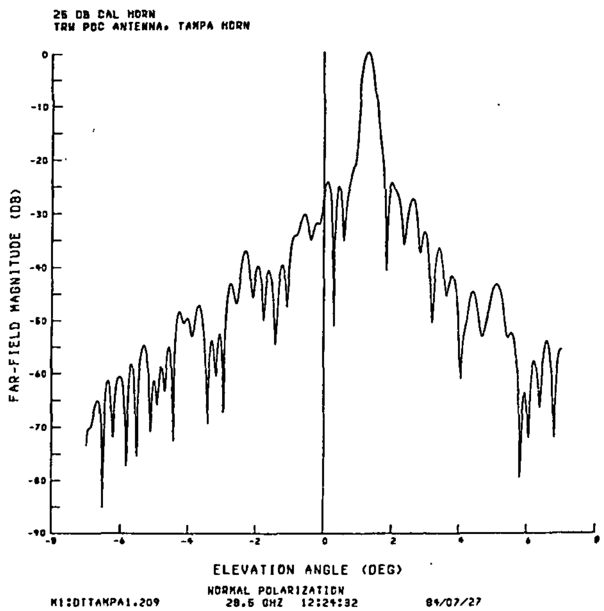

Figure 20. - Far-field elevation angle cut at AZIMUTH = 0.859 deg.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-83785		

4. Title and Subtitle	5. Report Date
Characteristics and Capabilities of the NASA Lewis Research Center High Precision 6.7- by 6.7-m Planar Near-Field Scanner	
	6. Performing Organization Code 506-58-22
7. Author(s) G. R. Sharp, R. J. Zakrajsek, R. R. Kunath, C. A. Raquet, and R. E. Alexovich	8. Performing Organization Report No. E-2281
	10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Meeting of the Antenna Measurement Techniques Association, San Diego, California, October 2-4, 1984.

16. Abstract

A very precise 6.7- by 6.7-m planar near-field scanner has recently become operational at the NASA Lewis Research Center. The scanner acquires amplitude and phase data at discrete points over a vertical rectangular grid. During the design phase for this scanner, special emphasis was given to the dimensional stability of the structures and the ease of adjustment of the rails that determine the accuracy of the scan plane. A laser measurement system is used for rail alignment and probe positioning. This has resulted in very repeatable horizontal and vertical motion of the probe cart and hence precise positioning in the plane described by the probe tip. The resulting accuracy will support near-field measurements at 60 GHz without corrections. Subsystem design including laser, electronic and mechanical and their performance is described. Summary data are presented on the scan plane flatness and environmental temperature stability. Representative near-field data and calculated far-field test results are presented. Prospective scanner improvements to increase test capability are also discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Near-field; Planar scanner; High precision	Unclassified - unlimited STAR Category 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

U.S. MAIL

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return