NEAR-FIELD MEASUREMENT EXPERIENCE AT SCIENTIFIC-ATLANTA

Doren W. Hess

Scientific-Atlanta, Inc.
3845 Pleasantdale Road
Atlanta, GA 30340-4266
U.S.A.

ABSTRACT

The experience with near-field scanning at Scientific-Atlanta began with a system based upon a analog computer for computing the two-dimensional Fourier transform of the main polarization component. When coupled with a phase/amplitude receiver and a modest planar near-field scanner this system could produce far-field patterns from near-field scanning measurements.

In the 1970's it came to be recognized that the same advances, which made the more sophisticated probe-corrected planar near field measurements possible, would enable conventional far-field range hardware to be used on near-field ranges employing spherical coordinates. In 1980 Scientific-Atlanta first introduced a spherical near-field scanning system based upon a minicomputer already used to automate data acquisition and display.

In 1990, to meet the need of measuring complex multistate phased-array antennas, Scientific-Atlanta began planning a system to support the high volume data requirement and high speed measurement need represented by this challenge. Today Scientific-Atlanta is again pursuing planar near-field scanning as the method of choice for this test problem.

Keywords: Near-Field Scanning; Planar Near-Field; Spherical Near-Field.

INTRODUCTION

The history of near-field scanning measurement techniques has been documented in the set of invited papers which appears in the Special Issue on Near-Field Scanning Techniques published by IEEE Antenna and Propagation Society and edited by E. S. Gillespie. The information presented here augments that history. It is presented from the point of view of a technologist who wishes to employ the techniques in practical applications.

Although the history of near-field scanning measurements can be traced back to the 1940's as an idea to be applied to microwave antenna measurements and even back to Huygens for the origin of the theoretical principle, the modern near-field scanning measurement systems have their basis in key developments that occurred in the 1960's. These key developments can be summarized as follows:

(1) Simultaneous Measurement of Amplitude and Phase
(2) Digital Electronics for Data Acquisition and Processing
(3) Development of Transmission Equations based upon Modal Expansions of Fields

These key developments occurred between 1960 and 1980 and gave rise to what has now become a well accepted and often-practiced method of measurement.

In this paper I describe the roles played by Scientific-Atlanta as the near-field scanning technique(s) have developed from 1960 up to the present.

THE EARLY YEARS OF NEAR-FIELD SCANNING

In the early 1960's Scientific-Atlanta began development of products that were key to implementing planar near-field scanning measurements. Figure 1 shows a complete near-field system capable of measurement and calculation of the far field described in a 1963 Scientific-Atlanta publication. The key products were (1) a computer (based on analog circuitry) which permitted the far-field to be calculated from near-field data (2) a phase-amplitude measurement receiver and (3) a planar near-field scanner. An early three axis version appears in Figure 1.

To perform the computation of the far-field pattern from the near-field data an analog computer was used. In 1960 Scientific-Atlanta offered a product called a Fourier Integral Computer which was used by antenna design engineers to model aperture distributions mathematically. More than 10 of these units were produced over the decade of the 60's. See Figure 2 for a photograph.

The Model CF-1 enabled the far field to be calculated from the near field on a two dimensional basis. The computer took its input from plots on special chart paper by scanning the chart paper with a light sensitive detector. Separate traces of amplitude and phase were used. The traces might either have been derived from a mathematical function or recorded in an x-y scanning measurement.

The process of near-field measurement began by recording amplitude and phase traces in either x or y while stepping the other axis. Then the Fourier Integral Computer was used to compute the one-dimensional Fourier transform of each scan. From the set of transformed scans an "equivalent slit distribution" was created and plotted as an intermediate result. Then the computer was used to make a Fourier transform of the equivalent slit distribution which gave the far-field pattern. A block diagram of the Fourier Integral Computer is shown in Figure 4.

There were two phase-amplitude receivers produced by the company in the 1960's -- a Model 1650 receiver early in the decade followed by the Model 1750 receiver in 1967. Both receivers were based on the principle of phase and amplitude correspondence between RF and IF signals in the process of frequency down-conversion. By separately down-converting both a test signal and a reference signal, using a common local oscillator signal, the relative phase of the test signal can be determined. In the earlier Model 1650, the phase of the test signal was determined by offsetting the IF reference signal with a cyclic phase shifter driven by a motor and then using a phase comparator at audio frequency to develop an analog voltage proportional to the phase of the test signal. In the later Model 1750, phase was determined by counting pulses to measure the time offset between the zero-crossings of the test and reference signals after two successive stages of down-conversion -- first to an IF of 45 MHz and then to a second IF of 1 kHz. Photographs of the Models 1650 and 1750 are shown in Figures 5 and 6.

The planar near-field scanner produced by Scientific-Atlanta in the late 1960's as a commercial product had a scan area of 100 by 100 inches. It consisted of a heavy steel frame that supported a vertical member which translated horizontally, guided by two precision rails, one at the top and one at the bottom of the frame. The vertical member itself supported two rails that guided a carriage for the probe antenna. The probe could be scanned in x or y motion by an operator who would set one axis and then arrange for the other axis to be scanned, while a chart was driven in synchronism and a pen plotted the amplitude or phase of the received signal. The x- and y-motions were derived from DC motors and synchros read out the x- and y-positions by gears monitoring the drive shafts of the two axes. A photograph is shown in Figure 3. The RF path connecting the RF probe horn with a fixed point on the frame of the scanner consisted of a two-segment articulated arm with three rotary joints for phase stability.

An x-y scanner of this type was donated to Georgia Institute of Technology in the late 1960's and it was used in investigations of more advanced techniques than those available commercially.

An example of a far-field pattern, shown in Figure 7, was computed from near-field scanning measurements and compared to patterns measured directly on a far-field range. The antenna was a small paraboloidal dish operating at 13.5 GHz.

THE 1970'S -- AN ERA OF CHANGE

The late 1960's and early 1970's saw a major advance in the theory of near-field scanning: the invention of the transmission equation(s). The transmission equation enabled the vector character of the electromagnetic field to be accounted for and correction for the directivity pattern of the probe antenna to be performed in the process of computing the far field.

This was also an era of great change in the technology base of the electronics industry as the influence of digital circuitry took hold. Digitally-based instruments and minicomputer based systems became prevalent.

These changes set the stage for the development by Scientific-Atlanta in the late 1970's of a minicomputer-based near-field system. In the meantime, a new programmable receiver the Model 1770 was introduced.

THE 1980'S -- SPHERICAL NEAR FIELD

In 1980 Scientific-Atlanta introduced a complete minicomputer-based spherical near-field system that could process the spherical near-field to far-field transform on the same computer that was used to acquire and display data. The transform was based upon the spherical transmission equation and the numerical algorithm of Wacker. The advantage of the system was that it could utilize standard positioners and an automatic system that already had been built for far-field antenna ranges and anechoic chambers. The spherical algorithm was a module or block of the data-processing sequence that could be interposed between the acquisition and display modules in the automatic system. A photograph of this system -- the Model 2022 is shown in Figure 8.

The 1980's also saw further innovation in the phase-amplitude receivers. The Model 2022 automatic system was based upon a Model 1770 phase-amplitude receiver that enabled programmable control of its frequency but which depended upon external instruments to convert the downconverted signals -- 1 kHz replicas of the microwave signals -- into digitized representations of phase and amplitude. A successor to the 1770 -- the Model 1780 -- provided a completely digital interface at its output. Furthermore it offered as a standard feature the ability to handle two signal channels -- a critical consideration in saving time in near-field scanning data acquisition. The 1780 was the first antenna measurement receiver that was compatible with the IEEE-488 bus interface. A photograph is shown in Figure 9. The 1780 was used in the Model 2022A Spherical Near-Field System.

The ability of the Scientific-Atlanta 1780 to acquire two signal channels of near-field scanning data simultaneously made evident the need for a dual-ported near-field probe horn for spherical scanning. Since the probe-corrected spherical near-field algorithm is based upon probe horns whose modal content is restricted to azimuthal indices of values ± 1 only, it became important that a series of dual-ported probe horns be developed based upon round waveguide. This resulted in the Scientific-Atlanta Model 31 series of horns. See Figure 10. These were integrated into probe assemblies for the purpose of making repeatable probe corrected measurements.

An essential feature of near-field measurements was the need to make accurate position measurements along with accurate phase and amplitude measurements. In spherical positioning this then meant that a two-axis positioner must have very high resolution readouts and an adjustable upper axis mount so that the axis intersection distance and deviation from orthogonality can be minimized. An example of such a positioner, outfitted with encoders is shown in Figure 11. It was capable of handling a test antenna up to 4 meters in diameter and 250 kg in mass.

Accurate positioning is also reflected in the need to make careful range alignments to maintain control of the probe's position and orientation. A source tower that makes alignment easy and which provides for phase stability of the RF path and automatic polarization switching is shown in Figure 12, with a dual-ported probe. Several versions of this has been built at various range axis heights, from 2 meters to 7.5 meters.

The evolution of products for spherical near-field scanning culminated in the mid 1980's in two automatic systems the Models 2022A and 2023 that could support complete probe-corrected spherical near-field measurements including three antenna polarization measurements, probe pattern measurements, gain measurements by comparison to a standard, correction for thermal drift and probe pattern correction of the test antenna pattern.

With the advance in computer speed, the spherical near-field to far-field transform could now easily be accomplished in less than 60 minutes for the beachmark case of a 1 degree spherical coordinate grid. The data acquisition process is limited by the speed at which an antenna can be rotated; typically a complete sphere at 1 degree spacing takes about 3 hours to acquire data. A major innovation of the Scientific-Atlanta spherical near-field system was its support of partial sphere data, which reduces the data acquisition requirement to under an hour and the corresponding transform time to less than one-half hour.

An example comparing the result of a spherical near-field measurement with a compact range measurement is shown in Figure 13. This comparison was obtained first in 1980 and displays the wide angle coverage and good dynamic range typical of spherical near-field measurements. The test antenna was a 24 inch paraboloidal dish designed for the purpose of serving as a pattern standard; it was operated at 13 GHz.

THE 1990'S RETURN TO PLANAR NEAR-FIELD SCANNING

During the 1980's both spherical and planar near-field measurement techniques became well accepted as a reliable method of antenna testing as the algorithms became well understood and more experience was gained with the methods. However even today near-field scanning is not consistently the method of choice when an antenna measurement problem is presented.

The reason is that the near-field schemes must compete with the compact range technique which had also become much more popular in the 1980's. The compact range method enjoys the advantage of providing real-time data, very much like a far-field range, but indoors, under laboratory conditions.

The spherical measurement technique is a general method that provides full spherical coverage at frequencies down to 100 MHz, where the compact range becomes less desirable. The planar near-field method has the advantage that it can provide reliable diagnostic information for planar array antennas and that the test antenna does not have to be rotated or moved for the test.

In the 1990's, the major challenge confronting the antenna measurement community is the need to test complex planar phased array antennas with many test states and perhaps active elements. To verify that such antennas are working requires aperture diagnostics and reliable far-field patterns. The thrust of the Scientific-Atlanta development work in near-field scanning in the early '90's is to support high volume automated planar near-field scanning of electronically steerable antennas.

The latest phase-amplitude receiver offered by Scientific-Atlanta is the Model 1795 which supports the test signals and 5000 measurements per second, a factor of 50 in increased speed over the 1780. See Figure 15. The latest automatic system, the Model 2095 is designed to support this same speed of measurement at the system level. The system architecture of the 2095 will support high level multiplexing of data among the various beam directions, frequencies and ports that can comprise the test scenario of modern phased array antenna. Acquiring 100 dual polarized patterns during a single near-field scan over an x-y plane would not be unusual with the Model 2095 Antenna Measurement System. This capability forms a significant contrast to the first planar near-field system.

BIBLIOGRAPHY

1. Calculation of microwave antenna radiation patterns by the Fourier integral method. L. Clayton and J. S. Hollis. Scientific-Atlanta Essay, No. 1 March 1960.
   and
   Calculation of microwave antenna radiation systems by the Fourier integral method, L. Clayton, Jr. and J. S. Hollis, Microwave Journal, p. 59, September 1960.
2. A wide frequency range microwave phase-amplitude measuring system, L. Clayton, Jr., J. S. Hollis and H. H. Teegardin, Scientific-Atlanta, No. 4 September 1963, (originally presented at Eleventh annual symposium, USAF antenna research and development program, University of Illinois, 1961).
3. Determination of far-field antenna patterns from near-field measurements, R. C. Johnson, H. A. Ecker and J. S. Hollis, Proc. IEEE, 61, No. 12, 1668-1694, 1973.
4. Preface, Special Issue on Near-Field Scanning Techniques, E. S. Gillespie, IEEE Trans. AP-36 725 (1988).
5. A brief history of near-field measurements of antennas at the National Bureau of Standards, R. C. Baird, A. C. Newell, C. B. Stubenrauch, IEEE Trans., AP-36 727, (1988).
6. A brief history of the development of the near-field measurement technique at the Georgia Institute of Technology, E. B. Joy, IEEE Trans., AP-36 740, (1988).
7. Spherical near-field scanning at the Technical University of Denmark, J. E. Hansen and F. Jensen, IEEE Trans., AP-36 734, (1988).
8. Spherical near-field antenna measurement with the Scientific-Atlanta Model 2022, Joseph J. Tavormina and Doren W. Hess, Proceedings, Antenna Measurement Techniques Association, October, 1980.
9. A dual-ported dual-polarized spherical near-field probe, J. R. Jones and D. P. Hardin, Proceedings, Antenna Measurement Techniques Association, September, 1983.
10. Spherical near-field antenna measurements improve through expanded software features, D. W. Hess, J. R. Jones, C. Green, B. Melson, J. Proctor, Microwave System News, Vol. 15, No. 3, March 1985.

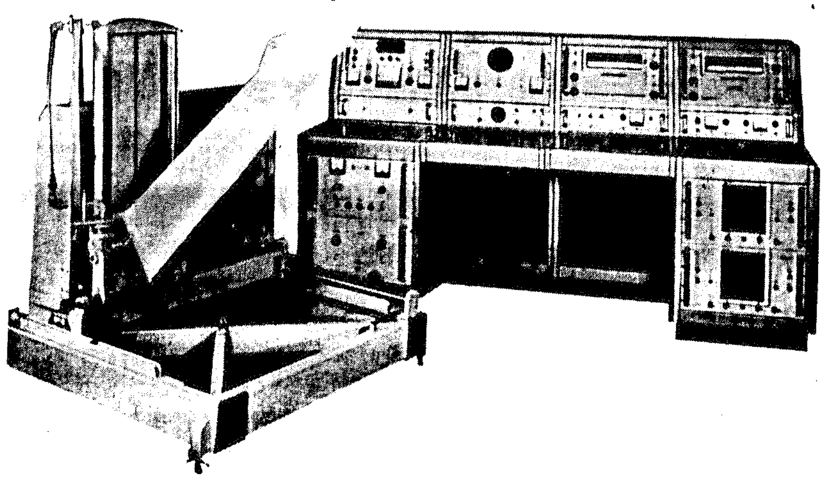

Figure 1
A Near-Field Scanning System of 1963
Based upon a Fourier Integral Computer

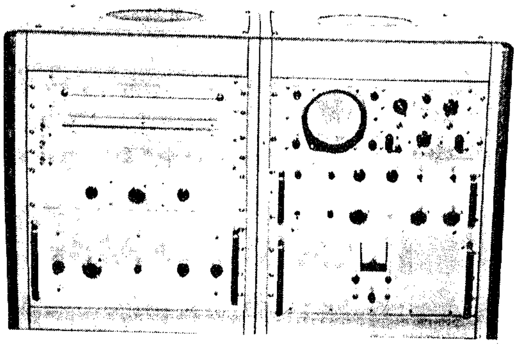

Figure 2
The Model CF I Fourier Integral Computer of the 1960s.
More Than 10 of These Were Produced.

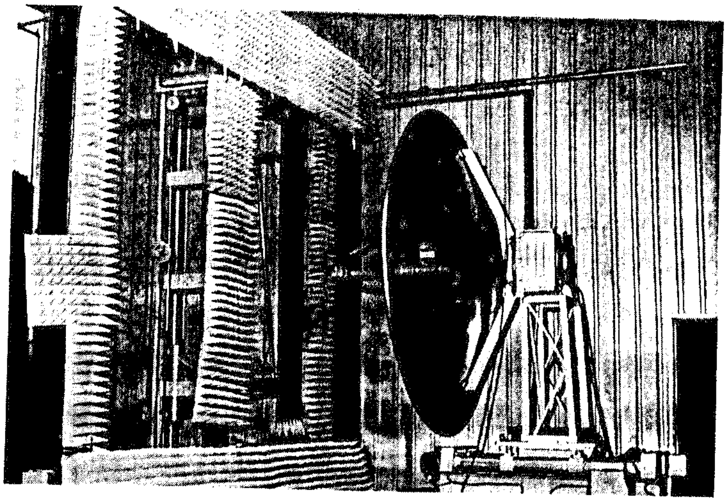

Figure 3
A Planar Near-Field Scanner Produced by Scientific-Atlanta
in the Late 1960s Having a Travel of 100 x 100 Inches

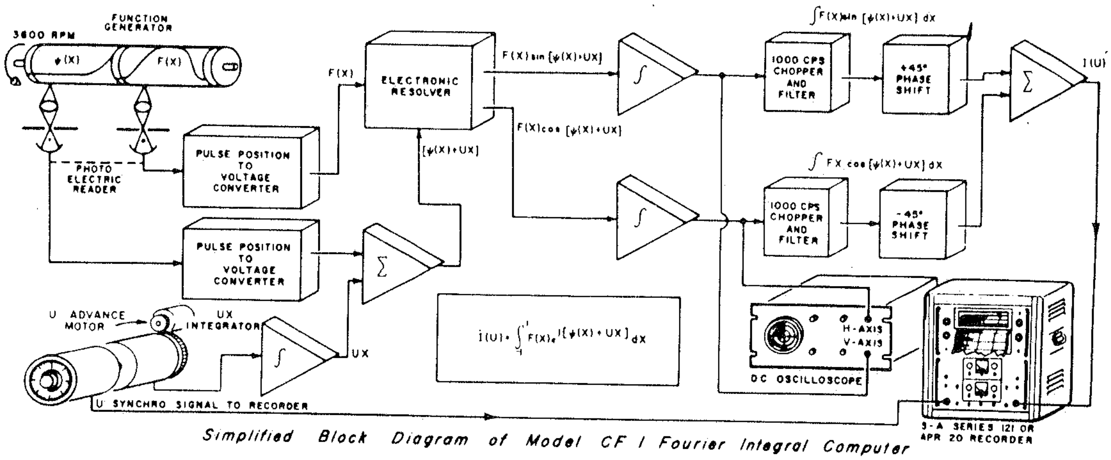

Figure 4
Analog Circuitry Block Diagram of the Fourier Integral Computer

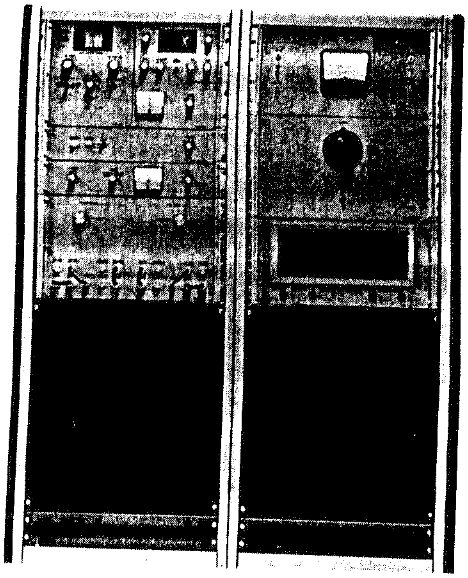

Figure 5
The Model 1650 Receiver was the First
Phase/Amplitude Receiver
Produced by Scientific-Atlanta

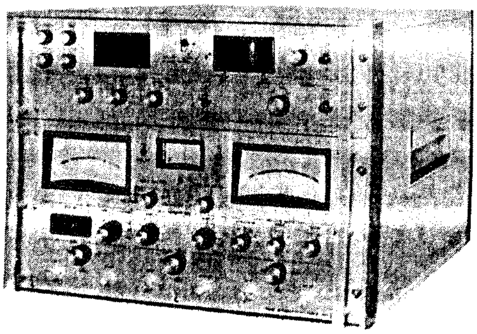

Figure 6
The Model 1750 Receiver Provided Reliable
Phase/Amplitude Measurements
in a Reduced Package

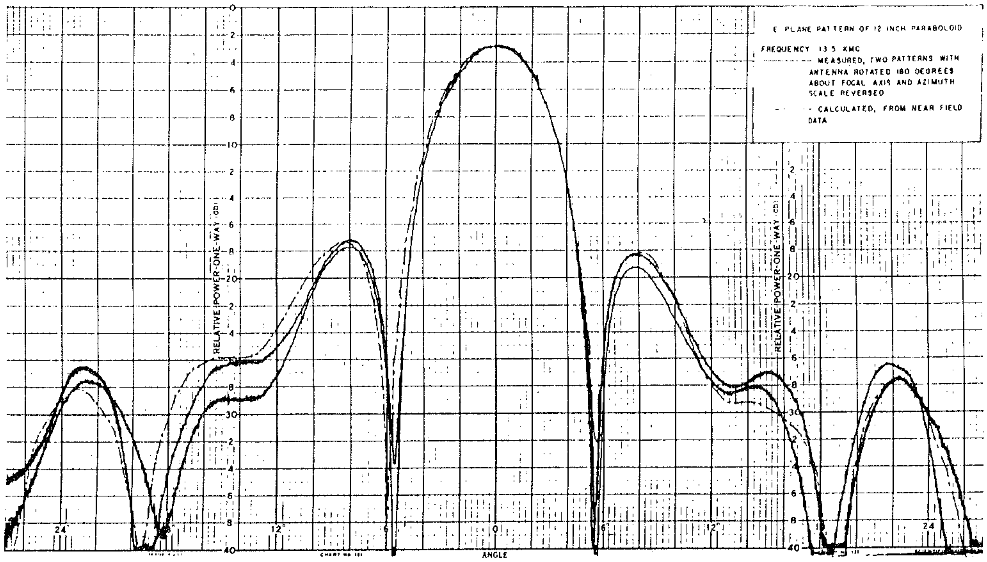

Figure 7
Comparison between Near-Field and Far-Field Patterns Produced Using the Fourier Integral Computer and Near-Field Measured Data

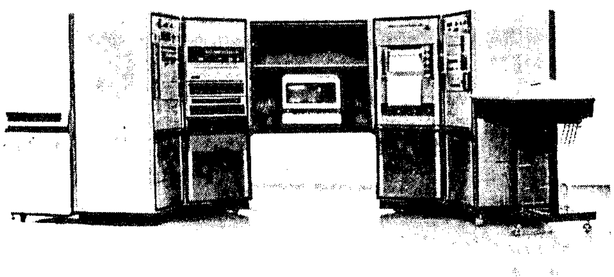

Figure 8
The Model 2022A Spherical Near-Field Measurement System Performed the Data Acquisition, Transformation, and Display Functions for the Same Computer

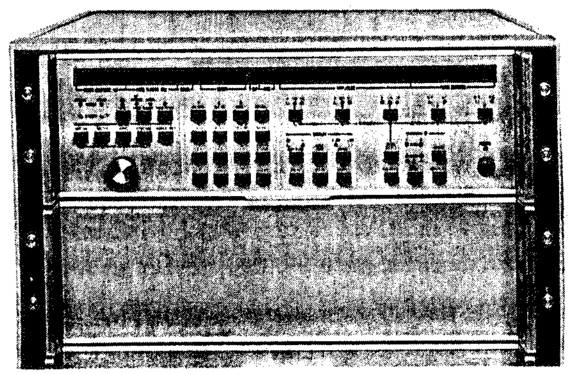

Figure 9
The Model 1780 Receiver Provided a Complete Digital Interface for System Applications

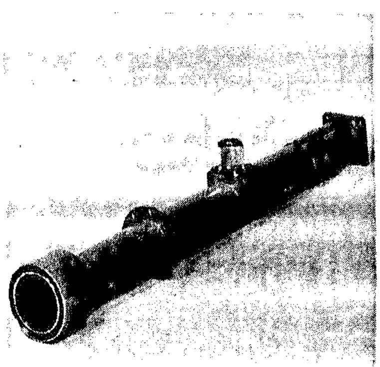

Figure 10
A Model 31 Dual-Ported Polarized Horn for Spherical Near-Field Scanning

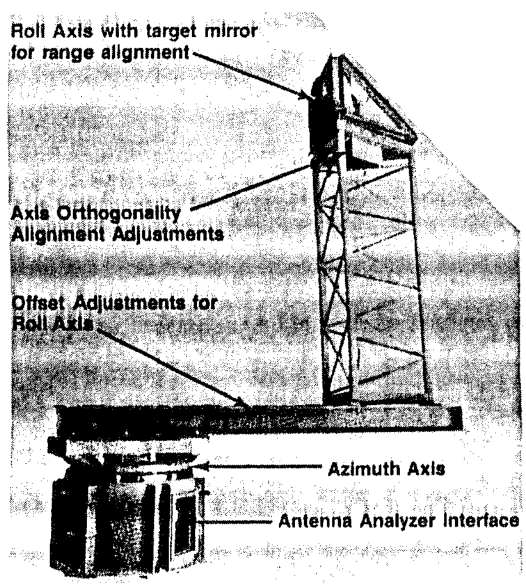

Figure 11
A Two-Axis Roll-Over-Azimuth Positioner with High Accuracy Encoders and Adjustments for Axis Intersection and Orthogonality for Spherical Near-Field Scanning

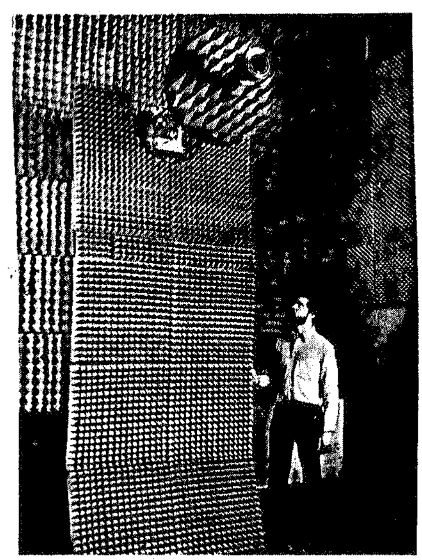

Figure 12
A Source Tower for Spherical Near-Field Ranges That Integrates a Polarization Switch, a Phase Stable RF Path, Automatic Control of the Polarization Axis, and Adjustments for Range Alignment to Support a Dual-Ported Probe Horn and a Range Signal Source

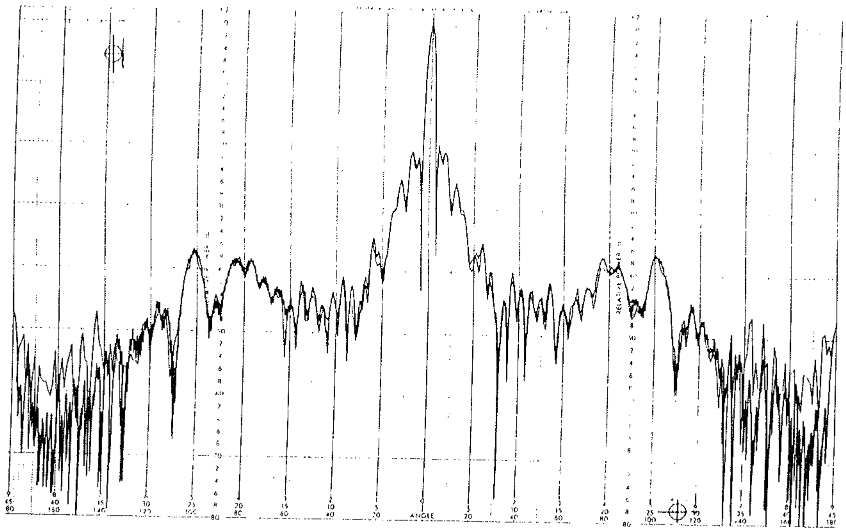

Figure 13
Comparison of Antenna Patterns Between the
Spherical Near-Field Technique and the Compact Range Method

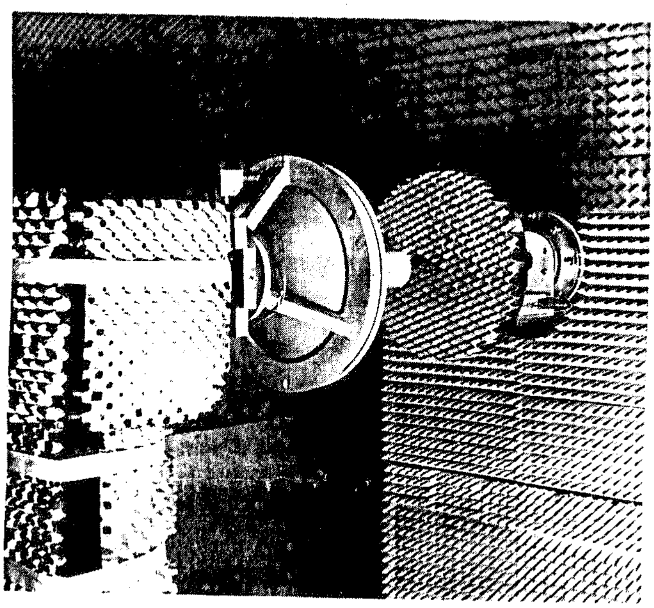

Figure 14
The Spherical Near-Field Range Used for Verification
of the Spherical Algorithm at Scientific-Atlanta

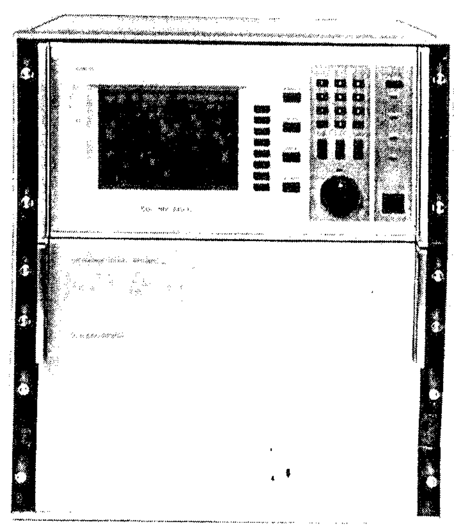

Figure 15
The Model 1795 Receiver Will Form the Basis for
Near-Field Measurement Systems of the 1990s