

GAIN COMPARISON MEASUREMENTS IN SPHERICAL NEAR-FIELD SCANNING

Doren W. Hess and John R. Jones
Scientific-Atlanta, Inc.

ABSTRACT

A set of near-field measurements has been performed by combining the methods of non-probe-corrected spherical near-field scanning and gain standard substitution. In this paper we describe the technique used and report on the results obtained for a particular 24 inch 13 GHz paraboloidal dish. We demonstrate that the gain comparison measurement used with spherical near-field scanning gives results in excellent agreement with gain comparison used with compact range measurement. Lastly we demonstrate a novel utilization of near-field scanning which permits a gain comparison measurement with a single spherical scan.

INTRODUCTION

Conventionally, near-field scanning gain measurements have been performed by range insertion loss measurements treating the test antenna and probe antenna pair as a two-port. Particularly for the case of planar near-field scanning this has been found to be both practical and accurate. More recently interest has been expressed in making near-field scanning gain measurements by

substitution - i.e., comparison to a standard. This paper describes the results of a trial with such a comparison procedure and demonstrates the reliability of the method, by showing that the results are in close agreement with compact range results.

SINGLE MODEL FOR FAR-FIELD AND NEAR-FIELD COMPARISON MEASUREMENTS

Disregarding the significant details of polarization and mismatch correction, one can idealize the usual far-field gain comparison method as a simple power level comparison between two identically illuminated receiving antennas - one an antenna of unknown gain (or more properly, effective area) and the other a gain standard whose gain is assumed known. It is easiest also to take the case of pure linear polarization for illustration.

Under plane wave illumination conditions let

G_{AUT} = gain of the unknown antenna under test

G_{STD} = known gain of the standard

$P_{\text{AUT}}^{\text{FF}}$ = power level measured at the port of the antenna under test

$P_{\text{STD}}^{\text{FF}}$ = power level measured at the port of the gain standard antenna

Recall that the result of the measurement is given by the far-field comparison formula

$$G_{\text{AUT}} = \frac{P_{\text{AUT}}^{\text{FF}}}{P_{\text{STD}}^{\text{FF}}} G_{\text{STD}}$$

In logarithmic form this is

$$10 \log G_{\text{AUT}} = 10 \log G_{\text{STD}} + 10 \log \frac{P_{\text{AUT}}^{\text{FF}}}{P_{\text{STD}}^{\text{FF}}}$$

(This equation can be applied directly only to the case of linear polarization in which a partial gain measurement of one polarization alone suffices to characterize the result.) The measurement procedure calls simply for making a comparison of signal levels $P_{\text{AUT}}^{\text{FF}}$ and $P_{\text{STD}}^{\text{FF}}$ for the test antenna and the standard.

In making a far-field gain comparison measurement one must always be satisfied with only an approximation to uniform plane wave illumination. In any actual far-field measurement the wavefront is somewhat spherically curved due to the finite distance of the source antenna away from the test zone. This wavefront curvature results in a small amplitude error in the received signal level. Testing in the near-field region of an antenna means the amplitude error due to the finite range length is so large that it cannot be neglected and grouped with other error contributions. In performing a gain comparison measurement in the near field, one must correct for phase curvature of the illuminating wavefront with data obtained from scanning.

Thus near-field gain comparison measurements are similar to far-field measurements, but with the addition of near-field scanning. In the near field measurement, near-field patterns are measured and far-field patterns are computed for both the AUT and the gain standard. The difference in amplitude between the near-field pattern and the far-field pattern in the direction of interest for each antenna is included in the gain calculation formula.

Define a near-field to far-field power ratio, $K_{\text{ANTENNA,NFFF}}$ for each antenna as follows:

$$K_{\text{ANTENNA,NFFF}} = E_{\text{FF}}^2(\theta_0, \phi_0) / E_{\text{NF}}^2(\theta_0, \phi_0) = P_{\text{ANT}}^{\text{FF}}(\theta_0, \phi_0) / P_{\text{ANT}}^{\text{NF}}(\theta_0, \phi_0)$$

where

$E_{FF}(\theta_0, \phi_0)$ = normalized magnitude of the E-field for the antenna at the far-field distance in the direction of known gain for the gain standard or in the direction for which the gain is desired for the AUT, and

$E_{NF}(\theta_0, \phi_0)$ = normalized E-field magnitude at the near-field distance in the same direction.

The gain comparison formula can be rewritten to read

$$G_{AUT} = \frac{P_{AUT}^{FF}}{P_{AUT}^{NF}} \frac{P_{AUT}^{NF}}{P_{STD}^{NF}} \frac{P_{STD}^{NF}}{P_{STD}^{FF}} G_{STD}$$

or

$$G_{AUT} = K_{AUT, NFFF} \frac{P_{AUT}^{NF}}{P_{STD}^{NF}} \frac{1}{K_{STD, NFFF}} G_{STD}$$

for the near-field case.

The three terms in the near-field gain comparison equation correspond to the three measurements required. A near-field power level comparison measurement $P_{AUT}^{NF}/P_{STD}^{NF}$, and two range length correction factors $P_{AUT}^{FF}/P_{AUT}^{NF}$, $P_{STD}^{FF}/P_{STD}^{NF}$ from the near-field scanning and transform operations. Thus the simplified measurement procedure calls for a comparison of signal levels P_{AUT}^{NF} , P_{STD}^{NF} under identical near-field illumination and for two scanning measurements of the test antenna and gain standard followed by two near-field to far-field transforms. Note that the gain comparison calculation formula reduce to the far-field formula as the range length correction factors approach unity.

This simple gain comparison formula is all that we have used in the non-probe-corrected spherical near-field gain comparison method reported here. It does not account for impedance mismatch, polarization correction or probe pattern illumination correction. Nevertheless it yields respectable results within its domain of validity - i.e., for well-matched linearly polarized antennas.

BASIC NEAR-FIELD GAIN COMPARISON TECHNIQUES

A schematic diagram of the spherical near-field range configuration is shown in Figure 1. The axis configuration used was roll-over-azimuth with the main beam of the test antenna along the roll axis. The instruments shown are part of a Scientific-Atlanta Model 2022A Antenna Analyzer.

The standard gain horn was measured using near-field scanning and the results transformed to the far field. Similarly the antenna under test was measured and the data transformed. The test antenna was a 24 inch diameter paraboloidal reflector antenna operated at 13.0 GHz, the standard gain horn was a Scientific-Atlanta Model 12-12 pyramidal horn. The near-field to far-field transform was performed using the standard software package available with the 2022A analyzer. Care was taken to align the peak of the gain standard pattern with the peak of the test antenna pattern.

In Figures 2 and 3 we show the results of near-field scanning and the near-field to far-field transform. Figure 2 shows both principal planes for the standard gain horn and Figure 3 both principal planes for a 2-foot dish used throughout as the AUT. Inset in both figures are listings of the data from which the plots were generated.

As Figure 2 indicates, the location (angular coordinates) and magnitude of the near-field and far-field peaks are the same for the standard gain

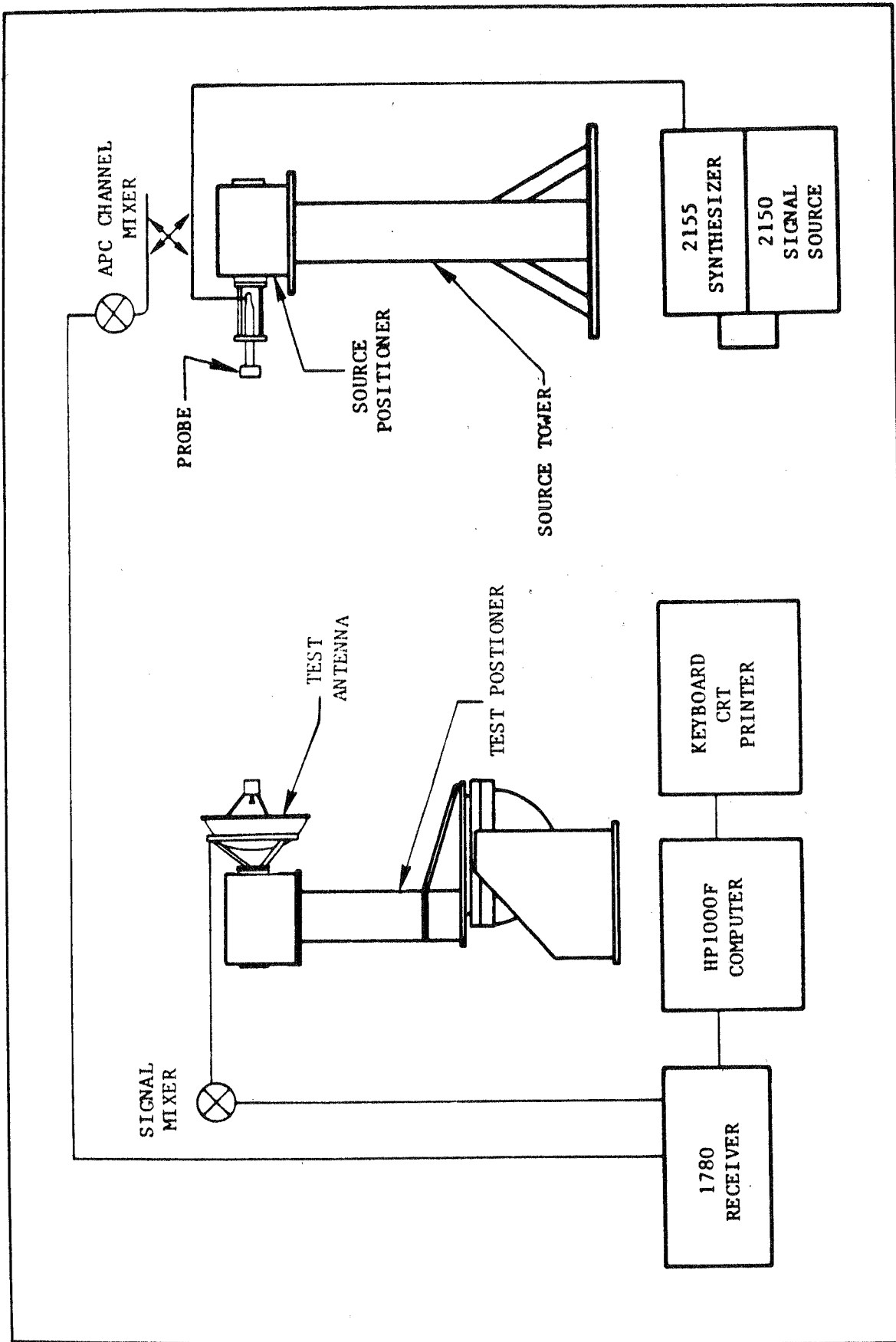
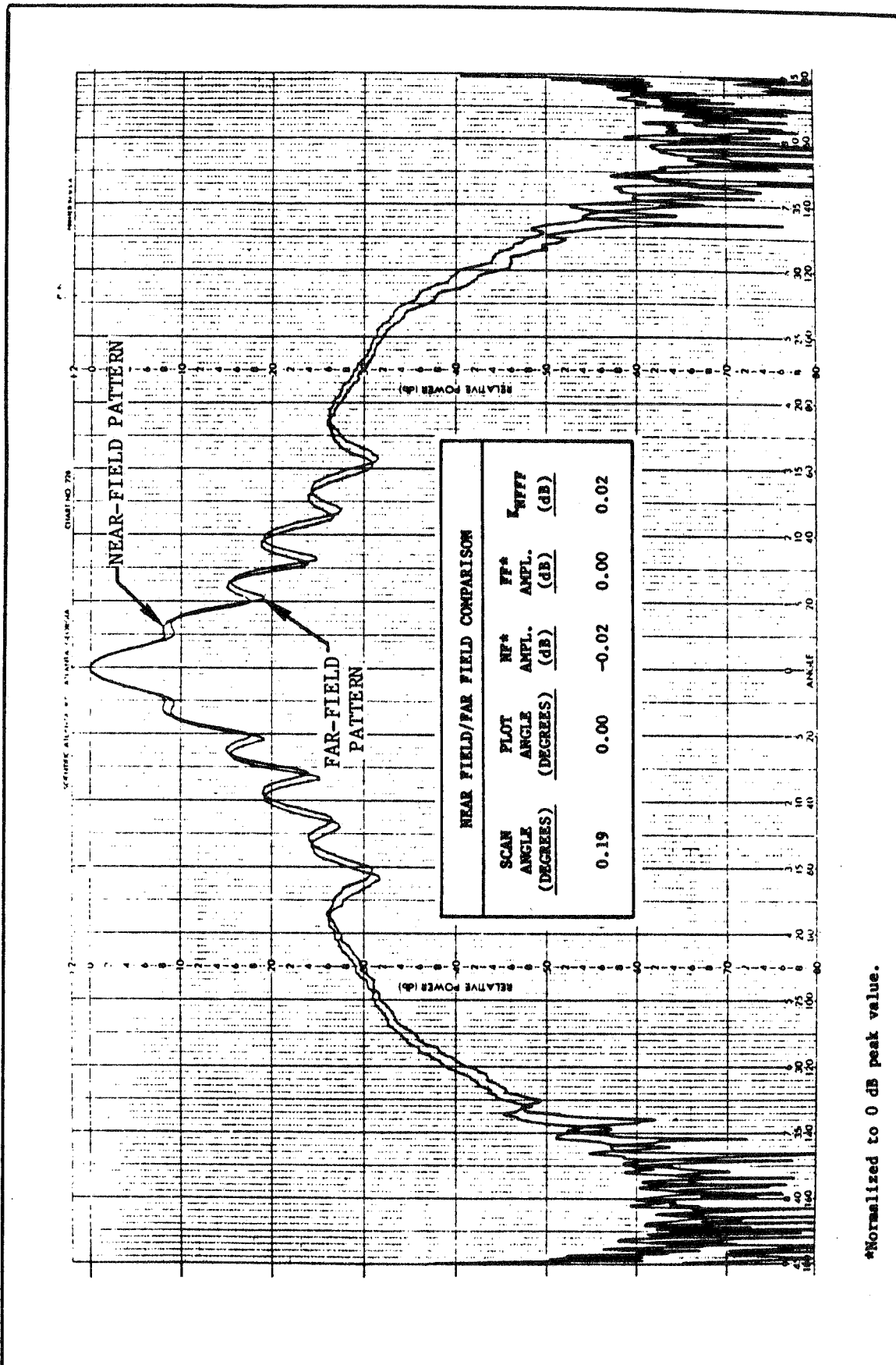


Figure 1. Schematic Diagram of Polar Mount Spherical Near-Field Scanning Configuration



*Normalized to 0 dB peak value.

Figure 2a. E-Plane Near-Field vs. Far-Field Pattern for Standard Gain Horn in Polar Mount

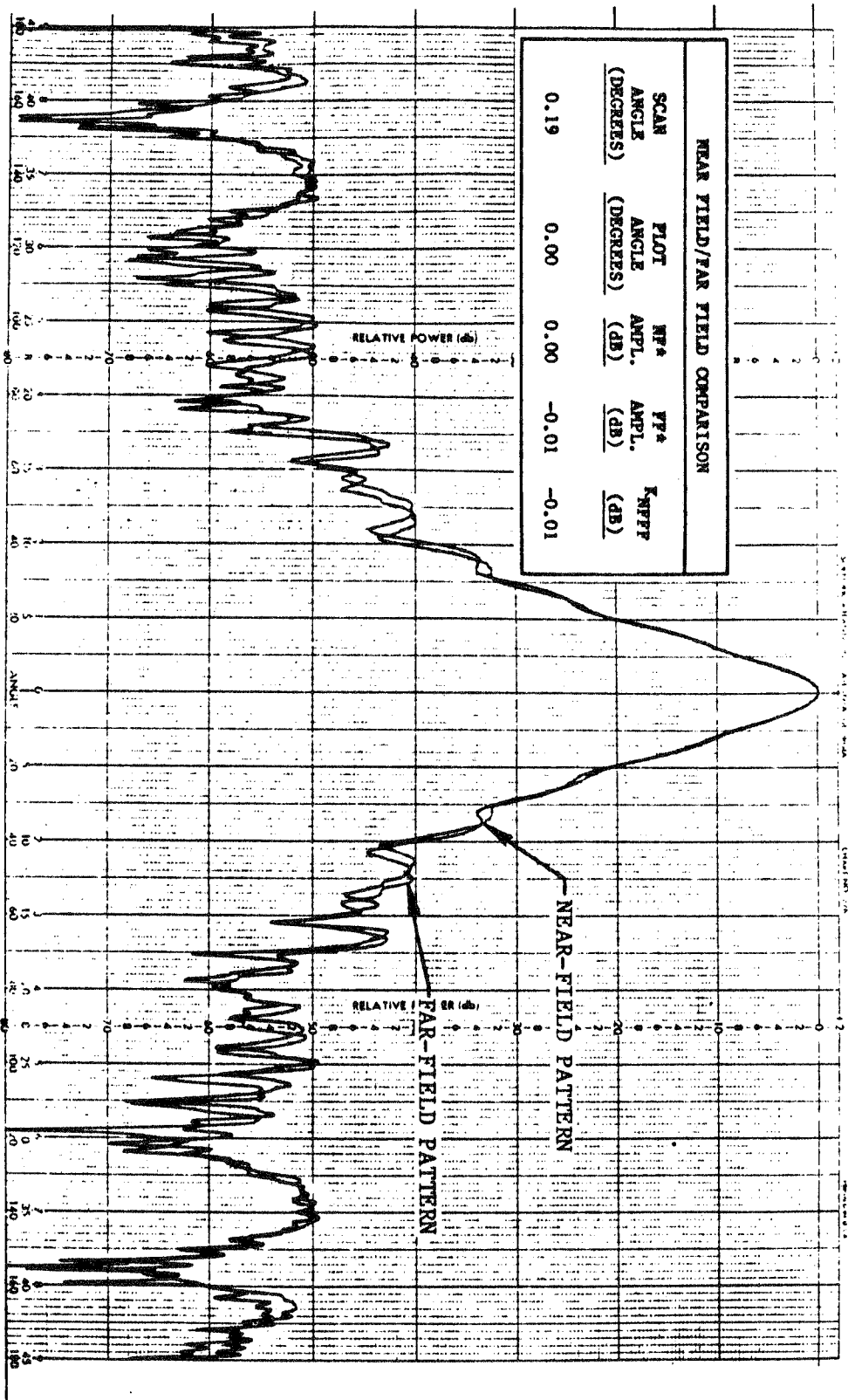


Figure 2b. H-Plane Near-Field vs. Far-Field Pattern for Standard Gain Horn in Polar Mount

*Normalized to 0 dB peak value.

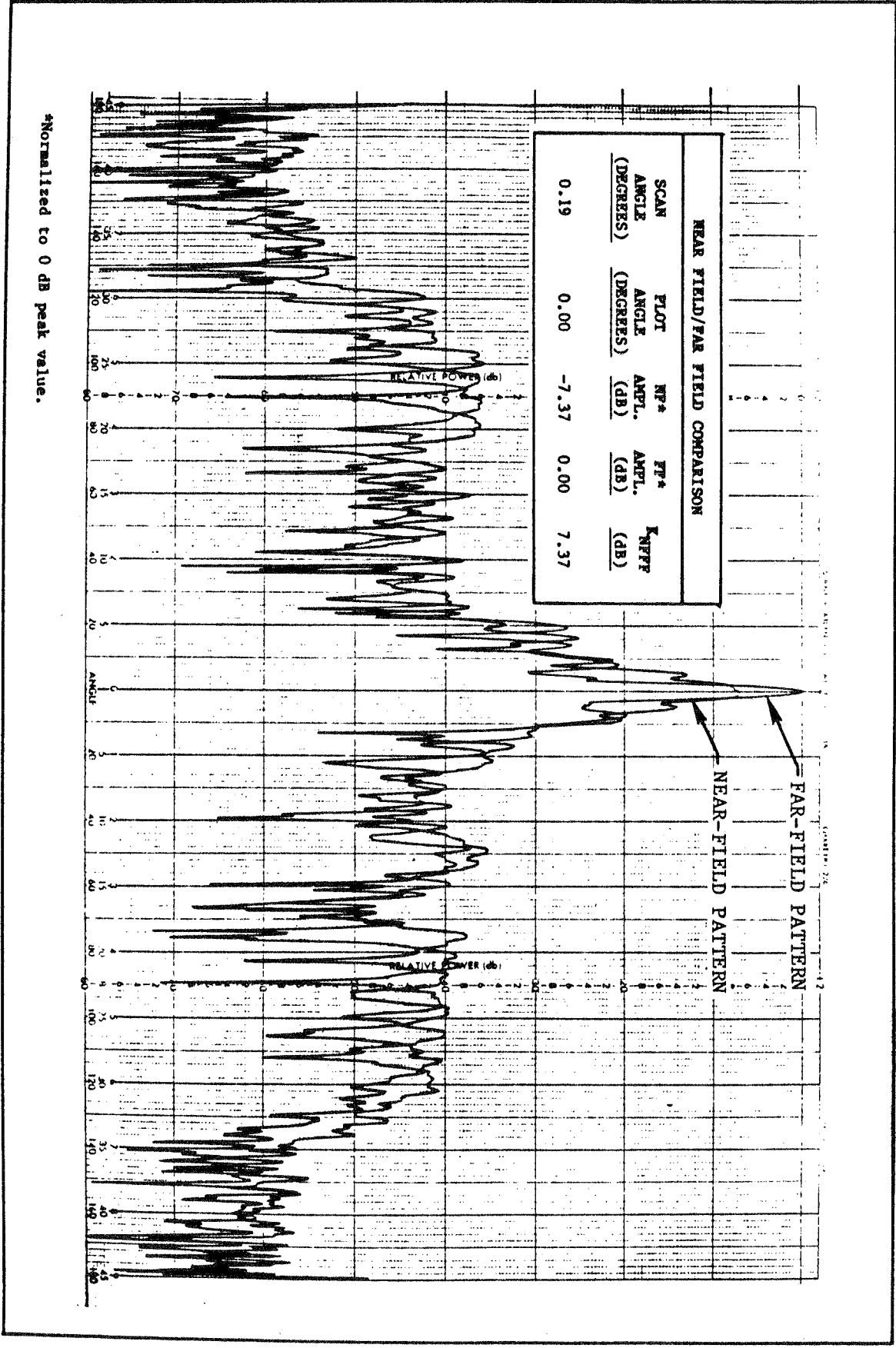
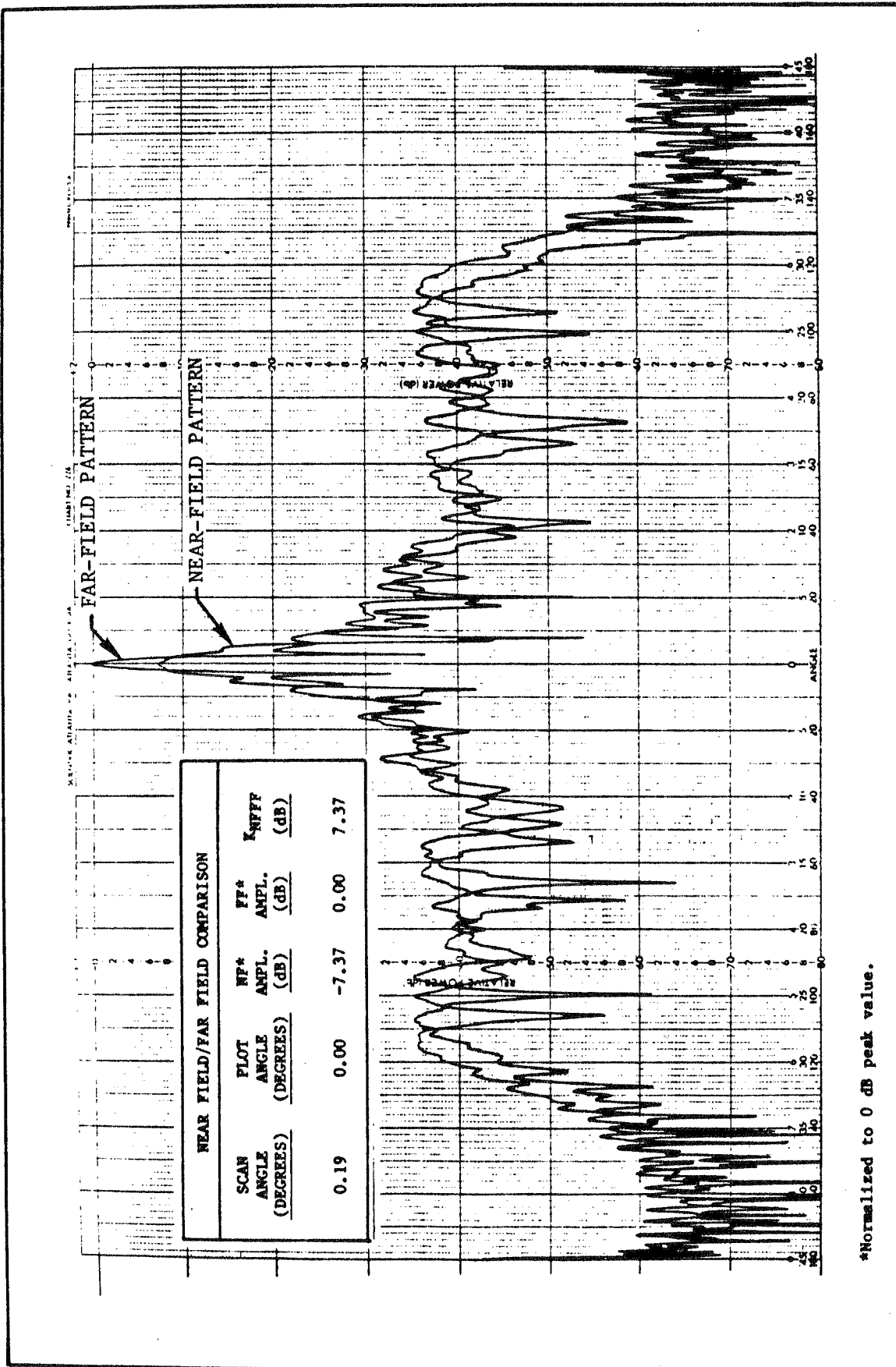


Figure 3a. E-Plane Near-Field vs. Far-Field Pattern for AUT in Polar Mount



*Normalized to 0 dB peak value.

Figure 3b. H-Plane Near-Field vs. Far-Field Pattern for AUT in Polar Mount

horn. This data was acquired with a range length of 311.4 cm which is about $3D^2/\lambda$ - greater than the usual far-field criterion. Even so, the near-field and far-field patterns are different. For the standard gain horn as shown in Figure 2, $K_{SGH,NFFF} = 1$.

As shown in Figure 3, the far-field peak for the AUT is larger in magnitude than the near-field level in this direction. For the AUT, $K_{AUT,NFFF} = 7.37 \text{ dB} = 5.46$. Note that in this case the direction of the near-field peak is the same as that of the far-field peak.

The signal power levels of the ports of the test antenna and the gain standard were compared as the gain horn was dismounted from the test positioner and the test antenna put in place.

The near-field signal level comparison measurement is illustrated in Figure 4. (As in the far-field gain comparison measurement, mismatch error produces the largest uncertainty in this measurement.) A Scientific-Atlanta Model 14-5 mixer with a 20 dB matching pad was used as a detector for this measurement. The measured difference in power level between the terminals of the AUT and of the gain standard was 2.73 dB or a factor of 1.88. Using the last equation for the near-field gain comparison formula we get $G_{AUT} = 2,440 = 33.87 \text{ dB}$. The gain of the standard gain horn was 23.76 dB.

POLAR VERSUS EQUATORIAL MOUNTING

All of the above measurements were made with the AUT and the gain standard mounted in polar configuration. That is, each antenna was mounted so that its main beam was centered on the north pole of the measurement sphere. We performed the measurements described above with the antennas in equatorial mount also, and some practical simplifications were achieved. Figure 5 illustrates the geometry of polar and equatorial mounting configurations and

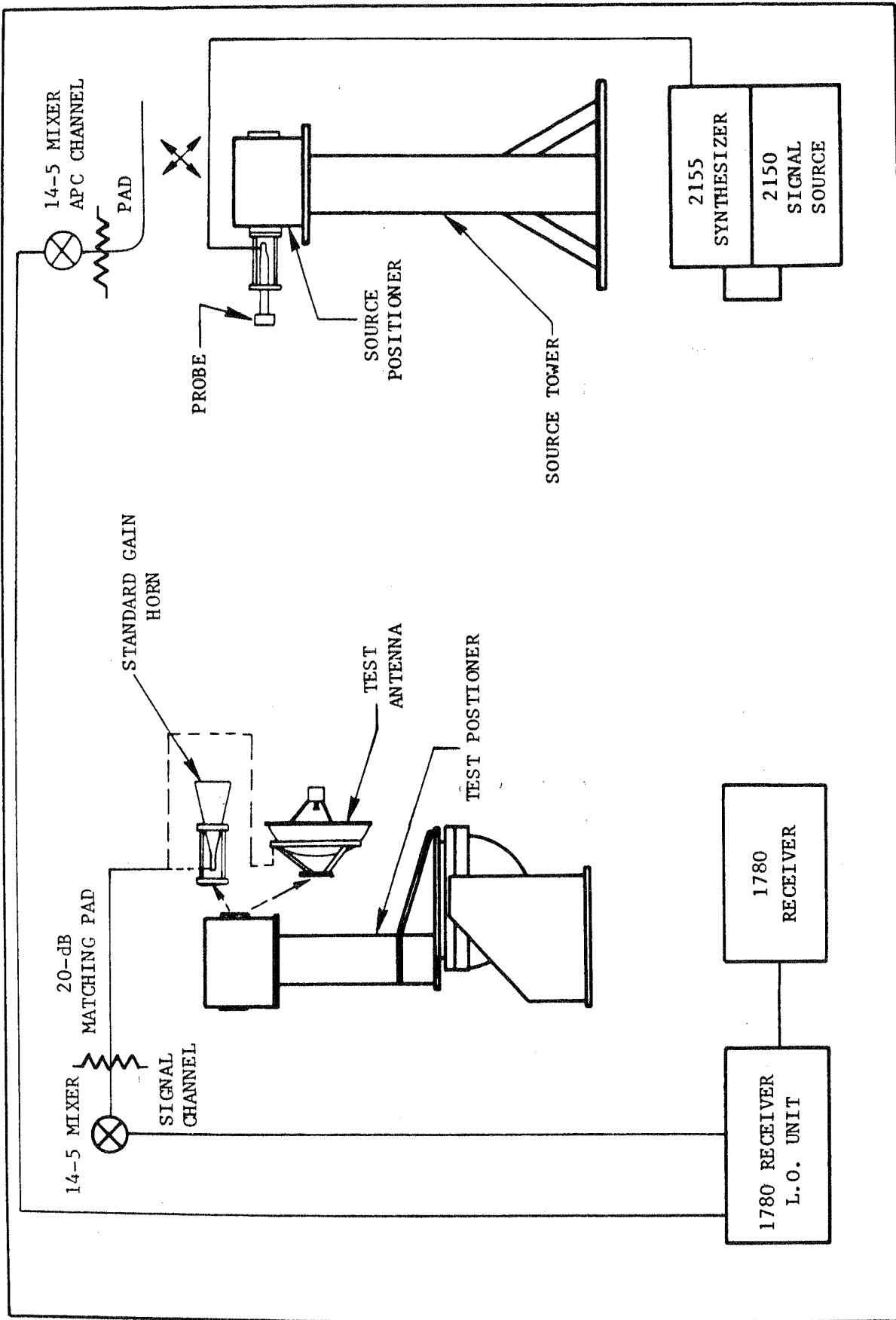


Figure 4. Power Level Comparison Measurement

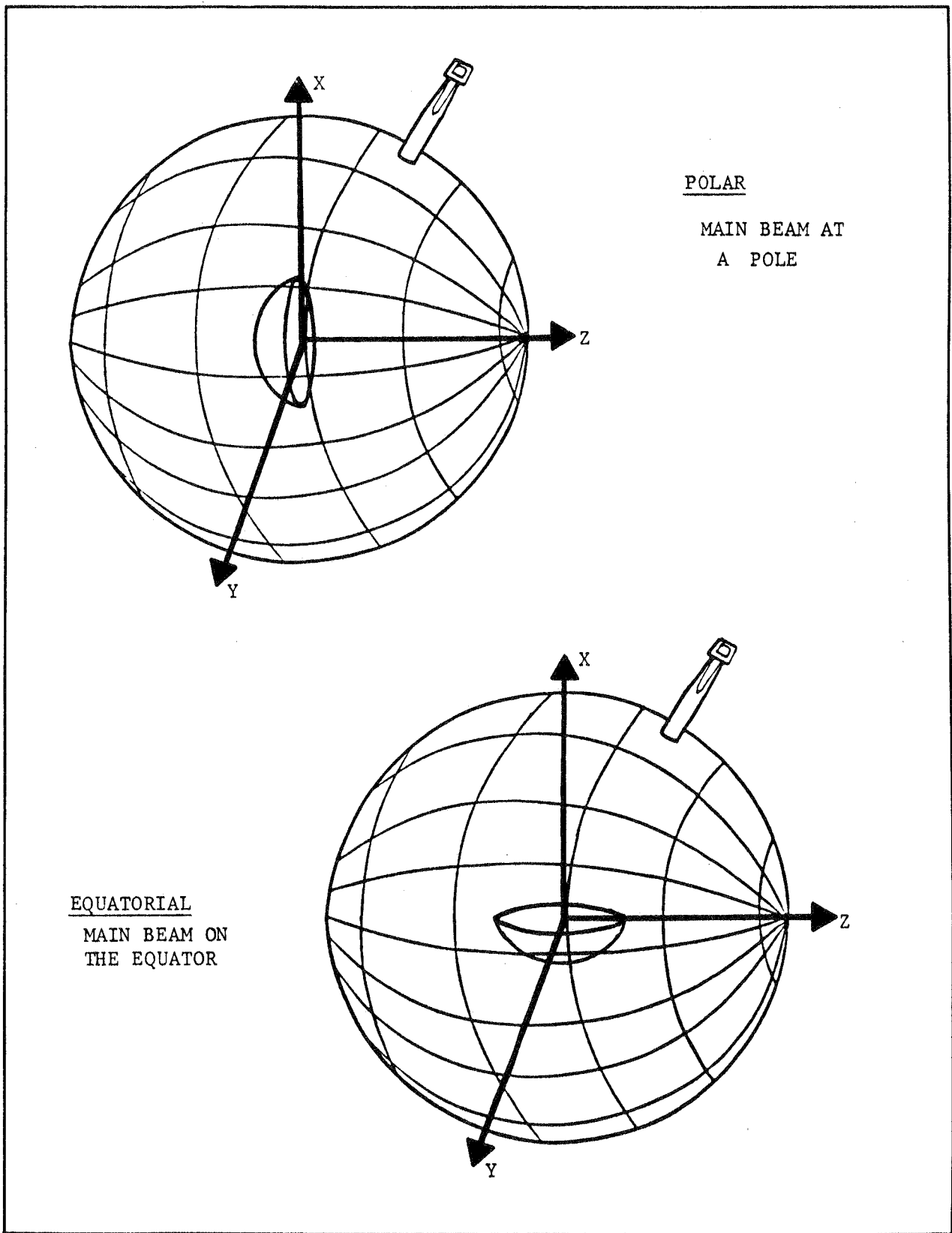


Figure 5. Geometry for Polar and Equatorial Mounting Configurations

Figure 6 illustrates schematically the measurement setup used. Note that the roll axis of the test positioner resembles the switch axis setup commonly used for far-field gain comparison measurements.

Figures 7 and 8 show measured near-field and calculated far-field patterns for both principal planes of each antenna in the mounting configuration of Figure 6. From Figure 7 we note that $K_{STD,NFFF} = -1.21 \text{ dB} = .76$ for this mounting configuration. The far-field pattern is significantly different from the near-field pattern for this mounting configuration.

From Figure 8 we get $K_{AUT,NFFF} = 8.08 \text{ dB} = 6.43$. The measurement of the power level difference between the two antennas was particularly convenient for this mounting configuration since both antennas were already mounted. It was necessary only to rotate the "switch" axis by 180° and move the padded mixer from the AUT to the standard gain horn. The power at the AUT was .82 dB a factor of 1.21, greater than the power at the standard gain horn. The equation for the gain of the AUT in this case yields $G_{AUT} = 2,433 = 33.86 \text{ dB}$, which is essentially the same result as for the polar mount case.

GAIN COMPARISON BY NEAR-FIELD SCANNING VERSUS GAIN COMPARISON BY COMPACT RANGE ILLUMINATION

The compact range approach to antenna measurement has been used before to verify the goodness of spherical near-field scanning pattern measurements. It offers an excellent means of plane wave illumination for antenna testing. In order to assess the goodness of our gain comparison measurement, we compared the spherical near-field measurements to gain comparison measurements performed on the compact range. Figure 9 illustrates the difference in the compact range and spherical near-field measurement configurations. The compact range procedure is identical to a far-field measurement. Table I

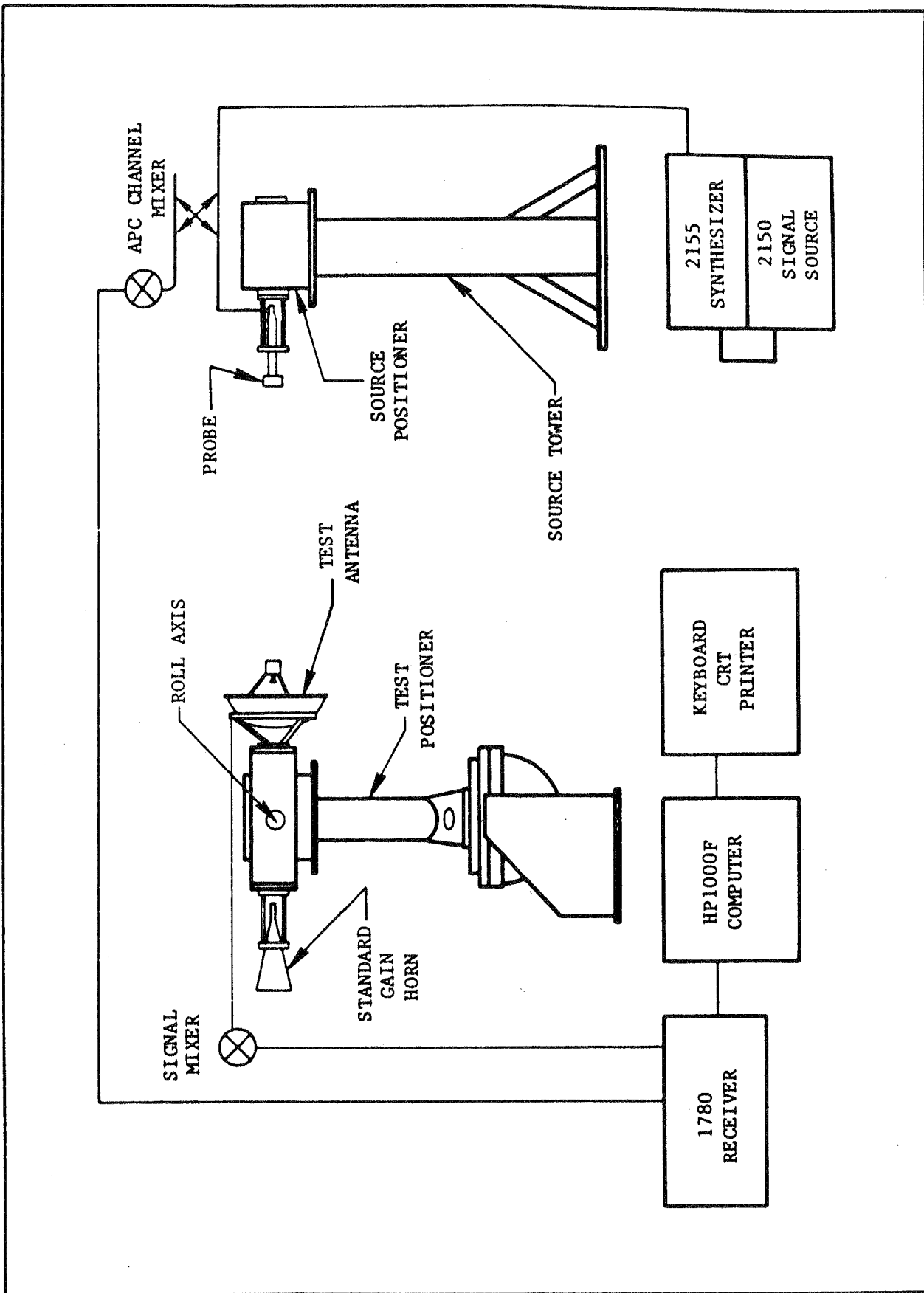
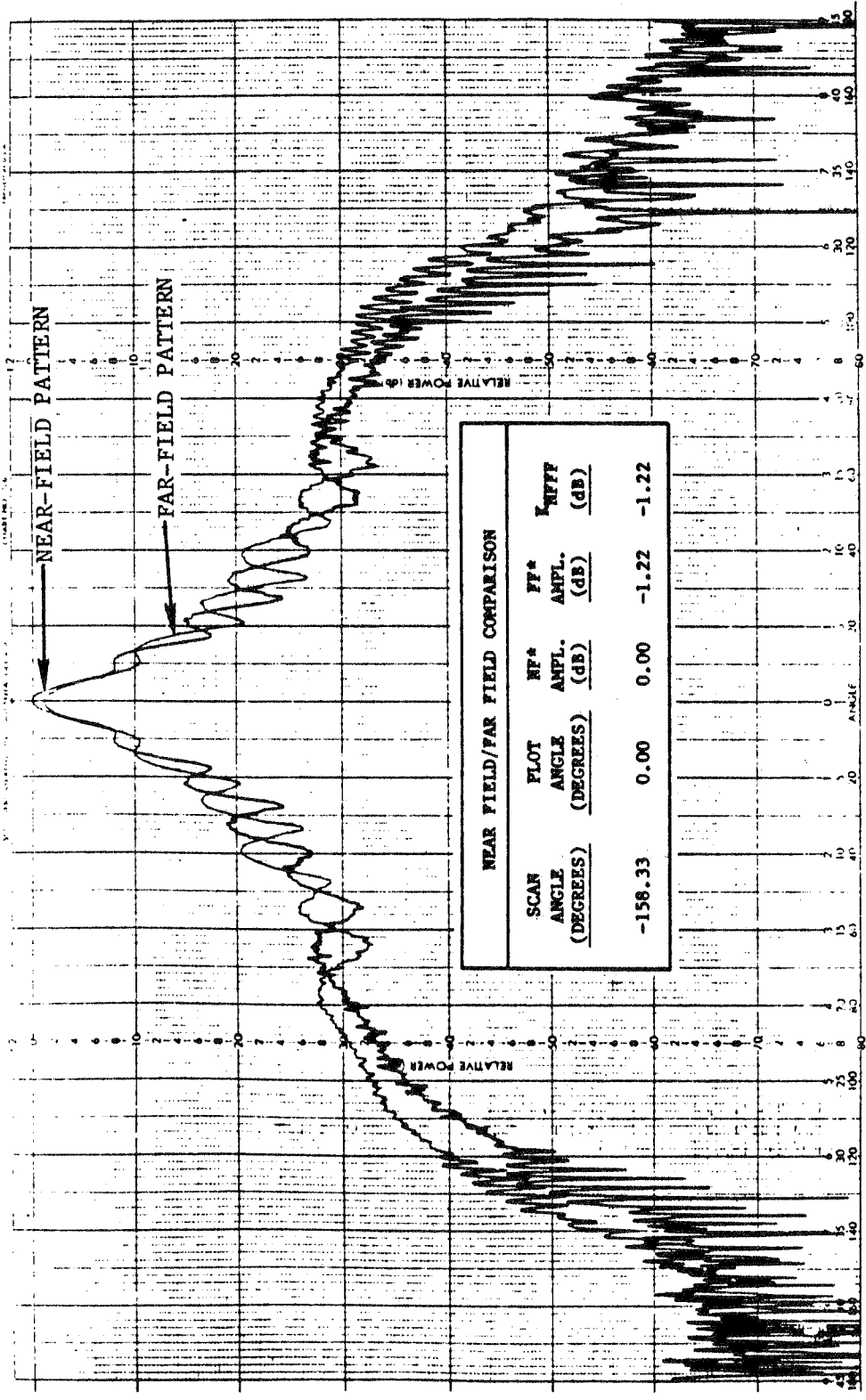
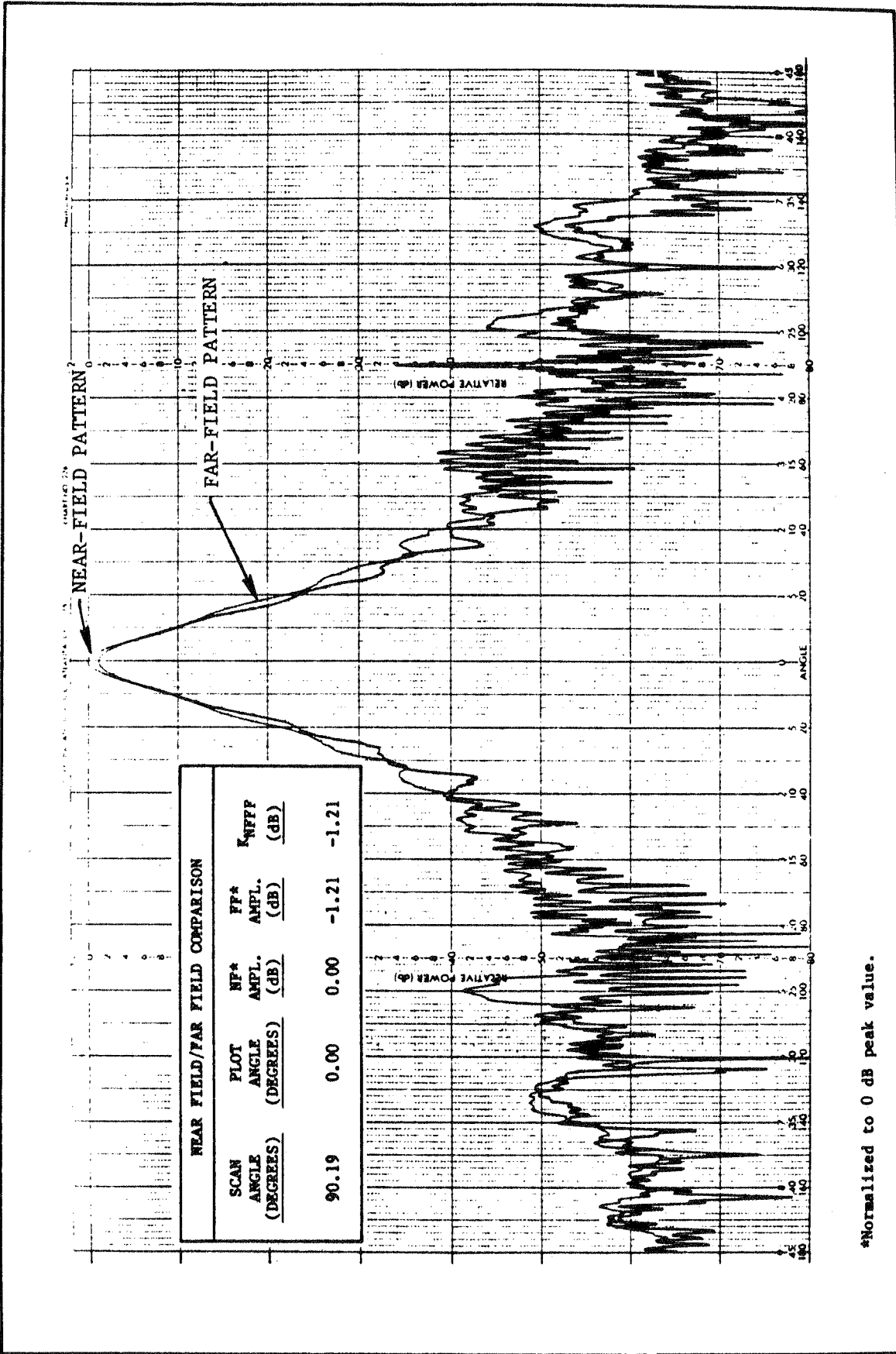


Figure 6. Schematic Diagram of Equatorial Mount Spherical Near-Field Scanning Configuration



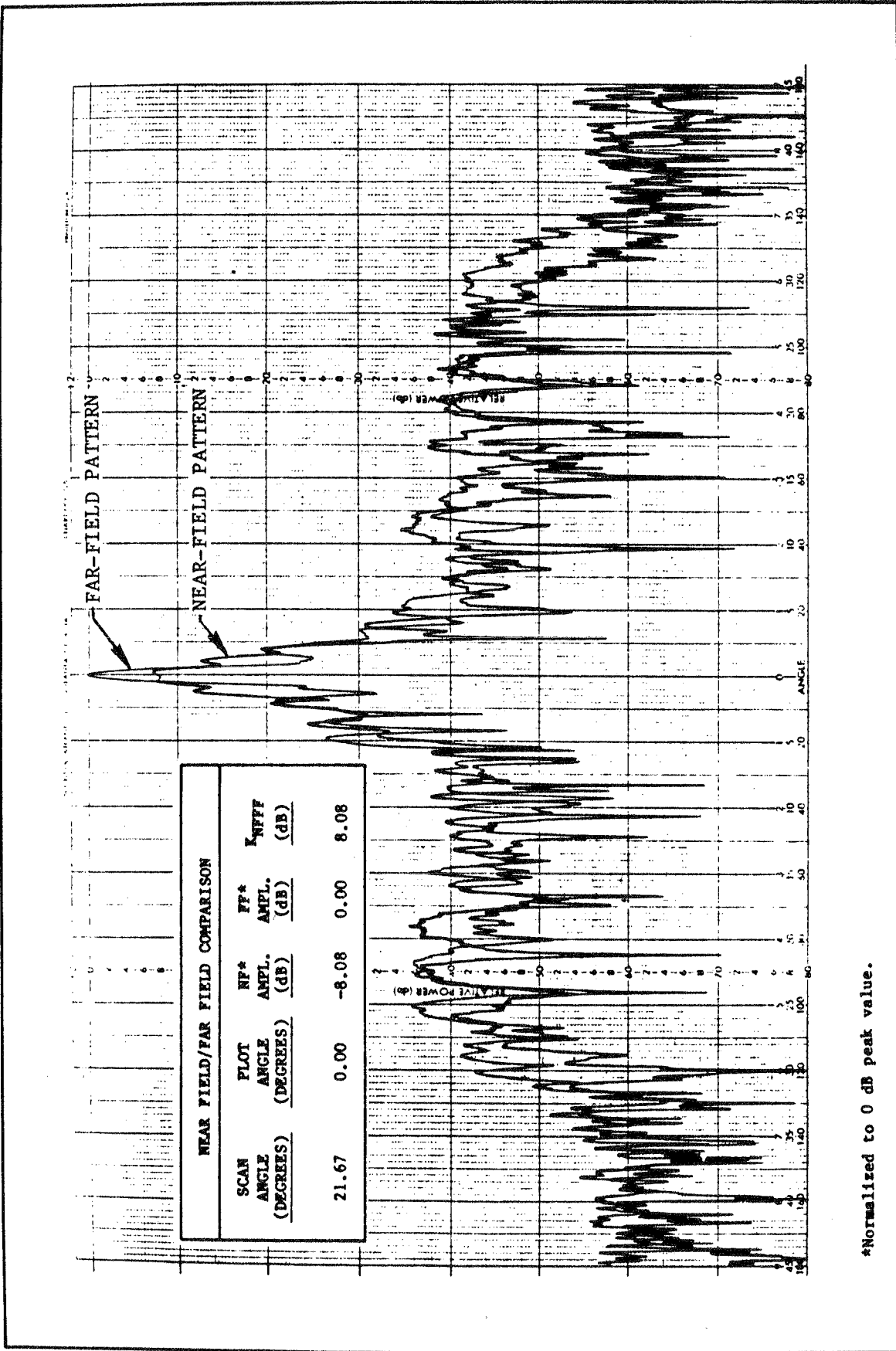
*Normalized to 0 dB peak value.

Figure 7a. E-Plane Near-Field vs. Far-Field Pattern for Standard Gain Horn in Equatorial Mount



*Normalized to 0 dB peak value.

Figure 7b. H-Plane Near-Field vs. Far-Field Pattern for Standard Gain Horn in Equatorial Mount



*Normalized to 0 dB peak value.

Figure 8a. E-Plane Near-Field vs. Far-Field Pattern for AUT in Equatorial Mount

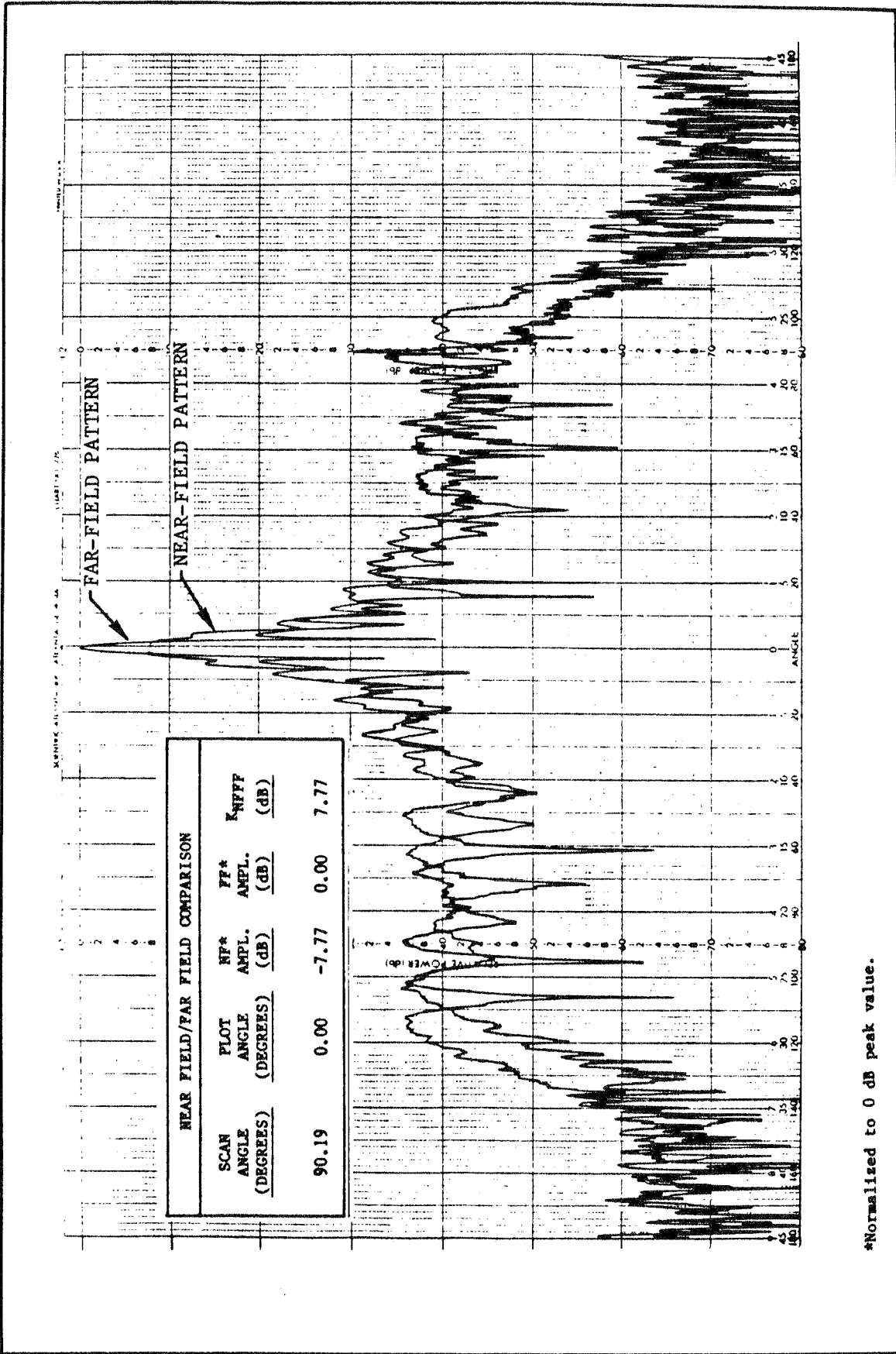
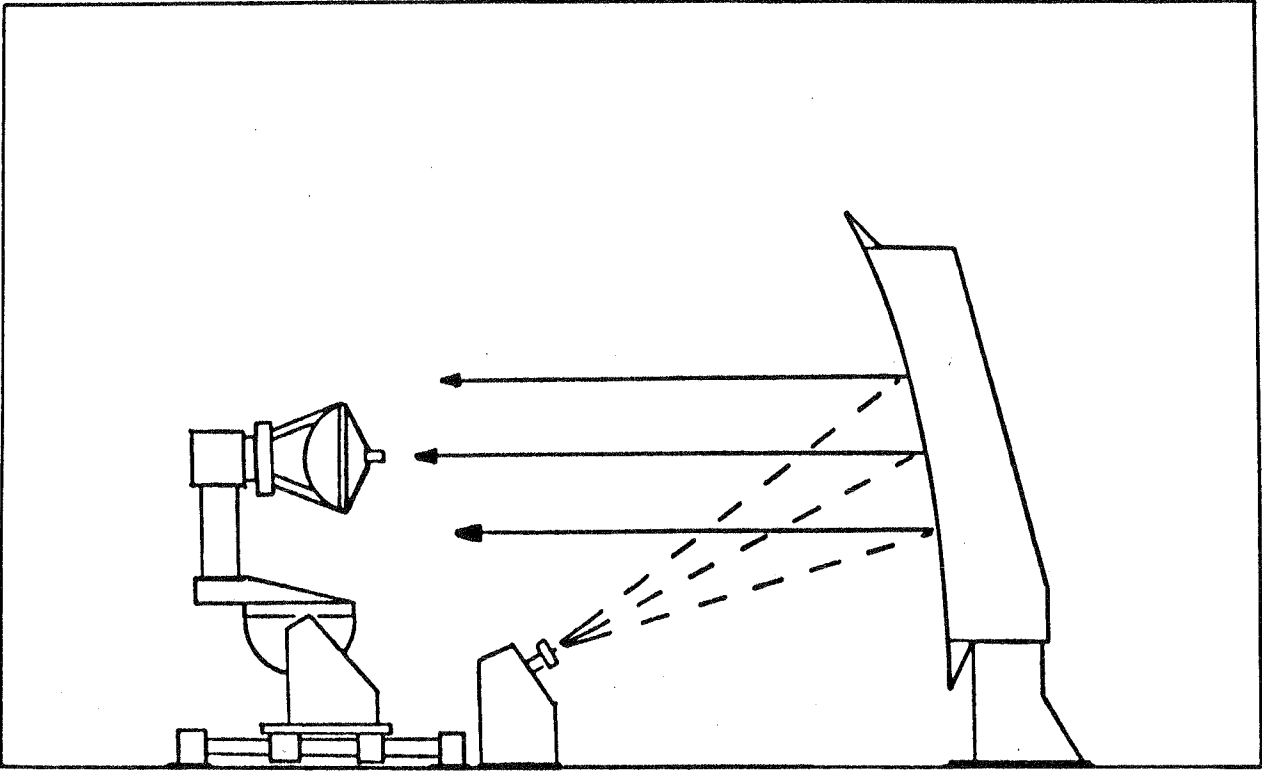
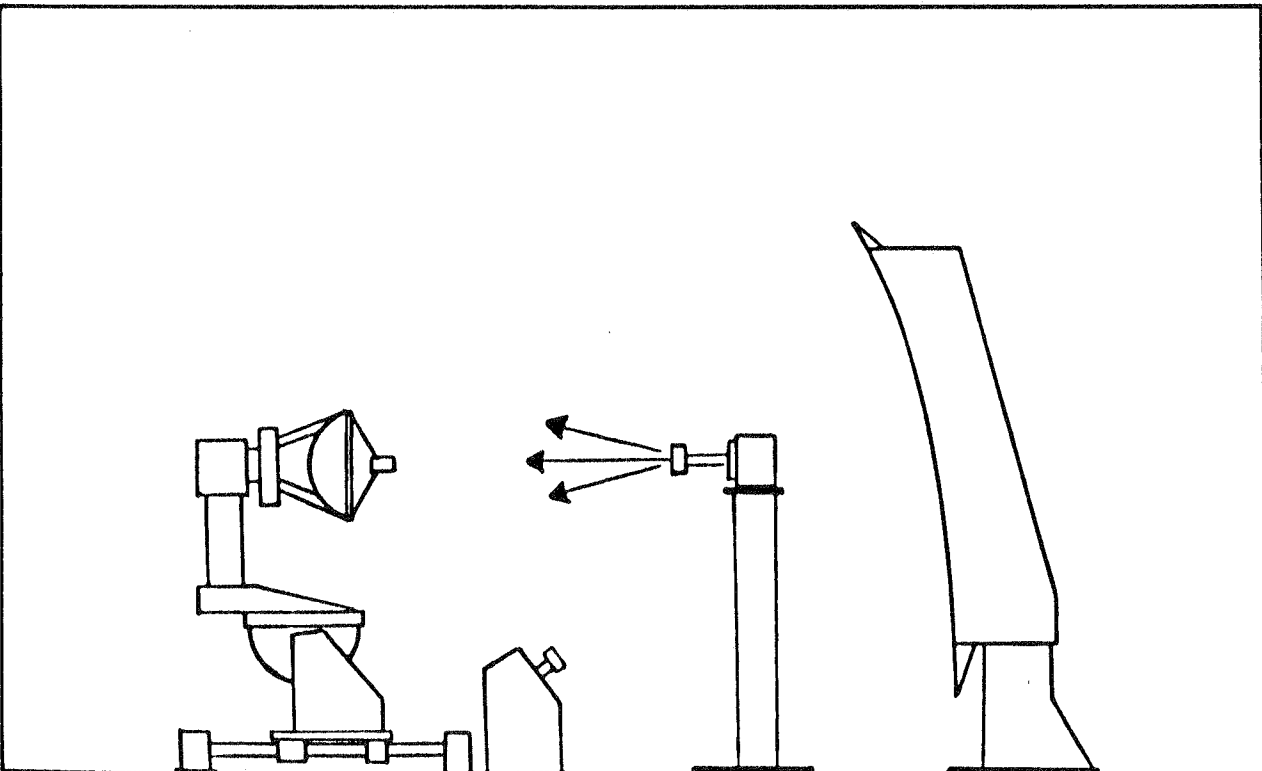


Figure 8b. H-Plane Near-Field vs. Far-Field Pattern for AUT in Equatorial Mount



(a)



(b)

Figure 9. Compact Range (a) vs. Spherical Near-Field (b) Measurement Configurations

TABLE I

Results of Near-Field and Compact Range Gain Measurements

	Compact Range	Spherical Near-Field
Polar Mount	33.84 dBi± .56 dB	33.87 dBi± .55 dB
Equatorial Mount	33.82 dBi± .56 dB	33.86 dBi± .55 dB

compares the results of all the measurements made along with calculated RSS errors. For the error calculation, all errors unique to near-field scanning (drift during the scan, noise, crosstalk, and receiver non-linearity at low pattern levels, etc.) were modeled as an equivalent stray signal level in the calculated far-field patterns. The RSS errors were computed by the method given in IEEE Standard 149-1979 modified to account for the additional "stray-signal". As the table indicates, the measurement was extremely repeatable and the calculated RSS errors are on the order of .5 dB.

SHARED-SCAN GAIN COMPARISON MEASUREMENTS

In an effort to reduce the lengthy data acquisition and data transformation times required to perform successive near-field scans we have devised a novel range configuration which halves the measurement time. It permits both the test antenna and gain standards to share the same mechanical scan but with the main beams occupying different coverage regions. The arrangement used called for mounting both antennas in equatorial configuration with their main beam peaks located at diametrically opposite positions on the equator. In principle the same approach is possible in polar mounting orientation but our positioner was not convenient for the polar case. The ports of the two antenna are coupled together so that the receiver signal is the sum of the two phasors, and both patterns show up in the data. An assumption here is that both antennas have negligible backlobes. See Figure 10. This setup makes the AUT and the standard gain horn look like one composite antenna with two main beams. Figures 11 and 12 show near-field vs. far-field patterns for the two principal planes in this configuration. All the data was acquired in a single scan. The measured gain of the AUT for this case was 33.80 dB.

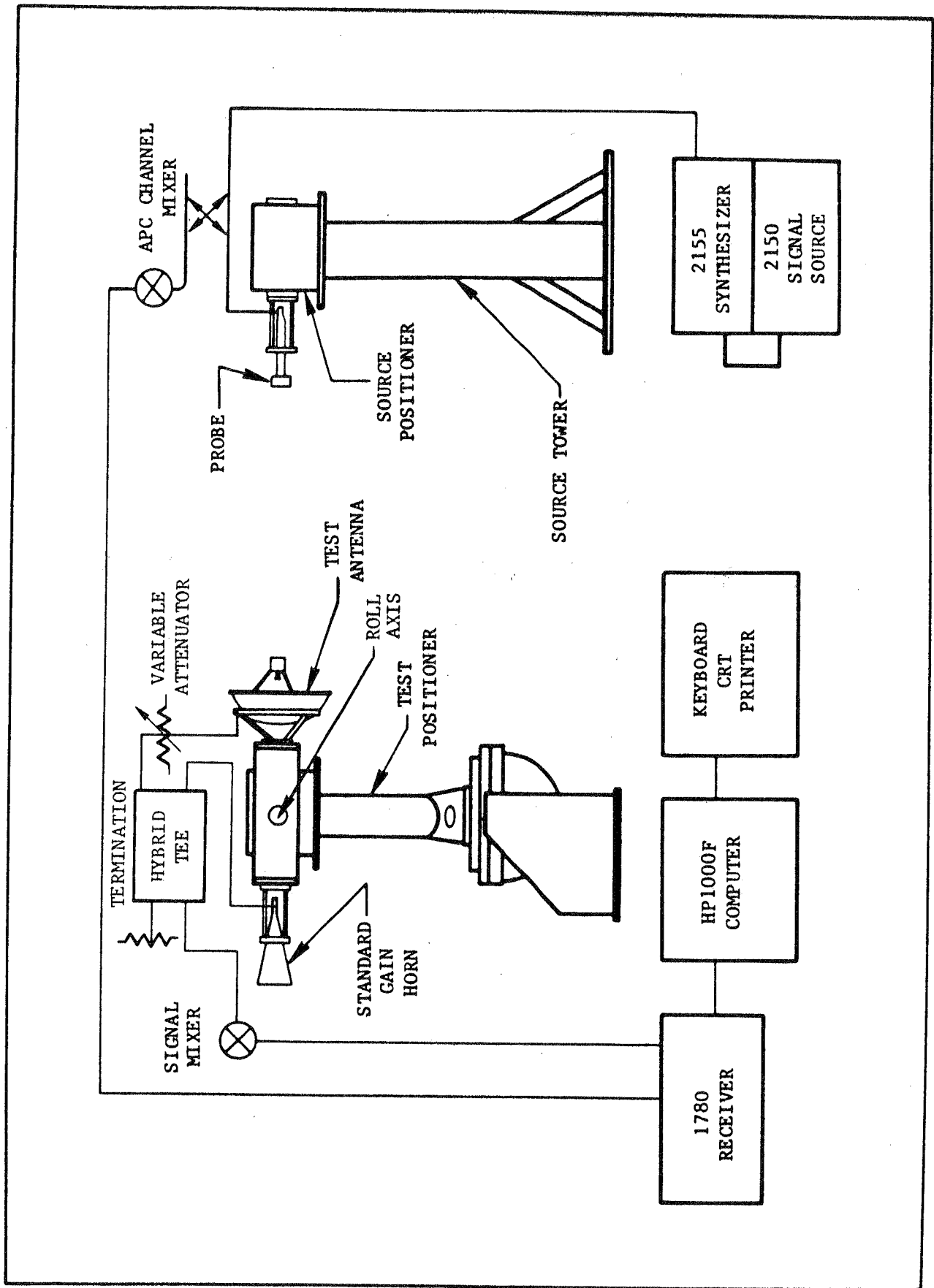
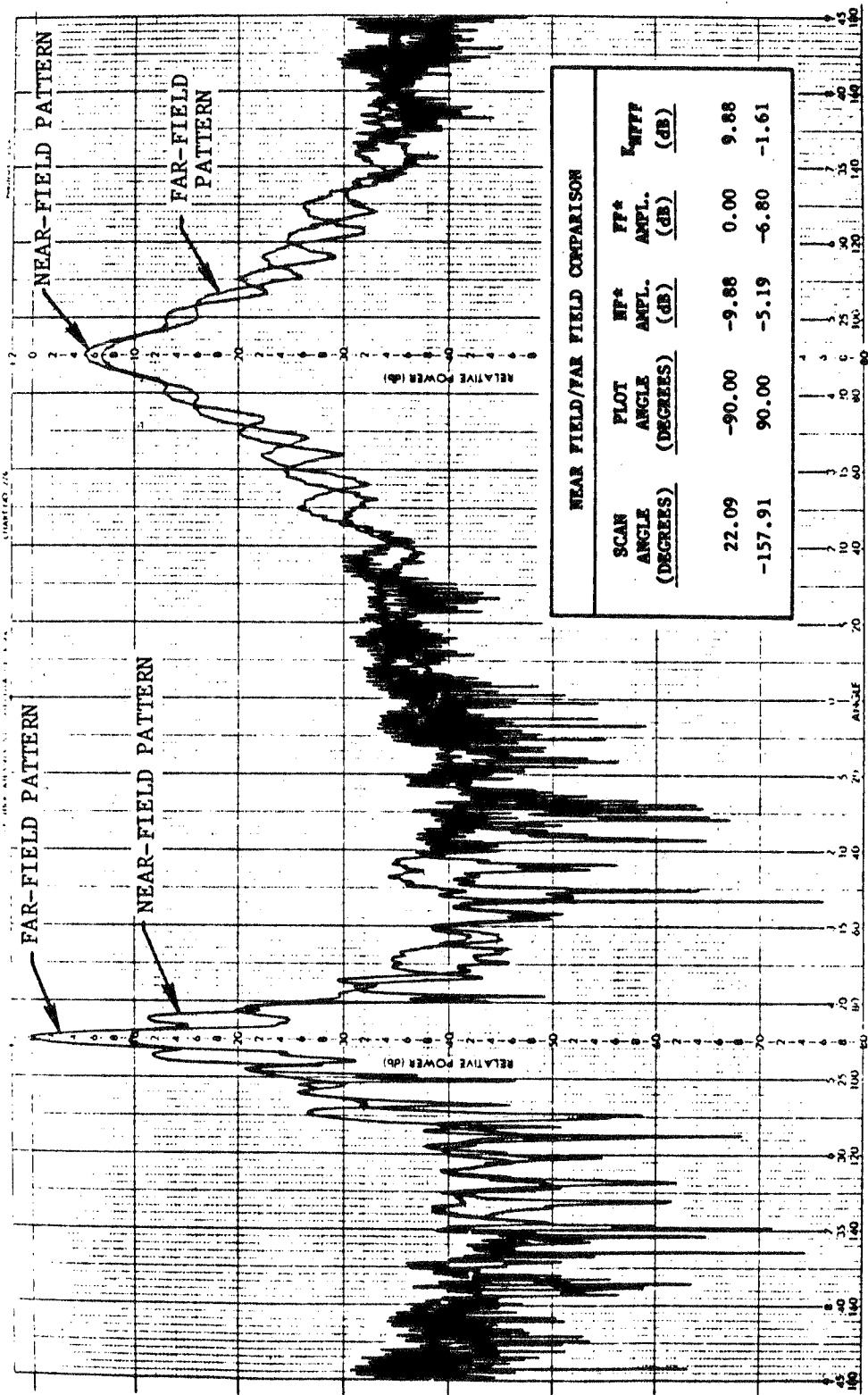
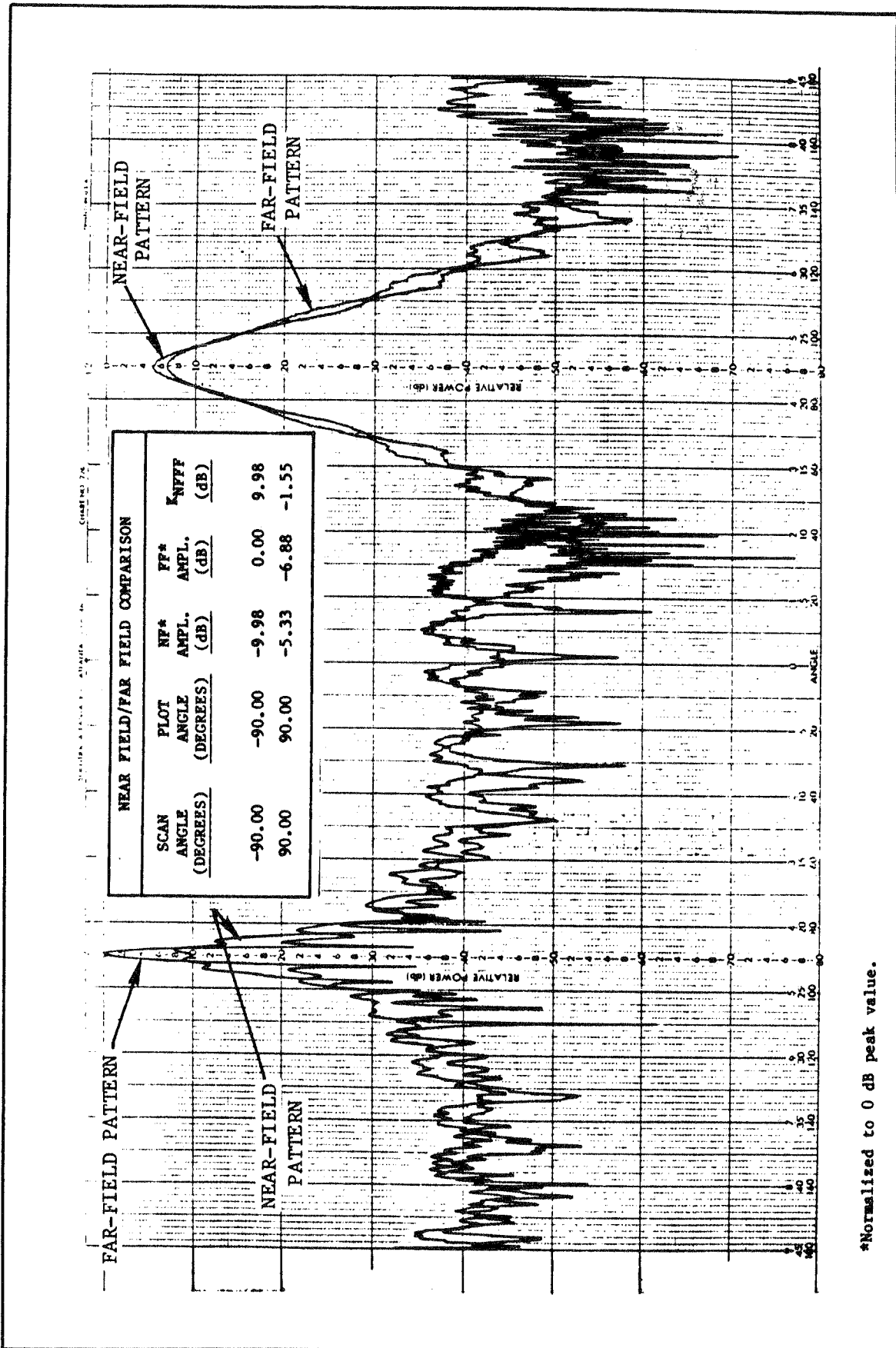


Figure 10. Coupled Antennas in Equatorial Mount



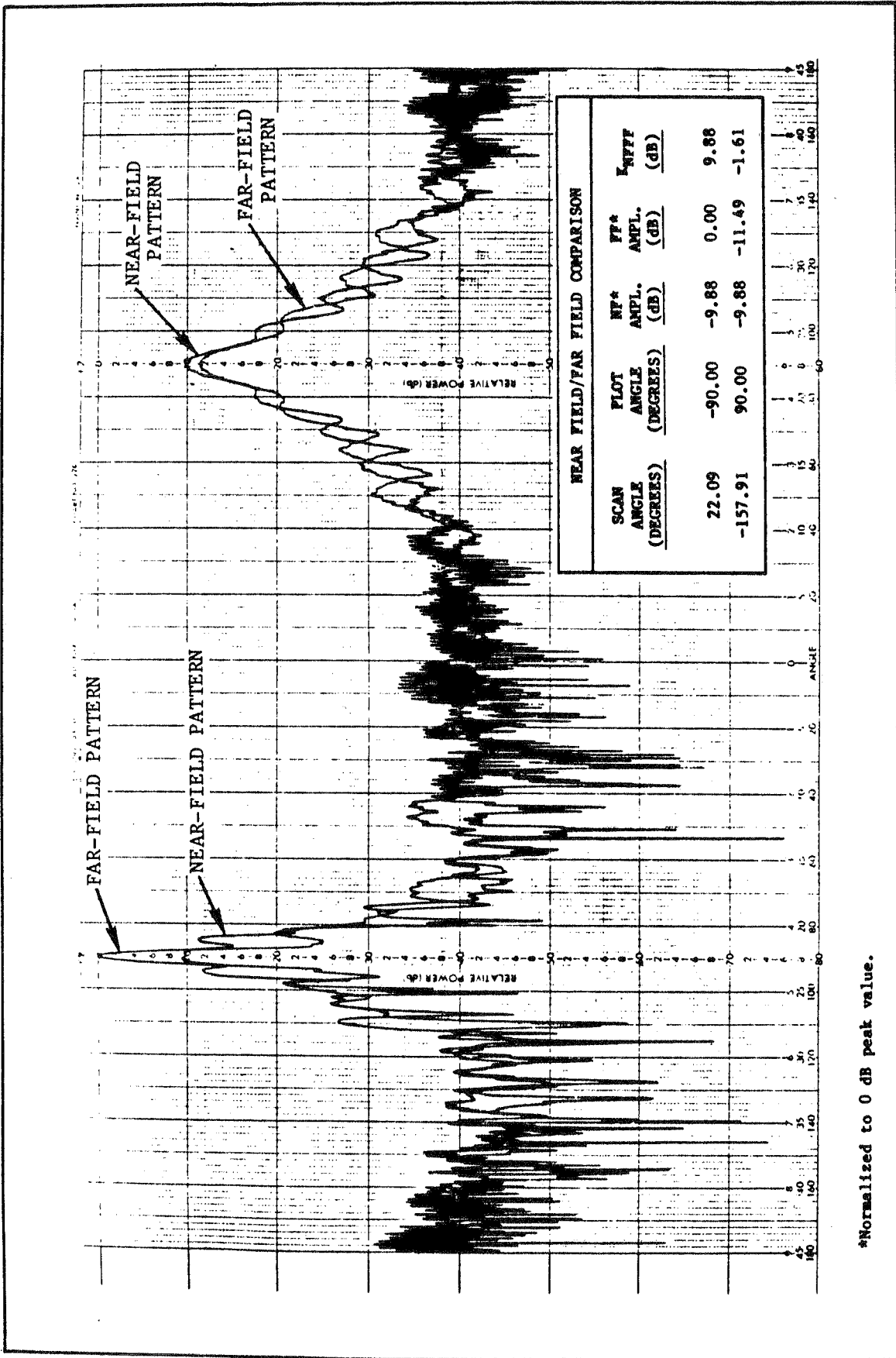
*Normalized to 0 dB peak value.

Figure 11. E-Plane Near-Field vs. Far-Field Pattern for Coupled Antennas



*Normalized to 0 dB peak value.

Figure 12. H-Plane Near-Field vs. Far-Field Pattern for Coupled Antennas



*Normalized to 0 dB peak value.

Figure 13. E-Plane Near-Field vs. Far-Field Pattern for Synthesized Amplitude-Corrected Coupled Antennas

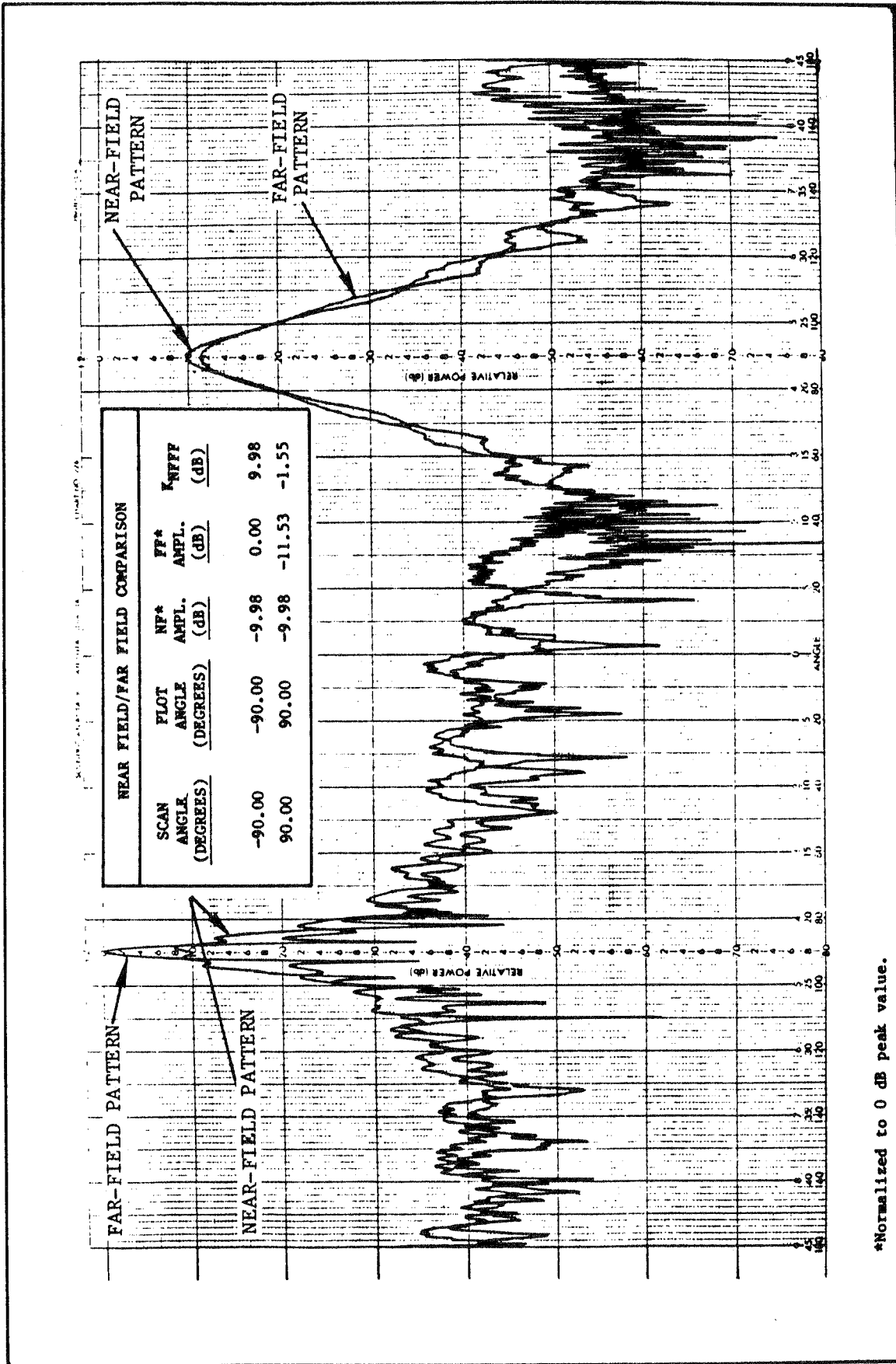


Figure 14. H-Plane Near-Field vs. Far-Field Pattern for Synthesized Amplitude-Corrected Coupled Antennas

The variable attenuator shown in Figure 10 was not used for the measurements of Figures 11 and 12. Had we used it and adjusted its level so that the near-field levels in the directions of interest were equal for both antennas, as shown in Figures 13 and 14, the quantity $K_{AUT,NFFF} - K_{SGH,NFFF}$ would have fallen directly out of the transformed data.

SUMMARY

We have performed gain comparison measurements using spherical near-field scanning. The measurements were made using standard RF hardware with the currently available Scientific-Atlanta 2022A Spherical Near-Field Antenna Analyzer. Measurement errors on the order of .5 dB were estimated, and measurement of impedance mismatch and accurate gain standard calibration could reduce these errors significantly. A method for combining the signals at the terminals of the two antennas involved (thereby effectively making them one antenna) was developed. This halved the data acquisition time since only one spherical near-field scan was required. The Scientific-Atlanta 2022A Spherical Near-Field Antenna Analyzer can be used with the procedures described above to make gain comparison measurements at near-field range lengths, thereby providing the same advantages for gain measurements as it already provides for pattern measurements.