

IEEE Recommended Practice for Near-Field Antenna Measurements

IEEE Antennas and Propagation Society

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Sponsor

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of the
IEEE Antennas and Propagation Society

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Abstract: Near-field test practices for the measurement of antenna properties are described in this document and near-field measurement practices for the three principal geometries: cylindrical, planar, and spherical are recommended. Measurement practices for the calibration of probes used as reference antennas in near-field measurements are also recommended.

Keywords: antenna measurements, antenna near-field measurements, cylindrical near-field measurements, IEEE 1720, near-field measurements, planar near-field measurements, probe calibrations, spherical near-field measurements

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Introduction

This introduction is not part of IEEE Std 1720TM-2012, IEEE Recommended Practice for Near-Field Antenna Measurements.

When IEEE Std 149TM-1979 (IEEE Standard Test Procedures for Antennas) was first developed, near-field antenna measurement was in its infancy. In the mid-1980s, the use of near-field methods for measuring antennas started becoming more widespread, especially for testing communication satellite antennas. Today, more than 200 facilities worldwide employ near-field methods for measuring antenna parameters. Many believe the time had come to develop a set of recommended practices for these measurements.

This document lays out recommended practices for near-field measurements for the three principal geometries: cylindrical, planar, and spherical. It also indicates recommended measurement practices for the calibration of probes used as reference antennas in near-field measurements.

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1. Overview

1.1 Scope

This document describes near-field test practices for the measurement of antenna properties. It provides information on developments in near-field measurements that have occurred since the writing of IEEE Std 149™-1979 (IEEE Standard Test Procedures for Antennas). This document recommends near-field measurement practices for the three principal geometries: cylindrical, planar, and spherical, and also recommends measurement practices for the calibration of probes used as reference antennas in near-field measurements.

1.2 Purpose

The purpose of this recommended practice document is to provide practical guidance to those who are planning to do near-field measurements. This document also specifies capabilities required of a near-field measurement system.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 145™, IEEE Standard Definitions of Terms for Antennas.^{1,2}

IEEE Std 149, IEEE Standard Test Procedures for Antennas.

IEEE Antennas and Propagation Society, “Special Issue on Near-Field Scanning Techniques,” *IEEE Transactions on Antennas and Propagation*, vol. 36, no. 6, pp. 727–901, 1988.

3. Background

3.1 Antenna patterns

We consider an $\exp(-i\omega t)$ time dependence with frequency $f = \omega/(2\pi)$, wave number $k = 2\pi/\lambda$, and wavelength λ . Note that modern receivers generally use the $\exp(+j\omega t)$ time dependence. However much of the early theory and current software uses the $\exp(-i\omega t)$ convention. The practitioner needs to be aware of the potential conflict. A minus sign needs to be added to the phase of a receiver using the $+j\omega t$ convention to get the proper result from software using the $-i\omega t$ convention.

Sufficiently distant from a radiating antenna, the electric field is transverse and is given by the expression

$$\mathbf{E}_t(\mathbf{r}) \underset{r \rightarrow \infty}{\sim} \mathbf{t}(\hat{\mathbf{r}}) \frac{\exp(ikr)}{ikr} a_0 \quad (1)$$

$$\hat{\mathbf{r}} \cdot \mathbf{t}(\hat{\mathbf{r}}) = 0. \quad (2)$$

In any direction, the *transmitting function* $\mathbf{t}(\hat{\mathbf{r}})$ is characterized by amplitude and phase (or real and imaginary part) and complex polarization. Equation (1) embodies the linear relation between the radiated field and the excitation a_0 .

The power accepted by the transmitting antenna is

$$P_0 = K_1(1 - |\Gamma_t|^2) |a_0|^2, \quad (3)$$

where

Γ_t is the impedance reflection coefficient, looking into the transmitting antenna
 K_1 is an arbitrary constant.

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² IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

Once K_1 is fixed, P_0 determines $|a_0|$, and hence $\mathbf{t}(\hat{\mathbf{r}})$, up to an arbitrary (and unimportant) overall phase factor.

A common rule of thumb states that Equation (1) is valid in the *far-field region* $r > r_f$ (e.g., IEEE Std 145, IEEE Standard Definitions of Terms for Antennas) where

$$r_f \sim \frac{2D^2}{\lambda}, 10D, \text{ or } 10\lambda, \quad (4)$$

whichever is greatest. D is the diameter of the smallest sphere that encloses the radiating parts of the antenna. Larger values of r_f may be needed depending on antenna type or accuracy requirements.

Consider an incident plane wave

$$\mathbf{E}_i(\mathbf{r}) = \frac{\mathbf{E}_0}{2\pi} \exp(i\mathbf{k} \cdot \mathbf{r}) \quad (5)$$

$$\mathbf{k} \cdot \mathbf{E}_0 = 0, \quad \mathbf{k} \cdot \mathbf{k} = k^2 = \omega^2 / c^2. \quad (6)$$

The response of a receiving antenna is given in terms of the *receiving function* $\mathbf{s}(\hat{\mathbf{k}})$:

$$(1 - \Gamma_\ell \Gamma_r) b_0 = \mathbf{s}(\hat{\mathbf{k}}) \cdot \mathbf{E}_0. \quad (7)$$

The received power P_r and the available power P_a are

$$\begin{aligned} P_r &= K_2 (1 - |\Gamma_\ell|^2) |b_0|^2 \\ P_a &= K_2 (1 - |\Gamma_r|^2) |b_0|^2 \end{aligned} \quad (8)$$

Here K_2 is an arbitrary constant, Γ_ℓ and Γ_r are the reflection coefficients looking into the load and receiving antenna, respectively.

To be definitive, we use the normalizations

$$K = K_1 = K_2 = \frac{1}{2k^2 Z_0}, \quad (9)$$

where $Z_0 = \sqrt{\mu_0 / \epsilon_0} \approx 377\Omega$ is the impedance of free space. With this choice, a_0 and b_0 have the dimensions of electric field [V/m] and the transmitting and receiving functions are dimensionless.

Following IEEE Std 145, the directional *gain* of the transmitting antenna and the *effective area* of the receiving antenna are given by

$$G(\hat{\mathbf{r}}) = \frac{4\pi}{1-|\Gamma_t|^2} |\mathbf{t}(\hat{\mathbf{r}})|^2 \quad (10)$$

$$\sigma(\hat{\mathbf{r}}) = \frac{\lambda^2}{1-|\Gamma_r|^2} |\mathbf{s}(\hat{\mathbf{r}})|^2. \quad (11)$$

Also when Equation (9) is adopted, reciprocity implies that

$$\mathbf{s}(\hat{\mathbf{r}}) = \mathbf{t}(-\hat{\mathbf{r}}) \quad (12)$$

or

$$\sigma(\hat{\mathbf{r}}) = \frac{\lambda^2}{4\pi} G(-\hat{\mathbf{r}}). \quad (13)$$

Throughout this document, we assume that the antenna under test (AUT) is a passive, linear, reciprocal device. Consequently, it can be measured in either the transmitting or receiving mode. However, many of the test practices can be adapted for measuring antennas with active, nonlinear, or nonreciprocal components.

We also use the term *pattern* to refer to the transmitting or receiving function when a specific normalization is not implied. A pattern can be normalized easily to satisfy Equation (11), Equation (11), or Equation (12) if the gain or directivity is known in some direction.

3.2 Basic near-field measurement theory

Near-field measurement methods require the development of transmission formulas that describe the coupling of two antennas in close proximity.

First, expand the vector field of the test antenna in a complete set of modes $\mathbf{u}_n(\mathbf{r})$

$$\mathbf{u}(\mathbf{r}) \approx \sum_{n=1}^N t_n \mathbf{u}_n(\mathbf{r}) a_0, \quad (14)$$

where N is the total number of modes. It needs to be possible to represent $\mathbf{u}(\mathbf{r})$ to acceptable accuracy using a finite summation. (In cases where modes are not discrete, the sum is replaced by an integral.) The expansion, Equation (14), needs to be valid where measurements are made and in the far-field region, as well, so that

$$\mathbf{t}(\hat{\mathbf{r}}) \underset{r \rightarrow \infty}{\sim} \frac{\mathbf{u}(\mathbf{r})}{a_0} \frac{ikr}{\exp(ikr)}. \quad (15)$$

First consider an ideal probe that measures the actual field at a point. In principle, to determine the coefficients t_n , it suffices to make independent measurements at P many points r_i ($1 \leq i \leq P \geq N$) and to find the least-squares solution to the system of linear equations that results from Equation (14). This would require $O(N^3)$ operations using, for example, Gaussian elimination. N will be specified for each of the three geometries in what follows.

For many practical antenna problems $10^4 < N < 10^6$ and computational efficiency is a major concern. For this reason, near-field measurements are made so that data points lie in regular grids on planar, cylindrical, or spherical surfaces. Separability of coordinates and modal orthogonality arising in these geometries allow significant reductions in processing time. The computational complexity is $O(N \log N)$ for planar and cylindrical sampling, and $O(N^{3/2})$ for spherical sampling, where N is the total number of modes to be determined.

Practical probes do not (or only approximately) measure the vector field at a point in space. This fact is especially important in close proximity to a source where fields may vary significantly over the volume of the probe. The probe converts the incident vector field to a complex voltage that is measured and recorded by the data collection system. This conversion can be mathematically represented by the generic transmission equation

$$w(\mathbf{r}, \chi, \theta, \phi) = [\mathbf{P} \bullet \mathbf{u}](\mathbf{r}, \chi, \theta, \phi) = a_0 \sum_{n=1}^N t_n \mathbf{P} \bullet \mathbf{u}_n(\mathbf{r}, \chi, \theta, \phi), \quad (16)$$

where $\mathbf{P}$ is an operator that depends on the properties of the probe. This transmission equation will be specialized to the three coordinate systems (planar, spherical, and cylindrical) in subsequent sections. To account for probe effects, it is necessary to catalog the response (via probe characterization) of a probe to each mode in Equation (14)

$$w_n(\mathbf{r}, \chi, \theta, \phi) = [\mathbf{P} \bullet \mathbf{u}_n](\mathbf{r}, \chi, \theta, \phi). \quad (17)$$

Arguments give the probe position vector $\mathbf{r}$ and the Euler angles (χ, θ, ϕ) describing probe orientation (see section 19.2.4.2 in Francis and Wittmann [B37]³).

Equation (16) assumes that the presence of the probe does not affect the test antenna field. (Discrepancies due to probe-test antenna interaction are often called *multiple-reflection errors*. None of the present near-field-to-far-field transformations with probe correction accounts for the effect of multiple reflections, since this would require considering (generally unknown) scattering characteristics of antenna and probe. The approaches to compensate for the effect of multiple reflections, in those cases when this effect is not small, are described in 9.4.11.) The probe response $w(\mathbf{r}, \chi, \theta, \phi)$ is typically normalized to correspond to unit excitation ($a_0 = 1$) and reflectionless load ($\Gamma_\ell = 0$).

Again, to determine t_n , it suffices to make independent measurements at the points r_i ($1 \leq i \leq P \geq N$) and to find the least-squares solution to the linear system that follows from the transmission equation, Equation (17). The need for numerical efficiency limits practical implementations to planar, cylindrical, or spherical scanning.

³ The numbers in brackets correspond to those of the bibliography in Annex A.

A brief history of early near-field measurements can be found in the June 1988 issue of the *IEEE Transactions on Antennas and Propagation Special Issue on Near-Field Scanning Techniques* [B6], [B42], [B48], [B63]. During the 1940s and 1950s, near-field measurements of antennas were used primarily for diagnostic purposes (Gillespie [B42]). However, these measurements did not correct for probe-pattern effects. In the early 1960s, theories were developed by Kerns and Dayhoff [B72], Brown and Jull [B10], and Leach and Paris [B84] that accounted for these effects in planar and cylindrical geometries. These developments made it practical to determine the far-field properties of an antenna from measurements in the radiating near field.

3.3 Far-field versus near-field measurements

The far-field pattern can be measured directly, direction by direction, if the probe-AUT separation can be made sufficiently large. (This may be impractical for some electrically large antennas.)

Although near-field methods are more complicated physically and mathematically, the ability to use small separation distances means that it is possible to make many measurements in the climate- and electromagnetic-controlled environment of an antenna measurement facility (or range). Potentially, this fact can result in improvements in security, accuracy, and throughput.

All near-field techniques require the acquisition and processing of two complex, (nearly) orthogonal polarization components (Yaghjian [B126]). Knowledge of this information helps ensure that both co-polar and cross-polar far-field radiation pattern information can be recovered. During the near-field acquisition, no reference needs to be made to the AUT polarization sense or the preferred definition of co-polarization or cross polarization. The near-field data set is converted to a far-field data set within a specific coordinate system, using a specific polarization definition (Ludwig [B85]). It is therefore possible to determine the AUT polarization sense during the processing phase of the measurement process. Since the two measured polarization components are orthogonal and therefore independent, it follows that circularly polarized (CP) AUTs can be measured using linearly polarized probes since any CP signal can be represented as the sum of two linearly polarized signals (Stutzman [B112]). However, in this case the CP component is the small difference between two large quantities and this tends to have a larger uncertainty than if measured with two orthogonal CP measurements.

3.4 Executive summary

Clause 4 covers measurement systems. The geometries for the planar, cylindrical, and spherical near-field scanning methods necessitate data point acquisition on a plane, cylinder, and sphere respectively. For each of these near-field methods, there is a multitude of practical implementations of mechanical and electrical systems, depending on a particular need, suitability, or importance of one or the other factor. All scanning methods require a radio-frequency (RF) transmit and receive system with some type of computerized scanning, data acquisition, and analysis ability. A probe is selected depending on the geometry of the scan surface as well as to minimize its influence on the calculated far-field characteristics of the AUT. There are electrical requirements that need to be characterized and optimized when possible. Clause 4 discusses the various scanning subsystem configurations and their implementation and requirements.

Clause 5 presents a brief summary of the planar near-field theory, followed by a discussion of the practical aspects of implementation. The planar near-field scanning method was the first geometry for which probe-corrected theory was developed. This method is ideally suited for measuring moderately to highly directive antennas. The probe is scanned over a planar surface in front of the test antenna. In many instances, the near-to-far-field transform is accomplished with an FFT. Probe correction is performed direction by direction.

Clause 6 deals with the near-field-to-far-field transformation techniques using the cylindrical scanning. At the cost of a moderate increase in the analytical and computational complication with respect to the planar scanning, they allow reconstruction of the antenna complete radiation pattern except for the zones surrounding the + and – cylindrical axis. This method is ideally suited for fan-beam type antennas. In a cylindrical scanning facility, the AUT is mounted on a rotating table, whereas the probe moves along a line parallel to the rotation axis of the table. In such a way, the probe can measure the near-field data on a cylindrical grid for two different orientations of the probe. By taking into account the probe effects, it is possible to compute the far-field pattern.

Clause 7 covers spherical scanning. A basic explanation of the theory is included. Descriptions of the geometry and implementation are provided and the benefits of the use of a probe with special symmetry properties (referred to as a $\mu = \pm 1$ probe) are explained.

Clause 8 discusses probe calibration and selection. To accurately determine the far field of a test antenna from near-field data, it is necessary to correct for the effects of the probe. This requires knowledge of the probe's on-axis gain and polarization, as well as the probe's co-polarization and cross-polarization patterns. This section describes how to measure and determine these probe properties and provides guidance on selecting an appropriate probe.

Clause 9 treats the analysis of measurement uncertainty. The sources of uncertainty will be delineated and methods of estimating the magnitudes of these uncertainties are discussed.

Finally, Clause 10 deals with special topics. This section considers topics outside the routine near-field/far-field measurements of determining gain, polarization, and pattern. Some of the special topics include (but are not limited to) the description of how to determine effective isotropic radiated power (EIRP), saturated flux density, and array evaluation.

4. Measurements systems

The geometries for the spherical, cylindrical, and planar near-field scanning methods necessitate data point acquisition on a sphere, cylinder, and plane, respectively. For each of these near-field methods, there is not one unique physical, mechanical, or electrical solution. All scanning methods require a radio-frequency (RF) transmit and receive system with some type of automated scanning, a data collection and control system (DCCS), and computerized analysis ability. A probe with known characteristics is selected to measure the AUT and minimize the distortion of its far-field characteristics. There are electrical and mechanical parameters that should be optimized. This section discusses the various scanning subsystem configurations and their implementation and requirements.

4.1 Mechanical scanning subsystems

For any near-field measurement method, amplitude and phase data are acquired in an organized fashion on some specific surface. Given the surface geometry, data, and reference antenna (probe) properties, an efficient transform is preferably used to determine the far field of the AUT. The most common scanning techniques are planar near field (PNF), cylindrical near field (CNF), and spherical near field (SNF). Each of these typically requires a combination of translation and rotation to complete the scanning over the desired surface.

4.1.1 Planar near-field (PNF) scanning

PNF scanning requires a less-extensive anechoic surrounding and alignment technique, and a fairly simple mathematical analysis. This technique is best used for highly directive antennas such as a dish or phased-array antennas where nearly all the received or transmitted energy passes through the planar scan area.

Rectangular scanning is a common PNF technique where the data are gathered at specific x, y locations on a grid, illustrated in Figure 1. The probe is positioned along the y axis using a linear slide. The y axis slide is positioned along an x axis using a second slide. Details of rectangular PNF measurements are found in Newell, Ward, and McFarlane [B101]. Data sampling typically uses an increment of $\lambda/2$ or smaller. Other implementations of planar scanning are possible. Examples include plane-polar (Rahmat-Samii, Galindo-Israel, and Mittra [B102]), which uses a combination of translation and rotation to acquire data on a plane and plane bi-polar scanning (Williams, Rahmat-Samii, and Yaccarino [B118]), which uses two rotations to acquire data on a plane.

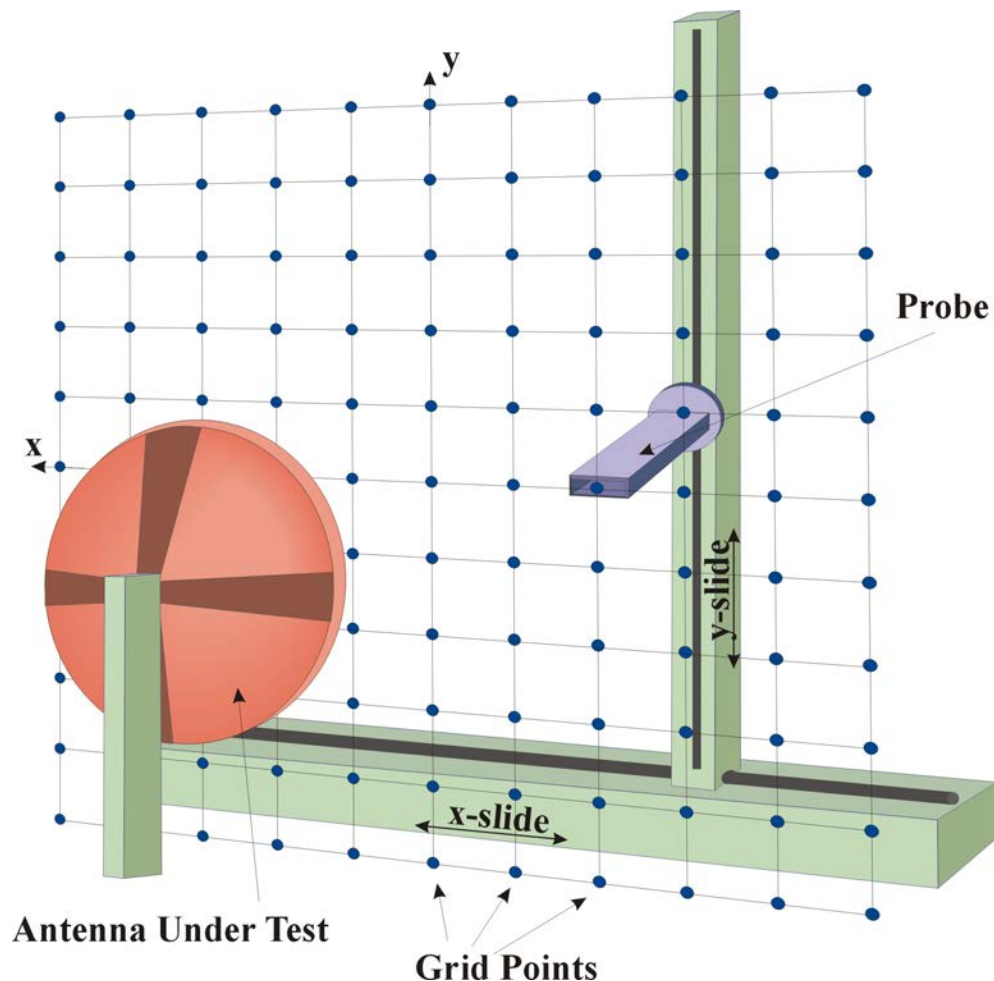


Figure 1—Illustration of rectangular PNF scanning

4.1.2 Cylindrical near-field (CNF) scanning

For CNF scanning the data are gathered on a cylindrical surface (Yaghjian [B128]). This technique is useful for fan-beam antennas where the energy is directional in one axis and broad in the orthogonal axis, such as cell phone base station antennas. Figure 2 illustrates the z and ϕ coordinate system typically used for CNF. Typically, the probe is positioned in the z coordinate using a linear slide. The AUT is typically mounted on a rotator that positions the AUT in the ϕ coordinate.

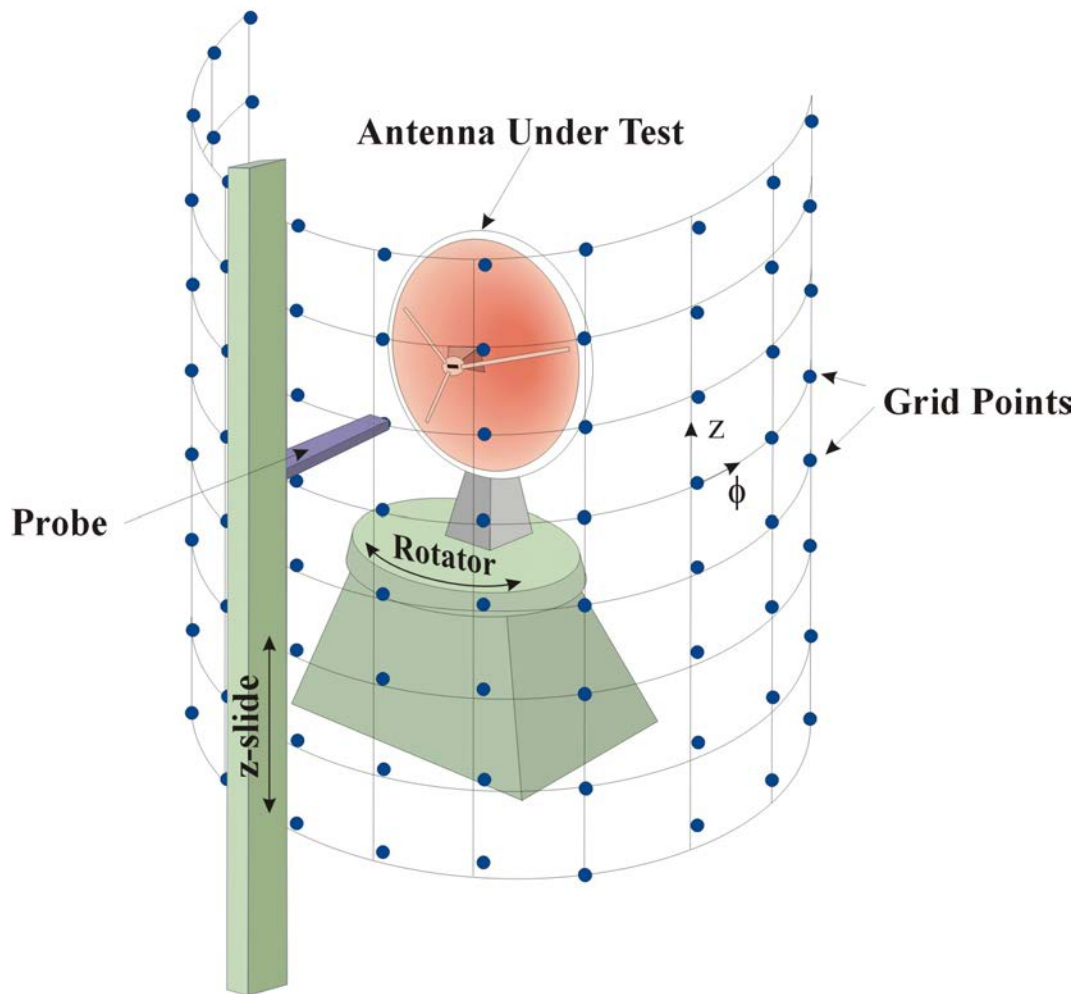


Figure 2—Illustration of CNF scanning configuration

4.1.3 Spherical near-field (SNF) scanning

In SNF scanning the data are gathered on a spherical surface that surrounds the AUT. This technique can be used to measure any antenna and is especially useful for isotropic or nearly isotropic antennas for which the planar and cylindrical methods are not suited. There are several scanning configurations that can be employed for SNF scanning (Hansen [B47], Wittmann and Stubenrauch [B123]). One configuration is to have the probe fixed, while the AUT is positioned to allow the probe to map out a sphere. The roll-over-azimuth configuration is commonly used for this, where the data are gathered in the θ and ϕ coordinate system, as illustrated in Figure 3. The AUT is mounted on a rotator that positions the ϕ axis (roll). This rotator is mounted onto another rotator that positions the θ axis (azimuthal).

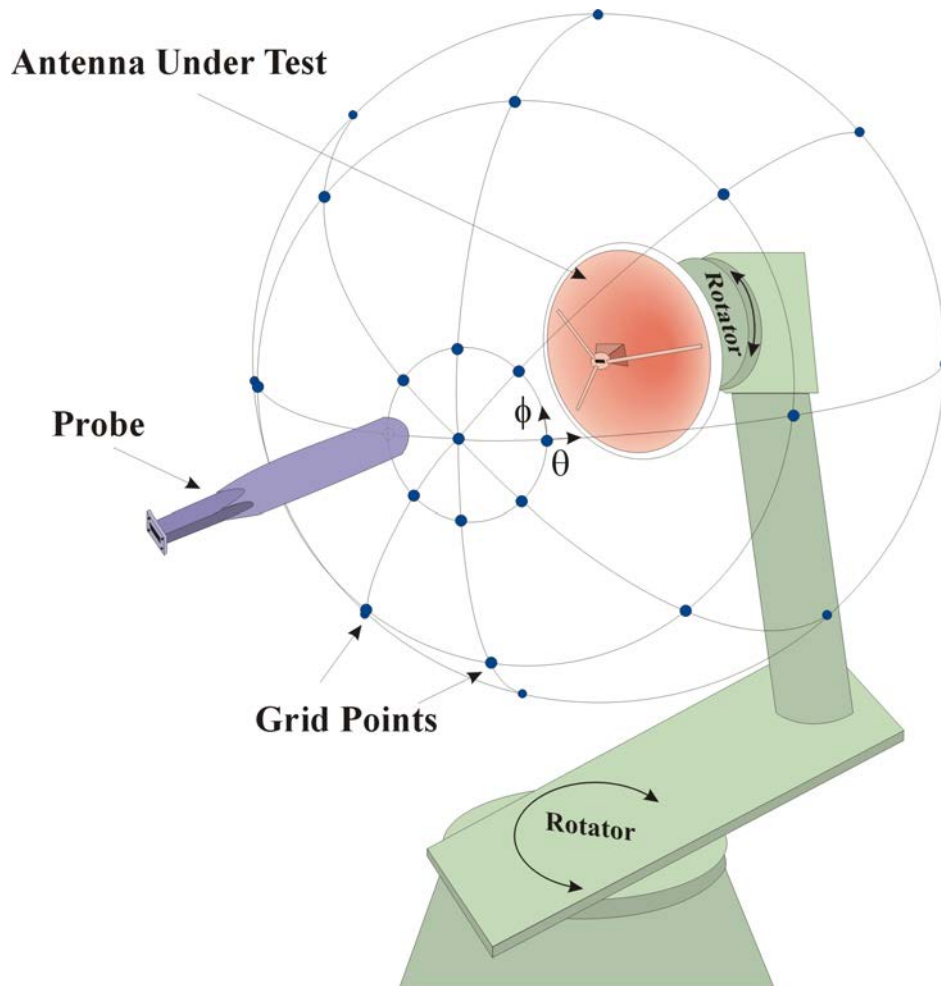


Figure 3—Illustration of the roll-over-azimuth SNF scanning configuration

Another example of a spherical implementation is the combination consisting of an arch carrying a probe on a circular arc and an azimuth axis rotating the antenna. The plane of the circular arc might be vertical and the azimuth axis vertical and lying within the plane. An example is shown in Figure 4.

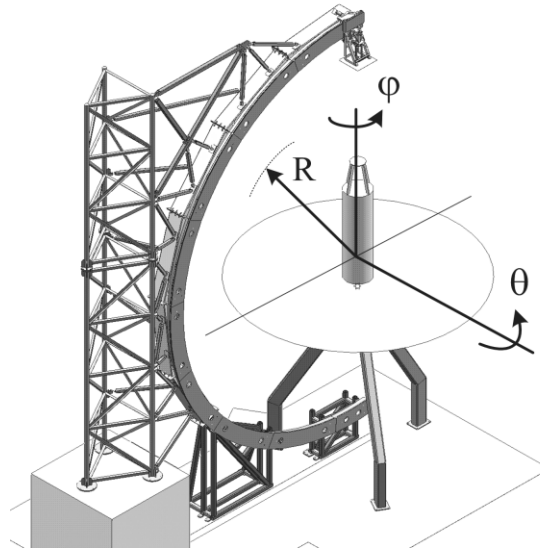


Figure 4—Illustration of the azimuth/arch SNF scanning configuration

4.2 Typical RF subsystem

Figure 5 illustrates a typical RF system. The simplest RF subsystem consists of some type of source that supplies the AUT with RF power and a receiver that detects the signal received by the probe. To measure phase, a reference line is needed between the source and receiver. An attenuator used for RF leveling can be inserted between the source and AUT. It is also good practice to use isolators at the interface to the AUT and probe to minimize any reflections due to the measurement system. For gain measurements, this is important to help ensure good matching to the source and receiver transmission lines and thus help avoid standing waves that introduce additional uncertainties. Some receivers have remote mixing capabilities to enhance system dynamic range. It is good practice to use attenuators of about 10 dB to protect the mixer.

A vector network analyzer (VNA) is often used in near-field set-ups. In this case the VNA generates the source signal and also serves as the receiver. For frequencies above 20 GHz (in some instances up to 600 GHz) frequency extenders are frequently used.

Cables are another component of the RF subsystem. The cable and connector type need to support the frequency range of the measurements. It is important that any moving cables remain amplitude and phase stable over the measurement surface. Rotary joints are necessary for any configurations where the AUT rotates and are sometimes used to minimize scanner cable motion. The user should evaluate the effects of phase and amplitude of the rotary joint with rotation.

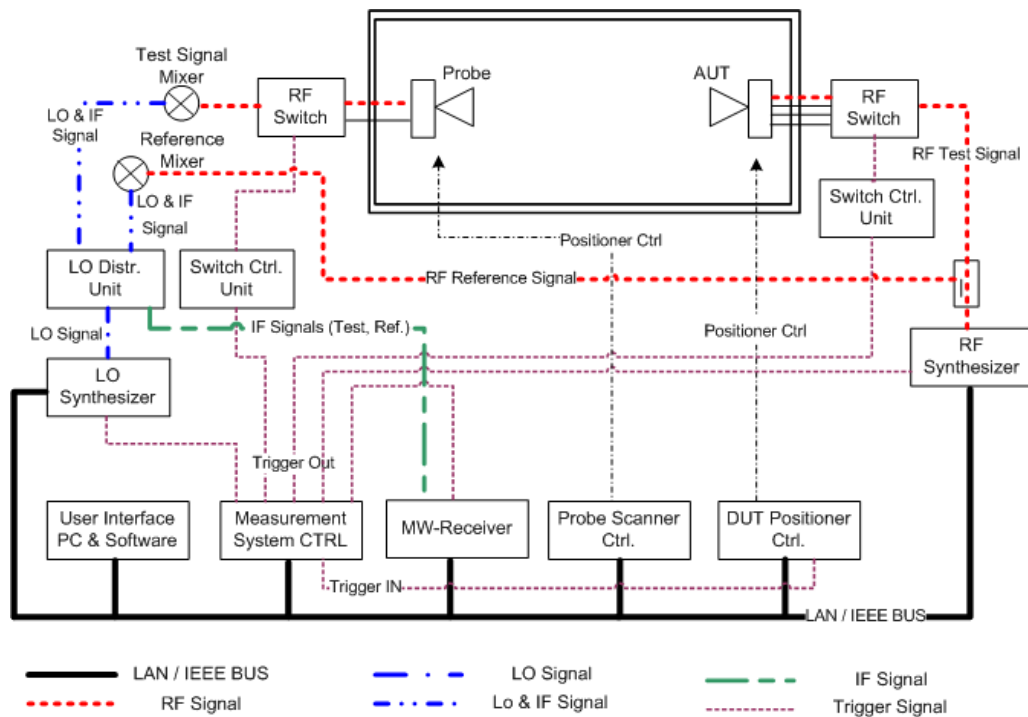


Figure 5—Illustration of a typical RF system

4.3 Typical data collection subsystem

The amplitude and phase data are collected at known locations on the measurement surface. This is achieved through knowledge of the location of the probe coordinate origin on the measurement surface and triggering the receiver to record data at the appropriate position. An illustration of a typical data acquisition system is shown in Figure 6.

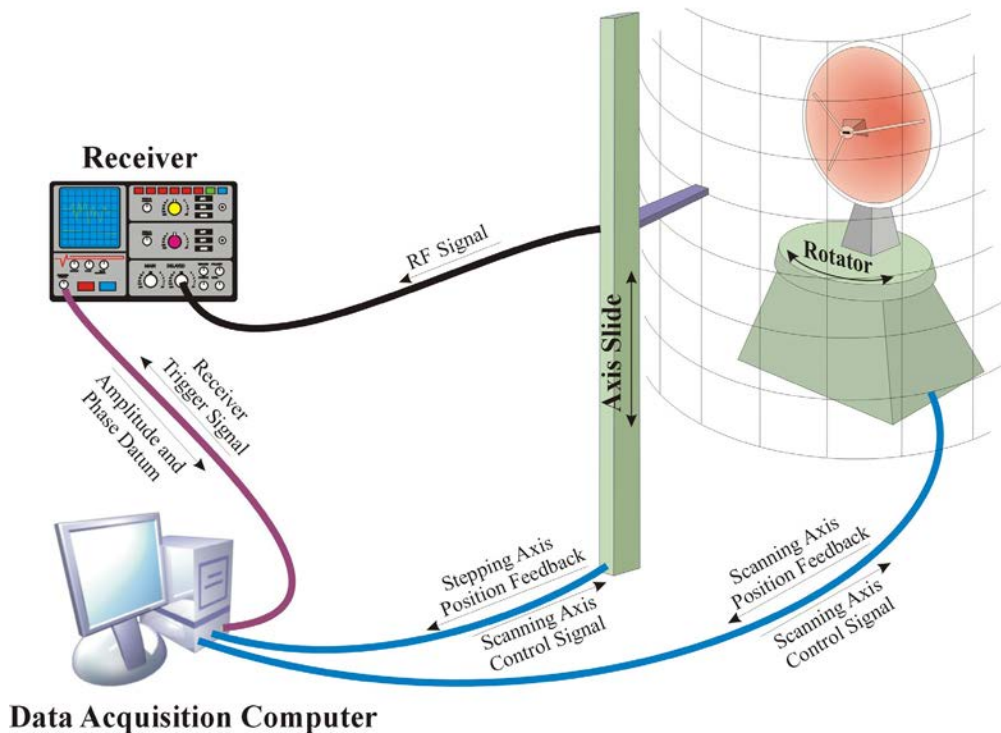


Figure 6—Illustration of typical data acquisition system

The data collection and control system (DCCS) monitors and controls all the instruments and positioning systems in the set-up. Since this is a very complex system, an automated and fully computer-controlled DCCS is needed. It is necessary that the data-processing system be able to send and receive very large amounts of measured and processed data.

For linear positioning equipment, a distance-measuring laser interferometer system can be used to measure location. If a stepper/servo motor is used to drive the linear position, the encoder feedback of the motor can be used to determine location. To save cost, a stepper motor can be used and position determined by counting the number of steps; however this method is not preferred where high accuracy is needed.

For rotational positioning, a rotary encoder feedback from the drive motor usually determines the angular position.

A laser tracker can also be used to monitor the probe aperture location. The laser tracks a target mirror affixed to the probe mount. The probe aperture location is referenced to the mirror location. This method provides real time location of the probe over a limited scanning area. It also needs integration of the laser tracker's controller.

4.4 Data processing

In the early years of near-field measurements, computer processing capabilities were limited. Much of the work was performed at government facilities, universities, or very large companies that had access to large main frame computers. Creative short cuts were used to minimize the amount of data needed. The data processing was performed offline. Today's personal computers have more than enough power to process the large practical data sets and the computational intensive analysis routines.

4.5 Measurement accuracy

It is important to choose the appropriate near-field method for the AUT measurement and to understand the correct technique to provide an accurate measurement. The probe should be carefully chosen to match the AUT and measurement method. The mechanical subsystem needs to meet the positioning and alignment tolerances needed for the measurement. The RF subsystem needs to be mechanically, temporally, and temperature stable to maintain the integrity of the amplitude and phase. Stability requirements depend on the desired accuracy. Better accuracy at lower side lobes generally implies greater phase and amplitude stability and better signal-to-noise ratio are needed.

4.5.1 Measurement environment

Temperature, humidity, and vibration are environmental conditions that can effect measurements. The extent depends on sensitivity of components to these environmental conditions and the frequency of measurement.

Temperature changes can cause thermal expansion in the mechanical subsystem components affecting the positioning accuracies. It can also cause amplitude and phase changes in RF subsystem components such as cables, couplers, and mixers and cause tracking laser beam scintillation.

Temperature and humidity can interfere with stability of the receivers and sources in the RF subsystem. Humidity affects the performance and durability of the absorber. Poor humidity conditions affect the reflectivity of the absorber. Conditions that are too dry lead to a brittle absorber that breaks easily. Conditions that are too humid lead to water absorption, which deforms the absorber due to the added weight.

Vibrations can have an effect on mechanical subsystem positioning accuracies and the stability of RF subsystem components.

As the measurement frequency increases the sensitivity of the components to all of the environmental conditions increases primarily through phase stability.

4.5.2 Choice and use of near-field method

The PNF method performs best for antennas with highly directional patterns. It can be used for gain measurements of directive antennas, but its limited area of pattern coverage can engender difficulty for directivity measurements. The CNF method is most useful for measuring antennas with fan-beam patterns like cell phone base station antennas, where the radiation pattern is largely restricted to a small range in elevations. In the SNF method a truncation of the measurement surface is not necessary and it can therefore be used for accurate determination of far-out side lobes for any antenna type. Because of the ability to cover a wide range of angles, it is especially useful in measuring nearly isotropic antennas, such as mobile phone handset antennas, and in measuring directivity.

4.5.3 Choice of probe antenna

The choice of probe depends on the near-field technique. The best accuracy is achieved by using one probe that is polarization matched to the co-polarized component and a second probe that is matched to the cross-polarized component. The second probe could be the first probe rotated 90° (for a linearly polarized probe) or the second port of a dual-polarized probe. A physically small probe will cause less disruption to the far field of the AUT. Details on the selection of a probe can be found in Clause 8.

4.5.4 Mechanical subsystem accuracies

The needed probe-position accuracy for the mechanical subsystem is dependent on the measurement frequency and types of measurement parameters. For accurate side lobe measurements, a probe-position accuracy of a fraction of a wavelength is required, but it is not as crucial for gain measurements. The needed probe-position accuracy will depend on the accuracies needed for the far-field pattern. Periodic position errors will concentrate errors in specific directions, while random position errors will spread the errors out over many directions.

A translational error within the scan plane for PNF measurements, shown as Δx and Δy in Figure 7, could result in a null or side lobe position uncertainty in the far-field results. Uncertainties in Δz primarily affect uncertainties in the measured near-field phase. Also shown in Figure 7, $\Delta \text{azimuth}$ and $\Delta \text{elevation}$ uncertainties affect uncertainties in the pointing direction of the main beam.

A constant translation offset in x and/or y of the probe will introduce a linear gradient in the far-field phase but will not result in an amplitude change in the far field. For practical probes that have a very broad beam compared to the beam width of the AUT, the shift in the main beam pointing will be small due to azimuth or elevation uncertainties in the probe alignment. The azimuth and elevation misalignment will cause a small error in the magnitude of the probe correction in the side lobe region where the slope of the probe pattern is larger. The Δroll uncertainty affects uncertainty in the polarization measurements. These position errors cause similar effects in all near-field scanning geometries. See also Clause 9 for additional details.

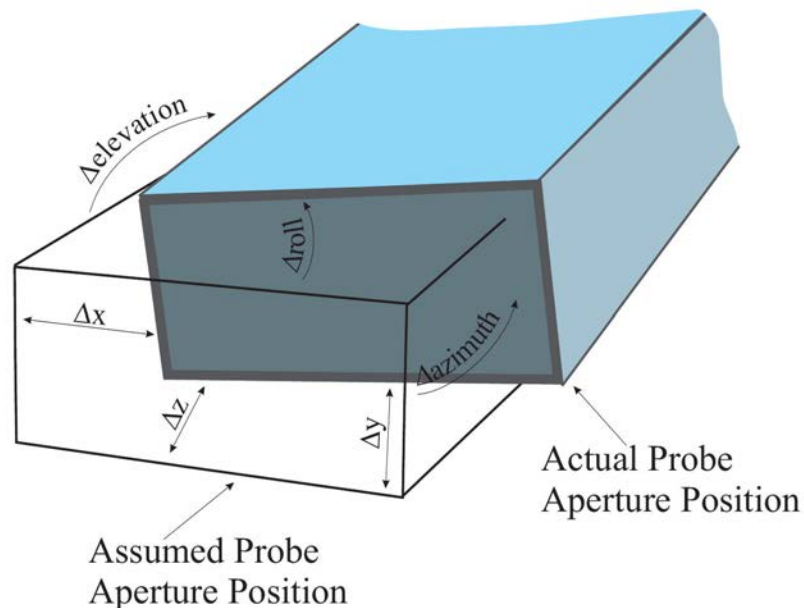


Figure 7—Probe-position uncertainties for PNF measurements

4.5.5 RF subsystem accuracies

An unstable RF system has the potential of introducing uncertainties directly into the measured amplitude and phase. Some of the sources of uncertainty are illustrated in Figure 8. Interference signals from outside sources can be minimized in shielded chambers. Leakage can come from leaky sources, receivers, loose connections, coaxial and waveguide, and from damaged system components. Relocating equipment can reduce the effects of leakage and noise. It is important to keep RF and motor cabling separated to minimize motor noise on the RF cable. Noise is also caused by dynamic range limitations of the receiver at low amplitudes and thermal effects on RF cables. Multiple reflections between the AUT and probe can be reduced depending on separation distance. Proper absorber placement can reduce multipath and leakage.

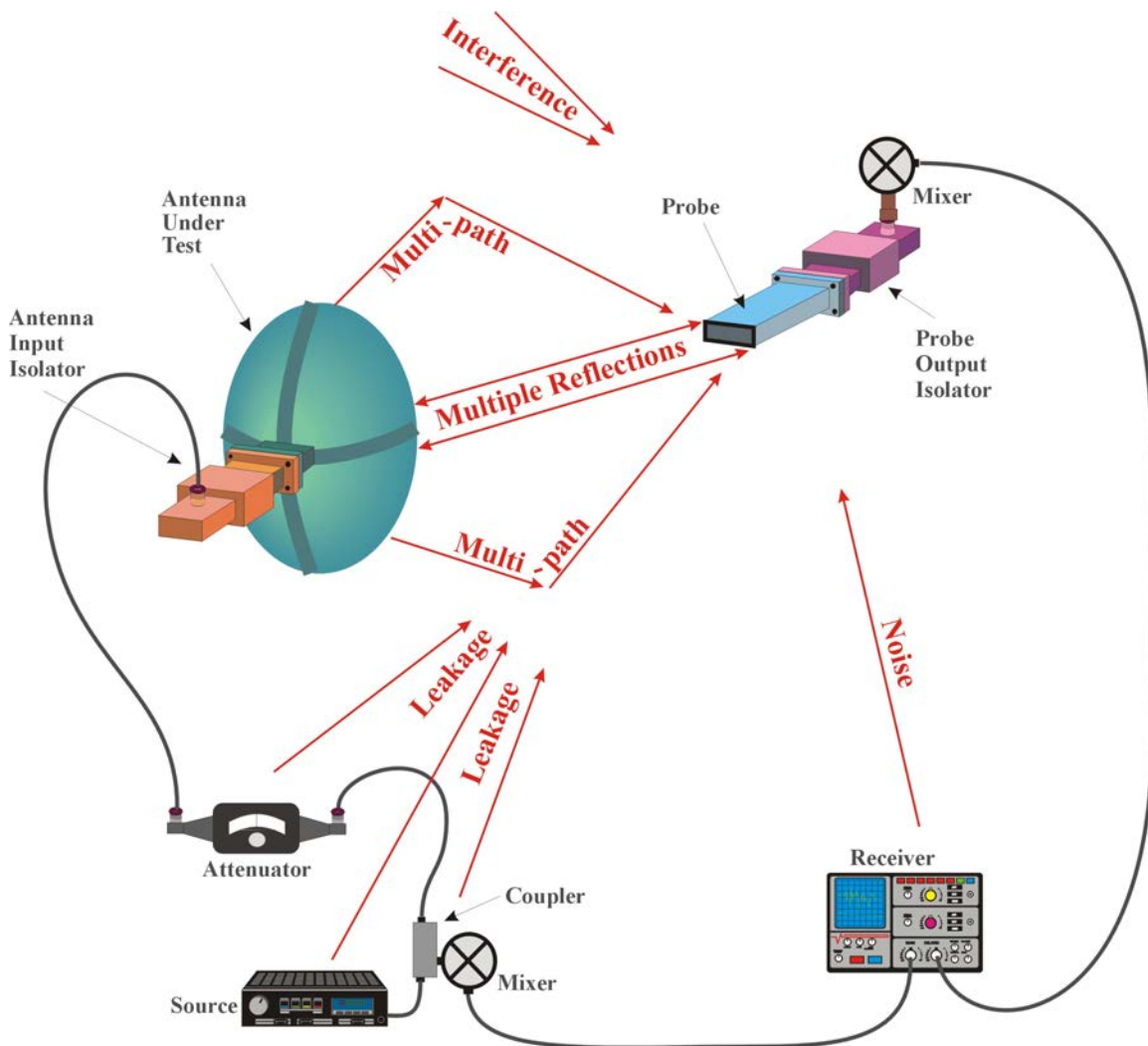


Figure 8—RF measurements sources of uncertainty

4.6 Correction schemes

Many correction schemes have been developed to mitigate the effects of the non-ideal measurement systems. The more common ones are thermal drift correction, impedance mismatch correction, probe-position correction, and cable variation correction.

4.6.1 Thermal drift correction

As discussed in 4.5.1, temperature can cause changes in the amplitude and phase measurements. There are two methods of correcting for thermal drift.

When the scanning and stepping axes are reversed, as shown in Figure 9, this is commonly referred to as a *tie scan* and is used to correct for thermal and power supply drift.

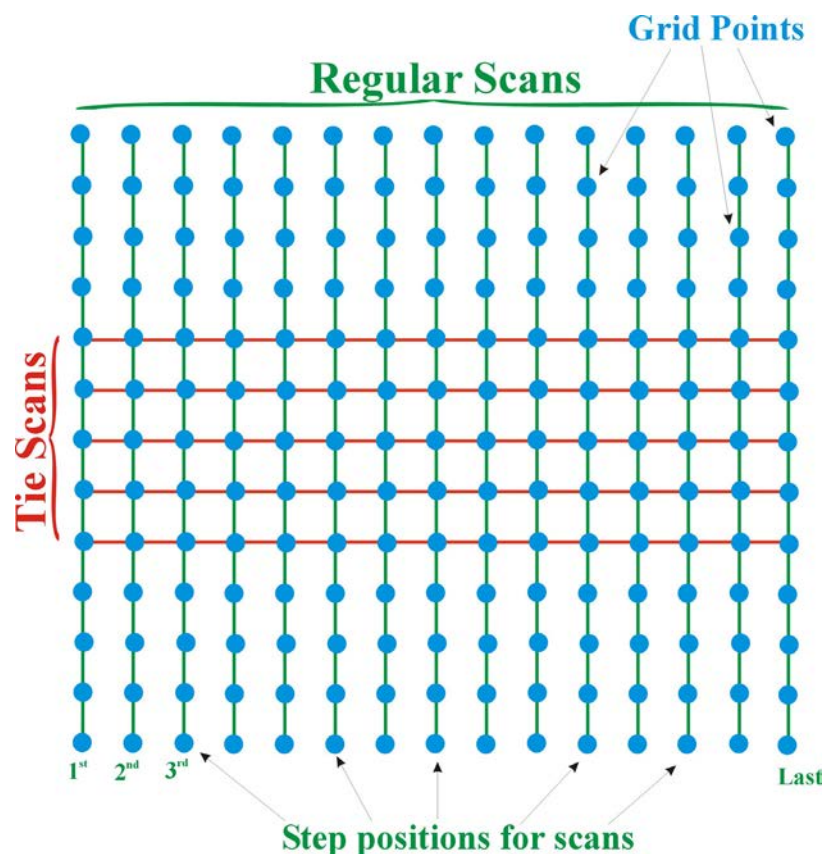


Figure 9—Illustration of tie scans

During the time difference between the first and last regular scans, the amplitude and phase reference value can experience a drift. The tie scan gathers the data at the same row position for each regular scan in a short amount of time greatly reducing the risk for drift. Using this information, a correction can be applied to the data set.

Another technique of correcting for thermal drift is known as *return-to-point* (Hess et al. [B52], Melson, Hess, and Jones [B87]). In this method, a point that has a high signal level is selected from the scan; this point is designated as the *selected point*. The technique consists of measuring and recording this selected

point repeatedly during the scanning process and thereby monitoring the thermal and power supply drift that occurs. For completeness, the time of measurement may also be recorded. To accomplish this, the scanning process is interrupted periodically to return the probe to this point of the scan. After the scan is finished the phase/amplitude data from each scan line is corrected by the amount of thermal drift that was seen in the selected point.

The advantage of this technique over the tie scan technique is that it overcomes the difficulty of the position offsets across the sampling interval for highly multiplexed data sets and a continuously moving probe.

4.6.2 Impedance mismatch correction

To obtain the correct gain, a mismatch correction needs to be included. The impedance mismatch correction applies to the gain measurements. It accounts for the small portion of the signal that is reflected at the measurement ports. These reflection terms are represented as Γ_a for the AUT, Γ_g for the generator, Γ_p for the probe, and Γ_ℓ for the load as shown in Figure 10. When an insertion loss method with the probe as the gain standard is used then the uncorrected (for mismatch) gain needs to be multiplied by the correction factor M_c (Kummer and Gillespie [B75])

$$M_c = \frac{|1 - \Gamma_p \Gamma_\ell|^2 |1 - \Gamma_a \Gamma_g|^2}{(1 - |\Gamma_p|^2)(1 - |\Gamma_a|^2) |1 - \Gamma_g \Gamma_\ell|^2} \quad (18)$$

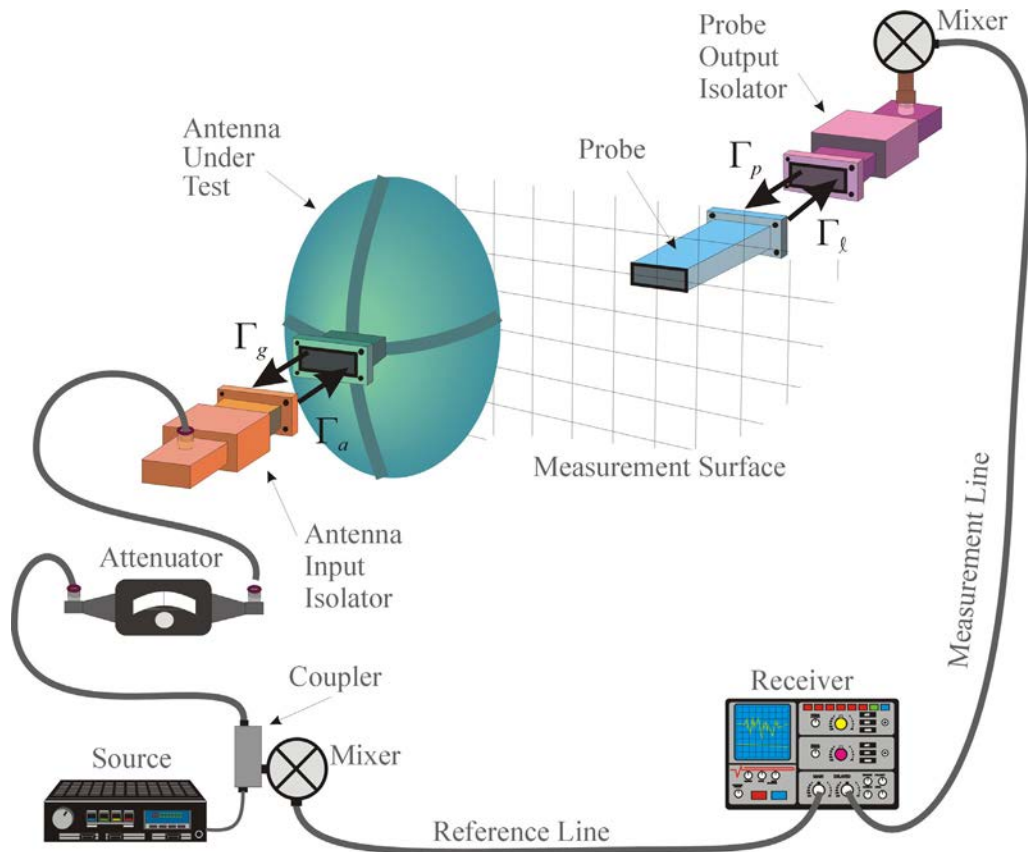


Figure 10—Impedance mismatch

When the gain transfer standard method is used, the uncorrected gain needs to be multiplied by

$$M'_c = \frac{|1 - \Gamma_g \Gamma_a|^2 (1 - |\Gamma_s|^2)}{|1 - \Gamma_g \Gamma_s|^2 (1 - |\Gamma_a|^2)}, \quad (19)$$

where Γ_s is the reflection coefficient of the gain standard.

4.6.3 Probe-position correction

If actual measurement points are recorded (rather than assumed ideal), then it is possible to correct for non-ideal probe positioning. For example, the simple k -correction method (Francis [B34]) will approximately correct the pattern. More rigorous approaches are described by Corey [B23] and Wittmann, Alpert, and Francis [B121], [B122]. The latter method can correct position errors to a level characteristic of the position-measuring device. Probe-position correction is discussed in 10.6.

4.6.4 Cable variation correction

All measurement set-ups for near-field scanning necessarily have at least one RF path that undergoes motion. The purpose of the moving path is to transfer a continuous wave analog signal, characterized by its phase and amplitude, from the port of an antenna undergoing relative rotary or translational motion, to a stationary point in the laboratory. This signal is commonly the received signal at the port of the moving probe; however in some set-ups it may be a reference signal used for phase measurement. The perturbation of this analog signal by the flexure of the moving path can often be a significant contributor to RF measurement uncertainty. Usually one addresses this problem by choice of a sufficiently good cable, designed to minimize the variation in phase due to cable flexure. Where rotary positioners are utilized, RF rotary joints are alternately employed that are designed to minimize the phase (and amplitude) variation as a function of rotation.

Various approaches to correction for the effects of cable variation have been suggested and implemented. Choice of a particular scheme depends upon whether the system employs remote mixers and whether it is to operate at microwave or at millimeter wave frequencies.

A method utilizing analog signals has been suggested by Newell [B94]. However, most approaches in current use entail digitally recording auxiliary measurements of the cable path, simultaneously with the near-field scanning measurement, then applying a correction to the acquired near-field data by post-processing.

For operation in the microwave regime, a three-cable measurement approach has been devised by Hess [B49]. The changes in the primary cable—which carries the signal from the moving probe to the stationary receiver—are monitored by the receiving subsystem, assisted by a thermally stabilized switching network (Caldwell [B20], Hess [B50]). The scheme may be understood by analogy to the three-antenna technique. The primary cable is measured in transmission as a member of a pair; its transmission characteristic is determined from a set of three pair-wise measurements among a set of three similarly positioned cables, as illustrated in the Figure 11. Along with the received signal from the probe, these auxiliary data are acquired at each grid point. Each of the three cables can vary in its own way. The only assumption regarding stability is that no changes occur during the fraction of a second when the three pairs are measured and the probe's signal is sampled. In a post-processing step, the received signal at each grid point is modified by the observed change in the transmission characteristic of the primary cable.