Near-field vs Far-field

Any antenna can be successfully measured on either a near-field or far-field range, with appropriate implementation. There are significant cost, size, and complexity details which will lead to a recommendation of one type over the other. In general, far-field ranges are a better choice for lower frequency antennas and where simple pattern cut measurements are required, and near-field ranges are a better choice for higher frequency antennas and where complete pattern and polarization measurements are required.

Each measurement type has additional sub-types which have certain advantages and disadvantages, and this makes generalized comparisons between near-field and far-field techniques difficult. One common advantage cited for near-field measurement techniques is that testing can be accomplished indoors, eliminating problems due to weather, electromagnetic interference, security concerns, etc. however the same advantages can be quoted for indoor far-field measurements using anechoic chambers and compact ranges. Cost of facility implementation is a critical determining factor in range selection. Far-field ranges are often considered to be less expensive than near-field ranges. When considering the value of the real-estate required for an outdoor far-field range, the situation may reverse. An indoor far-field compact range would typically cost 3-4 times more than a planar near-field range capable of testing the same size aperture, due to the larger chamber size required and cost of the compact range reflectors. The following table summarizes some general tradeoffs to help you in your selection criteria. Many of the characterizations are difficult to make without caveats, and there will certainly be exceptions. Antenna engineers are a creative group and, over the years, have certainly developed innovative ways to maximize the use of their test ranges to get acceptable results. Your NSI sales representative can help you evaluate the tradeoffs further.

	NEAR-FIELD			FAR-FIELD		
	PLANAR	CYLINDRICAL	SPHERICAL	OUTDOOR RANGE	ANECHOIC CHAMBER	COMPACT RANGE
High gain antenna	Excellent	Good	Good	Adequate	Adequate	Excellent
Low gain antenna	Poor	Good	Good	Adequate	Good	Excellent
High frequency	Excellent	Excellent	Excellent	Good	Poor	Excellent
Low frequency	Poor	Poor	Good	Good	Fair	Poor
Gain measurement	Excellent	Good	Good	Excellent	Good	Excellent
Close sidelobes	Excellent	Excellent	Excellent	Good	Poor	Excellent
Far sidelobes	Adequate	Excellent	Excellent	Good	Poor	Good
Low sidelobes	Excellent	Excellent	Excellent	Variable	Poor	Good
Axial ratio	Excellent	Excellent	Excellent	Good	Poor	Good
Zero G effects	Excellent (horizontal mode)	Poor	Good (horizontal mode)	Poor	Poor	Poor
Multipath	Good	Good	Good	Adequate	Adequate	Good
Weather	Excellent	Excellent	Excellent	Poor	Excellent	Excellent
Security	Excellent	Excellent	Excellent	Poor	Excellent	Excellent
Facility cost	Low	Moderate	Moderate	High (land value)	Moderate	Very high
Operating cost	Moderate	Moderate	Moderate	High (remote)	Moderate	Moderate
Speed (complete measurements)	Excellent	Good	Fair	Fair	Fair	Fair
Speed (simple cuts)	Good	Fair	Fair	Excellent	Excellent	Excellent
Complexity	Moderate	Moderate	High	Moderate	Low	High
Mechanical surface measurements	Excellent	No	No	No	No	No
Antenna access	Excellent	Excellent	Excellent	Good	Good	Fair
Antenna alignment	Easy	Moderate	Difficult	Moderate	Moderate	Difficult

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Near-field Antenna Measurements

In 1991 Dan Slater wrote a comprehensive book titled "Near-Field Antenna Measurements" about the emerging antenna measurement technique known as near-field measurements. The book derives from Dan’s experience with a variety of near-field measurement systems he designed while a consultant to TRW's Antenna Systems Laboratory and later as NSI’s co-founder. The book is currently undergoing a second publication scheduled for release in 2002. Dan Slater co-founded NSI with Greg Hindman in 1988 after working together for many years at TRW. “Near-field Antenna Measurements” covers many aspects of near-field antenna measurements in a straightforward and consistent way.

After many years of development and independent industry evaluation, near-field antenna testing has come of age and is the preferred approach for characterizing antennas. Measurement of sidelobe levels 50 dB below the main beam peak and sub-milliradian pointing accuracies have become commonplace. Conventional far-field measurement ranges often are not adequate for testing such antennas accurately. Near-field measurement techniques have been developed to increase accuracy, throughput, lower costs, and provide antenna diagnostics. The most commonly used near-field techniques are planar, cylindrical and spherical. NSI can provide all three types of systems, as well as combination systems or alternate scanning design.

The radiation from an antenna transits three regions as shown. The transitions between these regions are not distinct and changes between them are gradual. The reactive near-field region is the region close to the antenna and up to about 1l away from any radiating surface. In the reactive region, the energy decays very rapidly with distance. In the radiating near-field region, the average energy density remains fairly constant at different distances from the antenna, although there are localized energy fluctuations.

The near-field test system measures the energy in the radiating near-field region and converts those measurements by a Fourier transform into the far-field result. The radiating near-field region extends from the reactive region boundary out to a distance defined as, 2D2/l with D being the largest dimension of the antenna aperture, and l being the wavelength. Beyond this distance is the far-field region where the angular distribution of the energy does not vary with distance, and the power level decays according to the inverse square law with distance.

The size of the measurement area is important when considering the accuracy of the planar near-field measurement technique. In the second diagram an antenna under test and a one-dimensional view of a finite sized planar measurement area is shown.

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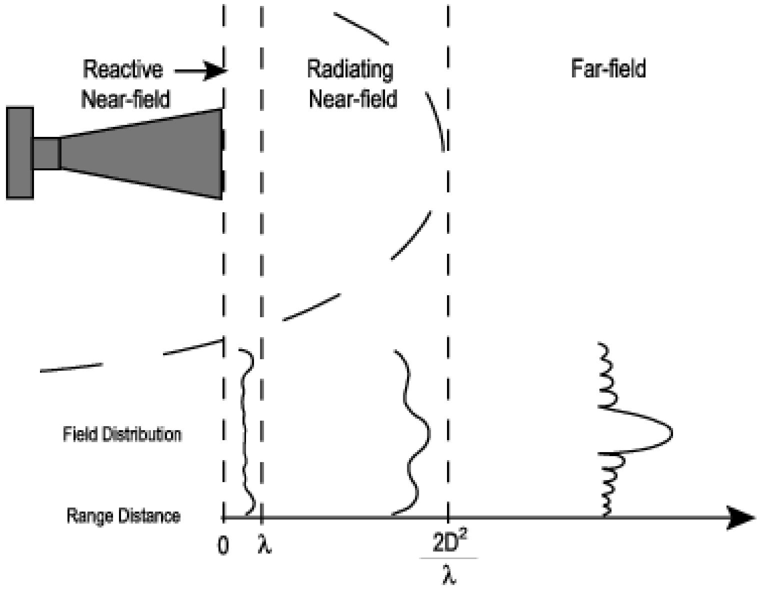
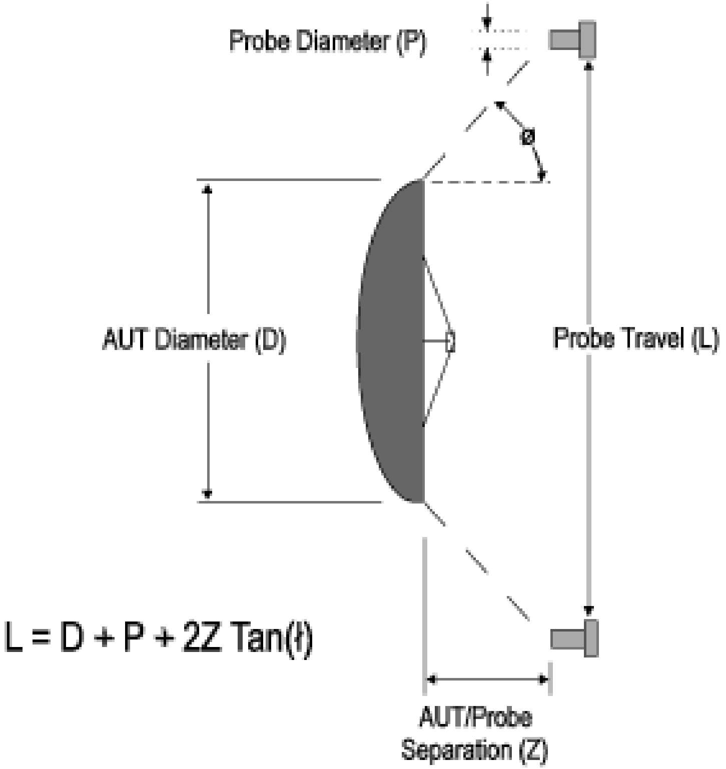


The size of the antenna under test and the size and location of the finite measurement area define the critical angle ø. The calculated far-field pattern of the antenna will be accurate in the region between ±ø. Complete angular coverage can be obtained in the spherical system by performing near-field measurements over the complete spherical near-field surface. Critical angles of about 70 degrees can be obtained using a planar surface located two wavelengths from the antenna and over-scanning the antenna aperture by about six wavelengths on each side. Thus the measurement area for high gain microwave and mm-wave antennas, if limited angular coverage is needed, is not much larger than the aperture of the antenna.

SCAN SIZE DETERMINATION



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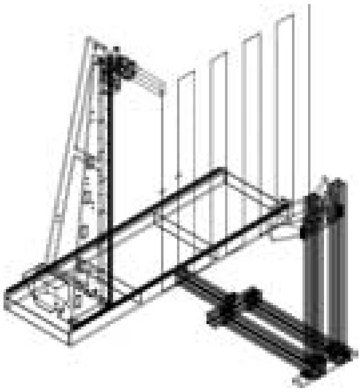
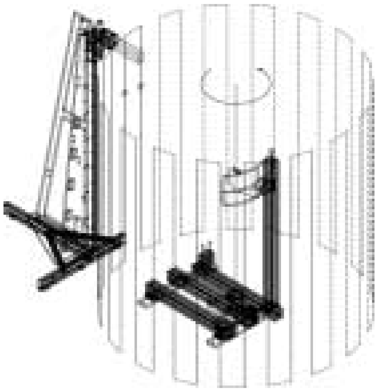
Configurations Overview

PLANAR



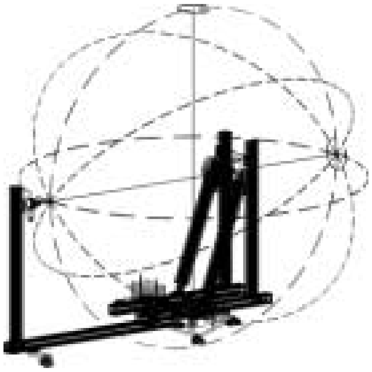
In this figure a planar near-field test setup is shown. The antenna under test is mounted in a stationary fashion (this is one of the main advantages of this type of testing) and the near-field probe is moved along a planar surface in both X and Y directions so that a grid of field samples can be taken.

CYLINDRICAL



This figure shows a cylindrical near-field test setup. In this case, a cylindrical surface is described around the antenna. This diagram shows an antenna under test, mounted on a single axis rotator. The near-field probe is moved along a line parallel to the axis of rotation. By rotating the antenna and moving the probe in the Y direction, a cylindrical surface is measured and a grid of field samples can be taken along azimuth and Y.

SPHERICAL



For a spherical near-field test setup, data are sampled on a spherical surface about the antenna under test. An antenna under test is shown mounted on a dual axis rotator with the near-field probe kept stationary and directed at the dual axis intersection. By rotating the antenna as shown in the figure, a spherical surface enclosing the antenna is measured and a grid of field samples can be taken along phi and theta.

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Choice of Configuration

When deciding on what near-field measurement configuration is best for a particular application, the fundamental limitations of each approach and the inherent advantages should be considered. It is also important to realize that seemingly “insignificant” limitations like having to deal with cable routings and rotations can be just as formidable to deal with than some of the “fundamental” limitations of a technique. From a theoretical viewpoint, spherical near-field measurements are the purest and most attractive of the three options. It is fairly probe-insensitive, low-cost, easy to build and allows one to measure any type of antenna. However, for testing large gravity sensitive antennas the movement of the antenna under test becomes restrictive. Also, the data processing is significantly more complex than that for planar near-field testing.

Cylindrical near-field testing requires single axis rotation of the antenna under test only, and this may have significant advantages for testing in certain instances. This type of testing is ideally suited for base station type PCS antennas (antennas that radiate in an omni-directional fashion in one plane with little energy radiated upwards or downwards).

Planar near-field testing is used for antennas of high directivity (typically >15 dBi). The main attraction of this measurement scheme is that the antenna under test remains stationary during testing. For large spacecraft antennas this is often the only feasible approach. Planar near-field testing is more intuitive than the other techniques, data processing is simpler, and the alignment procedures are easier to implement. In an antenna market where flat conformal antennas are becoming more popular, this technique will be used extensively.

The following chart compares the three standard configurations. You are encouraged to contact NSI’s staff for additional help in selecting a configuration for your needs.

ANTENNA TYPE/PARAMETER	PLANAR	CYLINDRICAL	SPHERICAL
High-gain Antennas	excellent	good	good
Low-gain Antennas	poor	good	excellent
Stationary AUT	yes	possible	possible
Zero-gravity Simulation	excellent	poor	variable
Alignment Ease	simple	difficult	difficult
Speed	fast	medium	slow

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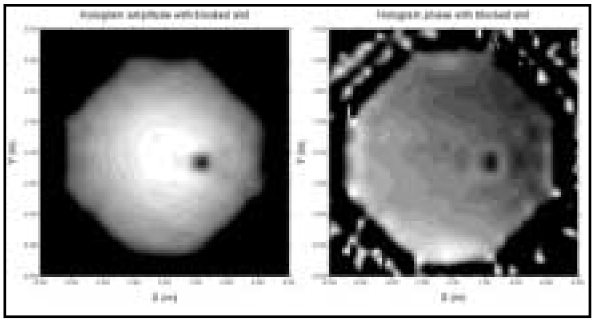
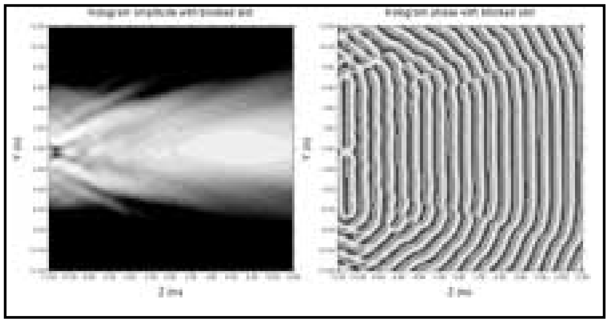
Microwave Holography Diagnostics

Near-field measurements also provide the necessary information to determine the radiating field at the surface of the antenna. This process is called microwave holography and involves back transformation of the near-field measurement. Back transformation is possible in all three near-field systems. The use of the back transformation has its greatest application in the phase alignment of phased-array antennas. The amplitude and phase of each element of a phased array can be determined accurately and is used to adjust the phase of the element, and to detect defective elements or phase shifters. Element phase accuracy of one degree RMS is being achieved on large microwave radar antennas. Other uses include the detection of anomalies in radomes and in detection of surface distortion in parabolic reflector antennas.

The following images show hologram back-projections performed on an X-band weather radar antenna. The left most image in each pair is the amplitude and the right most image in each pair is the phase. A blockage was intentionally introduced by covering one radiating slot with aluminum tape for this illustration. The pair at the left is a back-projection to the aperture of the antenna in the X-Y plane and shows the blocked slot quite clearly. An even more interesting image is shown in the right pair where the hologram plane has been turned 90°. This image shows the energy propagating from the aperture surface on the left toward the right. Each fringe shown in the phase pattern represents a 360° phase change for 1l distance. About 13l of travel distance in Z is shown in this image. The blocked slot and its diffraction effects can be seen and the start of far-field sidelobe formation is evident.



X-Y hologram at antenna aperture,
amplitude (left) and phase (right)



Y-Z hologram at blocked slot,
amplitude (left) and phase (right)

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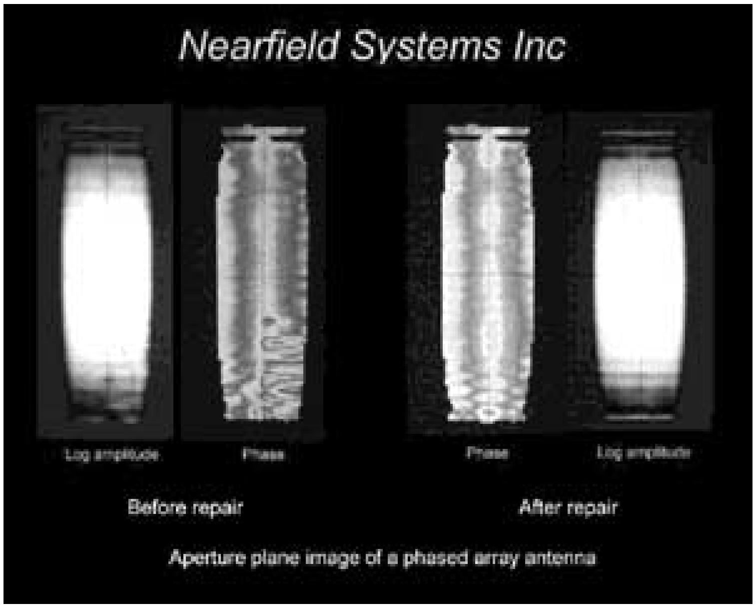
A real-world application of the holographic back-projection as a diagnostic tool is shown below. The holographic images are from near-field measurements on a Ku-band fighter aircraft radar antenna that was exhibiting problems with gain and sidelobe patterns. The back-projection in the left pair shows a problem in the amplitude and phase at the bottom right corner of the hologram. The unit was dismantled and it was discovered that jet fuel had leaked into the antenna. After cleaning and re-assembly, the unit was re-tested, resulting in the images at the right. The holographic back-projection technique proved quite effective at localizing the problem, allowing a quick and easy repair to be accomplished.



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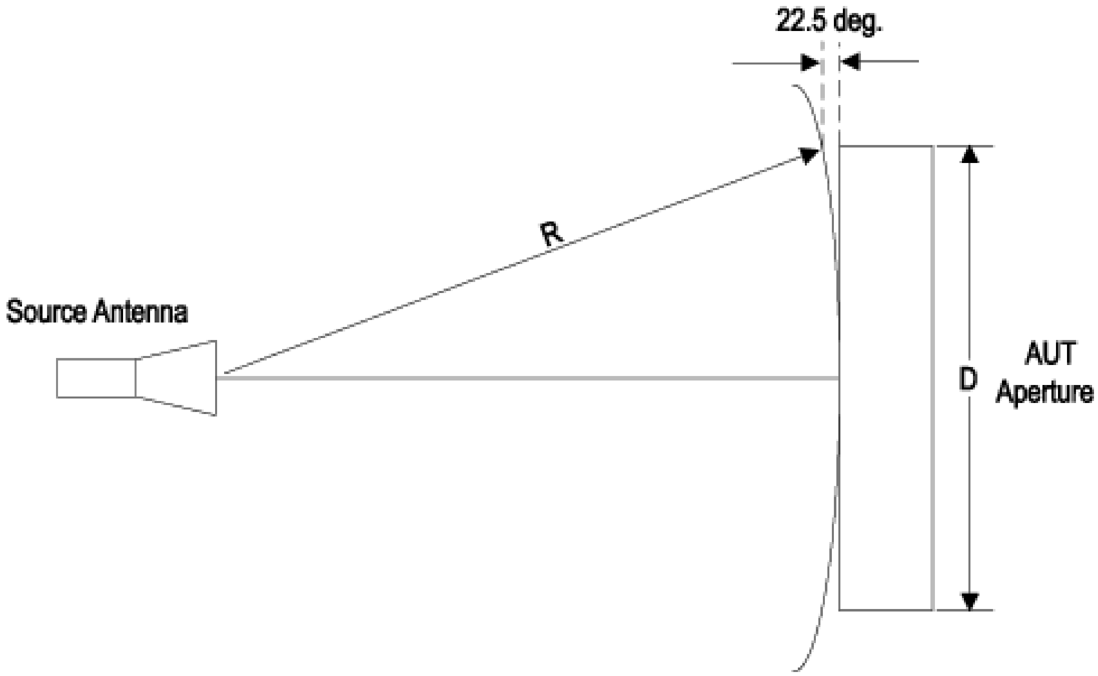
Far-field Antenna Measurements

For certain applications, far-field antenna measurements are the preferred technique for determining the amplitude and/or phase characteristics of an AUT. Low gain antennas operating below 1 GHz, and where partial radiation characteristics are required, are candidates for far-field measurements. On a traditional far-field antenna range the transmit and receive antennas are typically separated by enough distance to simulate the intended operating environment. The AUT is illuminated by a source antenna at a distance far enough to create a near-planar phase front over the electrical aperture of the AUT. The criteria commonly used in determining the minimum separation distance limits the phase taper to <22.5o as measured from the center to edge of the AUT.



Far-field distance determination:

The mathematical expression for determining the minimum separation distance is: $R > \frac{2D^2}{\lambda}$

Where:

R = Range length (separation distance between transmit and receive antennas)

D = Aperture of antenna under test

λ = Measurement wavelength (shortest of the ones tested)

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RANGE CONSIDERATIONS

The key consideration in designing a far-field range is to simulate the operating environment of the test antenna as closely as possible. Far-field measurements can be performed on indoor and outdoor ranges.

The selection of an appropriate test range is dependent on many factors such as:

- Availability, access, and cost of real estate suitable for quality measurements
- Weather
- Budget
- Security considerations
- Test frequency and aperture size
- Antenna handling requirements
- Pattern and gain measurement accuracy requirements

INDOOR RANGES

Where the combination of the antenna aperture and the operating frequency permit, measurements can be made indoors - typically, in a special room that has been lined with anechoic material that is designed to be highly absorptive at the test frequencies. This anechoic material reduces reflections off of the walls, floor, and ceiling that can combine with the main signal to distort the even illumination (both amplitude and phase) of the test aperture. The effects of the distortion can affect accurate gain and sidelobe measurements.

COMPACT RANGES

Where the test aperture size and measurement frequency make a direct illumination indoor far-field range impractical, shaped reflectors can be used. These reflectors focus the RF energy into a plane wave within a much shorter distance than would normally be required based on the spherical wavefront spreading. The combination of reflectors is normally referred to as a “compact range” since it is designed to create a plane wave at a distance considerably shorter than those needed under conventional far-field criteria. Compact ranges come in a variety of configurations including ones that employ single and dual reflectors. Compact ranges are costly and there are a number of factors that affect the compact range performance. Alignment of the reflectors as well as their surface tolerance is critical to producing a uniform plane wave in the test region. Other factors such as coupling between the AUT and feed, feed bandwidth, edge diffraction, and room reflections should be carefully considered in the design, installation, and operation of compact ranges. In many cases, a suitably sized near-field measurement system will provide similar measurement performance at a fraction of the facility cost.

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OUTDOOR RANGES

Antennas that are too large for measurement indoors may be measured on an outdoor far-field range. There are numerous variations including elevated, slant, free space, reflection, as well as other nontraditional types. Selection will depend primarily on the site topography and required accuracy levels. In all cases, careful design is required to maintain a uniform amplitude and phase distribution over the aperture of the AUT so as not to perturb the measured pattern or gain. Interference from a reflected signal that is 30 dB below the direct path can cause a gain error of +0.25dB and can cause serious distortion of the sidelobe pattern.

There are techniques that can be employed to significantly reduce the effects of pattern distortion due to reflections. Adjustment of the transmit and receive antenna height and the addition of diffraction fences at critical reflection points can serve to greatly improve range performance. More expensive techniques include illumination of the AUT with a moderate powered pulse and special gating hardware at the receive site to time gate out reflected signals. Similarly, time gating of reflected signals using software techniques can also be successfully applied to certain applications. In both cases the measurement bandwidth of the antennas and range instrumentation must be wide enough to allow discrimination of the primary and reflected signals.

On an outdoor antenna range the AUT is mounted to a single or multi-axis antenna positioner. The positioner may be located on a tower, rooftop, or other platform within direct sight of the source/receive tower. For most applications, a mixer is used to downconvert the test signal to a lower frequency IF signal (20 MHz for Agilent based RF subsystems) to minimize RF path loss through the cabling and maximize measurement sensitivity. The local oscillator (LO) for the downconversion is typically located at the base of the test AUT positioner in a weatherproof enclosure. A separate reference channel is used to provide a relative phase reference and normalize out variations of power fluctuations in the transmitter or other range effects. A radiated reference signal can be derived from a separate antenna oriented to receive a stable and sufficiently strong signal from the transmit source. The radiated reference is input to the receiver along with the test signal. Another technique to obtain a reference signal is by sampling the transmit signal prior to radiation by the source antenna. This sampled signal can be downconverted at the source end of the range to an IF frequency and routed to the receiver at a remote location via RF cables. This ‘cabled reference’ signal is not always as desirable as the radiated reference technique since the cable carrying the reference will react differently to changes in the environment causing changes in phase and amplitude.

Measurement automation permits high-speed characterization of various antenna parameters with reduced risk of error and greater repeatability. Unattended operation is now the norm for almost all new range installations. Automated data sorting and analysis tools also improve the efficiency of the range and permit better utilization of workforce.

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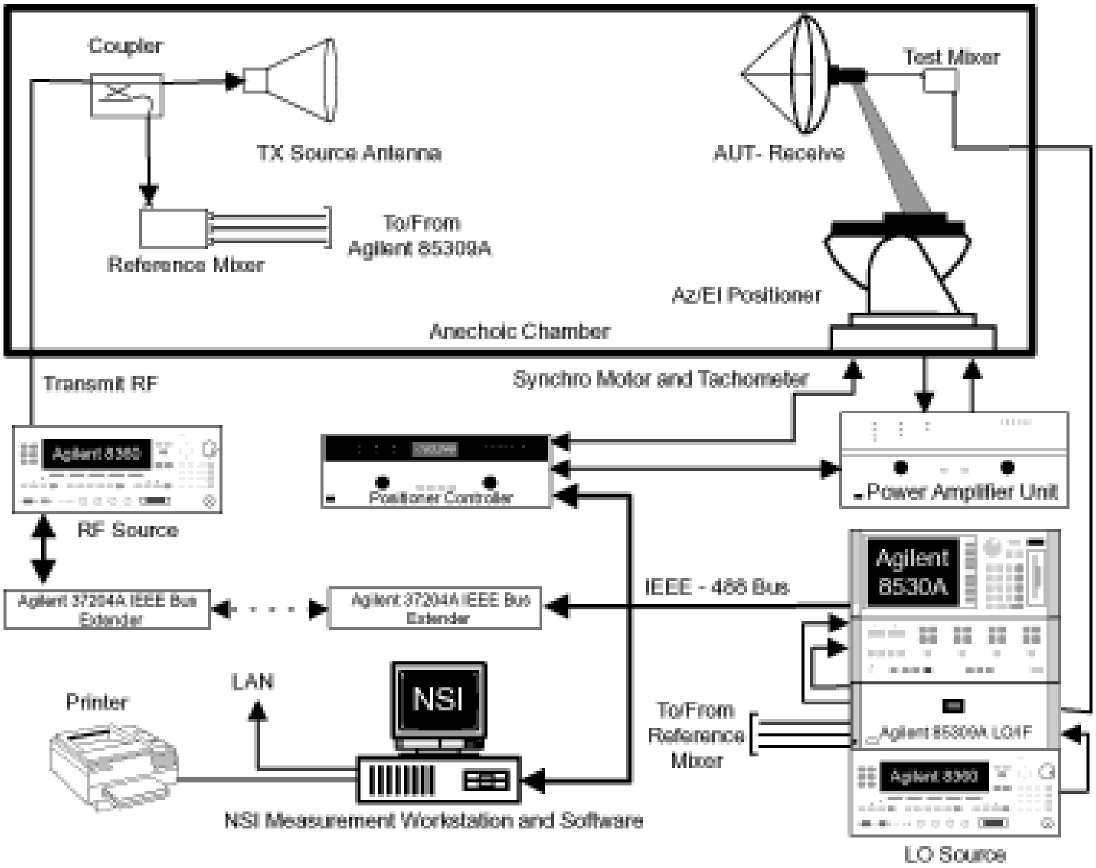
RANGE INSTRUMENTATION

Instrumentation of both indoor and outdoor far-field antenna ranges are similar in the type of equipment used. Consideration must be given to the location of various components and communications between them, the required power levels, and the degree of automation required. In general, instrumentation of an outdoor antenna range is more complex than for an indoor facility or compact range.

RANGE LAYOUT EXAMPLE:



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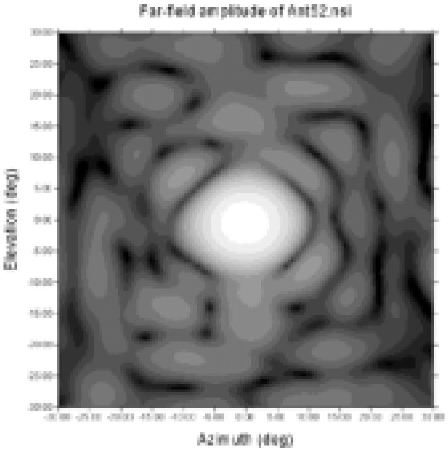
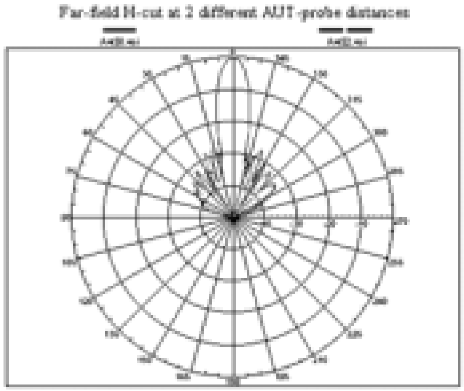
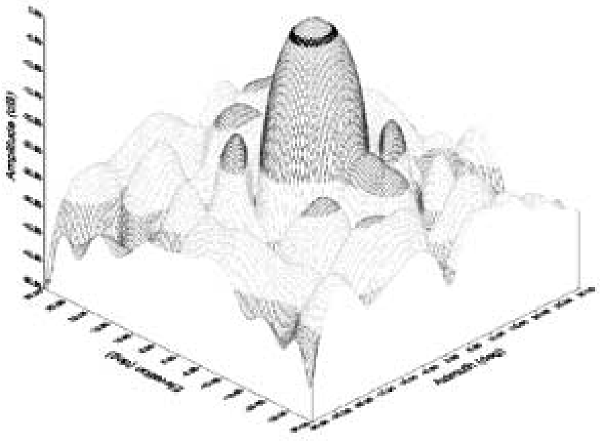
FAR-FIELD

To record the amplitude and phase as a function of angle, the AUT is mounted to a test positioner and rotated through various angles relative to the source antenna. The amplitude and phase are recorded as a function of angle to produce the desired measurement pattern.







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