INVITED PAPER

Selecting Probe Antennas for Near-Field Antenna Measurements

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With continuous growth in new applications for antennas operating at mmWave and sub-THz frequencies, the need for economical and accurate antenna measurement systems increases. At RF and microwave frequencies, the cost and size of antenna test ranges are often cost-prohibitive or impractical for many system developers. Antenna measurements for design verification and acceptance testing are commonly outsourced, frequently incurring high costs and long delays. At mmWave frequencies, the smaller footprint of antenna test ranges has the potential to make them much more practical for rapid prototype development and production testing.

Small-footprint antenna test chambers include near-field scanning systems as well as indirect far-field chambers. These are also known as compact antenna test ranges. This article briefly explores some of the issues surrounding near-field antenna measurements and how different probe antennas can affect measurement speed and data quality.

As an alternative to large and expensive far-field antenna test facilities, near-field test systems were developed to measure antennas using a much smaller anechoic environment. Near-field scanning systems differ from compact ranges in several respects. A compact antenna range typically employs a large reflector antenna or an antenna array to project a plane wave test signal toward the antenna under test (AUT). The transmitting antenna remains stationary while the AUT is rotated in azimuth and elevation. To the extent that the illuminating antenna projects a true plane wave toward the AUT, the signal source is effectively located in the far-zone of the AUT even though its actual location is well within the near zone.

In compact antenna test ranges, the power transferred over the signal path between the AUT and the measuring antenna is directly proportional to the far-zone gain of the AUT. As a result, compact ranges provide a straightforward measurement approach for obtaining antenna responses within a small anechoic environment. However, compact ranges can be difficult to design and construct and they are often limited in measurement accuracy due to a variety of influences. At higher frequencies, some of these influences become more difficult to control.

Near-field antenna test ranges use a moving probe to measure the transmission response between the probe and the AUT. Measurements are obtained with the probe located at various points within the near-field zone of the AUT. The collection of scan points forms a synthetic antenna aperture that captures the AUT antenna pattern as it exists within the near-field zone.

Many near-field test systems position the probe over a planar scan surface. This is shown in ***Figure 1***. Planar scans are well-suited for measuring directional antennas that do not exhibit significant gain outside of their main beam. The directional antenna pattern of the AUT allows a limited scan area to capture all the significant features in the radiation pattern.

For AUTs having low gain or significant

sidelobe levels, spherical or cylindrical scan surfaces may be used. Spherical near-field scanning systems typically use a probe with low gain that approximates an omnidirectional antenna for angles close to boresight. An example of this type of system is shown in ***Figure 2***. The low probe gain allows for greater variation in the probe's angular position or attitude relative to the AUT and it often eliminates the need for probe correction during data processing.

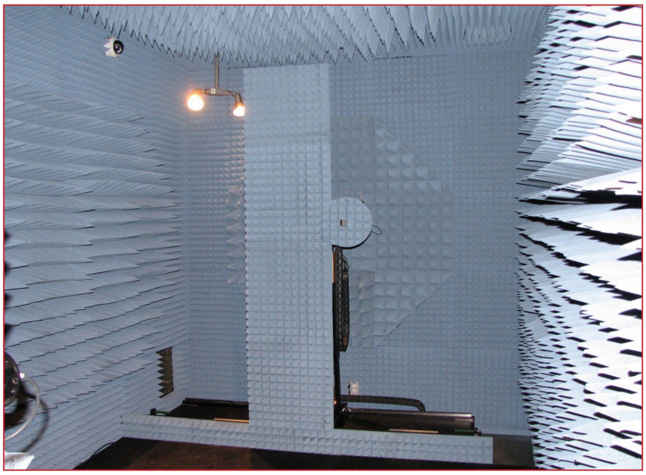

Fig. 1 **A near-field scanner moves an open-ended waveguide probe over a planar surface. *Source:* Concordia University in Montreal.**

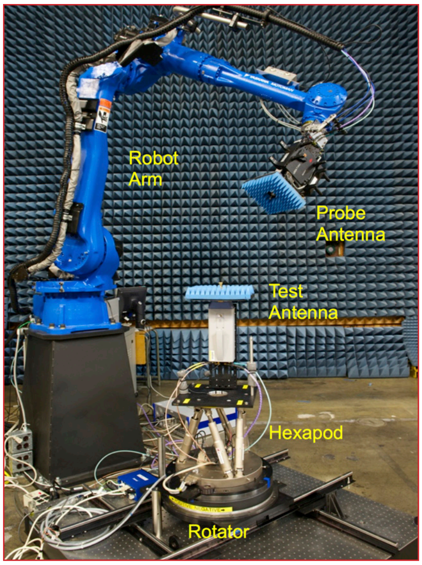

Fig. 2 **A near-field scanner performs spherical scans of an antenna under test. *Source:* NIST, Boulder Colo.**

The scan surface should be large enough to capture all significant near-field energy generated by the AUT. The required scan area and scan type is typically determined by the locations of the sidelobes that must be measured. As a rule of thumb for planar and cylindrical scans, the scan height should be approximately equal to the AUT height plus the probe height, plus twice the distance between the AUT and the probe multiplied by the tangent of the maximum processing angle from boresight. For example, if the probe and the AUT are both 1 cm high (apertures of 2 × 2 cm), with the distance between them 20 cm and the maximum measurement angle ±15 degrees, the recommended scan height above or below boresight would be ± [2 + 2 + 40 tan (15°)] cm, or ± 15 cm.

FAR-ZONE TRANSFORMATIONS

Both the amplitude and phase of the measured transmission path between the probe and the AUT are required to mathematically transform the near-field data into a far-zone antenna pattern. In most cases, a dedicated vector network analyzer performs this measurement task. For each measurement, the location of the probe must be known to within a fraction of a wavelength.

For planar near-field scans, the measured data is typically processed using Fourier optics techniques. If a raster scan is taken at regular intervals in the x- and y-dimensions, a two-dimensional Fourier transform of the measured data produces a spatial frequency spectrum on a scale indicating the number of cycles per unit of distance traversed across the scan plane. If probe correction is required, the measured spatial frequency spectrum is divided by the probe's spatial frequency spectrum over the same scan surface. This operation is equivalent to deconvolution in the near-field measurement domain. The resulting spatial frequency spectrum for the AUT is mapped onto an angular far-zone gain plot in either azimuth or elevation by computing the arcsine of the displacement from boresight multiplied by $2\pi/\lambda$. When other scanning surfaces or different scan patterns are used, the computations are more complex but the underlying mathematical and physical principles are the same.

NEAR-FIELD PROBE SELECTION

Selecting a probe antenna for near-field measurements requires an understanding of the probe's spatial filtering properties. Spatial filtering refers to the antenna pattern of the probe and its effects on the measurement results. Low gain probes are essentially omnidirectional sensors, with nearly constant gain for all measurement angles encountered between the probe and the AUT. Although low gain probes may eliminate the need for probe correction, they are more likely to pick up unwanted multipath signals.

Higher gain probes provide greater levels of spatial filtering. They function as angular bandpass filters. Data processing must include probe correction unless the probe is pointed directly toward the AUT for all measurements. Monopulse or nulling antennas function as angular band reject filters. They can measure low sidelobe levels in test systems that lack sufficient dynamic range to measure both the main beam and the sidelobes when a more conventional probe is used.

The most effective probe depends on the antenna being tested, the scan type employed, the severity of multipath effects in the test environment and the overall measurement goals. Open-ended waveguide probes are often favored because of their low cost and their ability to sample electric fields with negligible spatial filtering and their minimal disturbance of the electromagnetic fields. ***Figure 3*** shows a D-Band open-ended waveguide probe from Eravant. This probe has 6.5 dBi gain with a 3 dB beamwidth of 60 degrees. With antenna gain on the order of 6 dB, such probes are nearly omnidirectional for a wide range of measurement angles. They are commonly used in spherical scanning systems where the distances between the probe and the AUT may be small because of the higher cost of building a larger scanning system.

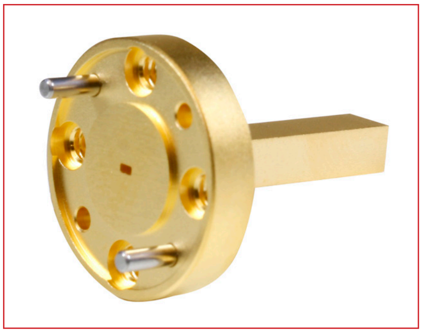

Fig. 3 **An Eravant D-Band open-ended waveguide probe.**

For planar near-field scans, probes with higher gain can provide significant advantages. A common choice is an axially symmetric horn paired with an ortho-mode transducer (OMT). The OMT and horn allow simultaneous measurements of signals that have orthogonal polarizations. One of the most effective probe types for planar scans is the conical scalar horn antenna. An example of an Eravant scalar horn antenna paired with an OMT is shown in ***Figure 4***. This configuration enables simultaneous measurements of orthogonal polarizations. Scalar horns have highly symmetrical beams and low sidelobe levels, resulting in minimal off-axis responses from multipath effects. The probe's higher gain can also reduce the sampling density required to satisfy Nyquist sampling criteria. Additionally, higher gain improves the overall signal-to-noise ratio (SNR) of the measurements. This allows greater measurement distances, lower signal power or a less sensitive receiver than a lower-gain probe would require.

One complication that arises when using a higher gain probe is the need to compensate for the probe's spatial filtering effects. Probe correction is readily accomplished when processing the near-field data. Probes with higher gain also have larger apertures, which can result in greater mutual coupling between the probe and the AUT. The edges of the probe are often tapered to mitigate probe reflections. Adding isolators to the probe and the AUT can further reduce mutual coupling between the antennas by absorbing any reflections caused by impedance mismatches.

Fig. 4 **An Eravant scalar horn antenna and ortho-mode transducer.**

The cross-polarization response of the probe can also be a significant source of measurement error. For this reason, near-field probe antennas should exhibit low cross-polarization. When a dual-polarized antenna is used with an OMT, high levels of port isolation and good impedance matching are critical for suppressing cross-polarization errors.

SUMMARY

In summary, two of the most common probe types used in near-field antenna ranges include the open-ended waveguide and the conical scalar horn. Open-ended waveguide probes have nearly constant gain over a wide beamwidth, while scalar horns provide higher gain with low sidelobe levels that can reduce multipath effects and improve the SNR of measurements. Probes with higher gain can also reduce the required sampling density, decreasing the measurement time and reducing computational burdens. The angular response of scalar horn probes is uniform and easily modeled for probe correction. The scalar horn may be combined with an OMT to enable simultaneous measurements of orthogonal polarizations. Low cross-polarization responses are desired to minimize measurement errors, and isolators should be used to minimize mutual coupling between the probe and the AUT. ■