# Multi-purpose Configurable Range for Antenna Testing Up To 220 GHz*

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***Abstract*—NIST has developed a multi-purpose test range for performing several types of antenna testing including spherical, cylindrical, and planar near-field scanning, as well as extrapolation measurements. This range uses a commercial, off-the-shelf, six-axis robot and a laser tracker to accomplish highly accurate positioning that allows scanning up to 220 GHz. Near-field measurements require positioning accuracies on the order of 0.01 to 0.02 wavelengths. We have evaluated the positioning capability of the robot and performed spherical near-field measurements at 183 GHz. We have performed spherical far-field and extrapolation measurements from 112 – 125 GHz. In addition, position data are acquired continuously using the laser tracker, which allows us to compensate for position errors in software. We report on the results of these measurements.**

***Index Terms*—extrapolation measurements, millimeter-wave antenna measurements, multi-frequency measurements, near-field measurements.**

## I. Introduction

Higher frequencies, multiple geometries, many antennas, multiple frequencies, rapid beam-state changes, shorter duration testing requirements… there is an increasing metrology need for all of these. There are requirements to test at higher frequencies for climate monitoring, security, and communications applications that require tighter tolerances for positioning, orientation, and timing between system components than are required at lower frequencies. The ability to test multiple geometries, such as planar scans at various orientations, or a spherical and extrapolation measurement with one setup, would allow for more rigorous testing with minimal increases in test time. Cell phones and spacecraft with many operational antennas need a test facility that can accommodate multiple testing requirements. Finally, the ability to rapidly move probe antennas around test objects while maintaining orientation relative to the object under test may have applications in medical and shielding tests.

The use of coordinated robotics with multiple degrees of freedom (DoF) and the use of laser-based positioning metrology equipment to guide and correct scan geometries may offer solutions to these antenna testing issues. Recently, the National Institute of Standards and Technology (NIST) has reported the capabilities of its new configurable robotic millimeter-wave antenna facility (CROMMA) and some preliminary antenna measurement results [1-6]. The CROMMA uses a commercial-off-the-shelf robotic system with six degrees of freedom (6DoF).

The major goal of this work is to develop a configurable platform that can use different measurement geometries with minimal setup. The 6DoF positioning capabilities of the antenna under test (AUT) and probe, guided by the laser tracker, allow for correcting both location and orientation throughout the scan geometry between the antenna and positioner with minimal effort. Near-field measurements typically require positioning accuracies on the order of $0.01\lambda$ to $0.02\lambda$ [7].

In a step toward the above goals, we report here on CROMMA antenna pattern measurements at 112 – 125 GHz and 183 GHz at the NIST laboratories. We also report on the results of extrapolation measurements performed at 112, 118, and 125 GHz, as well as the positional accuracies achieved in both the antenna pattern and gain measurements.

## II. The Measurement system

The measurement system, shown in Fig. 1, consists of a six-axis robot (with the probe antenna mounted on one end), a six-axis hexapod, which serves to align the test antenna relative to the azimuthal axis and an azimuthal rotator (for positioning the antenna under test), a laser tracker, and a RF

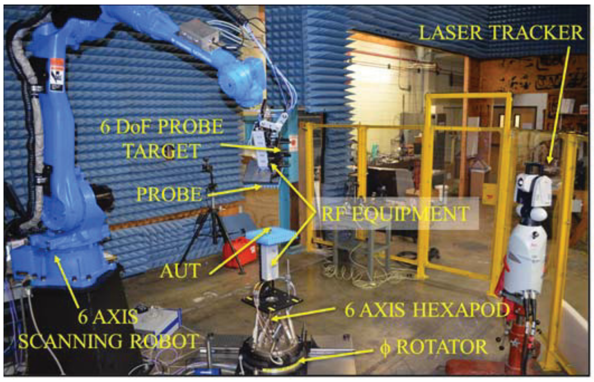


Fig 1. Major components of the Configurable MilliMeter-wave Robotic Antenna Facility (CROMMA).

network analyzer. The robot, in combination with the azimuthal rotator, allows scanning for several geometries including spherical, cylindrical, and planar geometries and, in principle, a combination thereof. Extrapolation measurements, where the probe antenna and test antenna point directly at each other while the separation distance increases, are also possible.

Out of the box the robot is capable of positioning to an uncertainty of 2 – 3 mm. However, feedback from the laser tracker can be used to improve its positioning to 20 – 25 µm [2]. The laser tracker itself can record positions to approximately 15 – 20 µm (due to uncertainties in the transverse encoders). This position information can be used in software to compensate for the probe position discrepancies.

## III. MEASUREMENT RESULTS

At 183 GHz, we performed spherical near-field antenna measurements, from which we determined the antenna far-field pattern. In the 112–125 GHz band we determined the antenna far field at 112, 118 and 125 GHz by a direct measurement of the far field, using spherical scanning. At 118 GHz, we determined the on-axis pair gain of a standard gain horn and $\mu = \pm 1$ probe.

### *A. 183 GHz Measurements*

We performed spherical near-field measurements at 183 GHz on a standard gain horn with an aperture size of 9.67 mm x 12.62 mm, using a $\mu$=±1 circular aperture probe with a diameter of 1.5 mm. (This $\mu$=±1 probe is described in [7].) Near-field measurements were done at a radius of 10 cm, then transformed to the far field, and a probe correction was performed. Fig. 2 shows a comparison of the theoretical far-field pattern and the transformed far-field pattern for the E-plane. As indicated earlier, the actual positions where the near-field data were taken were recorded using the laser tracker. There were small differences between these points and the ideal measurement locations. This information was used to do position compensation as described in [8,9].

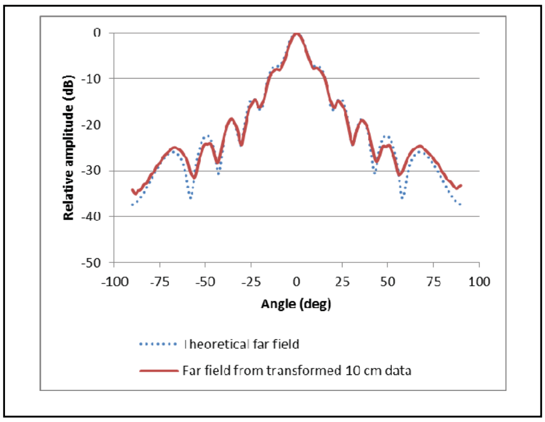


Fig. 2. Comparison of theoretical far field to that obtained from transforming 10 cm near-field data for the E-plane at 183 GHz.

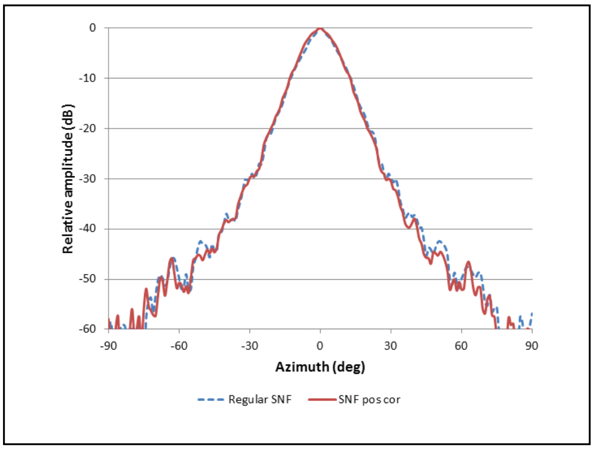


Fig. 3. Far-field H-plane pattern, derived from spherical near-field (SNF) measurements, of a WR-5 standard gain horn with position correction (red, solid) and without position correction (blue, dashed).

A comparison of the position-compensated pattern and the traditionally derived pattern is shown in Fig. 3 for the H-plane.

### *B. 112 – 125 GHz Measurements*

We performed spherical far-field measurements at three frequencies in the 112–125 GHz band for a $\mu$=±1 probe. Measurements were made at 100 mm, which corresponds to $4D^2/\lambda$. Sample co- and cross-polarization results are shown in Fig. 4. In this case, $\chi$=0° corresponds to the co-polarization and $\chi$=-90° corresponds to the cross polarization. The co-polarization peaks at 112, 118, and 125 GHz agree within ±0.5 dB. The cross polarization data are generally below the -40 dB level, which is the detectable limit for the measurement system.

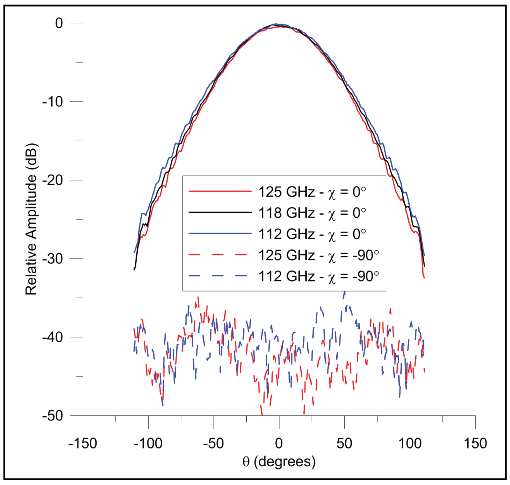


Fig. 4. E-plane pattern at a separation distance of 100 mm for three frequencies. The solid lines correspond to the co-pol patterns and the dashed lines to the cross-pol pattern.

The three-antenna extrapolation method is used to determine the gain of three antennas without having a priori knowledge of any of the antenna gains [10]. So far, we performed extrapolation measurements of only one pair of

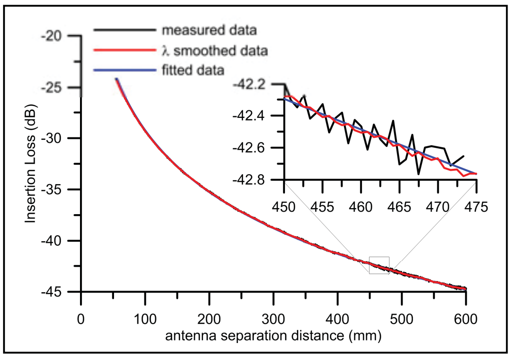


Fig. 5. Plot of extrapolation data at 118 GHz for the $\mu$=±1 probe versus a 15 dBi standard gain horn.

antennas at 118 GHz. Because we have measured only one pair, we are only able to determine a combined pair gain at this time. This pair gain is derived from the leading term of a power series fit to the data in $1/r^n$ [10]. Here $r$ is the separation distance between the two antennas. Sample extrapolation results are shown in Fig. 5. The smoothed data in Fig. 5 come from averaging data over a wavelength to account for multiple reflections between the two antennas. A pair gain of 24.69 dB was determined from these measurements. The data span a range of $2D^2/\lambda$ to $24D^2/\lambda$ (where $D$ is the diameter of the largest antenna).

## IV. CONCLUSIONS AND FUTURE WORK

We have demonstrated that a robotic arm is capable of scanning in more than one geometry (spherical, and extrapolation geometries, to date). We have demonstrated fine controls that allow CROMMA to control location with an uncertainty of 20 µm or better. Using the λ/50 rule, we can provide sufficient accuracy for extrapolation (and planar) measurements up to at least 300 GHz. Finally, we have demonstrated that we can compensate (in software) when location and polarization are not standard.

Future work will concentrate on increasing the scanning speed of the system, testing high-performance antennas and undertaking a thorough uncertainty analysis for the above measurements (including, for example, antenna-antenna multiple reflections and truncation). We would like to extend the capabilities to the *dynamic* testing of beamforming antennas. We want to begin measurements of side lobes and spurious emissions as the main beams scan or track targets, or *in-situ* testing of multi-beam systems using user-equipment emulation systems as probes. We will be improving processing software to use a standard interface and provide increased flexibility to handle frequency-multiplexed data, hybrid geometries, and pointing compensation.

## REFERENCES


[1] D. Novotny, J. Gordon, M. Francis, R. Wittmann, A. Curtin, J. Guerrieri, “Antenna measurement implementations and dynamic positional validation using a six axis robot,” Proc. of the 2015 Antenna Meas. Tech. Assoc., pp. 15 – 20, October 2015

[2] J. A. Gordon, D. R. Novotny, J. B. Coder, J. R. Guerrieri, B. Stillwell,“Robotically controlled mm-wave near-field pattern range,” Proc. of the 2012 Antenna Meas. Tech. Assoc., pp. 384 – 389, November 2012.

[3] L. Boehm, F. Boegelsack, M. Hitzler, C. Waldschmidt, “An automated millimeter-wave antenna measurement setup using a robotic arm,” 2015 International Symposium on Antennas and Propagation and North American Radio Science Meeting, TUP-A1.5A.7, 19-24 July 2015.

[4] M. H. Francis, R. C. Wittmann, D. R. Novotny, J. A. Gordon, ”Spherical near-field measurement results at millimeter-wave frequencies using robotic positioning,” Proc. of the 2014 Antenna Meas.Tech. Assoc., pp. 231 – 234, October 2014.

[5] D. R. Novotny, J. A. Gordon, J. R. Guerrieri, “Antenna alignment and positional validation of a mmWave antenna system using 6D coordinate metrology,” Proc. of the 2014 Antenna Meas. Tech. Assoc., pp. 247 – 252, October 2014.

[6] J. A. Gordon, D. R. Novotny, M. H. Francis, R. C. Wittmann, M. L. Butler, A. E. Curtin, J. R. Guerrieri, “Millimeter-Wave Near-Field Measurements Using Coordinated Robotics,” IEEE Trans. Antennas Propagat., Submitted May 2015.

[7] M.H. Francis and R.C. Wittmann, “Near-field scanning measurements: Theory and practice.” In *Modern Antenna Handbook*, edited by C.A. Balanis, Chp. 19, New York, NY: John Wiley & Sons, 2008.

[8] R.C. Wittmann, B.K. Alpert, M.H. Francis, “Near-field antenna measurements using nonideal measurement locations,” IEEE. Trans. Antennas Propagat., vol. AP-46, pp. 716 – 722, May 1998.

[9] R.C. Wittmann, B.K. Alpert, M.H. Francis, “Near-field, spherical-scanning antenna measurements with nonideal probe locations,” IEEE Trans. Antennas Propagat., vol. AP-52, pp. 2184 – 2186, August 2004.

[10] A.C. Newell, R.C. Baird, and P.F. Wacker, “Accurate measurement of antenna gain and polarization at reduced distances by an extrapolation technique,” IEEE Trans. Antennas Propagat., vol. AP-21, pp. 418 – 431, July 1973.