

# Antenna Metrology for 100-500 GHz: A New Approach

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**Abstract** — A typical near-field scanning range for antenna measurements is based on simple translation stages (planar) or stacked rotators (spherical), or both (cylindrical). Above 100 GHz, problems arise in both specialized waveguide components, such as precision rotators, and in positioning and alignment accuracy. NIST is pioneering a new approach based on an off-the-shelf, industrial six-degrees-of-freedom, articulated-arm robot. Pattern measurements at 118 GHz and 183 GHz, and positioning accuracies within 25  $\mu\text{m}$  confirm the effectiveness of the approach.

**Keywords** — antenna measurements, millimeter-wave, near-field scanning, robotics, spatial metrology

## I. INTRODUCTION

Near-field scanning at mm-wave frequencies by use of traditional stacked motion stages (linear, rotary) becomes difficult as waveguide components decrease in size, precision rotators become unavailable, and  $\lambda/50$  positioning accuracies prove challenging. The National Institute of Standards and Technology (NIST) is pioneering a new near-field scanning range based on an off-the-shelf industrial six-degrees-of-freedom (6DoF) robot. The robot allows for arbitrary scan geometries, takes advantage of stable cable routing to avoid the need for precision rotators, and in combination with a dynamic laser tracker system, allows for precision positioning and alignment in both location (x,y,z) and direction (pitch, roll, yaw). A coordinated spatial-metrology approach allows for the position of the scan probe and test antenna to be tracked in real time with known relation to an overall reference frame. This creates coordinated motion of the robotics in concert with the antenna apertures.

## II. ROBOTICS BASED ANTENNA RANGE

Fig. 1 shows the current robotics-based antenna range at NIST, designated as the configurable robotic millimeter-wave antenna facility, or CROMMA. The 6DoF articulated-arm robot (shown with mounted probe antenna) is coupled to a 6DoF hexapod positioner (shown with the test antenna) and both are linked to a dynamic laser tracker system [1]. The robotic arm can support a 35 kg payload and scan arbitrary paths over a volume of radius greater than 1 m with an uncorrected (out of the box) repeatability of better than 100  $\mu\text{m}$ . The hexapod supports a payload of 30 kg, has positioning accuracy and repeatability of around 1  $\mu\text{m}$ , a motion range of about 50 mm, and a pointing range of about 30°. The hexapod itself is located on a rotator and planar positioner to allow rough alignment first.

Together with the optical and spatial metrology coordination, the CROMMA specifications are summarized in Table I.

## III. OPTICAL METROLOGY

Spherical mirror reflectors (SMRs) and an optical frame system mounted on the robot arm allow frames of reference to be established between the robot arm and the hexapod for alignment, and for scans to be accurately traced and mechanically corrected. A new optical pixel probe has been developed to solve the problem of translating from the SMRs and optical frame location to the tip of the probe antenna [2]. Specifically, the pixel probe establishes a virtual point in space with known spatial coordinates linked to the laser tracker. This virtual point can then be used to map the aperture of the probe or test antenna to locate their rotational centers and aperture normals, all with accuracy on the order of 25  $\mu\text{m}$ . Using these tools together we can achieve very accurate alignment, critical to good near-field scans, for most any geometry of interest. Fig. 2 shows the pixel probe mapping a standard gain horn, while Fig. 3 shows the relative sizes of two SMRs and WR-05 circular probe antenna.

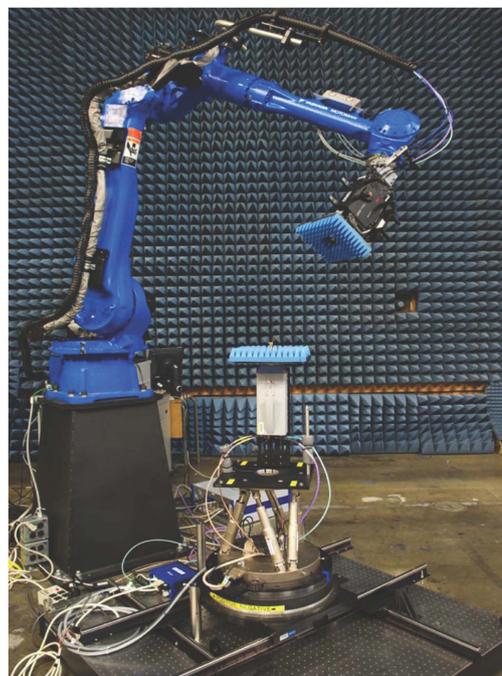


Fig. 1. 6DoF robotic arm with mounted probe antenna and the 6DoF hexapod positioner with mounted test antenna.

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Table I.  
NIST CROMMA FACILITY SPECIFICATIONS

Probe Payload	35 kg
AUT Payload	30 kg
Accuracy (X,Y,Z)	< 25 $\mu\text{m}$ (rms)
Repeatability (X,Y,Z)	< 25 $\mu\text{m}$ (rms)
Accuracy (Roll, Pitch, Yaw)	< 0.01° (rms)
Repeatability (Roll, Pitch, Yaw)	< 0.01° (rms)
Working Volume	1 m Radius
$\theta$ Range	$\pm 120^\circ$
$\phi$ Range	$\pm 360^\circ$
Frequency Range	75 GHz - 500 GHz



Fig. 2. Pixel probe mapping of a standard gain horn.

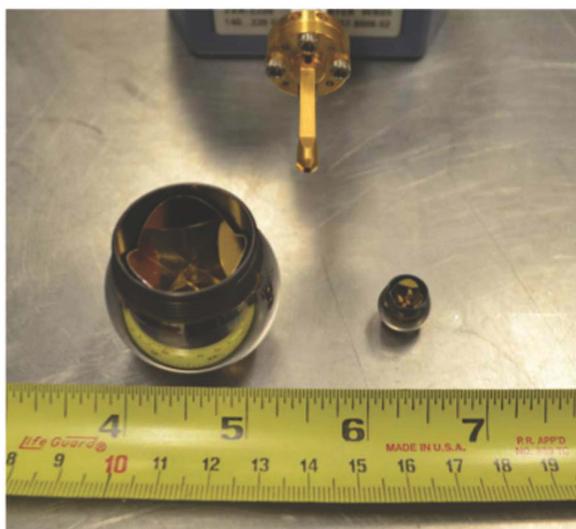


Fig. 3. 38 mm (1.5") and 13 mm (0.5") SMRs, and a 1.5 mm-diameter aperture probe antenna.

#### IV. SPATIAL METROLOGY

A knowledge of the local coordinate systems and alignment of the probe and test antennas, both linked to an overall coordinate system and the dynamic laser tracker allows

the accurate control of the robot kinematics. During a scan, position and motion are captured and can be compared to the target scan geometry and RF data acquisition grid. Corrections to scan geometries can then be calculated and converted to robot commands. Together, the system allows alignment, positional uncertainty, and motion during a scan to be recorded and analyzed. An example of a scan visualization is given in Fig. 4.

Further, knowledge of the exact locations of data acquisition across the scan, even if not on the ideal target grid (position errors), allow for analytical corrections on post processing [3]. Together, these mechanical, spatial, and analytical tools should allow the system to make accurate antenna measurements at frequencies up to and likely above 500 GHz ( $\lambda = 0.6$  mm,  $\lambda/50 = 12$   $\mu\text{m}$ ).

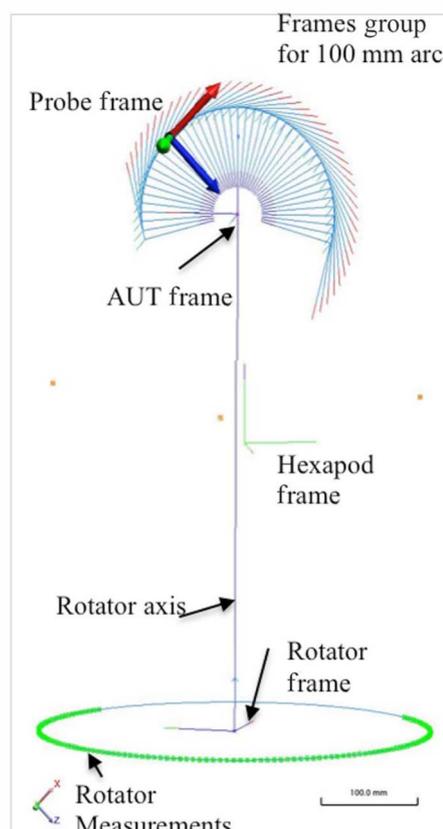


Fig. 4. Visualization of the local (probe, test antenna, hexapod and rotator) and global coordinate systems for a 100 mm radius spherical scan.

#### V. SAMPLE MEASUREMENT RESULTS

183 GHz represents an important water vapor line frequency in microwave radiometry. A standard gain horn was measured at a 100 mm radius (in the near-field), at a 1000 mm-radius (nominally in the far-field), and calculated theoretically (based on its physical dimensions). Agreement is good between all three patterns down to -20 dB below the peak, as shown in Fig. 5. Note the 1000 mm scan shows noise at low amplitude levels due to limitations on transmit power (-12 dBm).

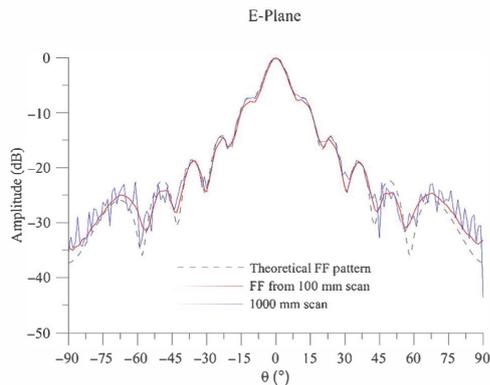


Fig. 5. E-plane data measured at 183 GHz: a) transformed far-field (FF) data from a 100 mm radius spherical near-field scan, b) direct FF data from a 1000 mm radius scan, and c) a theoretical FF pattern.

A second example shows spherical scan data over 118 – 125 GHz for a  $\mu = \pm 1$  probe (see Fig. 6). Measurements were made at a radius of 100 mm ( $\approx 4D^2/\lambda$ , where  $D$  is the probe diameter). Both co- and cross-polarization E-plane data are shown for several frequencies with the cross-polarization data generally below -40 dB, which represents the detectable limit for the system in this configuration.

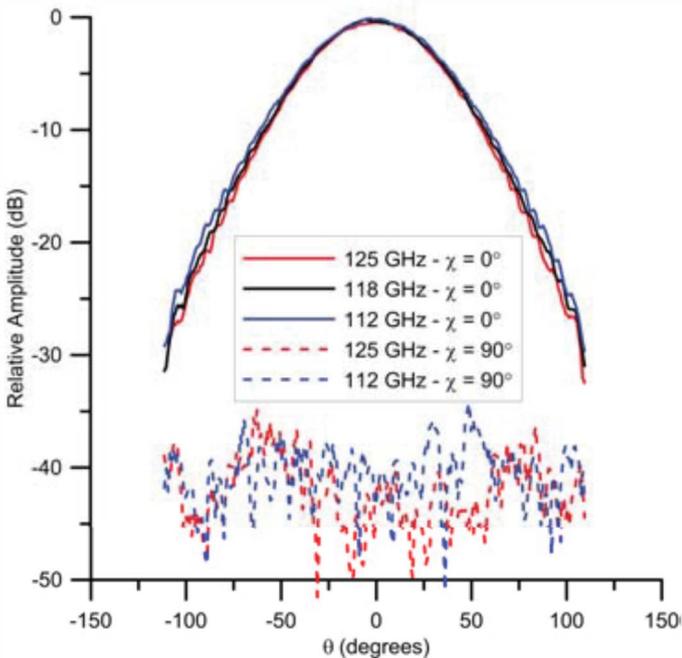


Fig. 6. E-plane patterns at three frequencies (112 GHz, 118 GHz, and 125 GHz) for a  $\mu = \pm 1$  probe processed from a 100 mm spherical near-field scan.

CROMMA can also be used in an extrapolation mode, i.e., a linear scan along the aperture normal over multiple wavelengths to estimate the antenna gain. Figure 7 shows extrapolation data for the above  $\mu = \pm 1$  probe at 118 GHz. The data represent a scan range of approximately  $2D^2/\lambda$  to  $24D^2/\lambda$ . For this measurement, only a pair of antennas were measured; three are needed to extract absolute gain via the three antenna method. However, a pair gain of 24.7 dB can be estimated from these data and agrees well with theoretical predictions.

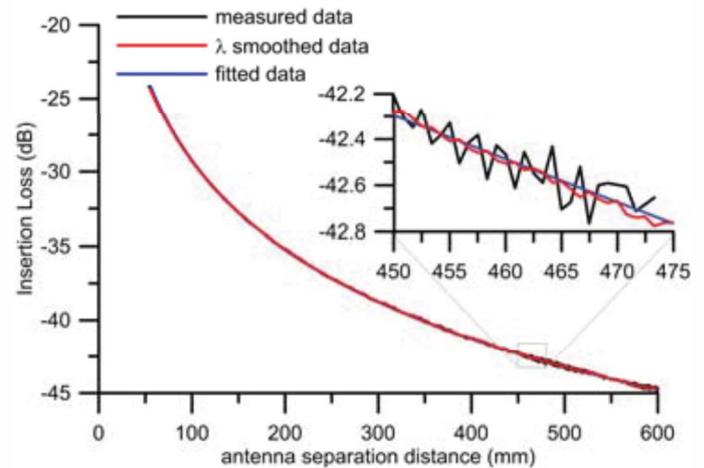


Fig. 7. Extrapolation scan data for the  $\mu = \pm 1$  probe paired with a 15 dB standard gain horn at 118 GHz.

## VI. SUMMARY

A robotics based near-field antenna range applicable to frequencies from 100 – 500 GHz and beyond has been described and sample measurement data at 183 GHz and near 118 GHz shown. The combination of optical and spatial metrology with coordinated robotics allows for quick and accurate alignment, yielding precision scans over a very flexible range of geometries. Future work will explore higher frequencies, more complicated test objects such as small satellites and printed antennas, as well as the continuing to refine the overall coordinated spatial and kinematic software capability.

## VII. REFERENCES

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