A Cost-Effective Open-Air, Compact Antenna Test Range (CATR) to Reach 330 GHz

Alexander Chen
Eravant
Torrance, USA
achen@eravant.com

Yonghui Shu
Eravant
Torrance, USA
yshu@eravant.com

Neda Khiabani
Nokia Bell Labs
Murray Hill, USA
neda.khiabani@nokia-bell-labs.com

***Abstract*— This paper presents a cost-effective, open-air compact antenna test range (CATR) developed for millimeter wave and Sub-THz antenna measurement with a 150 mm (6-inch) diameter quiet zone (QZ) and operating frequency range up to 330 GHz. The benchmark results presented suggest that the system is well implemented and accurate. In addition, a novel fixtured antenna array on a glass substrate was measured with CATR technology. The results indicate that the CATR is one of the most cost-effective industrial antenna pattern measurement systems that can achieve accurate results at sub-THz frequencies thus far.**

Keywords— Millimeter-wave, Sub-THz, Antenna Array, Glass Substrate, Antenna Test, Compact Antenna Test Range (CATR), Open-Air, Quiet Zone (QZ), WR-03, 6G.

I. Introduction

Current research and development efforts on antennas, transmitters, and other core technologies for 6G wireless communications are focused on the millimeter wave and sub-THz frequencies, which covers a combined frequency range from 30 to 300 GHz. Frequency spectrums in W-band (92-114 GHz), D-band (130-174.5 GHz), and J-band (252-325 GHz) have already been identified and allocated for current and future 6G development [1]. To qualify the performance of the antennas, radiation patterns need to be measured and characterized. Microwave antenna pattern measurements typically are performed using either far-field or near-field scanning methods. For far-field measurement, the antenna under test (AUT) must be positioned at a distance far enough and within direct line-of-sight from a source antenna such that it sees the source antenna's waveform as a planar wave. The far-field distance, R, is a function of the aperture diameter D and the wavelength λ, and is calculated as follows:

$$R \geq \frac{2D^2}{\lambda} \quad (1)$$

Antennas with large apertures that operate at mmWave and sub-THz frequencies require extremely large far-field distances and exceptionally powerful transmitters to overcome the over-the-air transmission losses. For these reasons, the compact antenna test range (CATR) is a commonly preferred method for measuring mmWave and sub-THz frequency antennas. The theory and operation behind the CATR are well studied and documented in textbook literature [2]. Previous studies done by researchers have achieved and reported results in the sub-THz frequencies using CATR, such as the measurement of a 668 GHz antenna using a custom two-reflector setup [3]. Published literature shows that commercially available CATR systems offered by dedicated antenna test solution providers have a specified upper operating range up to 110 GHz, though the manufacturers note that higher frequency designs up to 330 GHz are available via special-order and additional expense. Such custom-designed systems are out of reach for many new and upcoming researchers and engineers. In this paper, an affordable compact antenna test range designed for open-air operations up to 330 GHz is presented to lower the barrier of entry for millimeter wave and sub-THz antenna research and development. The comparison of the measured results in both open-air and anechoic chamber settings shows that the CATR system can be used in both scenarios without any discernable differences. The results confirmed the hypothesis of open-air operation accuracy of the CATR.

II. Reflector and Feed Horn Design

The compact range design is a center-fed configuration with the feed horn located at an angle and distance such that the horn's 10 dB beamwidth illuminates the entire reflector surface to create a uniform plane wave. A basic diagram of the design is shown in Figure 1.

The reflector itself is a parabolic body with blended rolled edge treatment to disperse errant reflections that would interfere with the quiet zone quality. The reflector's lowest operating frequency is determined by the rolled length edge, which is typically around 5-10 times the lowest frequency wavelength. The reflector's highest operating frequency is determined by the surface roughness, which for 200 GHz requires an Ra average roughness of at least 1.6 micrometers (63 microinches) or better [4]. The compact range feed horn is a choked slot horn antenna, which is known for good axisymmetric radiation characteristics, low cross polarization, wide beam angle, lower sidelobes, and stable phase center across the entire operating frequency range.

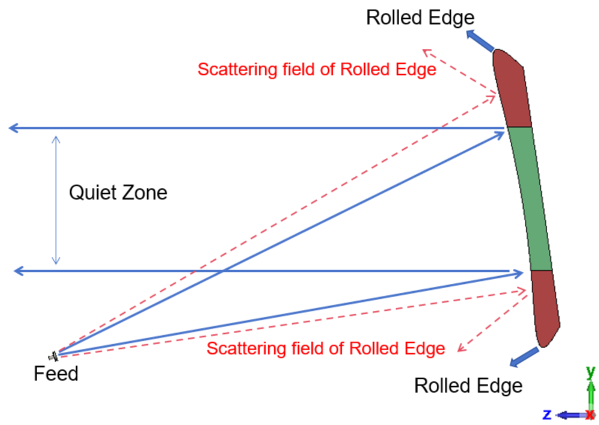

Fig. 1. Compact Range Basic Configuration

The feed horn, shown in Figure 2, was fabricated from brass with tolerances of ±0.0127 mm (±0.0005”) and gold plated. The reflector was machined from a single block of aluminum and treated with chemical film conversion coating for corrosion resistance. The surface profile accuracy requirements of the reflector were defined accordingly as three distinct subzones shown in Figure 3 and Table 1. The reflector surface was specified and machined with a roughness of 0.4 micrometers Ra (16 microinches Ra) or better to extend the upper frequency limit to at least 330 GHz.

The developed open-air CATR offers a low-cost solution for antenna measurements. The key technology in the CATR system includes a pair of WR-03 full-band Vector Network Analyzer (VNA) frequency transmitting and receiving extenders, rolled edged CATR reflector, WR-03 CATR feed and a 2-axis positioner. Modular T-slot aluminum extrusion profiles and optical grade rails were used to construct a cost effective and sturdy bed frame structure to mount and align the components together. The CATR system has the following electrical and mechanical specifications shown in Tables 2 and 3, which indicates that it is a portable system that can be set up in a lab environment with ease or flexibility.

Fig. 2. Final Fabricated WR-03 Feed Horn

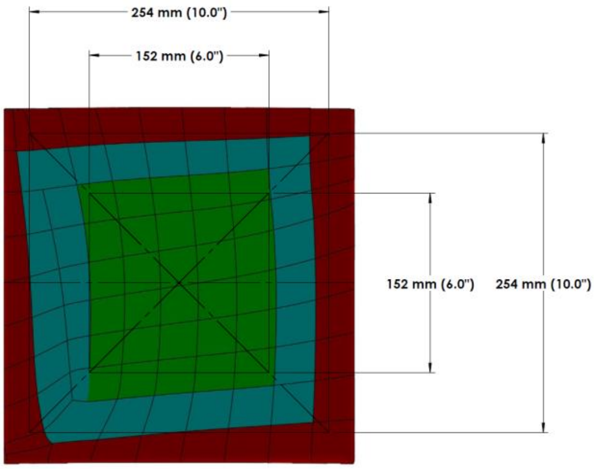

Fig. 3. Reflector Surface Accuracy Tolerance Divisions

TABLE I. SURFACE ACCURACY SPECIFICATIONS

Sub-Zone	Surface Profile Accuracy Specification
Green	±0.0152 mm (±0.0006”)
Blue	±0.0254 mm (±0.001”)
Red	±0.0508 mm (±0.002”)

TABLE II. CATR ELECTRICAL SPECIFICATIONS

Parameter	Specification
Frequency Range	24 to 330 GHz
Quiet Zone Shape	Circular
Quiet Zone Size	Ø150 mm (Ø6”)
Feed Layout	Center Fed
Feed Antenna Polarization	Linear

TABLE III. CATR MECHANICAL SPECIFICATIONS

Parameter	Specification
Reflector Dimensions	Approx. 0.3 m x 0.3 m (12”x 12”)
System Dimensions	Approx. 1.57 m x 0.44 m x 0.77 m (62” x 17.2” x 30.6”)
System Weight	Approx. 59 kg (130 lbs.)

III. BENCHMARK RESULTS

The sub-THz frequency horn antenna selected for the benchmark testing of the open-air CATR was a standard pyramidal gain horn with a standard WR-03 rectangular waveguide port interface and aperture dimensions of 8.51 mm x 6.81 mm (0.335” x 0.268”). The CATR was installed in an “open-air” environment and not in a traditional anechoic chamber setting as shown in Figure 4.

The gain horn was installed on the 2-axis positioner and swept ±90° in both the azimuth and elevation planes with a one-degree step size to obtain the H-plane and E-plane patterns. The measured patterns of the gain horn are presented in Figure 5 and Figure 6 with simulated data for comparison. The results are well correlated with the simulation as shown.

Another test of the same gain horn was conducted with the CATR system installed inside an anechoic chamber, shown in Figure 7. A comparison of the measured results from the open-air setup and in the anechoic chamber setup are shown in Figure 8 and Figure 9. As can be seen from the data, there is no significant difference in the quality and accuracy of the measurements in open-air environment compared to the anechoic chamber environment. The results confirmed that the CATR can be used in open-air operations to eliminate the need for expensive anechoic chambers.

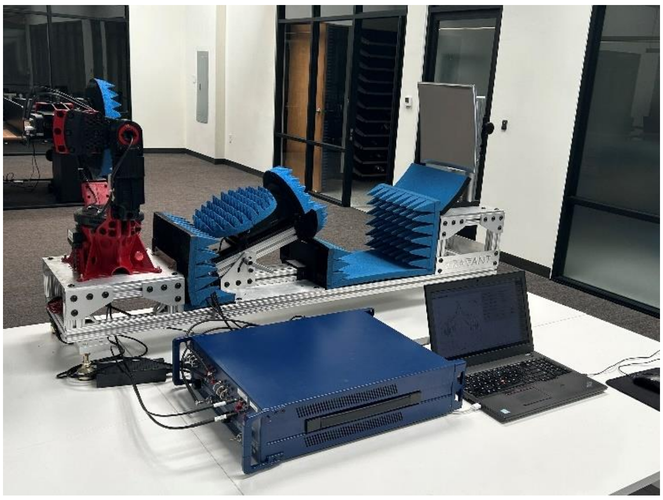

Fig. 4. Open-air test setup for the CATR system

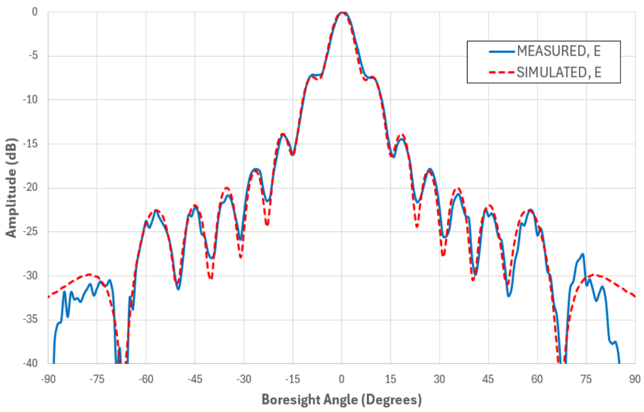

Fig. 5. CATR Test Results of the WR-03 Gain Horn at 330 GHz, E-Plane

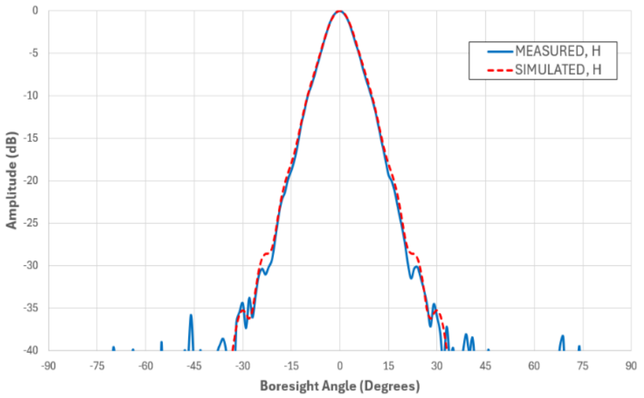

Fig. 6. CATR Test Results of the WR-03 Gain Horn at 330 GHz, H-Plane

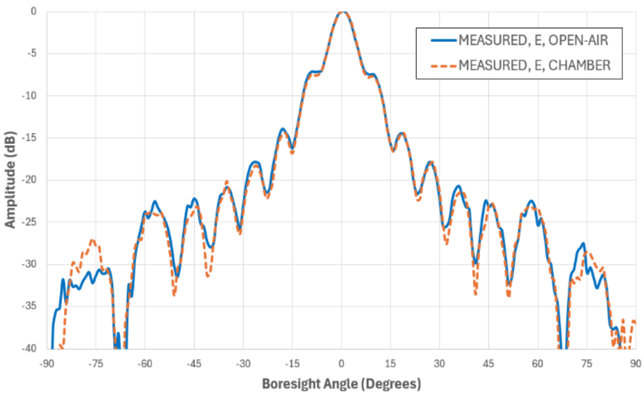

Fig. 8. CATR Test Results of the WR-03 Gain Horn at 330 GHz, E-Plane, in Open-Air vs Anechoic Chamber Environment

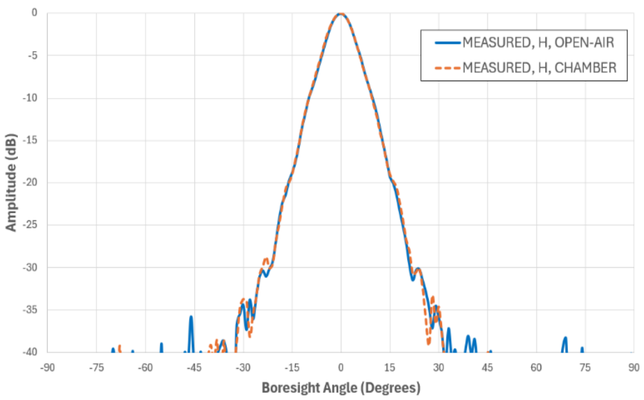

Fig. 9. CATR Test Results of the WR-03 Gain Horn at 330 GHz, H-Plane, in Open-Air vs Anechoic Chamber Environment

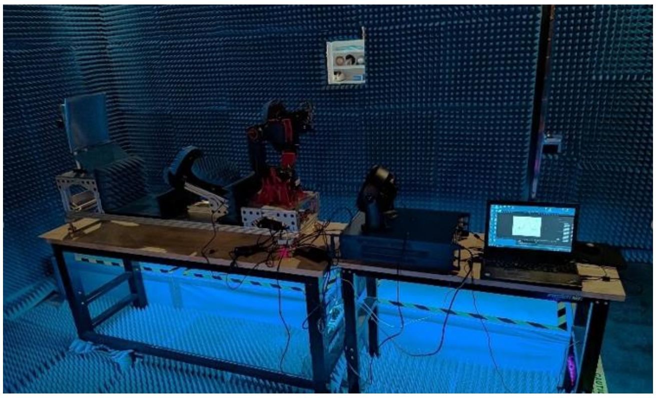

Fig. 7. Anechoic chamber test setup for the open-air CATR system

IV. FIXTURED ANTENNA ARRAY PATTERN MEASUREMENT

While bench-mark data were collected from a single aperture standard pyramidal gain horn, a novel 1x8 antipodal Vivaldi antenna array, shown in Figure 10, was measured in a MilliBox modular anechoic chamber by transferring the core components of the open-air CATR into the modular chamber. The antenna array was fabricated on a single layer glass substrate processed by Mosaic Microsystems and Samtec Glass Core Technology. A wideband corporate feed power divider based on substrate integrated waveguide (SIW) was employed to feed the linearly polarized antenna array. The antenna array was designed to cover the entire J-band frequency range from 220 to 330 GHz. The measured patterns at 300 GHz of the array are presented in Figure 11 and 12. Like the gain horn, they closely match the simulated results.

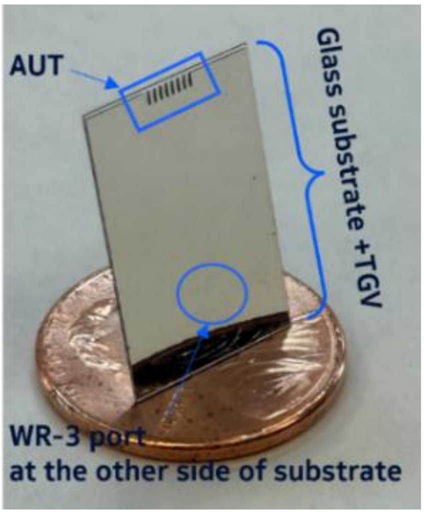

Fig. 10. 1x8 Glass Substrate Antenna Array

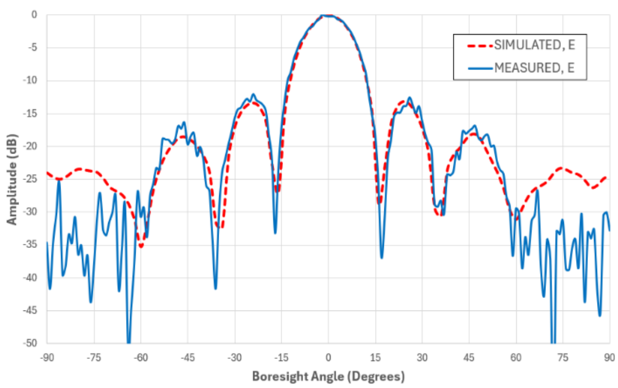

Fig. 11. CATR Test Results of the 1x8 Array at 300 GHz, E-Plane

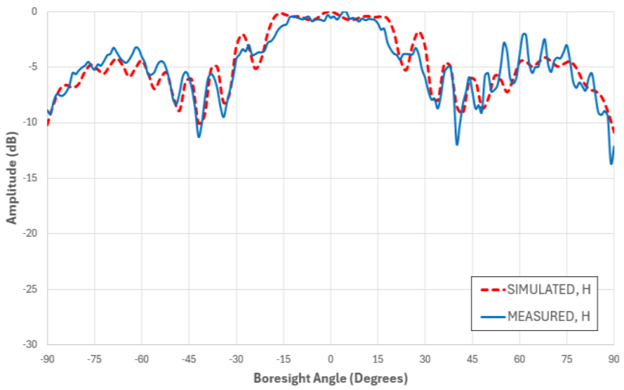

Fig. 12. CATR Test Results of the 1x8 Array at 300 GHz, H-Plane

V. Conclusion

A low-cost compact antenna range has been developed and tested with a standard WR-03 pyramidal horn at 330 GHz with accurate results in an open-air environment. The CATR was also tested in an anechoic chamber and there was no discernable difference in the accuracy of the measurements in the open-air setup compared with the anechoic chamber setup. The compact range has already found applications in 6G millimeter wave and sub-THz antenna research and development with the measurement of a custom designed 220 to 330 GHz 1x8 antenna array. Further development of the low-cost compact antenna range will focus on larger quiet zone sizes up to 300 mm (12”) in diameter.

Acknowledgment

The authors would like to thank Zi Wang from Eravant for assistance in setting up the open-air and anechoic chamber CATR bench-mark tests and Jean-marc Laurent and Chinh Doan from MilliBox for providing the 2-axis positioner and software used for the CATR tests and providing measured data for the fixtured antenna array on glass that was taken inside the MilliBox modular anechoic chamber.

References

[1] Keysight, Early Insights into the 220 to 330 GHz Sub-Terahertz Band. Santa Rosa, CA: Keysight Technologies, 2022. [Online]. Available: https://www.keysight.com/ie/en/assets/7122-1129/white-papers/Early-Insights-into-the-220-to-330-GHz-Sub-terahertz-Band.pdf

[2] C. Parini, S. Gregson, J. McCormick, and D. Janse van Rensburg, Theory and Practice of Modern Antenna Range Measurements. London, UK: IET, 2014.

[3] P. Heine et al., "(Sub-)mm-Wave Antenna Measurements Up to 668 GHz on the MetOp-SG Ice Cloud Imager in a Compensated Compact Range," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1-5

[4] C. Rowell, B. Derat, and A. Cardalda-García, "Multiple CATR Reflector System for Multiple Angles of Arrival Measurements of 5G Millimeter Wave Devices," IEEE Access, vol. 8, pp. 211324-211334, 2020.