A 300 mm (12-Inch) Quiet Zone Compact Antenna Test Range (CATR) to Reach 330 GHz for 6G Applications

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Abstract— **Increasing interest in research and development for 6G applications has spurred similar interest and requirements for accurate measurement systems for 6G antennas. In [1] an open-air, compact antenna test range (CATR) with a 150 mm (6-inch) circular quiet zone was shown to work up to 330 GHz. This paper extends upon the work presented by [1] by demonstrating a CATR with a larger 300 mm (12-inch) circular quiet zone and operating frequency up to 330 GHz. A 230 mm (9-inch) diameter, 53 dBi gain WR-03 Cassegrain antenna that operates from 220 to 330 GHz was fully tested and verified on the CATR with very close correlation between theoretical and measured results.**

I. INTRODUCTION

Since 2019, 5G technology has seen tremendous growth and success in the past six years. The number of 5G connections in North America grew from 587,000 in 2019 to over 339 million in Q2 2025, covering roughly 88% of the population. Worldwide, the number of 5G connections grew from approximately 5 million in 2019 to over 2.6 billion in Q2 2025. It is forecasted that the number of 5G connections worldwide will increase to 9 billion by 2030 [2]–[4]. As 5G technologies become more mature globally, research and development is already being conducted into the next generation, 6G (also known as IMT-2030), to address the ever-increasing demand for bandwidth and data from emerging technologies such as AI and driverless cars. As of 2025, the IMT-2030 rollout timeline as outlined by the International Telecommunication Union (ITU) clearly shows that 6G is still in its infancy, with many requirements yet to be clearly defined [5].

One of the challenges for millimeter-wave and sub-THz antennas for 6G communications are free-space path losses and absorption losses caused by oxygen and water vapor in the air. Several atmospheric windows above 92 GHz have been identified and configured for potential 6G applications, such as 92-114 GHz (W-Band), 130-174.5 GHz (D-Band), and 252-325 GHz (J-Band) [6]. The free-space path loss, PL, is calculated by (1), where f is the frequency in GHz and d is the distance in km between the transmitter and receiver antennas:

$$PL = 92.4 + 20\log f + 20\log d \tag{1}$$

At 1 km and 2 GHz, the calculated path loss is 98.4 dB. At the same distance for 92 GHz and 300 GHz, the path losses are 131.7 dB and 141.9 dB, respectively. Atmospheric losses for frequencies ranging from 100 to 300 GHz at 1 km contribute an additional 1.3 dB to 5.7 dB to the total loss [7]. Compared to the 2.4 GHz WiFi frequency spectrum, the proposed 6G spectrum within the 100-300 GHz band for the same distances must overcome an additional 35 dB to 50 dB in transmission losses. Such losses need to be compensated for with more powerful transmitters or higher gain antennas.

At millimeter-wave and sub-THz frequencies, it becomes impractical to measure high gain antennas using traditional far-field methods due to the high transmission losses as described previously. For example, a 0.3 m (12-inch) diameter antenna operating at 300 GHz has a calculated far-field distance greater than 180 m according to (2), where R is the far-field distance, D is the antenna diameter, and λ is the wavelength.

$$R \geq \frac{2D^2}{\lambda} \tag{2}$$

The free-space path loss at 300 GHz and 180 m is around 127 dB per (1), which severely limits the dynamic range and resolution of the patterns that can be obtained using commercial vector network analyzer (VNA) frequency extension modules at sub-THz frequencies. Because of this, near-field ranges and compact antenna ranges are the preferred measurement systems at these frequencies due to less distance required between the transmitter and receiver. Multiple studies have already been conducted using near-field ranges in characterizing high gain antennas at sub-THz frequencies [8], [9]. Published literature for high gain, sub-THz frequency antenna measurements using the CATR method are scarcer compared to that of near field, although there are some examples here and there [1]. This paper seeks to expand upon the work presented in [1], as well as supplement the findings presented in [8] and [9] by presenting a CATR system with a 300 mm (12-inch) quiet zone for measuring antennas up to 330 GHz. A 230 mm (9-inch) diameter Cassegrain antenna with a gain of 53 dBi was tested on the CATR and the resultant patterns were found to be closely matched with that of the simulated results, which confirms the accuracy and validity of the CATR for high gain, sub-THz antenna measurements.

II. CATR DESIGN

The CATR's basic components consist of the rolled edge parabolic reflector, feed horn, supporting structure, a 2-axis elevation over azimuth positioner and VNA frequency extension modules and accessories for transmitting and receiving RF signals.

The rolled edge reflector was designed with a parabolic section in the middle and blended roll sections at the edges, as shown in Figure 1. In general, the quiet zone size requires the overall reflector size to be twice as large. Based on that guideline, the reflector was designed with overall dimensions of 600 mm x 600 mm (24" x 24") with the center parabolic section being around 300 mm x 300 mm (12" x 12") to achieve the desired 300 mm (12-inch) circular quiet zone.

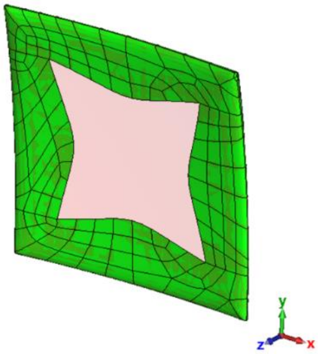

Figure. 1. 3D Contour Model of the 600 mm reflector.

The highest operating frequency of the reflector is determined by the surface roughness of the reflector. In [10], a roughness of 1.6 micrometers Ra (63 microinches Ra) was required to use the CATR at 200 GHz. At 330 GHz, the wavelength is smaller compared to 200 GHz by a factor of 1.7, so the roughness requirement for 330 GHz must be scaled by the same factor. For the 600 mm reflector, the surface roughness was specified to be at least 0.4 micrometers Ra (16 microinches Ra) to guarantee operation without doubt at 330 GHz and above.

The feed horn was designed with a wide beam angle (3 dB beamwidth greater than 60 degrees) to fully illuminate the quiet zone of the reflector. Corrugated choke slot structures were used to ensure axisymmetric radiation patterns and phase center stability across the standard WR-03 operating frequency range from 220 to 330 GHz. A picture of the fabricated WR-03 horn is shown in Figure 2.

The supporting structure was constructed from ordinary, off-the-shelf extruded aluminum profiles. The extruded profiles featured lower costs, more modularity, easier assembly, and lighter weight compared to custom-machined parts while still offering the required structural stiffness and integrity for mounting and supporting the reflector, antenna positioner, and RF accessories. The rest of the components, such as the 2-axis positioner and RF test equipment and accessories, were purchased from commercially available sources and integrated onto the CATR platform. The final CATR system after assembly is shown in Fig. 3 and the basic system specifications are summarized in Table 1.

Table 1. Specifications of the CATR

Parameter	Specification
Frequency Range	24 to 330 GHz
Quiet Zone Size	300 mm (Ø12")
Reflector Dimensions	0.62 m x 0.62 m (24.5" x 24.5")
System Dimensions	2.48 m x 0.76 m x 1.3 m (97.5" x 30" x 51")
System Weight	Approx. 317.5 kg (700 lbs.)

Figure. 2. WR-03 Feed Horn for the CATR.

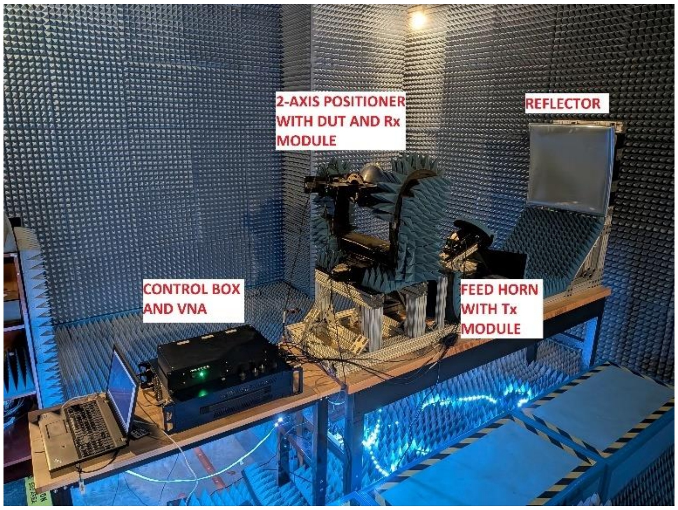

Figure. 3. CATR System Setup.

III. TEST RESULTS OF THE CASSEGRAIN ANTENNA

In conjunction with the development of the CATR, a 230 mm (9-inch) diameter Cassegrain antenna with a gain of 53 dBi, 3 dB beamwidth of 0.3 degrees, and an operating frequency range from 220 to 330 GHz was also designed and assembled to serve as the antenna under test (AUT) for performing the benchmark testing of the CATR. The antenna was connected directly to the WR-03 receiver module, and both components were mounted onto the 2-axis positioner. A close-up view of the AUT is shown on Fig. 4. Since the antenna has such a narrow beamwidth, very fine resolution was required to fully characterize the main lobe and sidelobes, so the step size was set at 0.05 degrees. To reduce the overall testing time, the pattern angular coverage was set from -5 to +5 degrees from boresight. A total of 603 data points were collected at 220 GHz, 275 GHz, and 330 GHz, and the measured results were plotted and compared against the simulated data in Figures 5 through 10. The measured pattern results are consistent with simulation, especially at 220 GHz, and indicate the CATR system is well suited for high gain/directivity measurements at sub-THz frequencies.

In addition to the patterns, the gain of the antenna was obtained with antenna substitution method by using a 23 dBi gain, WR-03 pyramidal horn as the reference antenna. The gain is plotted in Figure 11, and the antenna efficiency of the AUT was calculated to be around 36% at 220 GHz to 32% at 330 GHz, which is reasonable given the high metal conductive losses at these frequencies. The antenna efficiency could be improved by optimizing the f/d ratio of the reflector dish and specifying a smoother surface roughness for the waveguide channels in the feed horn and on the dish's surface to reduce conductive losses.

The asymmetric patterns and higher sidelobes at 275 and 330 GHz can be attributed to assembly tolerances and machining imperfections and misalignment of the antenna's sub reflector relative to the dish's focal point. Indeed, during testing the sub-reflector had to be adjusted multiple times to obtain the best pattern results shown.

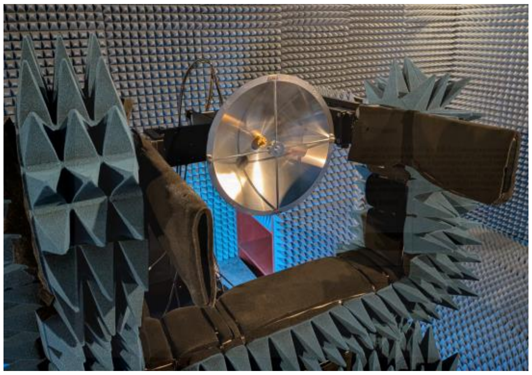

Figure. 4. AUT Test Setup on the 2-Axis Positioner.

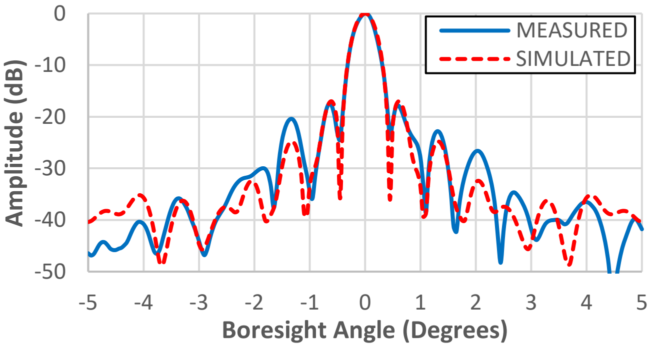

Figure. 5. Simulated vs Measured Results of the AUT at 220 GHz, E-Plane

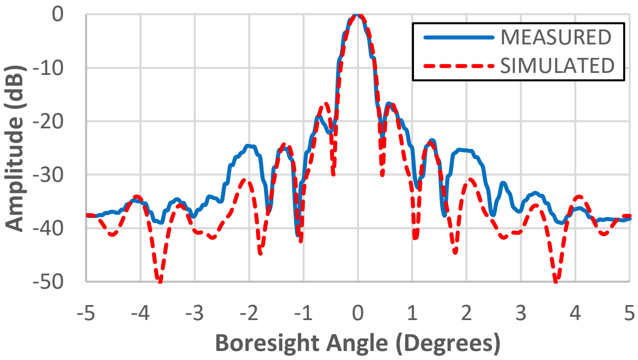

Figure. 6. Simulated vs Measured Results of the AUT at 220 GHz, H-Plane

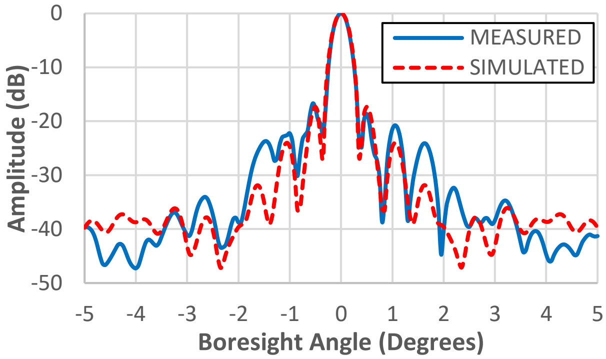

Figure. 7. Simulated vs Measured Results of the AUT at 275 GHz, E-Plane

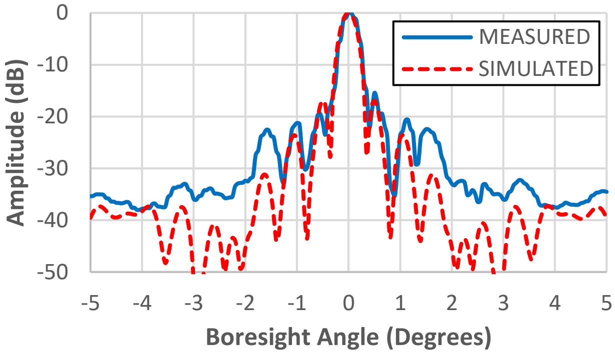

Figure. 8. Simulated vs Measured Results of the AUT at 275 GHz, H-Plane

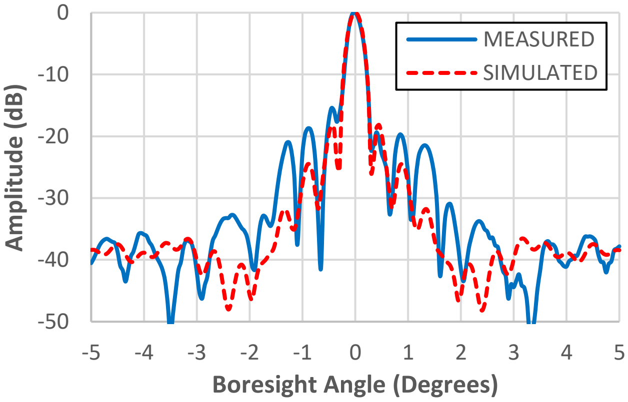

Figure. 9. Simulated vs Measured Results of the AUT at 330 GHz, E-Plane

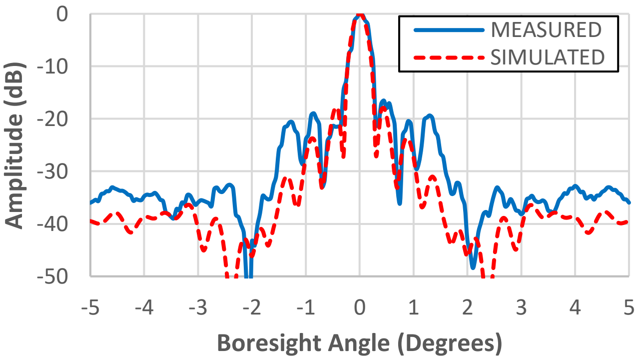

Figure. 10. Simulated vs Measured Results of the AUT at 330 GHz, H-Plane

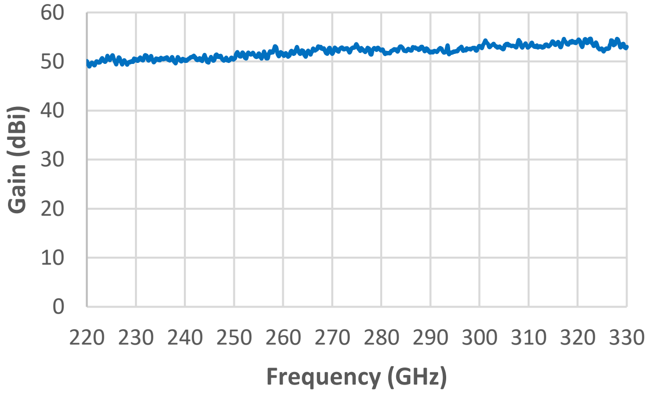

Figure. 11. Measured Gain Results of the AUT from 220 to 330 GHz

CONCLUSION

A CATR system with a 300 mm (12-inch) quiet zone was demonstrated to work successfully up to 330 GHz with the measurement of a 230 mm (9-inch) diameter, 53 dBi gain Cassegrain antenna. The measured patterns closely matched those of the simulation, and the calculated gain was within expectations. The results validate the CATR as an accurate, high performance measurement tool for characterizing high gain antennas operating at sub-THz frequencies for 6G applications.

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REFERENCES

[1] A. Chen, Y. Shu, and N. Khiabani, "A cost-effective open-air, compact antenna test range (CATR) to reach 330 GHz," to be published in Proc. IEEE Microwaves, Antennas and Propag. Conf. (MAPCON), Dec. 2025.

[2] C. Sbeglia Nin, "Global 5G connections reach 17.7M, LTE connections exceed 5.3B: Report," RCR Wireless News, Mar. 25, 2020. [Online]. Available:https://www.rcrwireless.com/20200325/5g/global-5g-connections-lte-connections-report. [Accessed: Nov. 24, 2025]

[3] Juniper Research, "5G Connections to Reach 1.5 Billion Globally by 2025, as US and South Korea Establish 5G Leadership," Press Release, Jan. 13, 2020. [Online]. Available: https://www.juniperresearch.com/press/5g-connections-to-reach-15-billion-globally-by-2025-as-us-and-south-korea-establish-5g-leadership/. [Accessed: Nov. 24, 2025].

[4] 5G Americas, "North America Sets Global Pace as 5G Growth Hits 2.6 Billion Connections Worldwide," 5G Americas, Sep. 23, 2025. [Online]. Available: https://www.5gamericas.org/north-america-sets-global-pace-as-5g-growth-hits-2-6-billion-connections-worldwide/. [Accessed: Nov. 24, 2025].

[5] International Telecommunication Union, "IMT towards 2030 and beyond (IMT-2030)," ITU. [Online]. Available: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/pages/default.aspx. [Accessed: Nov. 24, 2025].

[6] 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

[7] International Telecommunication Union, "Technical feasibility of IMT in bands above 100 GHz," Report ITU-R M.2541-0, Geneva, Switzerland, May 2024. [Online]. Available: https://www.itu.int/publ/R-REP-M.2541-2024

[8] K. Watanabe, A. Hirata, I. Watanabe, N. Sekine and A. Kasamatsu, "Measurement of Far Field Radiation Pattern of 300GHz-band Cassegrain Antenna," 2021 International Symposium on Antennas and Propagation (ISAP), Taipei, Taiwan, 2021, pp. 1-2, doi: 10.23919/ISAP47258.2021.9614528.

[9] Y. Tanaka, H. Arisesa, A. Kanno, N. Sekine, J. Nakajima and S. Hisatake, "Near-field measurement and far-field characterization of a high-gain Cassegrain antenna at 300 GHz band base on a photonics technology," 2020 XXXIIIrd General Assembly and Scientific Symposium of the International Union of Radio Science, Rome, Italy, 2020, pp. 1-3, doi: 10.23919/URSIGASS49373.2020.9232141.

[10] C. Rowell, B. Derat and A. Cardalda-García, "Multiple CATR Reflector System for Multiple Angles of Arrival Measurements of 5G Millimeter Wave Devices," in IEEE Access, vol. 8, pp. 211324-211334, 2020, doi: 10.1109/ACCESS.2020.3038597.