A QV-Band Dual-Polarized Cassegrain Reflector Antenna for New Space Satellite Ground Station Applications

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***Abstract*— This paper presents a high-performance Q/V-band dual-polarized Cassegrain reflector antenna developed for next-generation space communication ground station applications. The antenna operates over the 37–51.5 GHz frequency range, delivering a gain of 58 dBi, a half-power beamwidth of 0.2 degrees, and sidelobe levels at least 15 dB below the main lobe nominally. The antenna system comprises a 2.4-meter (96-inch) diameter main reflector, a sub-reflector, a feedhorn, and a complex feed network that integrates a linear-to-circular polarizer, an orthomode transducer (OMT), and two frequency diplexers. Due to the electrically large aperture, performance testing was conducted in a newly developed near-field measurement range capable of characterizing antennas up to 3.0 meters in diameter at frequencies up to 110 GHz. The measured results confirm that the fabricated antenna meets the original design specifications. Achieving the antenna's high performance, along with accurate pattern and gain measurements, involves substantial technical, manufacturing, and testing challenges. These accomplishments represent a state-of-the-art milestone in the design and production of electrically large antennas operating in this frequency range.**

Keywords*— Millimeter-wave, satellite communication, LEO, Cassegrain reflector antenna, waveguide diplexer, waveguide polarizer, dual-polarization, orthomode transducer, near-field, antenna range, WR-22, Q/V-band, ground station, new space

I. Introduction

Due to the increasing demand for high data throughput and congestion in the lower frequency bands, C through Ka band, the Q/V-band is emerging as the next-generation frequency spectrum for "New Space" satellite communication applications, which includes high-throughput satellites (HTS), inter-satellite links, ground-to-space communications for broadband internet, Earth observation, and deep space missions [1]. For Q/V-band satellite to ground station communications, commonly used frequencies for Uplink (Earth to Satellite) are 47.2 to 52.4 GHz and Downlink (Satellite to Earth) are 37.5 to 42.5 GHz. Many new systems are under development [2], [3], which in turn has triggered the research and development of many new supporting components and sub-assemblies [4], [5]. In [6], a 0.7 m diameter Q/V-band Cassegrain antenna was designed, fabricated, and launched onboard a GEO satellite. This paper presents a newly developed, high-gain, high-performance, narrow beamwidth Q/V-band Cassegrain reflector antenna designed for next-generation satellite ground station applications. The antenna consists of a 2.4 m (96") diameter ruggedized fiberglass composite parabolic reflector dish, an optimized sub-reflector, a corrugated feedhorn, and a 4-port backend feed network that includes an integrated linear-to-circular polarizer, an orthomode transducer (OMT), and two frequency diplexers. The antenna exhibits a nominal 58 dBi gain, 3 dB beamwidth of 0.2 degrees and -15 dB sidelobes.

To measure this electrically large antenna, a 3.5 m x 3.5 m (138" x 138") planar near-field antenna test range was developed and installed with the capability of testing antennas with apertures up to 3 m (118") in diameter and frequencies up to 110 GHz. The antenna measurement was performed in the newly developed near field range and the final measured results fall within the expected design specifications. The antenna's performance and accuracy of the measurement results presented significant technical challenges and represents state-of-the-art antenna development and technology advancement for Q/V-band communication system implementations.

II. Antenna Design and Fabrication

The required electrical and mechanical specifications of the ground-station Q/V-band antenna are listed in Tables 1 and 2. To minimize Tx and Rx channel crosstalk, the transmitting and receiving frequency bands must support both left and right-handed circular polarization (LHCP, RHCP) and be isolated from each other. To accomplish this, the antenna employs a high-performance corrugated feed horn that is connected to a quad-ridge type circular polarizer, a turnstile-junction OMT, and two diplexers. This configuration results in four ports for transmitting and receiving in both LHCP and RHCP. A diagram of the network is shown in Figure 1.

TABLE I. ANTENNA ELECTRICAL SPECIFICATIONS

Parameter	Specification
Tx Frequency Range	45.4 to 51.5 GHz
Rx Frequency Range	37 to 42.5 GHz
Gain	58 dBi
3 dB Beamwidth	0.2°
Sidelobes	-15 dB
Return Loss	12 dB
Tx-LHCP to Rx-LHCP Isolation Tx-RHCP to Rx-RHCP Isolation	50 dB
Tx-LHCP to Rx-RHCP Isolation Tx-RHCP to Rx-LHCP Isolation	70 dB
Tx-LHCP to Tx-RHCP Isolation Rx-LHCP to Rx-RHCP Isolation	20 dB

TABLE II. ANTENNA MECHANICAL SPECIFICATIONS

Parameter	Specification
Effective Aperture Size (Diameter)	⌀2.4 m (⌀96")
Total Size (Diameter x Depth)	⌀2.54 m x 1.19 m (⌀100" x 47")
Total Weight	118 kg (260 lbs.)
Tx/Rx Port Configuration	WR-22 Waveguide
Number of Tx Ports	2
Number of Rx Ports	2

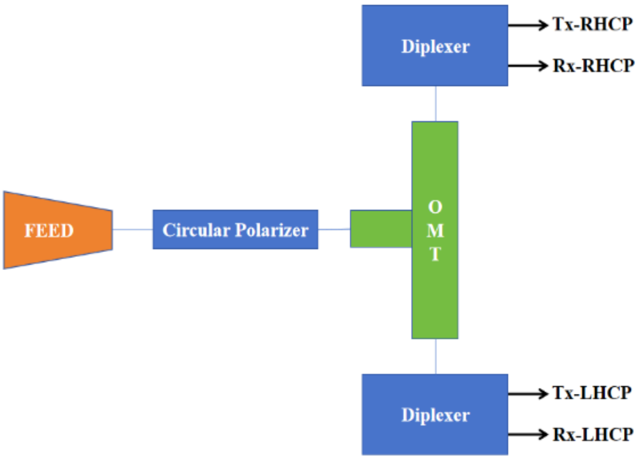

Fig. 1. Block Diagram of the Backend Feed Network

The Cassegrain reflector, feed, and feed network components (OMT, polarizer, diplexer) were modeled and simulated by utilizing an electro-magnetic field simulator. The guideline for the diameter ratio of the secondary reflector to the primary reflector of Cassegrain antenna is generally designed to be between 0.1 to 0.2. For this antenna, the sub-reflector was designed with a ratio of 0.14. The simulated far-field patterns at 37 GHz and 51 GHz are shown in Figures 2 and 3. As seen from the plots, the simulated gain is around 57.5 dBi at 37 GHz and 60 dBi at 51 GHz.

The electrical design geometry of the feed horn, polarizer, OMT, and diplexer are shown in Figure 4.

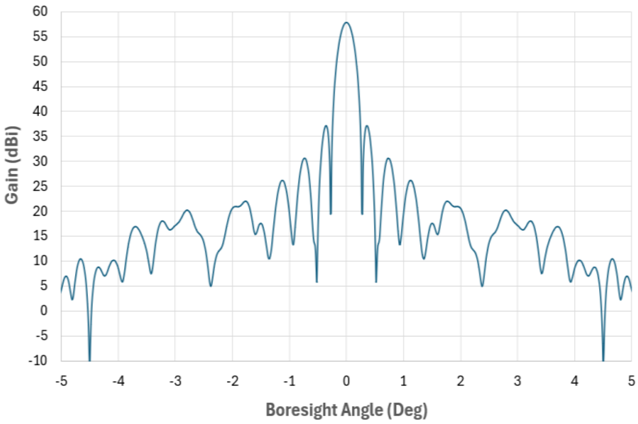

Fig. 2. Simulated Far Field Antenna Pattern at 37 GHz

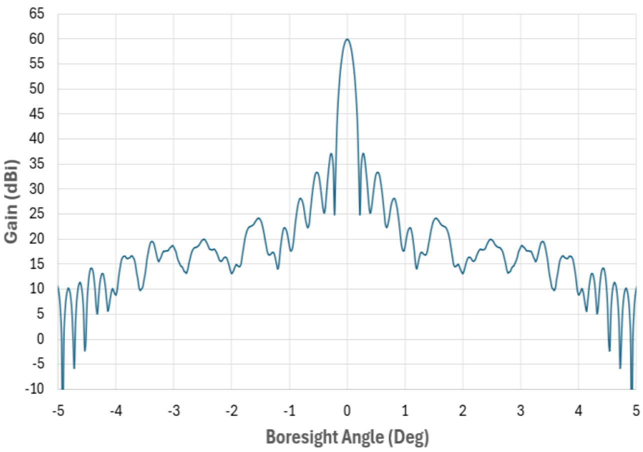

Fig. 3. Simulated Far Field Antenna Pattern at 51 GHz

A corrugated-type horn antenna was chosen to serve as the reflector feed since it is well known for its axisymmetric radiation patterns, stable phase center, and low cross polarization.

The circular polarizer design uses a quad-ridge type structure inside a standard circular waveguide. The size of the circular waveguide is fixed, so the cutoff wavelength and phase constant of the TE11 (H) and TE11 (V) modes of the quad-ridge waveguide are only related to the ridge spacing and thickness. By properly optimizing the ridge geometry, the phase difference of the two orthogonal modes H and V can be set 90° apart, which results in circular polarization.

The OMT employs a cross-turnstile junction structure with symmetrical branches for both orthogonal polarized signals. In Figure 4, Port 1 is the common port, Port 2 the horizontal polarized port, and Port 3 the vertical polarized port.

The diplexer is a three-port device composed of two filters and a shunt device. The Rx and Tx signals pass through the common port, and the Tx signal is coupled into its own separate channel through the broad side of the common port waveguide. The Rx channel contains a low-pass filter which rejects the Tx frequencies and passes the Rx frequencies. At the same time, the side coupling port in the Tx channel acts as a high pass filter that rejects the Rx frequencies and passes Tx frequencies. The simulated data of the diplexer is shown in Figure 5.

The main reflector was fabricated using a commercially available lightweight fiberglass composite structure with a silver metallization coating. The feed components were CNC machined out of aluminum and surface treated with chemical film for corrosion resistance. Figure 6 shows the final Q/V-band antenna assembly.

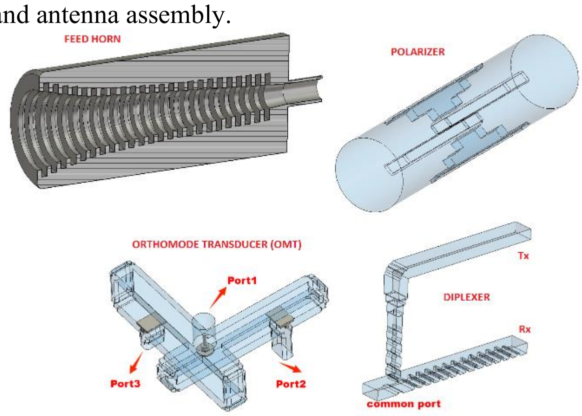

Fig. 4. Feed Horn and Backend Feed Component Electrical Design

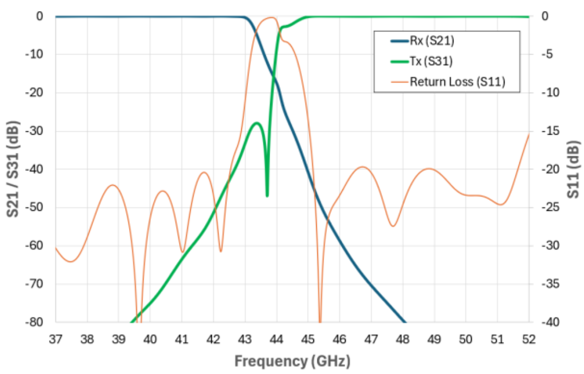

Fig. 5. Diplexer Simulated Results

Fig. 6. Q/V-band antenna assembly

III. ANTENNA TEST RESULTS ON NEAR-FIELD RANGE

The Q/V-band antenna testing was divided into two sections: testing of the backend feed network and its components on a vector network analyzer (VNA) and testing of the antenna reflector with the feed and sub reflector on the near-field range. The feed network was connected to the feed horn of the antenna and the isolation between the four ports was measured and plotted in Figure 7. The results indicate that the Tx and Rx ports are well isolated within the operating frequency range.

The antenna under test, mounted on the planar near-field range, is shown in Figure 8. The near-field testing parameters were configured to allow for a sufficiently large scan area to obtain far-field patterns with at least ± 5 degrees of coverage from the antenna boresight. The measured patterns for 37 GHz and 51 GHz are shown in Figures 9 through 12 with the simulated data overlaid. As seen from the plots, the measured patterns results are well correlated with the simulation data. The gain was measured on the near-field range using gain substitution method with a standard WR-22 pyramidal horn antenna. The final gain of the antenna assembly, summarized in Table 3, was obtained by adding the path losses of the backend feed network. The resultant gain results indicate an antenna efficiency near 50%, which is close to the maximum theoretical efficiency for the Cassegrain antenna.

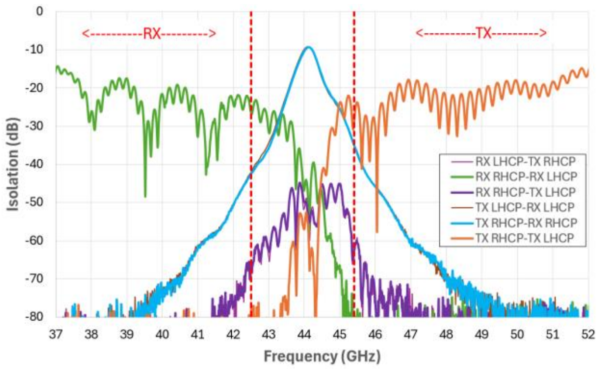

Fig. 7. Measured Isolation Between the Tx and Rx Ports

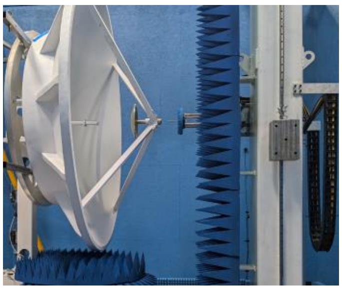

Fig. 8. Test Setup of the Antenna Reflector on the Planar Near Field Range

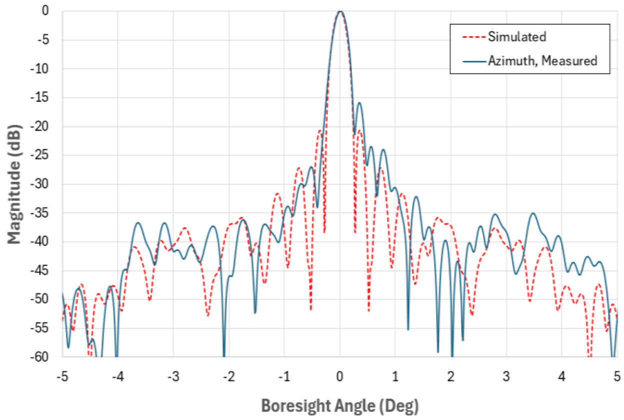

Fig. 9. Test Results of the Q/V-Band Antenna at 37 GHz, Azimuth

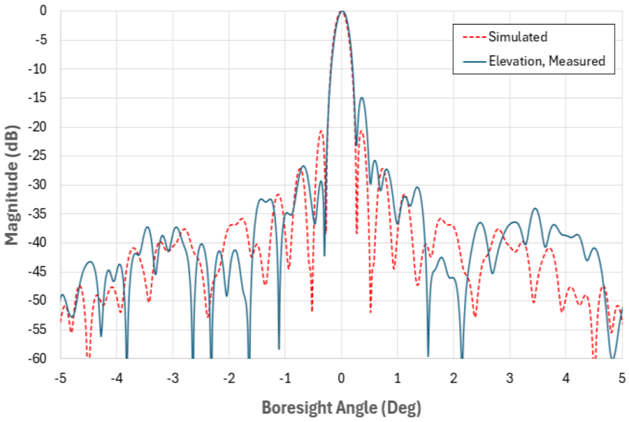

Fig. 10. Test Results of the Q/V-Band Antenna at 37 GHz, Elevation

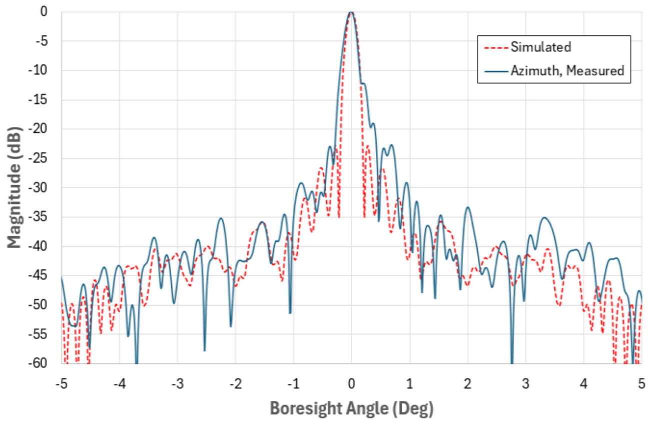

Fig. 11. Test Results of the Q/V-Band Antenna at 51 GHz, Azimuth

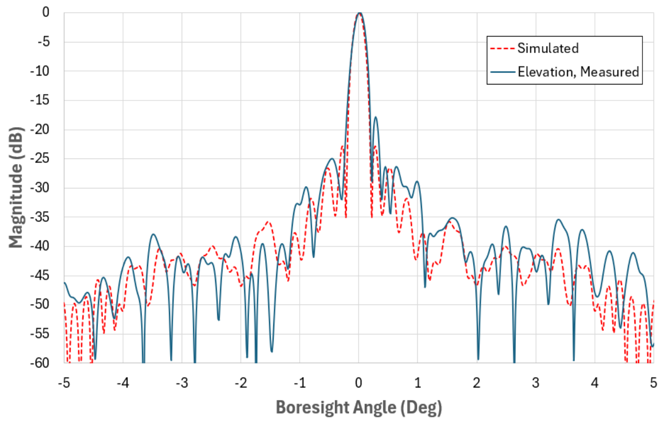

Fig. 12. Test Results of the Q/V-Band Antenna at 51 GHz, Elevation

TABLE III. RESULTANT ANTENNA GAIN TABLE

Frequency (GHz)	Gain (dBi)			
	Tx-LHCP	***Tx-RHCP***	***Rx-LHCP***	***Rx-RHCP***
37	-	-	56.4	56.4
40	-	-	56.6	56.7
42.5	-	-	57.3	57.3
45.4	58.0	58.0	-	-
48.5	59.3	59.3	-	-
51.5	59.0	59.0	-	-

The asymmetry of the patterns can be attributed mainly to minor mechanical misalignments and tolerance variations in the antenna assembly, fiberglass reflector and machined components. A simulation study was conducted to determine the effect that assembly misalignments have on the pattern symmetry and sidelobes. The study determined that an angular offset misalignment of just 0.2 degrees between the feed and sub reflector in one direction would cause the sidelobes to be 5 dB worse in the opposite direction. This indicates that the machining and assembly tolerance controls are equally important to achieve the high-performance requirements of the antenna. Furthermore, the repeatability and stability of the scanner mechanical moving structure of the near-field range could be a contributing factor during the pattern measurements. An additional five antennas were fabricated and tested. All were tested on the near-field range using the same test setup and showed similar results as the original prototype, which confirmed that the high precision machining, assembling and measurement process for such an electrically large antenna is well established.

IV. CONCLUSION

A Q/V-band dual-polarized Cassegrain reflector antenna has been developed for next-generation space communication system ground station applications. The antenna features a 2.4 m (96”) diameter main reflector, a sub-reflector, a feedhorn, and a sophisticated feed network integrating a linear-to-circular polarizer, an orthomode transducer (OMT), and two frequency diplexers. The antenna achieves state-of-the-art performance across the 37–51.5 GHz frequency range, delivering a gain of 58 dBi, a half-power beamwidth of 0.2 degrees, and sidelobe levels 15 dB below the main lobe, nominally. The measured gain results indicate an antenna efficiency near 50%, which is close to the maximum theoretical efficiency for the Cassegrain antenna. Testing was conducted in a newly developed near-field antenna measurement range, capable of characterizing apertures up to 3 meters in size at frequencies up to 110 GHz with a maximum scanning range of 3.5 m x 3.5 m. Multiple units were fabricated and tested, all demonstrating consistent performance. These results confirm that the high-precision machining, assembly, and measurement processes required for electrically large antennas at these frequencies are established and ready for large scale production implementations.

ACKNOWLEDGMENT

The authors would like to thank Craig Roberts, Dayong Yang, Zi Wang, and George Yang from Eravant for their endless effort and support during the near-field antenna measurement system establishment and every challenge of the assembly and testing of the antenna.

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