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RESEARCH AND DESIGN OF QUADRUPLE-RIDGED HORN ANTENNA

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Abstract—This paper presents a novel design of dual-linear-polarized broadband horn antenna for 6∼18 GHz frequency band. Applying commercial software Ansoft HFSS, parametric analysis is taken with respect to the best antenna performance and manufacturing tolerance. The proposed antenna is finally fabricated and measured, and the measured results show that the designed antenna exhibits low VSWR (< 2), high gain (13 dBi∼19.5 dBi) and high isolation (> 25 dB) without beam splitting in the entire operation band.

1. INTRODUCTION

Horn antennas are widely used because of their special features of simple construction, easy excitation, high directivity performance, and high peak power handling capacity. They are commonly employed as feed elements in satellite tracking systems or communication systems and serve as standard antenna for calibration and gain measurement.

To extend the maximum practical bandwidth of horn antennas, ridges are introduced both in the waveguide transition portion and the flare section [1–5]. To have dual linear polarization, [6] has reported a novel double-ridged horn antenna with VSWR < 2 in the range of 8∼18 GHz employing five layers polarizers. In [7], a physically compact quad-ridged horn antenna with a maximum VSWR of 3.5 : 1 over a 3 to 1 operational bandwidth was described. [8] introduced a new technique for tapering the flared section to improve the impedance matching, but the VSWR (< 2.6) in the operation band was not satisfactory. A new dual-polarized broadband horn antenna over the 2∼26.5 GHz bandwidth with VSWR < 3.1 was reported in [9]

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using a novel technique for transition from coaxial line to quad-ridged waveguide. However, the semi-spherical cavity attached to the back of the waveguide via a two-step changed in width was difficult to construct. [10] presented a novel design of dual-polarized broadband 2–18 GHz horn antenna with VSWR < 2.2, but only simulation results were given.

In this paper, we present a new broadband quadruple-ridged horn antenna with dual linear polarizations. A novel shorting structure is introduced to improve the return loss. The designed and fabricated antenna exhibits low return loss (VSWR < 2), high isolation ($I > 25$ dB) and high gain (13 dBi$\sim$19.5 dBi) performance in the operation band of 6$\sim$18 GHz. Furthermore, our designed antenna has no beam splitting according to the measured far-field radiation patterns.

2. QUADRUPLE-RIDGED HORN ANTENNA CONFIGURATION

Figure 1 illustrates the geometry of our proposed dual-linear-polarized broadband horn antenna. The horn antenna can be decomposed into four main parts: the cavity located at the back of the waveguide, the feeding section, the quadruple-ridged waveguide section and the remaining flared portion of the horn with exponential tapered quadruple-ridges.

The feeding section consists of two coaxial-to-circular ridged waveguide adapters so as to symmetrically excite two orthogonal polarizations: one for vertical polarization and the other for horizontal polarization. In order to obtain a lower return loss in waveguide transmission, a cylindrical shorting cavity is attached to the end of the waveguide section. The waveguide section is a circular waveguide

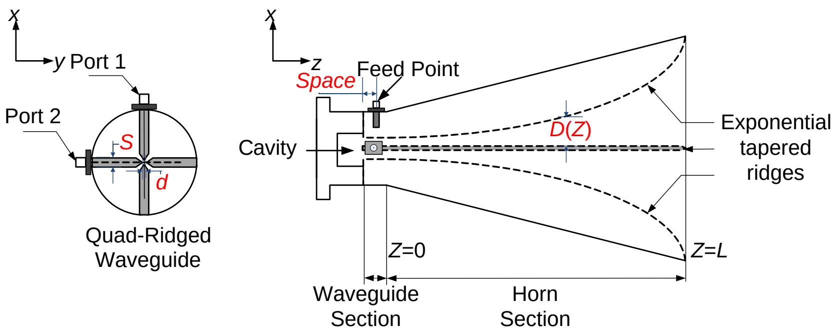

Figure 1. Configuration of dual-linear-polarized horn antenna.

loaded with four ridges of the same size while the tapered horn section consists of four identical ridges which are of exponential shapes. The ridges are mainly used to achieve a smooth impedance transition from the quadruple-ridged waveguide impedance (50 Ohm or less) to the free space impedance (377 Ohm). The curvature of the ridges along the longitudinal direction is determined by a modified exponential function:

$$D(z) = D(0)e^{kz} + 0.02z \quad (1)$$

$$k = (1/L)\ln(D(L)/D(0)) \quad (2)$$

where L being the length of the horn section [11]. The linear taper superimposed on the exponential curve is introduced to improve the antenna's return loss.

3. PARAMETRIC ANALYSIS OF THE DESIGNED ANTENNA

The antenna was designed using Ansoft High Frequency Structure Simulator (HFSS 12). Parametric analysis was performed over a couple of parameters including: the curvature of the ridge, ridge gap (d), distance between the coax inner conductor and the shorting plate ($space$), and ridge thickness (s). In the following section, we will give a detailed discussion.

3.1. Analysis of the Cavity

Simulated results show that the shape of the shorting cavity influences the return loss especially those in the lower frequency band. Meanwhile, considering the manufacturing convenience, we finally

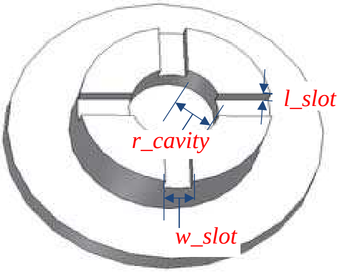

Figure 2. Modified shorting cavity structure.

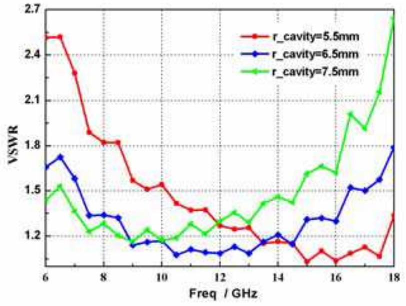

Figure 3. Simulated VSWR with various *r_cavity*.

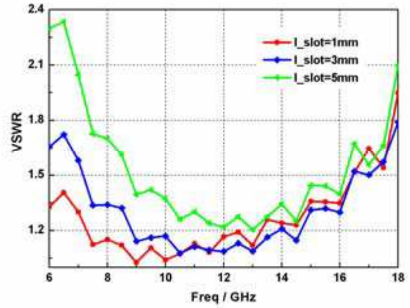

Figure 4. Simulated VSWR with various *l_slot*.

modified the conventional cylindrical cavity into the one as Figure 2 shows.

In the modified cavity, the slot width (*w_slot*) is fixed as the ridge thickness (s), the length of the slot (*l_slot*) and the radius of the cylindrical cavity (*r_cavity*) are determined according to their effects on the return loss.

Figure 3 and Figure 4 show the simulated VSWR with various *r_cavity* and *l_slot* respectively. As *r_cavity* becomes larger, the VSWR in the lower frequency band becomes worse while those in the upper frequency band becomes better, so there exists a critical value for *r_cavity*. VSWR in lower frequency band is more sensitive to the changes of *l_slot*, as *l_slot* becomes larger, VSWR in the entire frequency band show a trend to become worse. Optimizations show that the best value for *r_cavity* and *l_slot* are 6.5 mm and 3 mm.

3.2. Analysis of the Ridges

According to the quadruple-ridged waveguides theory, the cutoff wavenumbers of both TE_{11} and TE_{21L} are more sensitive to the ridge gap (d) than to the ridge thickness (s). As the ridge gap (d) decreases, the cutoff wavenumber of the fundamental propagation mode TE_{11} decreases, therefore, a chamfered ridge is used (Figure 1) in the proposed horn antenna to obtain a smaller ridge gap.

As shown in Figure 5, VSWR in the lower frequency band is more sensitive to the changes of d. As d becomes smaller VSWR in lower frequency band becomes better quickly, however the ridge gap has a lower limit value to be larger than the diameter of the inner conductor of coaxial connector, the final value for d is chosen as 0.9 mm.

The effect of ridge thickness is not shown graphically but the

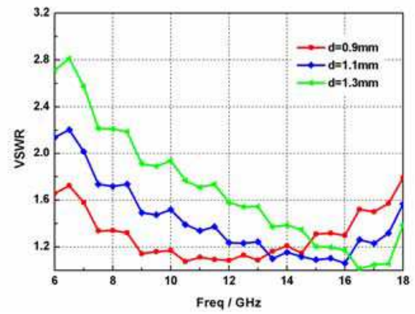

Figure 5. Simulated VSWR with various d.

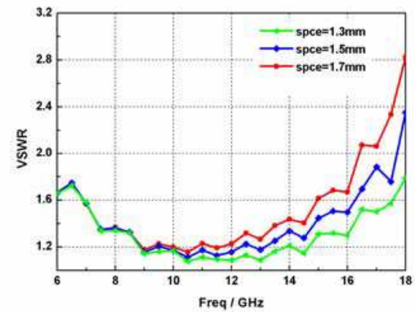

Figure 6. Simulated VSWR with various *space*.

gain almost remains the same with various s. Considering the manufacturing convenience and mechanical strength requirement, the selected ridge thickness is 4 mm.

3.3. Analysis of the Feeding Section

The transition from coaxial probes to the quadruple-ridged waveguide is critical to the return loss performance of the antenna. As shown in Figure 1, the center conductors of the coaxial connectors are placed right in the center of the ridges through an air-hole inside the ridges and connected to the opposite ridges. The size of the air-hole is so designed that the characteristic impedance of the coaxial air-line is maintained to be 50 Ohm.

As Figure 6 shows, VSWR in upper frequency band is sensitive to the distance between the coax inner conductor and the shorting plate (*space*), the smaller *space* is, the better VSWR we obtain. However, smaller *space* requires higher manufacturing capability, finally *space* is chosen as 1.3 mm.

4. RESULTS AND DISCUSSIONS

To verify our design experimentally, a sample of the designed antenna was fabricated out of aluminum and its EM characteristics were measured. Figure 7 shows the photography of the manufactured antenna, the overall length of the designed horn is 195 mm with an aperture size of ϕ 88 mm and its net weight is 0.55 kg.

Figure 8 presents the measured VSWR results of the designed horn antenna. It can be seen that both the rear port and front port have a VSWR of less than 2 over the wide frequency range of 6$\sim$18 GHz.

Figure 7. Photograph of the manufactured antenna.

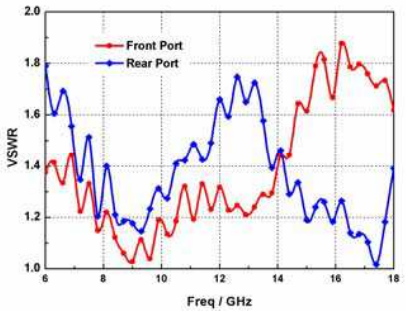

Figure 8. Measured VSWR of the horn antenna.

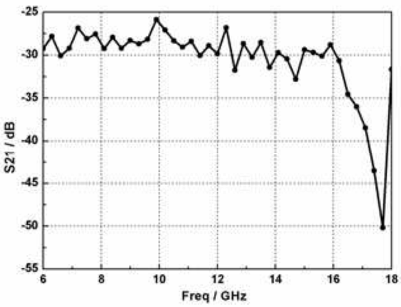

Figure 9. Measured isolation of the horn antenna.

The isolation between two coaxial ports as shown in Figure 9, is better than 25 dB over the entire frequency range.

Measured gain versus frequency results of the antenna are shown in Figure 10. Gain of both front port and rear port increase as frequency increases with a peak value around 18.5 dBi and 19.5 dBi respectively. More important is that the main beam does not split into lobes and the side lobe levels are better than 20 dB for both ports. Figure 11 and Figure 12 show measured far-field E-plane and H-plane radiation patterns of front port at 6, 12, 18 GHz, respectively. The same is true with the measured radiation pattern of rear port which is not shown graphically.

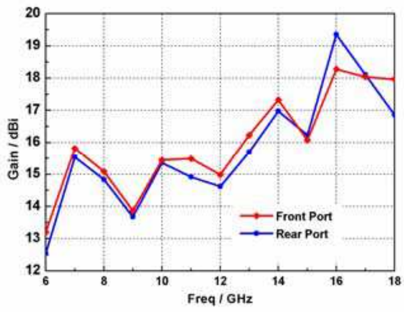

Figure 10. Measured gain of the horn antenna.

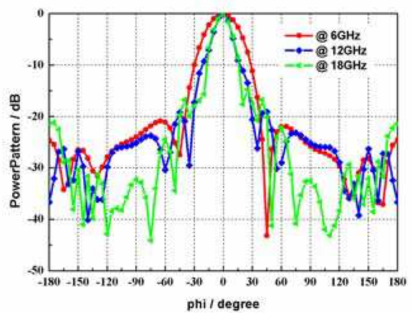

Figure 11. Measured E-plane radiation pattern of the horn antenna.

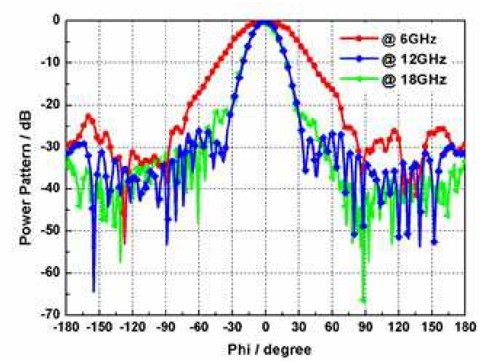

Figure 12. Measured H-plane radiation pattern of the horn antenna.

5. CONCLUSION

Based on the parametric studies and optimizations, we have designed, manufactured and measured a novel dual-linear-polarized broadband horn antenna. Measurement of the designed horn antenna has shown low return loss, high isolation and high gain performance without beam splitting over the wide frequency range of 6∼18 GHz. Moreover, it has compact size and weight and is easy to fabricate which is well suited for microwave measurement systems, radar and detection systems.

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