Design and Implementation of High Performance UWB Horn Antenna

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Abstract ─ Broadband horn antennas have been widely used in radar and communication systems. They have also been added to various state-of-the-art control systems to perform EMC measurements. EMC measurements traditionally use standard gain horn antennas for many practical reasons like needing 8 standard antennas to test a wide range of frequencies (e.g., 0.75-18 GHz). This results in space efficiency reductions (e.g., the anechoic chambers efficiency is reduced). To solve this problem, an ultra-wideband (UWB) double-ridged horn antenna is designed and tested in this study. The antenna exhibits improved gains, VSWRs, and radiation patterns. Radiation patterns maintain a single main lobe across the full band. This signifies that the designed antenna can fulfill the desired higher demands. We have fabricated the antenna and it has been applied to many related fields.

Index Terms ─ EMC, radiation patterns, ultra-wideband antenna, VSWR.

I. INTRODUCTION

Because of its simple structure, good directionality, and stable phase center, broadband horn antennas are widely used in communications, radar, electromagnetic compatibility, and electronic countermeasure applications. EMC measurements usually use standard gain horn antennas. Their use is more for practical reasons but has many problems. For example, an EMC applications require 8 standard antennas to test the frequencies 0.75-18 GHz. This reduces the space efficiency of microwave frequency anechoic chambers. To mitigate this problem, an ultra-wideband (0.7-18 GHz) double-ridged horn antenna needs to be designed. In the past, simulations of ridge horn antennas could not handle a broad operational frequency range and did not include coaxial feeds [1-3]. With the development of new and innovative antenna technology, horn antennas can achieve operational bandwidths of more than twenty times its standard bandwidth [4]. Generally, ridges are utilized to extend the single-mode operational bandwidth before the higher order modes occur [1, 2]. In the field of UWB horn antennas, most designs can obtain a frequency range from 1 to 18 GHz [5-8]. But patterns produced by this kind of antenna will begin to deteriorate above 12 GHz and the main beam splits into four large side lobes [9]. Additionally, getting a high gain, low VSWR, and small mechanical size when the operating frequency is less than 1 GHz.

To solve these problems, we designed a wideband (0.7-18 GHz) double-ridged horn antenna with metallic grid sidewalls to improve the performance at higher frequencies. The coaxial feed is utilized to make the excitation point in the center of the ridged waveguide. Test results show that the VSWR is 1.5 Typ. and 2.5 Max., the gain is 12 dBi Typ. and the radiation patterns maintain a single main lobe in the full band. The gains, VSWRs, and radiation patterns of the design ridge horn antenna were measured and we analyzed the data provided. The design was mass produced and its application was verified, with relatively ideal consistency and reliability. This demonstrates that the designed antenna can fulfill higher demands. The antenna has been fabricated and applied to many related fields.

II. DESIGN OF HIGH PERFORMANCE UWB ANTENNA

As shown in Fig. 1, a broadband dual-ridge horn antenna has been developed and manufactured. Generally horn antennas consist of three parts: coaxial dual-ridged waveguide conversion, horn section and double ridges. Table 1 shows the dimensions of the design.

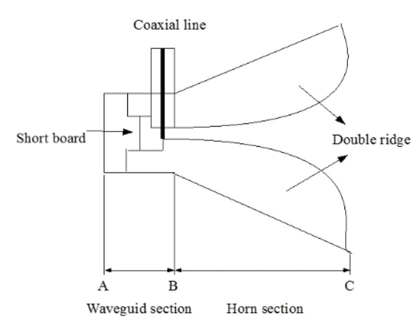

Fig. 1. Diagram of the dual-ridge horn antenna.

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Table 1: New 0.7-18 GHz dual-ridge horn antenna dimensions

Figure 1 Reference	Description	Dimension
AB	Waveguide length	43 mm
BC	Horn length	230 mm
	Weight	1.5 kg

The length of the horn should be greater than half the maximum operating wavelength to ensure that high order modes are not introduced during the impedance conversion. To ensure the impedance of the coaxial feed point 50 Ω smoothly transitions to the impedance of free space, 377 Ω, the impedance of the horn section is as follows:

$$z_0 = z_{0\infty}e^{kx}, 0 \le x \le {}^{l}/_{2}, \quad (1)$$

$$z_0 = 377 + z_{0\infty}\left(1 - e^{k(1-x)}\right), {}^{l}/_{2} \le x \le l, \quad (2)$$

where l is the length of the horn segment and k is a constant. Therefore, curved shaped of the double ridge structure (of the horn section) is also generally an exponential form. The addition of a linear term in the formula for a curve can be expressed as:

$$\mathrm{y} = Ae^{kx} + Cx. \quad (3)$$

By letting y represent the antenna's double ridged structure, we can analyze the effect that broadening the low-frequency bandwidth and shortening the axial length of the horn section can produce. Meanwhile, the coaxial connector in coaxial double-ridged waveguide transition is generally a 50 Ω impedance connector, such as SMA or N type connector. We require that the center conductor in the coaxial line should be long enough to pass through the near ridge. The calculation formula for the coaxial cutoff frequency is as follow:

$$f_{\infty} = \frac{190.8}{\sqrt{\varepsilon_r}(D+d)}. \quad (4)$$

We can calculate the radius of the outer conductor of the coaxial conductor according to (5) [10],

$$z_0 = \frac{138}{\sqrt{\varepsilon_r}}\lg\left(\frac{b}{a}\right). \quad (5)$$

Then, we insert the center conductor into the lower ridge to ensure the electrical contact is a short circuit that achieves good impedance matching. In the straight waveguide part of the transition, a straight waveguide is added to the back end of the ridge waveguide (the length is less than half the wavelength of the maximum frequency) to reduce the frequency of the main mode transmission.

Figure 2 shows the cross-section of the straight waveguide after ridged. The design is based on conventional ridge waveguide theory [11].

Equation 6 is the cut-off frequency expression of double ridge:

$$f_c = \frac{1}{\pi\sqrt{\mu\varepsilon}\sqrt{\left(\frac{a_1}{b_1}+\frac{2C_f}{\varepsilon}\right)(a-a_1)b}}. \quad (6)$$

Equation 7 is the cut-off wavelength expression of double ridge:

$$\lambda_c = \pi\sqrt{\left(\frac{a_1}{b_1}+\frac{2C_f}{\varepsilon}\right)(a-a_1)b}. \quad (7)$$

The characteristic impedance expression of a double ridge waveguide is as follow:

$$z_0 = \frac{z_{c0}}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}. \quad (8)$$

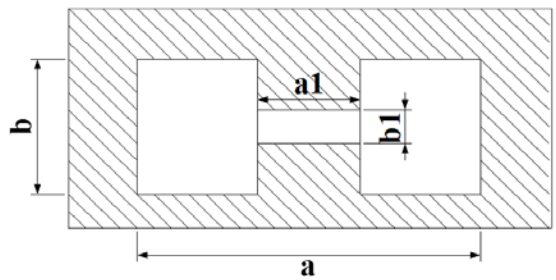
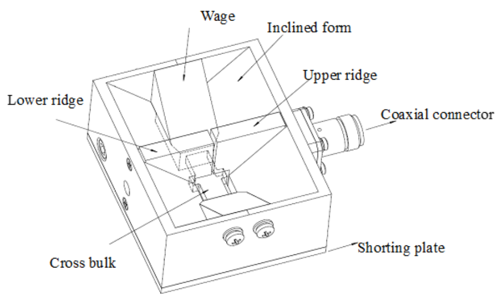


Fig. 2. Cross section of double-ridged waveguide.

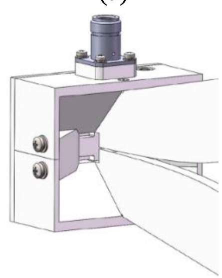
First, we determine the values of the sides a/b, interval b1 and ridge width a1 in the figure. According to the curve in reference [12], the following values can be obtained from the curve: cutoff wavelength λ_{CE10} of the mode TE10, cutoff wavelength λ_{CE30} of the mode TE30 and characteristic impedance $Z_{0\infty}$ of the mode. TE10 is used when the frequency is infinitely large. Using the coaxial feed, the excitation point is located at the center of the ridge waveguide, which restrains the TE20 mode and does not excite it. Hence the available bandwidth of a double-ridged waveguide is $\lambda_{CE10}/\lambda_{CE30}$. This may be the reason why the bandwidth of the horn antenna can reach more than 25.7 octaves.

Moreover, the design of the rear cavity plays an important role in the impedance matching step of the horn's input port [13]. As shown in Fig. 3, a cross-convex block is added to the short-circuit board and embedded in the rear cavity after the mode transition step. The back end of the straight waveguide is added with a short circuit plate to form a rear cavity to reduce the effect of the reflected radiation on backward or forward radiation. Additionally, the width of the broadening transformation can be modified by adjusting the distance between the coaxial excitation, the short circuit plate and the ridge height of the short circuit section.

The existence of the inclined form forces the narrow side of the cavity to gradually expand after the mode transformation; this transition can improve the standing wave coefficient of the antenna. The presence of a wedge can effectively improve the standing wave and the high-frequency radiation patterns of the antenna. The simulated wedge and structural size of the cross-convex block can achieve ideal high frequency radiation patterns via optimization.



(a)



(b)

Fig. 3. Structure of rear cavity.

Figure 4 shows the actual simulation model and related parameters marked in the figure.

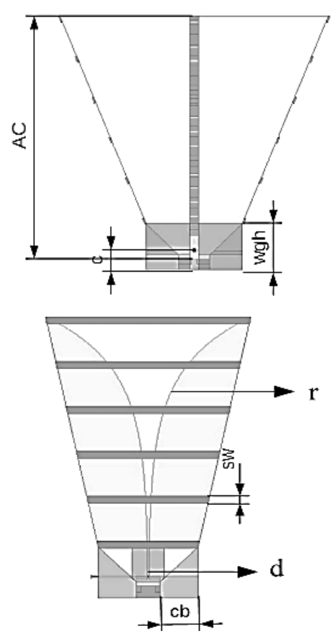
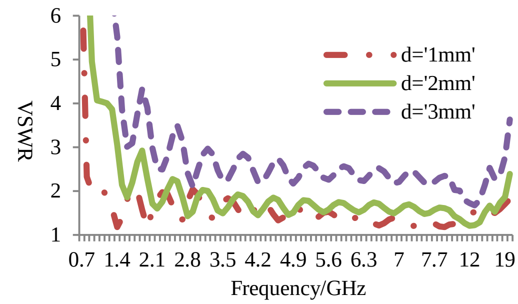


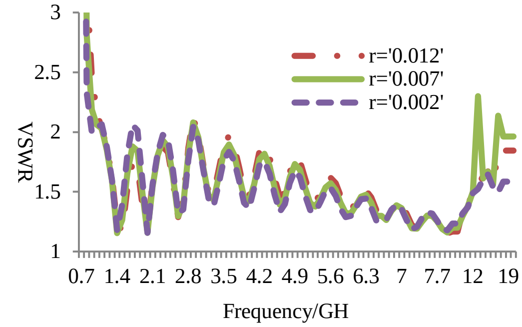
Fig. 4. Simulation model.

In Fig. 4, 'AC' is the length of ridge, c is the distance from the probe to the short board, 'wgh' is the height of the rear cavity, 'cb' is the width of the wage, 'sw' is the width of the metallic grid, 'd' is the distance between the ridges and 'r' is a parameter that influences the ridge curve.

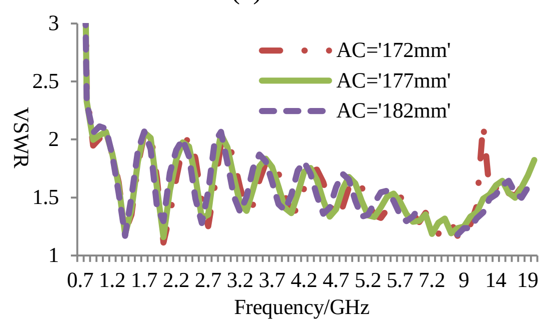
We choose several main parameters and provide the resulting curves in Fig. 5. When the parameters take on different values from various curves, we can see the relationship between the parameters and the performance of a ridge horn antenna.



(a) VSWR



(b) VSWR



(c) VSWR

Fig. 5. Simulated VSWR of ridge horn antenna with: (a) d, (b) r, and (c) AC.

Figure 5 shows the simulation results using the main parameters, which are related to the size of the ridge. We notice that parameter d (the distance between the ridges) has the greatest influence on the performance of the horn antenna. Parameter r (the ridge curve becomes steeper as parameter r increases) and parameter AC (the length of the ridge) mainly affects the performance of the higher frequency range. We can determine the optimal size of the antenna while performing the simulation. The test results of our most current ridge horn antenna design are discussed in the next section.

III. ANTENNA SIMULATION AND TEST RESULTS

We designed a ridge horn antenna with a 0.7-18 GHz operational frequency band and manufactured it as shown in Fig. 10 [13]. Double ridged horn antennas are highly sensitive to the tolerances during the machining and assembly stages. Different gaps implemented in the flared waveguide section will affect antenna performance [14]. Thus, great care is required when assembling the antenna components. We found via simulation that removing the narrow side wall of the traditional horn antenna can not only reduce weight, but also improves the gain and high-frequency directional pattern. After optimizing the design, the narrow sidewall is replaced by five evenly distributed narrow metal pieces. The final simulation and the measurement results validate the design goals.

The VSWR curves and the gain of the antenna, both simulated and measured, are shown in Fig. 6 and Fig. 7. The results show that the VSWR of the antenna is under 2.1:1 over the 0.75-18 GHz frequency range and the maximum value is 6.6 at 700 MHz. The gain is between 3.1 and 15.35 dBi for the entire design frequency band. The gain curve is flat and there are no large fluctuations.

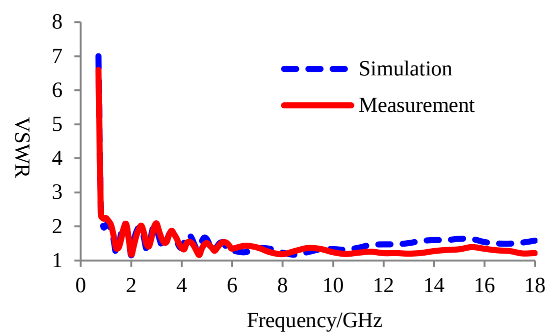


Fig. 6. VSWR.

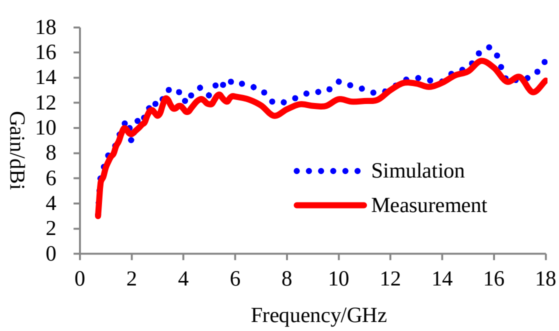


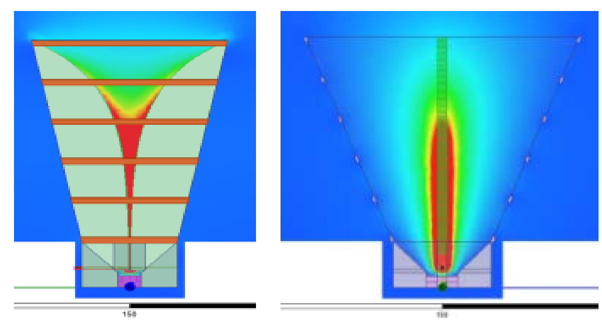
Fig. 7. Gain.

Figure 8 shows the E field of designed broadband horn antenna at 0.7 GHz and 18 GHz.

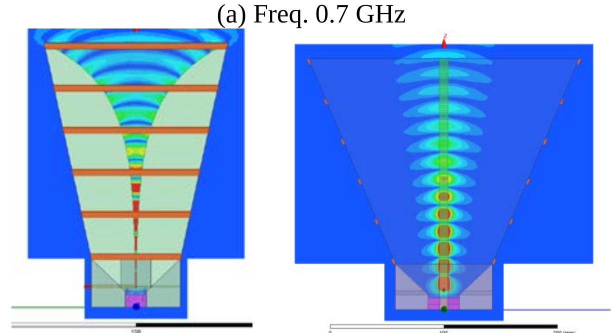
Figure 9 shows the simulation and measured patterns of the newly designed double-ridge horn antenna at 0.7 GHz, 10 GHz, and 18 GHz.

From Fig. 8 and Fig. 9, the measured results agree with the simulation results. The main lobe on the H-plane and E-plane pattern does not break apart (split) in the full frequency band.

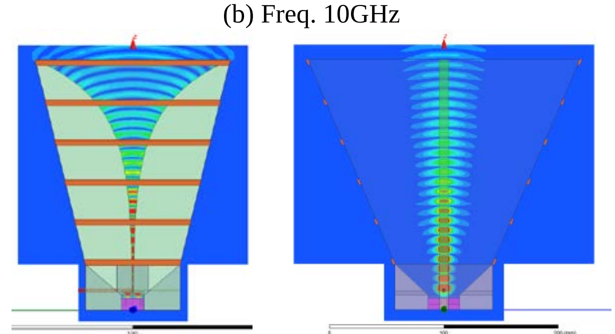
Figure 10 shows the antenna mechanical structure. The specific dimensions of the antenna are: an 244 × 160 mm area of the flared surface, a 92 × 77 mm area for the bottom of the waveguide section, a 43 mm long waveguide section, a 230 mm axial length of the horn, and a weight of approximately 1.5 kg. The antenna can use SMA female or N type female coaxial connectors, which can withstand an average power of 50 W and 300 W, respectively.



(a) Freq. 0.7 GHz

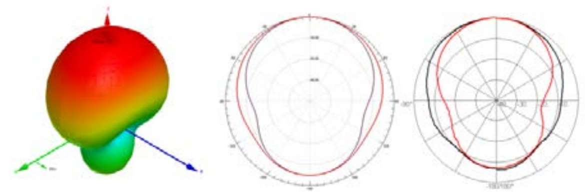


(b) Freq. 10GHz

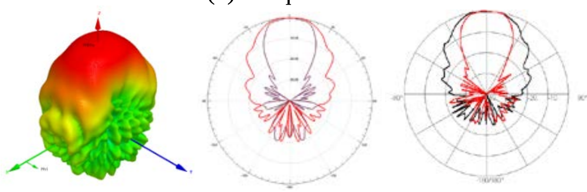


(c) Freq. 18 GHz

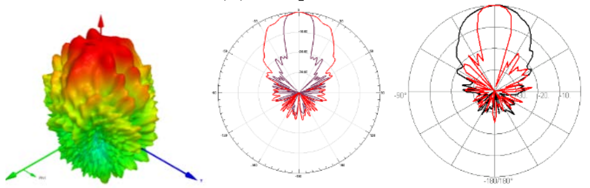
Fig. 8. E Field of designed broadband horn antenna.



(a) Freq. 0.7 GHz



(b) Freq.10 GHz



(c) Freq. 18 GHz

Fig. 9. Patterns: simulation (left) and measured (right).

Fig. 10. Photographs of fabricated horn antenna.

IV. CONCLUSION

To provide high UWB performance, an ultra-wideband horn antennas, typically used to measure electromagnetic compatibility in laboratory environments, are designed, tested and analyzed via a variety of methods. An example of a UWB double ridge horn antenna prototype is developed and tested. Both the simulation and test results are satisfactory. The VSWR of the antenna is under 2.1:1 over the frequency range of 0.75-18 GHz and the maximum value is 6.6 at 700 MHz. The gain varies between 3.1 and 15.35 dBi in the entire designed frequency band. The patterns don't split in full operational frequency range. The antenna is under mass production and widely used in microwave anechoic chambers, EMC testing environments, electronic counter measurement environments, and materials testing laboratories.

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