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DOUBLE-RIDGED ANTENNA FOR WIDEBAND APPLICATIONS

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Abstract—In this paper, the design, simulation, and fabrication of a double-ridged antenna is presented. The designed double-ridged antenna is most suitable as a feed element in reflectors of the radar systems and EMC applications. The designed antenna has a voltage standing wave ratio (VSWR) less than 2 for the frequency range of 8–18 GHz. Moreover, the proposed antenna exhibits satisfactory far-field radiation characteristics in the entire operating bandwidth. A coaxial line to rectangular double-ridged waveguide transition is introduced for coaxial feeding of the designed antenna. The proposed antenna is simulated with commercially available packages such as CST microwave studio and Ansoft HFSS in the operating frequency range. Simulation results for the VSWR, radiation patterns, and gain of the designed antenna over the frequency band 8–18 GHz are presented and discussed.

1. INTRODUCTION

Broadband, ultrawide band and high gain antennas are one of the most important devices for microwave and millimeter wave applications, electromagnetic compatibility testing, and standard measurements [1–9]. The proposed antenna is similar to horn antennas.

The conventional horn antennas have a limited bandwidth. To extend the maximum practical bandwidth of these antennas, ridges are introduced in the flare section of the antenna. The idea of using ridges in waveguides was adopted in horn by Walton and Sundberg [10], and completed by Kerr in early 1970 when they suggested the use of a feed horn launcher whose dimensions were found experimentally [11]. This

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is commonly done in waveguides to increase the cutoff frequency of the second propagating mode (TE11) and thus expands the single-mode range before higher order modes occur [12–14]. In [15, 16], an E-plane sectoral horn for broadband application using a double-ridged antenna is provided.

A detailed investigation on 1–18 GHz broadband pyramidal double-ridge horn (DRH) antenna was reported in [17]. As indicated in that paper there is some deterioration in the radiation pattern at higher frequencies. In [18], a broadband electromagnetic compatibility pyramidal DRH antenna for 1 to 14 GHz was reported by Botello, Aguilar and Ruiz. An improved design of the double-ridged pyramidal horn antenna was presented in [19]. Another design of the double-ridged pyramidal horn antenna in the 1–18 GHz frequency range with redesigned feeding section was presented in [20] where several modifications were made in the structure of a conventional double ridged guide horn antenna.

In this paper, based on the double-ridged rectangular waveguide, a double-ridged antenna including a 50 Ω coaxial feed input is proposed. Accordingly, a waveguide transition structure for the single-mode, the TE10 mode, with low return loss performance and a new technique for synthesizing the exponential taper is presented. The proposed antenna is simulated with commercially available packages such as Ansoft HFSS which is based on the finite element method and CST microwave studio which is based on the finite integral technique. Simulation results for the VSWR, gain, and radiation patterns of the designed antenna at various frequencies are presented.

2. DESCRIPTION OF THE ANTENNA CONFIGURATION

Figure 1 shows the configuration of the broadband double-ridged antenna. The overall length of the designed antenna and the distance between tow exponential taper in aperture are 43.5 mm and 22 mm, respectively. The double-ridged antenna is divided into three parts: a double-ridged rectangular waveguide, a cavity back, and the exponential tapered part. In the next sections design details for each part will be described.

2.1. Design of the Double-ridged Rectangular Waveguide

The double-ridged rectangular waveguide and a cavity back are the two main parts of the coax to waveguide transition. For single-mode operation, an increase of the bandwidth between the TE10 and the

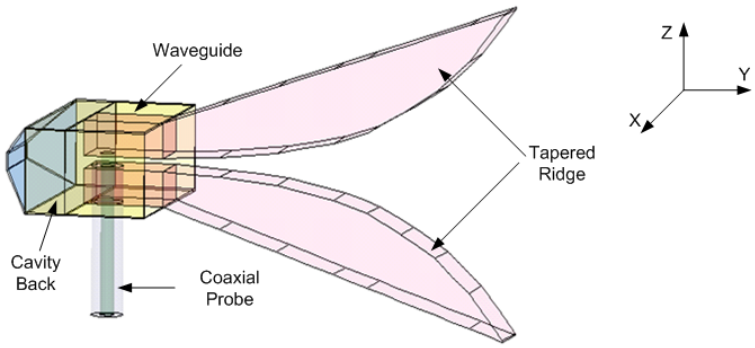


Figure 1. Configuration of the proposed antenna.

TE11 modes and an impedance match to the impedance of coaxial cable (50 Ω) can be obtained by loading ridges with a very small gap. In the first step, as shown in Fig. 2, a two-port rectangular waveguide without coaxial probe for single-mode (i.e., TE10 mode) operates in the frequency range 8–18 GHz is simulated with Ansoft HFSS. The height and width of the designed ridges and distance between the ridges are $h = 2.37\,\text{mm}$, $w = 4.6\,\text{mm}$, and $s = 0.86\,\text{mm}$, respectively which are loaded in a rectangular waveguide as shown in Fig. 1.

The dimensions and overall length of the rectangular waveguide are $a = 18\,\text{mm}$, $b = 5.6\,\text{mm}$ and $l = 7\,\text{mm}$, respectively. The S12 parameters of the TE10 and TE11 modes in the waveguide versus the frequency are presented in Fig. 3. It can be seen that the lowest mode (i.e., TE10) is the fundamental propagation mode in the waveguide. In Fig. 3, we observe that higher order modes (e.g., TE11) cannot propagate in the waveguide because the S12 parameter is much

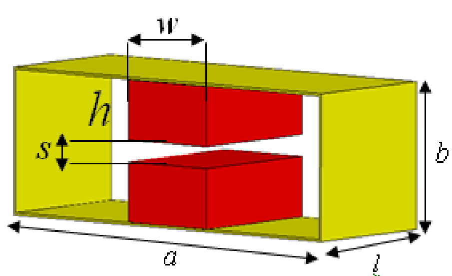


Figure 2. Two port double-ridged rectangular waveguide without coaxial probe.

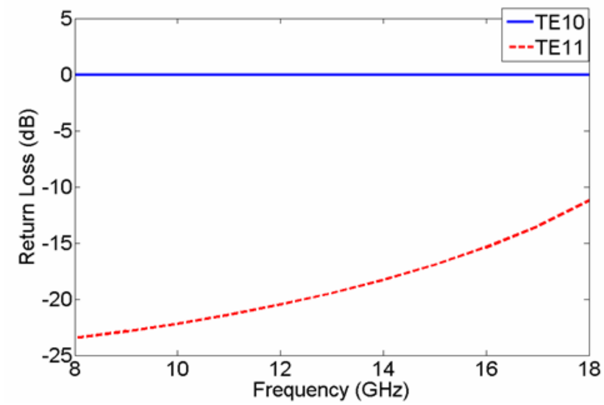


Figure 3. S12 parameter of the propagation mode (TE10) and non-propagation mode (TE11) versus frequency.

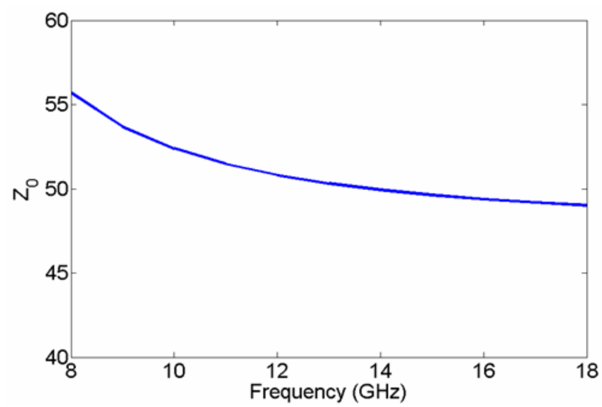


Figure 4. Characteristic impedance of the fundamental propagation mode (TE10) versus frequency.

lower than 0 dB. The characteristic impedance of the fundamental propagation mode (i.e., TE10) versus frequency is presented in Fig. 4. It is obvious from this figure that the characteristic impedance varies between $56\,\Omega$ and $48\,\Omega$. Therefore, we have very good impedance matching between the coaxial line and double-ridged rectangular waveguide for single-mode operation over the entire frequency band of 8–18 GHz.

2.2. Coaxial to Double-ridged Rectangular Waveguide Transition

It is necessary to use a transition between the coaxial probe and the double-ridged rectangular waveguide. The transition between the coaxial probe and the double-ridged waveguide is important to the return loss performance of the antenna. The principal goal is obtaining low levels of VSWR throughout the transformation of the TEM-mode in the coaxial section to the TE-mode in the waveguide. In order to achieve low VSWR, the cavity back length, the initial distance between ridges in the rectangular waveguide and probe spacing from the ridged edge should be optimized. From the optimization process it was found that the probe spacing from the ridged edge affects the gain of the antenna and shaping of the main lobe at high frequencies. Numerous simulations have been done to optimize the transitional performance using Ansoft HFSS. In our simulations we assumed that the double-ridged rectangular waveguide absorbs the full wave that propagates from the coaxial probe.

It is very common to use a cavity back to obtain a much lower return loss in coaxial to double-ridged waveguide transitions. It was found that the VSWR of the antenna is critically dependent on the shape and dimensions of the cavity back. We consider a pyramidal shaped cavity. The cavity dimensions which are obtained using the optimization method are shown in Fig. 5.

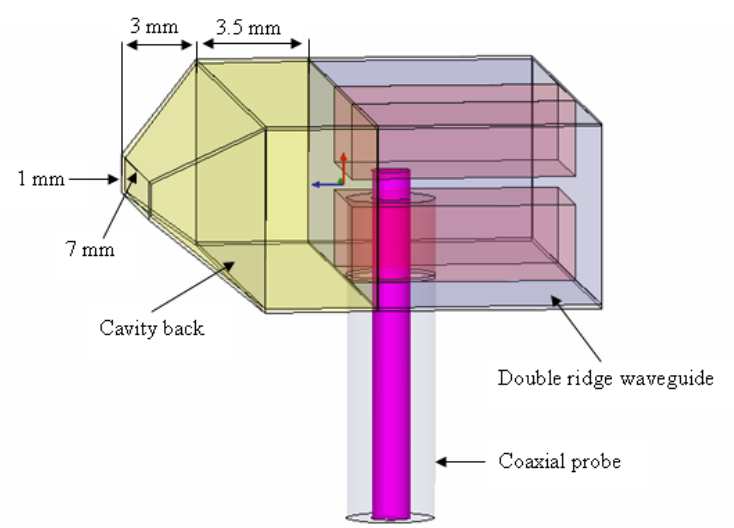


Figure 5. Cavity back for return loss improvement in the waveguide transition.

2.3. Design of the Exponential Tapered Part

The design of the exponential tapered part is the most significant part in the antenna design. The exponential tapered part varies the impedance of the guide from $50\,\Omega$ at the feeding point (double-ridged rectangular waveguide) to $377\,\Omega$ at the aperture of the antenna [6]. The impedance variation in the tapered part is as (1):

$$Z(y) = z_0 e^{ky}, \qquad (0 \leq y \leq L) \tag{1}$$

where y is the distance from the waveguide aperture and L is the axial length (with $L = 30\,\mathrm{mm}$) of the antenna opening (exponential tapered part). The k is calculated as follow [17]:

$$k = \frac{1}{L} \ln\left(\frac{Z_L}{Z_0}\right) \tag{2}$$

in which Z_0 and Z_L are the characteristic impedances of double-ridged rectangular waveguide and free space, respectively. In order to synthesize the exponential tapered part, the following algorithm is proposed:

The axial length of the antenna opening (L) is divided into eight sections, which results in 8 smaller double-ridged rectangular waveguides. Each corresponding aperture size is obtained from the main horn antenna structure. Then, the height of each double-ridged

Table 1. The detail design dimensions of the exponential tapered part.

waveguide number	Length of the waveguide aperture (mm)	Characteristic impedance (Ω)	height of the tapered ridge (mm)
1	2.8	50	2.37
2	4.16	70	3.5
3	5.53	98	4.45
4	6.9	137	5
5	7.72	168	5
6	8.54	205	4.5
7	9.36	251	3.8
8	10.18	308	2.4

rectangular waveguides should be optimized (by Ansoft HFSS) in such a way that the corresponding characteristic impedance be equal to (1). The detailed design dimensions of the exponential tapered part are shown in Table 1. After obtaining the height of the exponential tapered part we connect them together. The final shape appears as an exponential taper and is shown in Fig. 6. We can see that at first, the height of the section increases and then decreases.

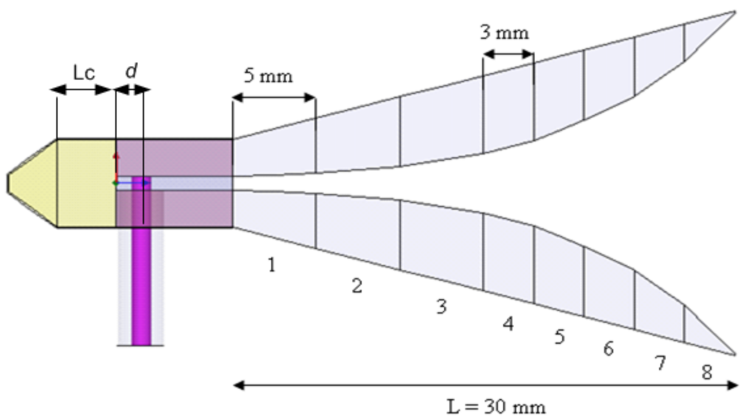


Figure 6. The proposed antenna made from eight smaller waveguides each of different height (cut view).

(a) (b)

Figure 7. Photograph of the fabricated antenna. (a) Overall view. (b) Front view.

3. RESULTS AND DISCUSSION

In this section simulation and measurement results of the proposed antenna are presented. To emphasize the validity of the simulated results, two commercially available software packages, HFSS and CST, have been used. Both show very close results confirming that the simulated results are reasonably accurate. Fig. 7 shows the photograph of the fabricated antenna. The VSWR of the designed antenna is presented in Fig. 8. As shown, the maximum value of the VSWR is less than 2 over the operating band of 8–18 GHz.

Figure 9 shows measured normalized far-field radiation patterns in Y-Z plane for various frequencies (8, 13, 18 GHz). Fig. 10 shows

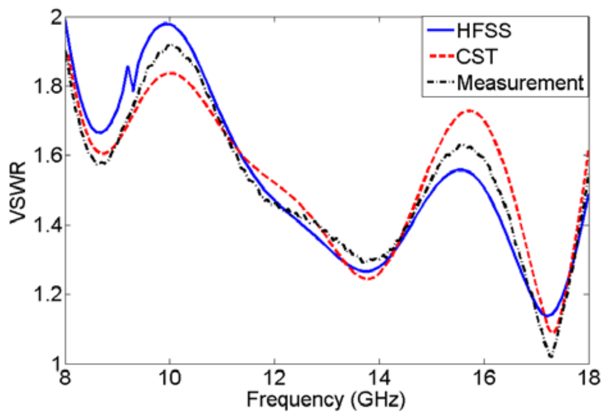


Figure 8. Simulated and measured VSWR of the designed antenna.

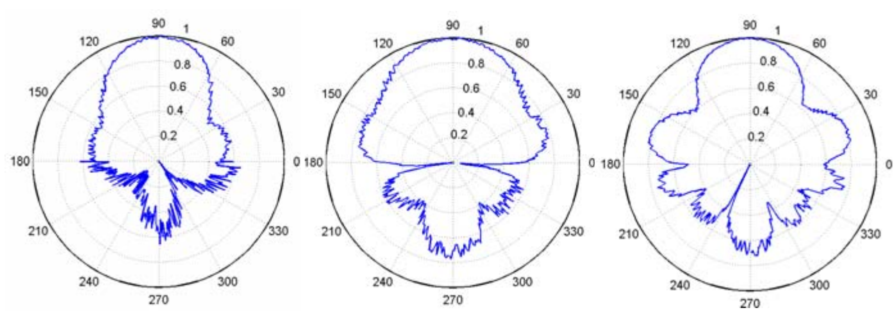
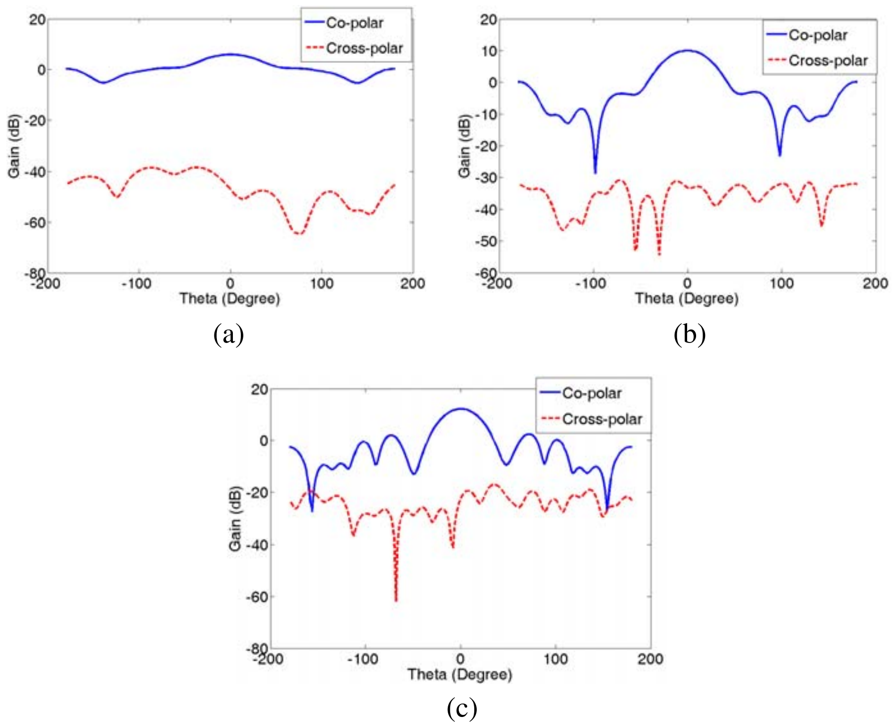


Figure 9. Measured radiation patterns of antenna at: (a) 8 GHz, (b) 13 GHz, (c) 18 GHz.



(a) (b) (c)

Figure 10. Simulated radiation patterns of antenna at: (a) 8 GHz, (b) 13 GHz, (c) 18 GHz.

simulated co- and cross-polar far-field radiation patterns in Y-Z plane for various frequencies (8, 13, 18 GHz). It can be seen that the designed antenna exhibits low cross polarization. To conclude, this antenna is capable of providing high gain and less distorted transmitted pulses for EMC applications. The gain of the proposed antenna versus frequency is shown in Fig. 11. It can be seen that the gain of the antenna increases as frequency increases. The maximum value of gain occurs at the end of the operating frequency band (18 GHz).

4. PARAMETRIC STUDIES AND DISCUSSION

A parametric study is investigated and it demonstrates that the following parameters influence the performance of the designed double-ridged antenna.

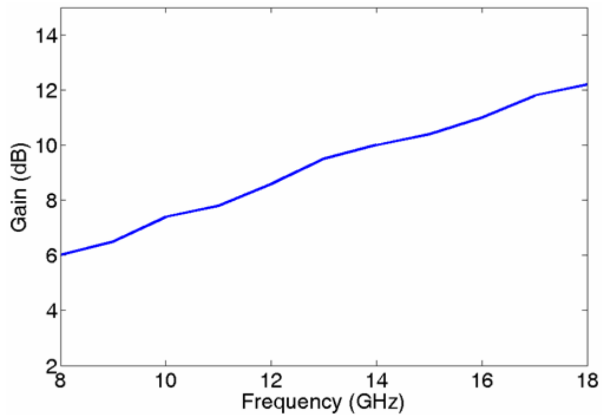


Figure 11. Gain versus frequency for the proposed antenna.

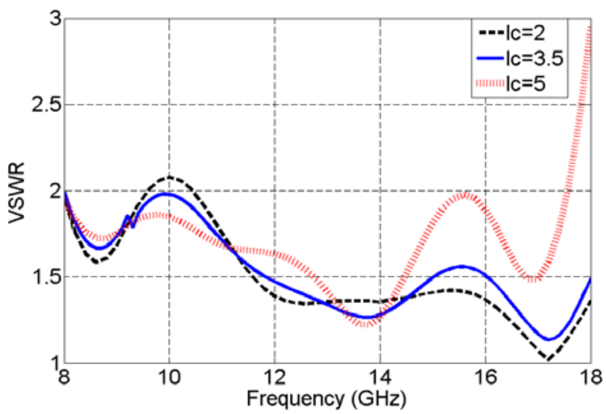


Figure 12. Simulated return losses of the antenna for various L_c.

4.1. Effect of Cavity Back Length (L_c)

It is found through the simulation that the VSWR of the proposed double-ridged antenna is dependent on the cavity back length. This factor affects the performance of the proposed antenna. Fig. 12 shows the relationship of L_c versus return loss. As shown in this figure, the return loss deteriorates within the whole band as L_c changes. The best value for L_c in the designed antenna is 3.5 mm.

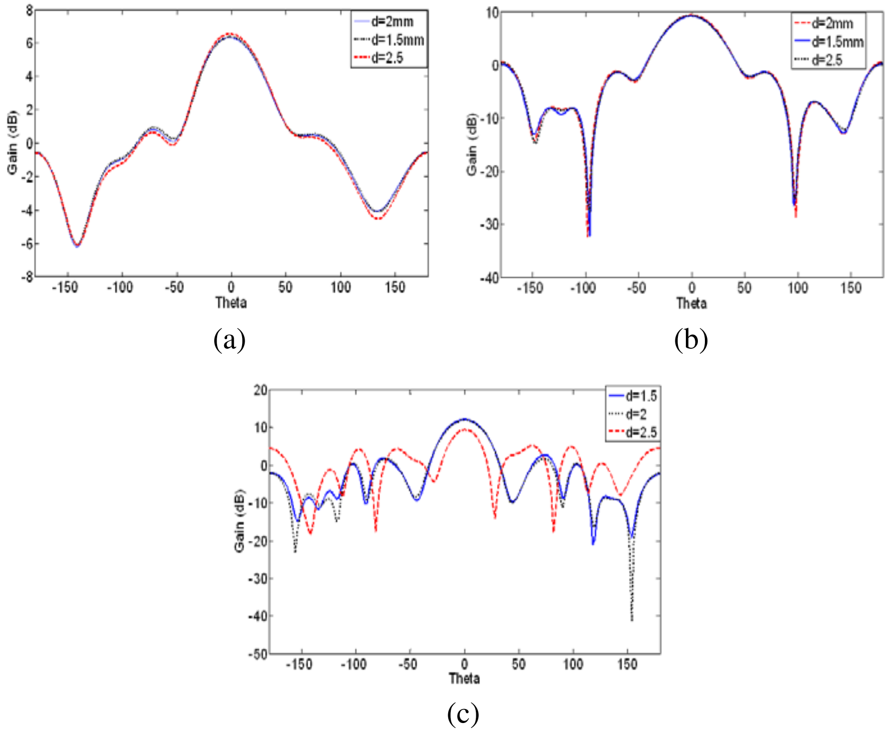


Figure 13. Simulated radiation patterns of the antenna for various d at: (a) 8 GHz, (b) 13 GHz, (c) 18 GHz.

4.2. Effect of Probe Spacing from Ridge Edge (d)

This parameter changes the far field radiation pattern at higher frequencies. As shown in Fig. 13, this parameter can obviously affect the high frequency performance but the low frequency performance of the proposed antenna is clearly independent of the d.

5. CONCLUSION

In this paper, a double-ridged antenna has been proposed for the 8–18 GHz band. Ansoft HFSS and CST softwares were used for the analysis of the designed antenna. Compared to conventional double-ridged horn antennas with rectangular apertures, the designed antenna (with lower size of aperture) has lower weight and low cross polarization. Incidentally, the fabrication of proposed antenna is much easier than double-ridged horn antennas. Furthermore, the designed antenna provides good VSWR (less than 2), and satisfactory far-field radiation characteristics over the operating frequency band. Based on these characteristics, the proposed antenna can be useful for EMC applications.

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