Modified Double-Ridged Antenna for 2-18 GHz

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***Abstract*─** In this paper, the design and simulation of a modified double-ridged antenna for 2-18 GHz is presented. The designed antenna has a voltage standing wave ratio (VSWR) less than 2.4 for the frequency range of 2-18 GHz and is most suitable as a feed element in the reflectors of the radar systems and EMC applications. The proposed antenna had distortion in radiation patterns in the 10-14 GHz frequency range. This problem has been modified by shaping of ridges. 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 2-18 GHz are presented and discussed.

***Index Terms*─** Horn antenna, Waveguide, Double-ridged Waveguide, VSWR, Polarization.

I. INTRODUCTION

Broad band, ultra wide 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.

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 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-ridge is provided.

A detailed investigation on 1–18 GHz broad-band 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.

The distortion of radiation patterns of higher frequencies, cross polarization, the back lobe, and side lobe level (SLL) are the significant disadvantages of the conventional double-ridged horn antenna. Based on the papers available in open literature, VSWR, cross polarization, side lobe level of double-ridged pyramidal horn antennas need to be improved [20].

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 is presented. It can be shown that the radiation pattern at higher frequencies, 10–14 GHz would deteriorate over the broadside direction. To overcome this problem, shaping of ridges is introduced leading to a better radiation pattern over the broadside direction. 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.

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II. DESCRIPTION OF THE ANTENNA CONFIGURATION

Figure 1 shows the configuration of the proposed antenna. The overall length of the designed antenna and the distance between tow exponential taper in aperture are 105 mm and 80 mm, respectively. This 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.

A. Double-Ridged Rectangular Waveguide Design

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 TE11 modes and an impedance match to the impedance of coaxial cable (50Ω) 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 2–18 GHz is simulated with Ansoft HFSS. The height and width of the designed ridges and distance between the ridges are h=12.2mm, w=2.5 mm, and s=0.6 mm, respectively which are loaded in a rectangular waveguide as shown in Fig. 1.

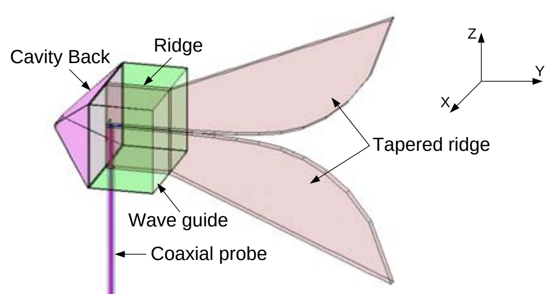


Fig. 1. Configuration of the proposed antenna.

The dimensions and overall length of the rectangular waveguide are a=40 mm, b=25 mm and l=20 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 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 49.5 Ω and 60 Ω. 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 2–18 GHz.

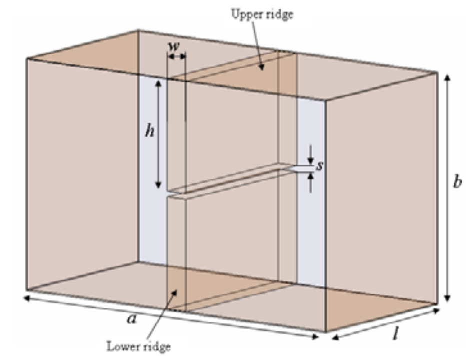


Fig. 2. Two port double-ridged rectangular waveguide without coaxial probe.

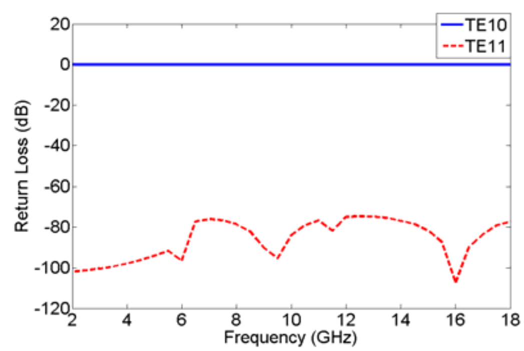


Fig. 3. S12 parameter of the propagation mode (TE10) and non propagation mode (TE11) versus frequency.

B. 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 and probe spacing from the ridged edge should be optimized. Numerous simulations have been made to optimize the transitional performance using Ansoft HFSS. In our simulations we assumed that the double-ridged rectangular waveguide absorbs the full wave that is propagated from the coaxial probe.

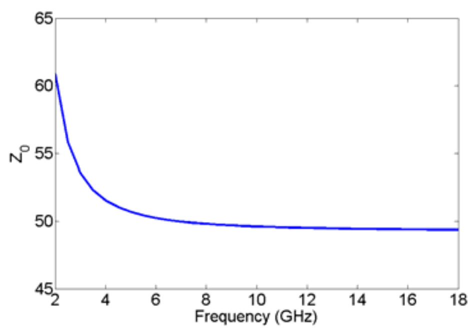


Fig. 4. Characteristic impedance of the fundamental propagation mode (TE10) versus frequency.

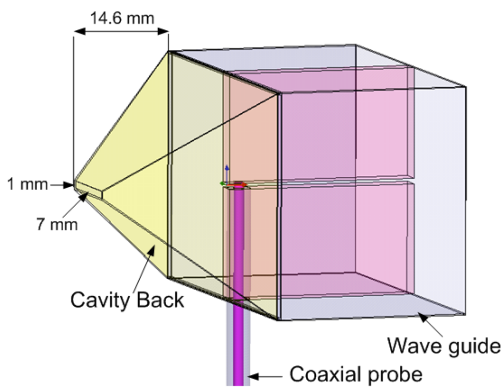


Fig. 5. Cavity back for return loss improvement in the waveguide transition.

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 conical shaped cavity. The cavity dimensions which are obtained using the optimization method are shown in Fig. 5.

C. Exponential Tapered Part Design

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 Ω at the feeding point (double-ridged rectangular waveguide) to 377 Ω at the aperture of the antenna [6]. The impedance variation in the tapered part is as (1):

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

where y is the distance from the waveguide aperture and L is the axial length (with L=70 mm) of the antenna opening (exponential tapered part). The *k* is calculated as follow [17]:

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

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:

Table 1: The detailed design dimensions of the flare section.

Waveguide number	Length of the wave-guide aperture (mm)	Character-istic impedance (Ω)	Height of the tap-ered ridge (mm)
1	12.5	50	12.2
2	15.25	61.2	14.86
3	18	74.9	17.4
4	20.75	91.6	19.86
5	23.5	112.2	22.07
6	26.25	137.3	23.8
7	29	168	24.5
8	31.75	205.6	23.65
9	34.5	251.7	21
10	37.25	308	15.2

The axial length of the antenna opening (L) is divided into ten sections, which results in 10 smaller double-ridged rectangular waveguides. Each corresponding aperture size is obtained from the main horn antenna structure. Then, the height of each double-ridged rectangular waveguides should be optimized (by Ansoft HFSS) in such a way that the corresponding characteristic impedance is 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.

III. SIMULATION RESULTS

In this section simulation results of the proposed antenna are presented. To emphasize on validity of the simulated results, two commercially available software packages, the HFSS and CST have been used. Both show very close results confirming that the simulated results are reasonably accurate. The VSWR of the designed antenna is presented in Fig. 7. As shown, the maximum value of the VSWR is less than 2.4 over the operating band of 2 to 18 GHz.

Fig. 8 shows co- and cross polar far-field radiation patterns in Y-Z plane for various frequencies (2, 7, 12, 18 GHz). It can be seen that the designed antenna exhibits low cross polarization in the entire operating bandwidth. Unfortunately, the proposed antenna has distortion in radiation patterns at higher frequencies (10-14 GHz). A new technique employed to improve this problem.

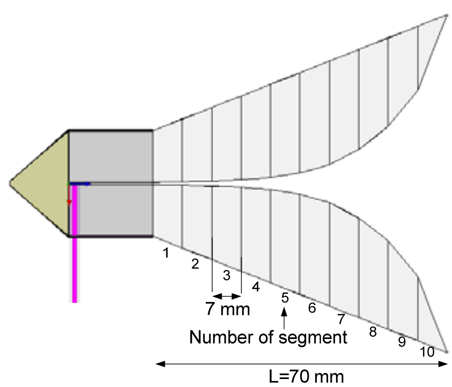


Fig. 6. The proposed antenna made from ten smaller waveguides each of different height (cut view).

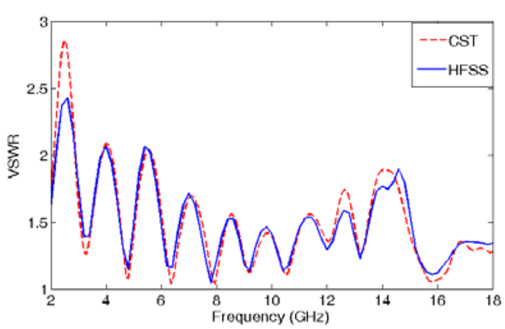


Fig. 7. Simulated VSWR of the designed antenna.

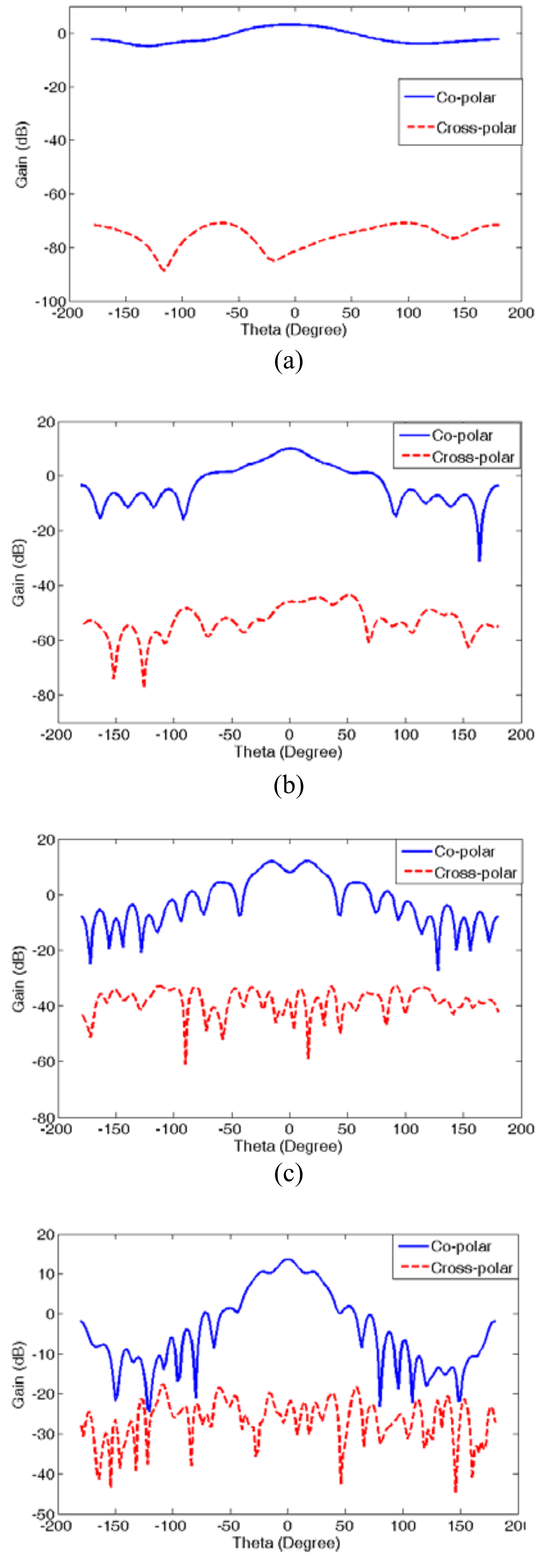


Fig. 8. Simulated radiation patterns of antenna at: (a) 2 GHz, (b) 7 GHz, (c) 12 GHz, and (d) 18 GHz.

IV. MODIFIED DESIGN OF THE PROPOSED ANTENNA

Radiation patterns of the proposed antenna at higher frequencies (10-14 GHz) deteriorate. This can be due to the field distribution over the aperture plane that has a destructive effect in the far field at the broadside direction. To overcome this by new technique a pair of added ridges were placed on the end and top of the exponential tapered part. The modified antenna is shown in Fig. 9. In order to achieve good radiation pattern, the dimensions of the added ridge should be optimized. Simulations show that this structure changes the dispensation of the fields over the antenna aperture that cause destroyer effects of them in the 10-14 GHz exterminate and hence we have a well-shaped main beam over the frequency range of 2–18 GHz. The corresponding VSWR of the modified antenna is shown in Fig. 10.

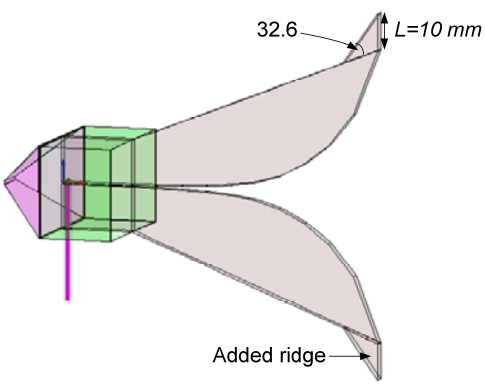


Fig. 9. Configuration of the modified proposed antenna.

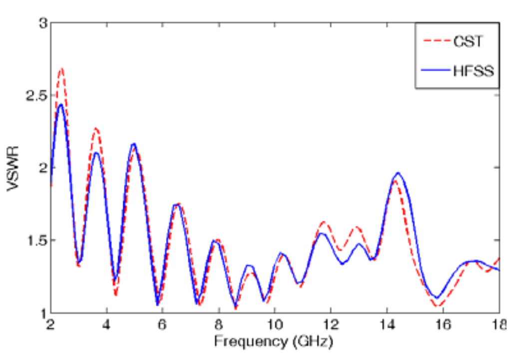
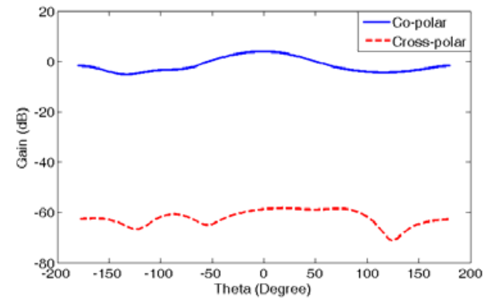
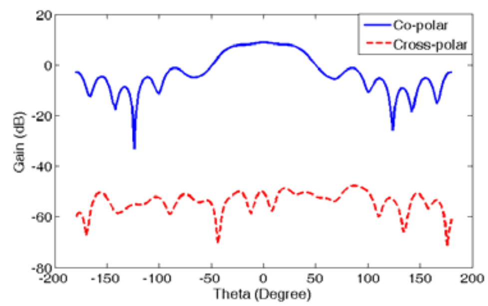


Fig. 10. Simulated VSWR of the modified proposed antenna.

The radiation patterns of the modified antenna are shown in Figs. 11 for the frequencies 2, 7, 12, 18 GHz. The gain of the proposed antenna versus frequency is shown in Fig. 12. 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).



(a)



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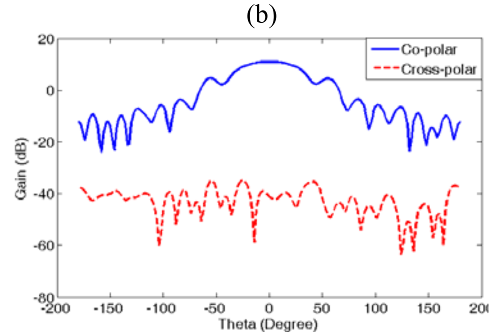

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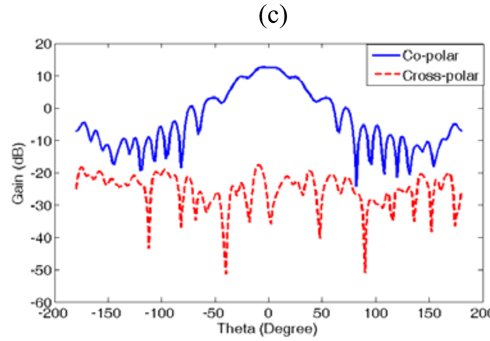

(d)

Fig. 11. Simulated radiation patterns of the modified proposed antenna at: (a) 2 GHz, (b) 7 GHz, (c) 12 GHz, (d) 18 GHz.

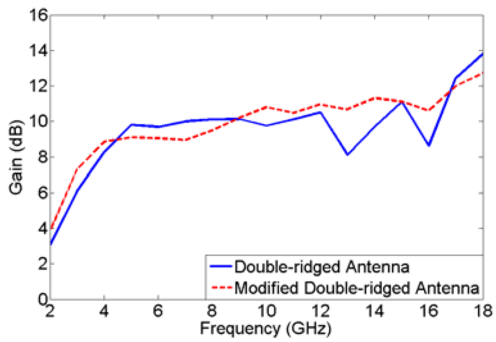

Fig. 12. Gain versus frequency for the proposed antenna.

V. CONCLUSION

In this paper, a modified double-ridged antenna has been proposed for the 2-18 GHz band. Ansoft HFSS and CST software were used for 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, fabrication of the proposed antenna is easier than for double-ridged horn antennas. The distortion of the radiation patterns at higher frequencies is the significant disadvantage of the conventional broadband double-ridged pyramidal horn antenna. Our proposed antenna doesn't show the above mentioned disadvantage at higher frequencies. Furthermore, the designed antenna provides good VSWR (less than 2.4) over the operating frequency band. Based on these characteristics, the proposed antenna can be useful for EMC applications.

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