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A NEW 2–18 GHZ QUAD-RIDGED HORN ANTENNA

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Abstract—A novel design of a dual-polarized broadband 2–18 GHz horn antenna with VSWR ≤ 2.2 is presented. The designed horn antenna is most suitable as a feed element in reflectors of the radar systems and EMC applications. A coaxial line to quadruple-ridged waveguide transition with a new conical cavity back and a technique for tapering the flared section of the horn is introduced to improve the return loss and matching of the impedance, respectively. In order to overcome the deterioration of the broadside radiation pattern at higher frequencies, common to broad band ridged horn antennas, a new modified horn antenna with arc shaped aperture is introduced. Results of simulation obtained via two different software packages, HFSS and CST, for VSWR, isolation, radiation patterns, and gain of the designed quad ridged horn antenna as well as the modified horn antenna are presented and discussed.

1. 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]. An antenna that can also be suitable for such applications is the horn antenna. The use of an electromagnetic horn as an antenna goes back to the beginning of the radio [10]. Horn antennas have a wide variety of uses, from small-aperture antennas as reflector feeds to large-aperture antennas used as a medium-gain antenna. Horns can be excited in any polarization or combination of polarizations. The conventional horn antennas have a limited bandwidth [11].

When broadband or ultra wideband (UWB) horn antennas are required, ridges in the waveguide transition portion as well as in the flare region are required. Inserting ridges in the E and/or H-plane of a waveguide lowers the lowest cutoff frequency and at the same time increases the cutoff frequency of the next higher mode as compared to an ordinary waveguide of the same dimension. As such ridges result in a waveguide that can operate over a 10 : 1 frequency range or more [12–14].

To have single polarization, double ridges can be employed inside the horn antenna. In [15, 16], an E sectoral horn antenna for broadband application using double-ridged is provided. On a pyramidal horn, a detailed investigation on 1–18 GHz broadband double-ridged horn antenna has been reported in [17]. As indicated in that paper there is some deterioration in the radiation pattern at higher frequencies. An improved design of the double-ridged horn antenna was presented by Rodriguez [18] showing that a good single radiation beam is maintained for the entire frequency 1–18 GHz range. Another design of the double-ridged horn antenna over 1–18 GHz range with a redesigned feed section has been presented in [19], where several modifications are made in the structure of a conventional double ridged horn antenna in order to overcome the deterioration of its radiation pattern at higher frequencies.

It is well known that in EMC applications, microwave communication and radar systems it is very useful and more popular to use dual polarization over an ultra wideband or broad band range of frequencies [20]. To have dual polarization, [21] has reported a novel double-ridged horn antenna operating over 8–18 GHz with VSWR<2. Five layer polarizer placed at the aperture of the horn is employed to provide dual polarization performance. Another method of producing double polarization is to use quad-ridged waveguide and horn antenna. In a previous paper [22], the MFIE technique was used to pursue cut off frequency solutions of quadruple-ridged waveguide modes. When we apply quadruple-ridged in square waveguide the cut off frequency of the TE11 mode becomes close to the TE10 mode resulting in an increase in bandwidth between the TE10 and TE20L modes. In [23] a physically compact quad-ridge horn antenna with dual linearly polarized and a maximum VSWR of 3.5 : 1 over a 3 to 1 operational bandwidth is described. Recently, a new dual-polarized broadband horn antenna over the 2–26.5 GHz bandwidth with VSWR<3.1 was reported in [24] where a novel technique for transition between coaxial line to quadruple-ridged waveguide is introduced to improve the return loss performance of the horn antenna. It is based on semi-spherical cavity that is placed in the back of the waveguide. In these last two papers the design of the waveguide transition and taper of the ridge in the horn are not sufficiently described and the VSWR in both papers needs to be improved. Furthermore, in [24] a semi-spherical cavity is attached to the back of the waveguide via a two step change in width which is rather difficult to construct. Also, the E-plane radiation pattern at 18 GHz is shown to shift from the broadside direction while at 26.5 GHz has a null in the broadside. In [25] a dual linearly polarized quad ridged horn antenna over 8–18 GHz has been presented that uses a new waveguide transition structure for the single-mode, the TE10 mode and a new technique for taper of the flare section leading to a VSWR ≤ 2.6.

In this paper, a new dual linearly polarized quad-ridged horn antenna over the 2–18 GHz band is presented. Using a new conical cavity back it is shown that a better VSWR performance of ≤ 2.2 for both coaxial cable feeds can be obtained. For broadband application such as 2–18 GHz, the size of the aperture required would be large. It can be shown that the radiation pattern at higher frequencies, 13–18 GHz would deteriorate over the broadside direction. To overcome this problem, a new arc shaped aperture modified horn antenna is introduced leading to a better radiation pattern over the broadside direction. The proposed quad-ridged horn antenna is simulated with two different commercially available packages Ansoft's HFSS and CST microwave studio over the 2–18 GHz frequency range. Simulated results of the designed antenna such as VSWR, isolation, radiation patterns and gain at various frequencies are provided.

2. QUAD-RIDGED HORN ANTENNA

Figure 1 shows the configuration of the proposed dual-polarized broadband quad ridged horn antenna operating over the 2–18 GHz band. The overall length of the designed horn is 14 cm with an aperture size of $10 \times 10\,\text{cm}^2$.

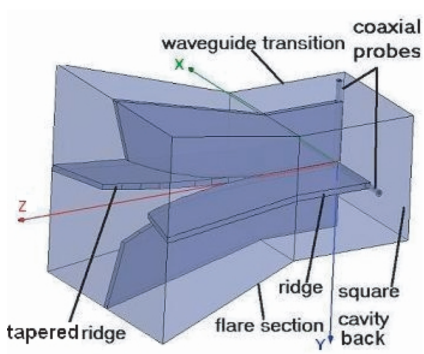

Figure 1. Configuration of the quad ridged horn antenna.

The construction of the horn antenna is divided into two parts: a waveguide transition and a flare section of the horn with tapered quadruple ridges. The design of the waveguide transition and the flare section of the horn with tapered quadruple ridges follow that of [25] that can be explained briefly here. The waveguide transition of the horn antenna can be divided into two parts: a square quadruple ridged waveguide and a shorting plate located at the back of the waveguide. When we apply quadruple-ridged in a square waveguide the cut off frequency of the TE11 mode becomes close to the TE10 mode resulting in an increase in bandwidth between the TE10 and TE20L modes. Single-mode operation and wide bandwidth between the TE10 and the TE20L modes and impedance matched to 50 ohm impedance of the coaxial cable can be obtained by loading the waveguide with four ridges having a very small gap in between. To achieve a single mode of operation in the waveguide transition over the 2–18 GHz band it can be shown through simulation that an aperture size of $6 \times 6\,\mathrm{cm}^2$ is required. To obtain orthogonal polarizations it is necessary to use two coaxial probes to feed the quadruple ridge in the waveguide. One probe is used for vertical and the other is used for horizontal polarization. Entrance of the coaxial probes to the quadruple ridge is critical for the return loss performance of the horn antenna. A lot of simulations have been carried out to optimize the transitional performance from which it can be noted that two features are necessary: (1) The inner conductor of each of the coaxial probes should be connected to the opposite ridge, (2) the inner conductor and shield of the coaxial probes must enter the waveguide at very near the edge of the ridges.

It should be noted that the vertical ridges are placed at the end of the waveguide transition while the horizontal ridges are placed

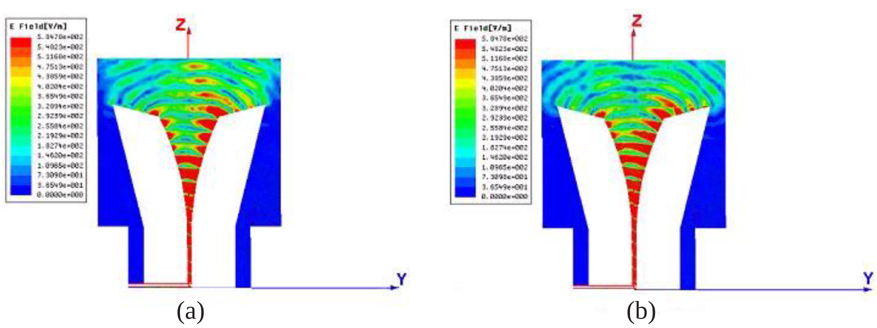

Figure 2. Distribution of E-field in y-z plane for the proposed antenna, (a) 13 GHz, (b) 18 GHz.

slightly before the vertical ridges. As the space between the two inner conductors of the coaxial probes is not sufficient at the edge between vertical and horizontal ridges, we cut a few part of the horizontal ridges edge and enter the inner conductor of horizontal coaxial probe. It is also common to use a shorting plate (cavity back) to obtain a much lower return loss in the waveguide transition.

The last step in the design of the antenna is the tapering of the four identical ridges which are of exponential shape. The ridge's height and width must be such that the associated impedance taper is a smooth transition from the waveguide impedance (50 Ω or less) to the free space impedance, 377 Ω. To improve the impedance matching between the quadruple-ridged waveguide and the free space, a modified exponential function can be used [13]:

$$Z(x) = 0.02x + Z_0 e^{k \cdot x} \quad 0 \leq x \leq L \tag{1}$$

where Z_o is the characteristic impedance of the waveguide, x is a position variable and L is the overall length of the flare section of the horn (with $L = 8\,\text{cm}$). k is a constant equal to $(1/L)\ln(Z(L)/Z_o)$, with $Z(L)$ being the impedance of the horn at the aperture (i.e., 377 Ω). To achieve a better impedance matching, in this paper, a correction factor for constant k needs to be used. A factor equal to 1.06 is chosen that must be multiplied by k. This particular value was obtained through simulation, resulting in a good impedance match particularly for the last ridge section near the aperture.

$$Z(x) = 0.02x + Z_0 e^{1.06k \cdot x} \quad 0 \leq x \leq L \tag{2}$$

L is divided into 10 sections of equal length, 0.8 cm. The aperture size of each of the smaller sections is obtained from the linear flare of the main horn antenna. Then the characteristic impedance of each of the ten smaller sections can be obtained from Eq. (2), where x would start from 0.8 cm for the first section and increases by 0.8 cm for each of the other sections. These ten quad-ridged small sections with constant width ridges and variable height are simulated with HFSS in order to match the characteristic impedance obtainable from Eq. (2). After obtaining the height of the ridges we connect them together in the flare section of the horn antenna. The final shape of the ridges appears as near-exponential taper and is shown in Fig. 1.

The simulation results for the proposed quad ridged horn antenna shows that this antenna for certain applications may have two pitfalls: (1) The radiation patterns over the broadside direction deteriorates at higher frequencies, 13–18 GHz and (2) the return loss is not low enough for those applications. Distribution of the E-field in y-z plane of this antenna is shown in Fig. 2 for two different frequencies, 13 and 18 GHz. From these figures we can see that radiation pattern in the far field is not in the broadside direction. In the following section a new antenna design that overcomes these would be described.

3. MODIFIED DESIGN OF 2–18 GHZ QUAD-RIDGED HORN ANTENNA

When the aperture size of the quad ridged horn antenna increases the radiation pattern at broadside especially over the higher frequencies deteriorates. 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, the straight edges of the horn and the ridges at the aperture, Fig. 1, are modified both in the E- and the H-planes, thus changing the field distribution over the aperture plane. As such, arc of circles which are tangent to the corners of the horn are used. Fig. 3 shows the placement of the arc of circle over one of the horn's side at the aperture plane resulting in an arc shaped horn along with modified tapered ridge. This procedure is also carried out for the other three sides of the horn. These arcs prevent the existence of sharp corners on the quad ridges in the flare section of the horn and the return of the radiation back to the horn in the broadside direction.

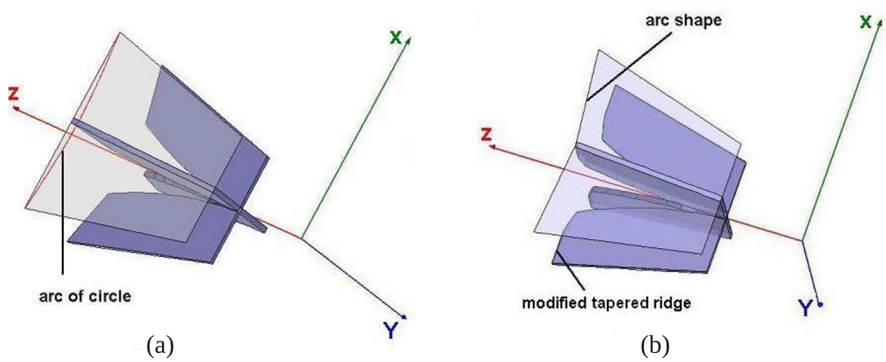

Figure 3. (a) Placing an arc of circle on one side of the horn antenna, (b) Arc shaped aperture and the modified tapered ridged antenna viewed from one side.

Distribution of the E-field of this aperture shaped horn antenna over y-z plane at 13 and 18 GHz are shown in Fig. 4. This figure can be compared to that of Fig. 2, showing that this modified structure leads to a stable pattern over the broadside direction at high frequencies.

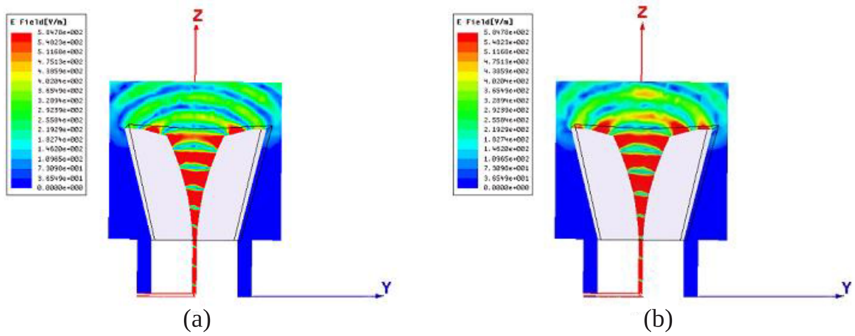

Figure 4. Distribution of the E-field over y-z plane for the modified antenna at (a) 13 GHz (b) 18 GHz.

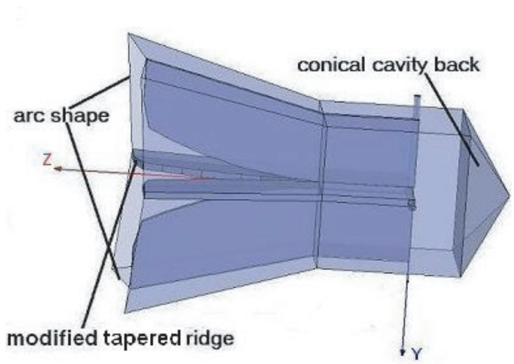

Figure 5. Modified quad ridged horn antenna including arc shaped horn, modified tapered quad-ridged and conical cavity back.

The VSWR ≤ 2.78 of the proposed horn antenna with square cavity back, Fig. 1 is not low enough for certain applications. To overcome this problem the square shaped cavity back with a flat shorting plate is replaced by a new cavity back of different length with a conical shape shorting plate (semi-spherical shape cavity back was also simulated but conical shape gives a better performance). This conical cavity back due to the tapering of the shorting plate absorbs more of the waves and less are reflected back towards the coaxial probes and the horn antenna, thus improving the impedance matching of the whole antenna structure. This conical cavity back along with the final modified configuration of the proposed antenna structure is shown in Fig. 5.

4. RESULT AND DISCUSSION

The proposed antenna structure, a quad ridged horn antenna and the modified quad ridged horn antenna are simulated and results on VSWR, isolation, radiation patterns and gain over various frequencies are obtained.

To check the accuracy of the simulated results, two commercially available software packages, the HFSS and CST have been used. Both show a very close results confirming that the simulated results are obtained with reasonable accuracy.

The voltage standing wave ratio (VSWR) results of the quad ridged horn antenna and the modified quad ridged horn antenna for both ports are presented in Figs. 6 and 7. It can be seen that for both of the coaxial ports VSWR ≤ 2.78 for the quad ridged horn and VSWR ≤ 2.2 for the modified horn antenna over the frequency range of 2–18 GHz is obtainable. Also, the effect of the conical cavity back is noticeable in Figs. 6(b) and 7(b) especially at the lower frequencies of the band.

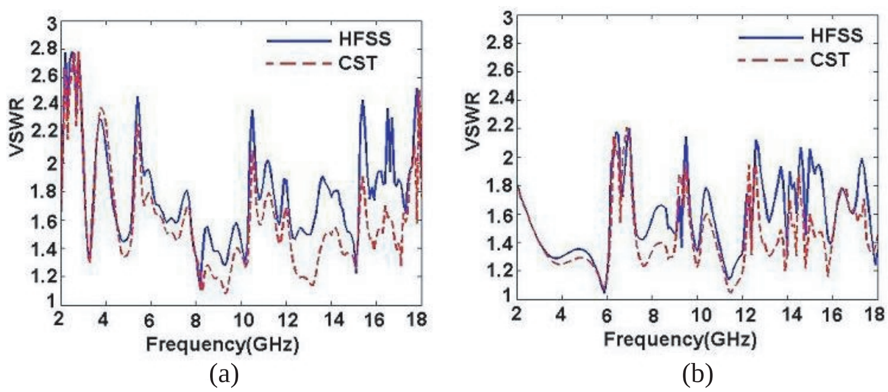

Figure 6. VSWR of Port 1, (a) quad ridged horn antenna, (b) modified quad ridged horn antenna.

The isolation, S12, between the two coaxial ports can be seen to be better than 18.15 for the quad ridge horn antenna, Fig. 8(a), and 19 dB for the modified horn antenna, Fig. 8(b), over the entire frequency range.

Figure 9 shows the simulated E and H-plane radiation patterns at 2, 10 and 18 GHz for both the quad ridged horn antenna and the modified quad ridged horn antenna. From this figure it is seen that, the back lobe and side lobe levels (SLL) are quite low. Furthermore,

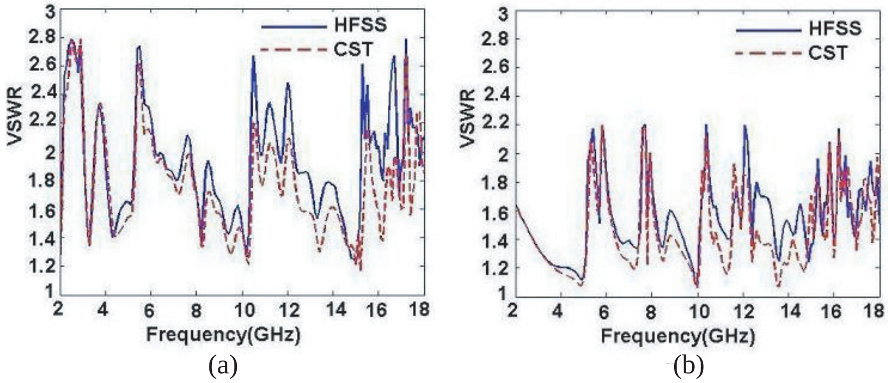

Figure 7. VSWR of Port 2, (a) quad ridged horn antenna, (b) modified quad ridged horn antenna.

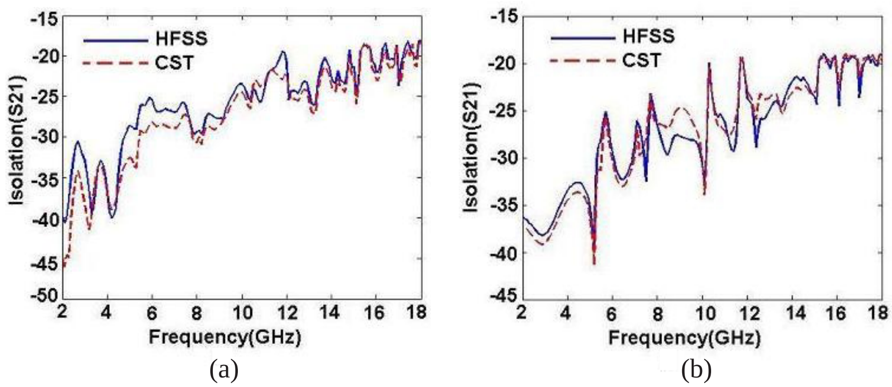

Figure 8. Isolation S12, (a) quad ridged horn antenna, (b) modified quad ridged horn antenna.

it is obvious that the cross polar radiation level is at least 15 dB below that of the co-polar field in the broadside direction over the frequency band. In Fig. 9(c) as mentioned before, deterioration of the main beam over broadside at 18 GHz is noticeable. This in fact is seen to occur for frequencies above 13 GHz. However, for the modified quad ridged horn antenna no such deterioration of the field patterns are seen, shown in Fig. 9(f). The radiation patterns of Fig. 9 are obtained through HFSS. Although not shown it can be shown that similar patterns can be obtained through CST. Fig. 10 shows the simulated gain of the quad ridged horn antenna and the modified horn antenna over various frequencies. The result shows that the gain at broadside direction for

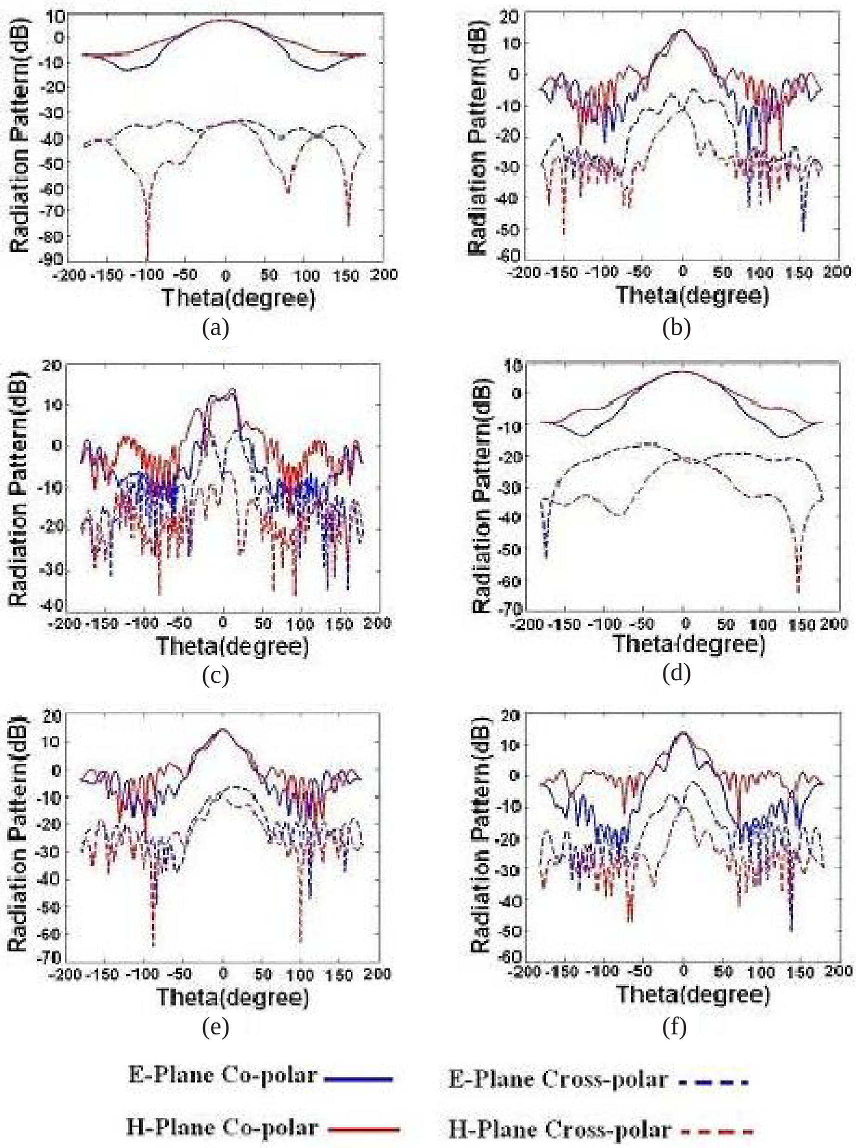

Figure 9. E and H-plane radiation pattern for: Quad ridge horn antenna at (a) 2 GHz, (b)10 GHz, (c) 18 GHz and for modified quad ridge horn antenna at (d) 2 GHz, (e) 10 GHz, (f) 18 GHz.

the modified quad ridged horn antenna increases with frequency, with a maximum value around 15.7 dB at 17 GHz while the gain for the quad ridged horn antenna has a peak value of 14 dB around 13 GHz and starts to decrease with increase in frequency (due to the deterioration of the field in the broadside).

Lastly, it is found from simulation that the gain and radiation pattern results are almost the same for both horizontal and vertical polarizations.

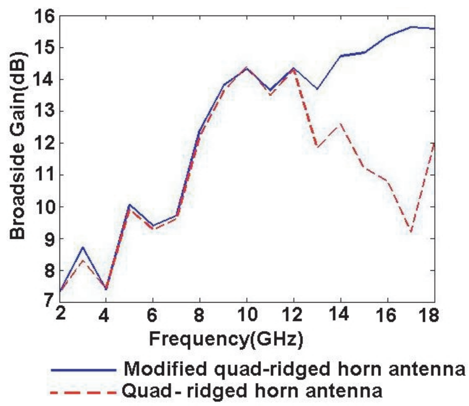

Figure 10. Gain at broadside of Quad-ridged horn antenna and Modified quad-ridged horn antenna.

5. CONCLUSION

This paper has presented a novel design of a dual-polarized broadband quad ridged horn antenna operating over 2–18 GHz band. The modified quad ridge horn antenna uses arc shaped edges for the horn and the ridges at the aperture plane and a conical cavity back leading to a VSWR ≤ 2.2, an isolation of less than 19 dB over the entire 2–18 GHz band and a maximum broadside gain of 15.7 dB. This modified quad ridged horn antenna has a stable radiation pattern at broadside over the entire frequency band as compared to the usual ridged horn antenna. This antenna that covers the 2–18 GHz range along with dual-polarization is very useful for radar systems and EMC applications.

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