Progress In Electromagnetics Research, PIER 90, 105–119, 2009

MODIFIED TEM HORN ANTENNA FOR BROADBAND APPLICATIONS

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Abstract—This paper presents a novel method to enhance the pattern characteristics of the TEM horn antenna for 2–14 GHz frequency band. The conventional TEM horn antenna introduces some fluctuations in the main lobe radiation pattern over the higher frequencies, i.e., 10–14 GHz. This motivated us to propose a new method to remove the aforementioned impact by carving an arc shape to the open end of exponentially tapered plates. The associated curvature of this arc is optimized to completely remove the fluctuation. The measurement results show that the improved TEM horn antenna structure exhibits low VSWR as well as radiation pattern over 2–14 GHz frequency band.

1. INTRODUCTION

Wideband antennas have received considerable attention to meet the current demand for a wide variety of applications, including electromagnetic compatibility (EMC) measurement, radar, detection systems, and broad-band communication systems. Bow-tie, log-periodic, spiral and double ridged antenna are some of the well established wideband antennas, which are extensively used for the aforementioned applications [1–6]. Specifically, transverse electromagnetic (TEM) horn antennas have been used as wideband antennas for various applications. Typical applications for these antennas include EMC experiments, Ground Penetrating Radar (GPR), Free-space Time-Domain (FTD) measurement systems, and feeds for reflectors [7–12].

This type of antenna has the advantages of wideband, no dispersion, unidirectional and easy construction. Several methods have

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been introduced to improve the performance of the antenna. In order to reduce the size of the antenna the Cornell Aeronautical Laboratory (CAL) designed a TEM horn with nonuniform-line matching from $50\,\Omega$ at the antenna throat to $377\,\Omega$ at the aperture [13]. The nonuniform-line matching was achieved by forming the TEM horn plates into empirically determined tear-drop shapes. A small resistance-card termination was placed at the tip of the aperture to provide adequate current attenuation for a traveling wave. With these empirical modifications, the length of the TEM horn was reduced to 0.33λ with a reasonable reflection coefficient for the frequency range of 100 MHz to 2 GHz.

One of the most important design goals for the TEM horn antenna is to attain the wide-band characteristics. Kanda [14] introduced the idea of improving the bandwidth by loading the TEM horn antenna with resistors. To reduce the distortion and the reflection at open end, Shlager [15] proposed the antenna with resistive sheet. Since, these antennas used resistive material, they had low efficiency. In [16], an exponentially tapered TEM horn antenna with a microstrip-type balun is proposed to increase the bandwidth and efficiency of the TEM horn antenna. So, the bandwidth of the TEM horn antenna becomes more than three times comparing to that of a linearly tapered TEM horn [12] for the same length. However, one common disadvantage for all these structures was having fluctuation in the radiation pattern at the higher end of the frequency band [16–19].

In this paper, an exponentially tapered TEM horn antenna with TEM double-ridged transition for the 2–14 GHz frequency band has been designed and manufactured. Although the proposed antenna has the capability to exhibit a low VSWR over a wide band of frequencies, it draws some fluctuations in the main lobe radiation pattern at some parts of the frequency bandwidth. Accordingly, a new method is proposed to compensate the aforementioned impact by carving an arc shape to the open end of exponentially tapered plates. The associated curvature of this arc is optimized to completely remove this fluctuation. The measurement results show that the improved TEM horn antenna structure exhibits low VSWR as well as good radiation pattern over 2–14 GHz frequency band which is useful for automated pattern measurement ranges, eliminating the need for time consuming measurement interruptions normally required to change the source antenna to accommodate different frequency bands. Modified antenna also has significant applications in impulse radar systems, detection of low-observables, and test instrumentations in geological surveys.

In the following section, the design method for the preliminary 2–14 GHz TEM horn is discussed in detail and in the Section 3 the proposed method for modification of the preliminary antenna is presented.

2. DESIGN OF THE PRELIMINARY TEM HORN ANTENNA WITH TEM DOUBLE-RIDGED TRANSITION

Figure 1 shows the configuration of the preliminary TEM horn antenna. The construction of the TEM horn antenna is divided into two parts, a TEM double-ridged transition and a flare section of the horn with tapered parallel plates. The design of the horn section follows that of [16] which is explained briefly here. The TEM double-ridged transition is divided into two parts, a TEM double-ridged waveguide and a shorting plate (cavity back) located at the back of the waveguide.

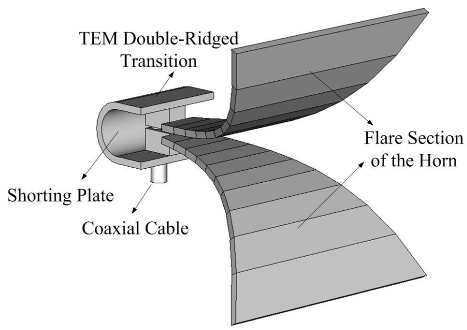


Figure 1. Configuration of the preliminary TEM horn antenna.

2.1. Design of the Horn Section

TEM horn antenna guides a spherical TEM-like mode between its two conductors. To radiate electromagnetic waves into the air, its flare angle, characteristic impedance variation between the two plates, plate length and width must be properly chosen, because these parameters are the most important design factors to achieve the wide-band characteristics of the TEM horn antenna.

The impedance variation of the tapered plates can be linear, exponential, Chebyshev or Hecken [19]. Linear tapered antennas can be built easily as compared to an exponentially tapered antenna. However, exponentially tapered plates have the advantage of smooth impedance variations. This approach reduces reflection coefficient and increases matching bandwidth [16]. A Chebyshev tapered structure improves directivity of the antenna, and yields the smallest minor-lobe amplitude for a fixed taper length [20].

In this paper, we use an exponentially tapered structure. Exponential impedance taper is used to match the characteristic impedance at the feed point to the impedance of the free space at the antenna aperture. In fact, the antenna acts as a transformer to match the transmission line and the free space. The configuration of the horn section is shown in Fig. 2. It is divided into ten sections, each section consists of a parallel plate waveguide.

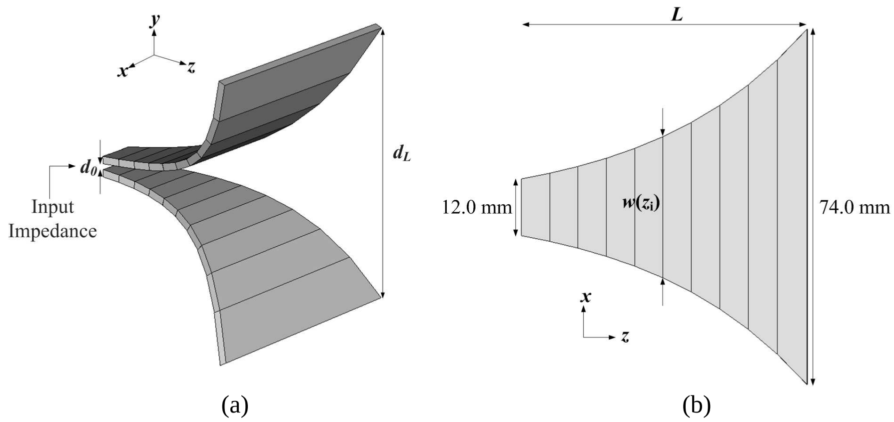


Figure 2. 3D Configuration of the horn section. (a) 3D view. (b) Top view. ($L = 60\,\mathrm{mm}$, $d_0 = 1.6\,\mathrm{mm}$, $d_L = 74.0\,\mathrm{mm}$).

Since the exponentially tapered matching technique is used, the characteristic impedance of each section, $Z(z_i)$, can be expressed as:

$$Z(z_i) = Z_0 \exp(\alpha z_i), \ z_i = \frac{iL}{N} \quad i = 1, 2, 3, \ldots, N; \ \alpha = \frac{1}{L} \ln\left(\frac{\eta}{Z_0}\right) \quad (1)$$

where Z_0 is the characteristic impedance of the feed line ($50\,\Omega$), η is the intrinsic impedance of the free space ($120\pi\Omega$), L is the antenna length, N is the number of the sections, and α is a constant value to be calculated using the intrinsic impedance of the free space, characteristic impedance of the feed line and the antenna length.

The separation between two parallel plates $d(z_i)$ is determined by an exponential function [16], so it is given by:

$$d(z_i) = a \exp(b z_i) \quad (2)$$

where a and b are constants to be determined using the separation between the plates at input d_0 and output aperture d_L, shown in

Fig. 2(a).

$$a = d_0 \quad b = \frac{1}{L}\ln\left(\frac{d_L}{d_0}\right) \tag{3}$$

To determine the plate width of the sections $w(z_i)$, the characteristic impedance of a parallel plate waveguide $Z(z_i)$, given by [21], is used:

$$Z(z_i) = \frac{d(z_i)}{w(z_i)}\eta \tag{4}$$

Design parameters of the horn section are calculated and optimized for 2–14 GHz using Eqs. (1)–(4). The length of the horn section is determined as $L = 0.4\lambda$, where λ is the wavelength at the lowest operating frequency and since the lowest operating frequency was selected as 2 GHz, the length of the horn section was determined as 60 mm. The dimensions of each section are shown in Table 1, which exhibits the lower size as compared to other similar antennas for EMC applications.

Table 1. Dimensions of the conventional TEM horn antenna.

Section (i)	z_i **(mm)**	$Z(z_i)$ **(Ohm)**	$w(z_i)$ **(mm)**	$d(z_i)$ **(mm)**
	0	50.00	12.05	1.60
1	6	61.18	14.45	2.34
2	12	74.88	17.32	3.44
3	18	91.63	20.77	5.04
4	24	112.14	24.91	7.40
5	30	137.24	29.86	10.88
6	36	167.95	35.80	15.96
7	42	205.53	42.93	23.42
8	48	251.53	51.47	34.36
9	54	307.81	61.71	50.42
10	60	376.76	74.00	74.00

2.2. Design of the Feed Section

In order to match the impedance of the horn section to the coaxial line, a TEM double-ridged transition is designed. Fig. 3 shows the calculated input impedance of the designed horn section. In Fig. 3, the real part gives a value around 40 Ω at the frequency band of 9.50 to 14.0 GHz and the imaginary part is close to zero. Since, the calculated input impedance of the TEM horn antenna is about 40 Ω, the TEM double-ridged waveguide is designed for a 40 Ω characteristic impedance to obtain low levels of VSWR throughout the transformation from the TEM-mode in the coaxial section to the TEM-mode in the parallel plate waveguide.

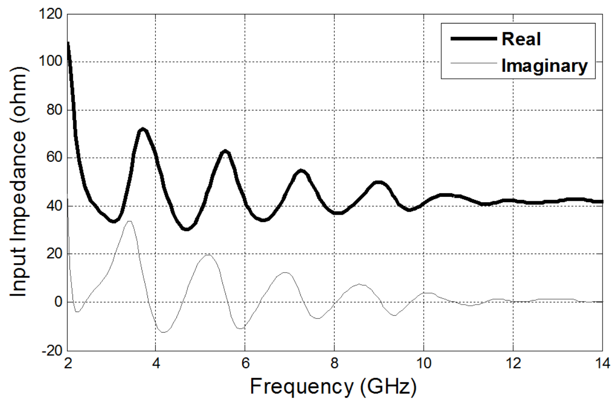


Figure 3. Calculated input impedance of the horn section.

The configuration of the feed section is shown in Fig. 4. As shown, the shield of the coaxial probe is connected to the lower ridge and its inner conductor is connected to the upper ridge by passing a tunnel through the lower ridge. For obtaining a low return loss, the inner conductor of the coaxial probe should be entered very close to the edge of the ridges.

It is very common to use a cavity back to obtain a much lower return loss in the 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. Hence, we consider an elliptical shaped cavity. The cavity dimensions are shown in Fig. 4. Since the cut-off frequency of the cavity is naturally higher than that of its cascaded ridged waveguide, at the low end of the frequency band the cavity essentially presents an open circuit in parallel with the coaxial probe so that all the energy is essentially directed along the ridged waveguide transmission line toward the antenna. At longer wavelengths, step discontinuities and short transmission line segments have lower order perturbations so that the impedance is almost entirely determined by the double-ridged rectangular waveguide.

As the frequency increases, radiation occurs closer to the cavity, this is because the traveling waves on the exponential TEM transmission line convert to radiating spherical modes sooner. At the higher end of the frequency band, the details of the ridged waveguide cavity become almost completely dominant and therefore control the impedance behavior of the antenna. These considerations lead the designer into an iterative design procedure wherein the low and high ends of the frequency band are matched by modifying the radiating structure and the waveguide cavity.

An experimental antenna is constructed using the results of the simulation, as shown in Fig. 5. The material for the conducting plates is aluminum with 4 mm thickness. The overall length of the antenna is 80 mm and the dimensions of the aperture are 74 mm × 74 mm. The antenna is fed through a SMA connector. The dimensions of the connector are shown in Fig. 4.

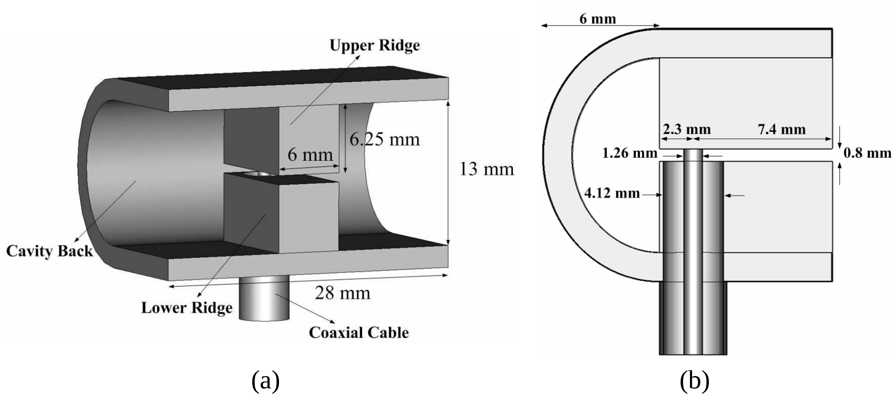


Figure 4. Configuration of the feed section. (a) 3D view. (b) Side view.

Figure 5. Photograph of the manufactured antenna.

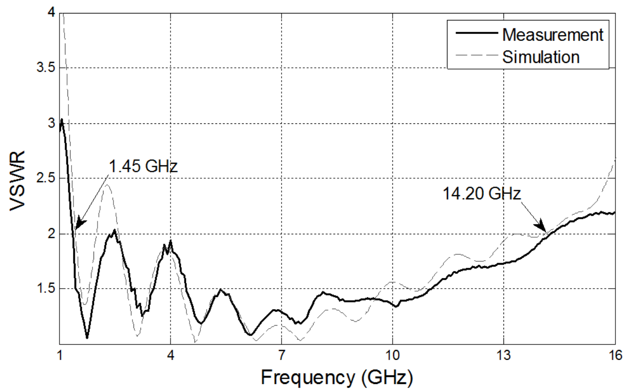


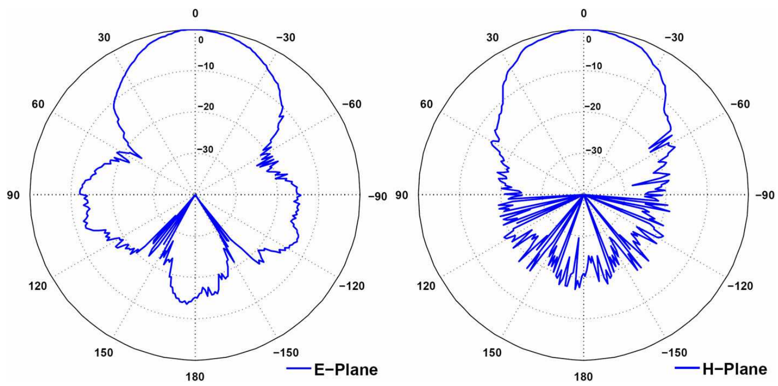
Figure 6. VSWR of the preliminary TEM horn antenna.

Figure 6 shows the measured and simulated VSWR characteristic for the TEM horn antenna, displayed in Fig. 5. The simulated performance was obtained using CST microwave studio simulator [22], and measurements are accomplished using Agilent 8722ES network analyzer. As shown, the measured and simulated VSWRs are similar to each other. The measured results present that the proposed TEM horn antenna has the frequency band of 1.45 to 14.20 GHz for VSWR ≤ 2.0.

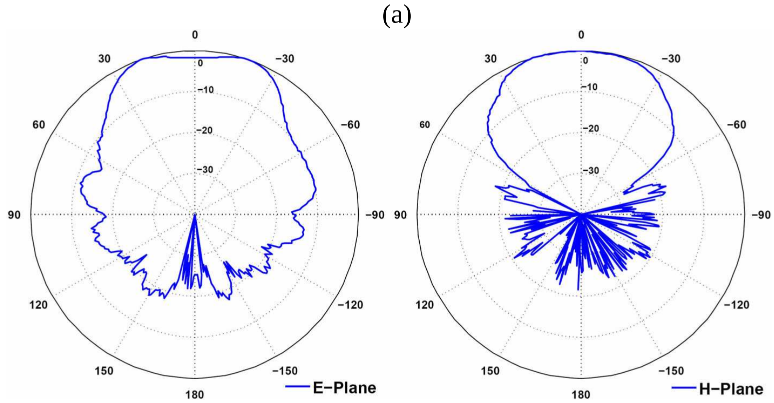
The antenna gain and radiation pattern are measured in a fully anechoic chamber. Fig. 7 shows measured E- and H-plane radiation patterns at three different frequencies. As shown, at higher frequencies, there is a fluctuation in radiation pattern; therefore the single main lobe is split into two large side lobes that grow in an equally spaced fashion around the 0° center axis while the main lobe appears to be strongly indented. 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. The presence of these side lobes is particularly problematic for EMC applications such as testing in an anechoic chamber, which usually depend on a well-defined radiation pattern with only a single main lobe. In the following section, a new method is proposed to remove this drawback For frequencies below 10 GHz, the radiation pattern looks as expected for a typical horn antenna, i.e., it has one dominant main lobe.

3. MODIFICATION OF THE TEM-HORN ANTENNA

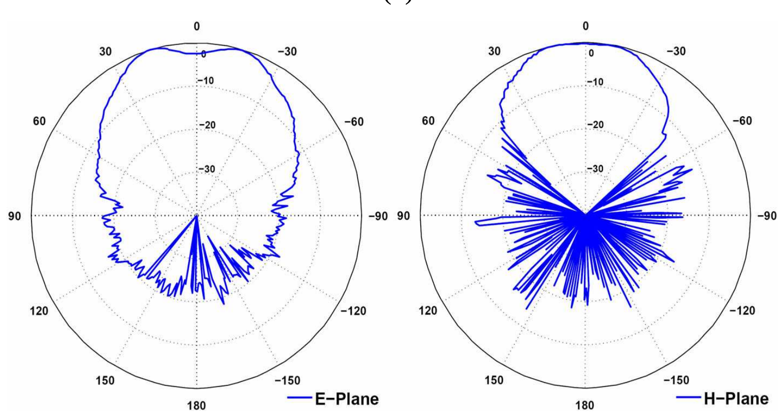
As shown in Fig. 8, to achieve the desired radiation pattern, an arc shape part is carved from the end of two exponentially tapered plates of this antenna structure. This changes the field distribution at the



(a)



(b)



(c)

Figure 7. Radiation patterns of the preliminary TEM horn antenna (a) 4 GHz, (b) 10 GHz, (c) 14 GHz.

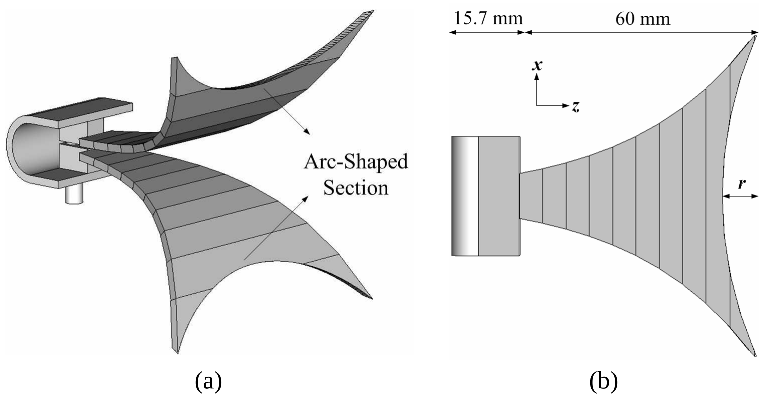


Figure 8. Modified TEM horn antenna. (a) 3D view. (b) Top view.

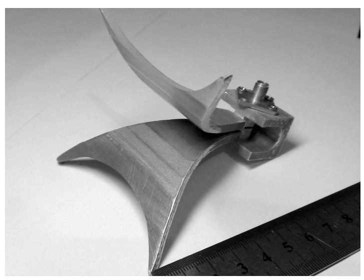


Figure 9. Photograph of the manufactured modified TEM horn antenna.

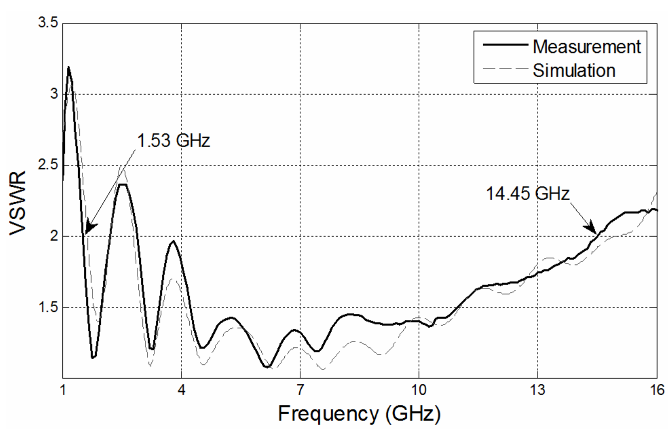


Figure 10. VSWR of the modified TEM horn antenna.

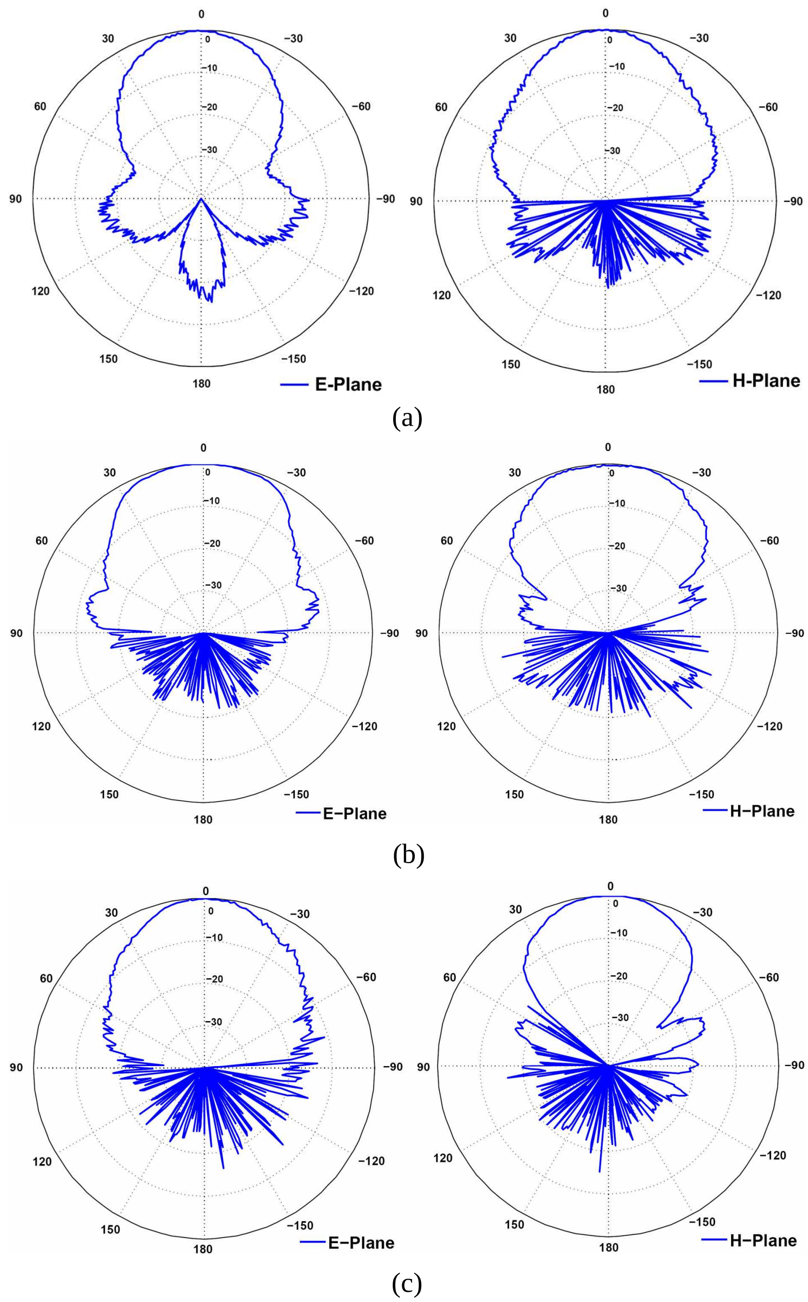


Figure 11. Radiation patterns of the modified TEM horn antenna (a) 4 GHz, (b) 10 GHz, (c) 14 GHz.

antenna aperture in such a way that the far field radiation pattern over the frequency range of 10 to 14 GHz, and along the main axis exhibits a constructive effect. To do this, the corresponding corner points of the arc are kept fixed, while the depth is optimized to achieve the desired field distribution at the antenna aperture. Through extensive simulation, the optimum value for r is 9.0 mm (Fig. 8). In order to confirm the correctness of the proposed method, as shown in Fig. 9, the aperture of the previously manufactured antenna is carved.

The corresponding VSWR of the modified TEM horn antenna is shown in Fig. 10. The VSWR of the preliminary and modified TEM horn antenna correspond extremely well, the only substantial difference is in the peak value at the 2.5 GHz.

Measured radiation patterns for the modified TEM horn antenna are shown in Fig. 11. The measured results confirm that the desired field distribution at the antenna aperture is achieved, so there is only one dominant main lobe over the entire frequency band. Also, from this figure it is seen that the back lobe and side lobe levels (SLL) are low. Furthermore as the frequency grows, the pattern becomes more directional.

Figure 12 shows the total gain of the preliminary and the modified TEM horn antenna over the frequency range of 2 to 14 GHz. The results show that the gain at broadside direction for the modified TEM horn antenna increases with frequency, with a maximum value around 12.58 dB at 14 GHz while the gain for the preliminary TEM horn antenna has a peak value of 11.52 dB.

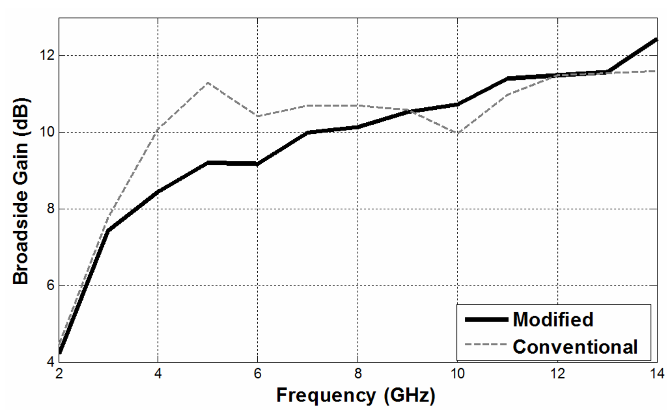


Figure 12. Total gain versus frequency for the conventional and modified TEM horn antenna.

4. CONCLUSIONS

A modified TEM horn antenna structure is proposed. In spite of the conventional TEM horn antenna which suffers from fluctuations in the radiation pattern's main lobe over some part of frequency band, the proposed antenna is shown to have a smooth shape, as well as low VSWR. To do this, an arc shape is carved from the open end of exponentially tapered plates. The associated curvature of this arc is optimized to completely remove the aforementioned fluctuation. This is done by changing the field distribution at the antenna aperture over the frequency band, wherein this fluctuation appears. The designed antenna has a small size, reduced weight and relatively high gain. As a result, the proposed antenna is well suited for broadband applications such as EMC and space borne applications..

ACKNOWLEDGMENT

This paper has the financial support of the Iran Telecommunication Research Centre.

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