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A Novel Ultra-Wide Band Magneto-Electric Dipole Antenna with Cavity Reflector

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Abstract—A magneto-electric dipole antenna with novel feed design with rectangular cavity is proposed, fabricated and analyzed. Due to this new feeding structure, the antenna has been able to achieve wide impedance bandwidth of 68.8% to accommodate various wireless communication applications. The stable peak gain of 10.45 dBi with unidirectional radiation pattern has also been reported for the entire range of operation. The antenna has also been able to achieve low cross polarization levels lower than −30 dB. The antenna exhibits low side lobe radiations and almost identical E plane and H plane radiation patterns in the operating frequency range of 2.0 GHz–4.1 GHz. Due to its good electrical characteristics, the antenna is suitable for various S-band wireless communication applications.

1. INTRODUCTION

With the rapid development of modern wireless communication systems, wideband low profile antenna with unidirectional radiation pattern having high electrical performance, such as low cross polarization, low back radiations and stable gain, are in great demand. Different methods were proposed to achieve these electrical parameters in literature. High gain antennas such as log-periodic, horn and reflector antennas, have disadvantage of bulky structure. A unidirectional patch antenna possesses many advantages, such as light weight, low profile and easy fabrication, but does not have wide impedance bandwidth, required for modern communications.

The concept of equal E-plane and H-plane radiation patterns was proposed by Clavin [1, 2], by exciting an electric dipole and a magnetic dipole simultaneously. But these antennas suffer major disadvantages of instable gain and complex circuitry over a wide operating frequency band. Recently, a wideband unidirectional antenna, with 43.8% impedance bandwidth and equal E-plane and H-plane radiation patterns, was proposed by Luk and Wong [3] and designated as magneto-electric dipole antenna. The antenna possesses many advantages, such as simple structure, equal E-plane and H-plane radiation patterns, low cross polarization level, wide impedance bandwidth and constant gain within the range of operating frequency. A wideband unidirectional antenna composed of shorted patch antenna and inverse bowtie electric dipole is given by [4]. In [5], a dual-polarized magneto-electric dipole antenna, fed by four Γ-shaped probes, achieved an impedance bandwidth of 24.9%, for GSM 1800 and GSM 1900 bands. A broadband dual-band antenna for mobile base station was designed in [6] using L-shaped feeding strips, to achieve an impedance bandwidth of 34% for 0.78 GHz–1.1 GHz and 49.5% for 1.58 GHz–2.62 GHz. Several improved designs for the antenna have been reported in the literature [7, 8]. The antenna has gained popularity especially in wireless base station system and many more wireless communication systems applications.

In this paper, first a novel E-shaped electric dipole and a shorted patch along with a novel feed design has been designed, fabricated and tested. Experimental results agree well with the simulation

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ones. With the novel feed design, the antenna has been able to achieve ultra-wide bandwidth of 70.9% from 2.0 GHz–4.2 GHz. A peak stable gain of 7.5 dBi has also been reported. Identical radiation patterns for both E-plane and H-plane have been observed due to the proposed feeding structure. After verification of experimental results with the simulated results, the antenna has been kept in rectangular cavity to improve the gain and reduce cross polarization level. The antenna has been able to provide peak gain of 10.45 dBi with 68.8% impedance bandwidth. Cross polarization level lower than −30 dB has also been observed within the operating range of frequency, giving improved polarization purity. Antenna efficiency greater than 90% has been reported.

Figure 1. Prototype of proposed antenna.

2. DESIGN AND SIMULATION OF E-SHAPED ANTENNA WITHOUT CAVITY

Figure 1 represents a photograph of the fabricated and proposed magneto-electric dipole antenna. The geometry of the proposed antenna is given in Fig. 2(a) and Fig. 2(b). The proposed antenna has been designed for the center frequency $f_0 = 2.5$ GHz. The length of ground plane, $G_L = 166$ mm, and width, $G_W = 118$ mm, have been taken after optimization of antenna parameters. The antenna has a mainly three-parts radiation structure, a feeding structure and a ground plane. The radiation structure has vertically oriented quarter wave shorted patch as magnetic dipole and a planar E-shaped dipole as an electric dipole. The height of the antenna $H = 30$ mm. The novel feeding structure has been designed in such a manner that it can provide equal excitation to magnetic and electric dipoles, for wide impedance matching. It consists of two inverted L-shaped plates, separated by $\Delta s = 2$ mm. The longest vertical portion of inverted L-shaped feed behaves as transmission line. A coaxial probe is connected to the center of two transmission lines via 8 mm long and 2.5 mm wide (Ws) copper strip. With each transmission line, a coupled line is connected to couple the electromagnetic energy to electric and magnetic dipoles. The coupled line consists of one horizontal copper strip and one vertical copper strip. The inductive reactance provided by the horizontal copper strip is counter balanced by capacitive reactance provided by the vertical copper strip. The coaxial feed makes the antenna d.c grounded and hence satisfying the requirement of many outdoor antennas for various wireless communication applications. Ground plane and all other parts of the proposed antenna have been made of copper with 0.3 mm thickness. One end of the coaxial cable is connected to SMA connector, which is located underneath the ground. The radius of SMA probe is 0.635 mm, and the length over the ground plane has been chosen as $\Delta h = 1$ mm. The designed antenna has been optimized and simulated on MOM based IE3D software. The purpose of the optimization is to maximize the impedance and gain bandwidth and also to maintain unidirectional stable radiation pattern in the range of operation. Table 1 gives the optimized geometrical parameters of the proposed antenna.

3. PRINCIPLE OF OPERATION

It is a known fact that an electric dipole gives figure eight radiation pattern in E-plane and figure O radiation pattern in H-plane. Whereas, the magnetic dipole gives figure O radiation pattern in E-plane and figure eight radiation pattern in H-plane. If an electric dipole and a magnetic dipole are excited simultaneously with proper amplitudes and phases, the radiating power will be reinforced in

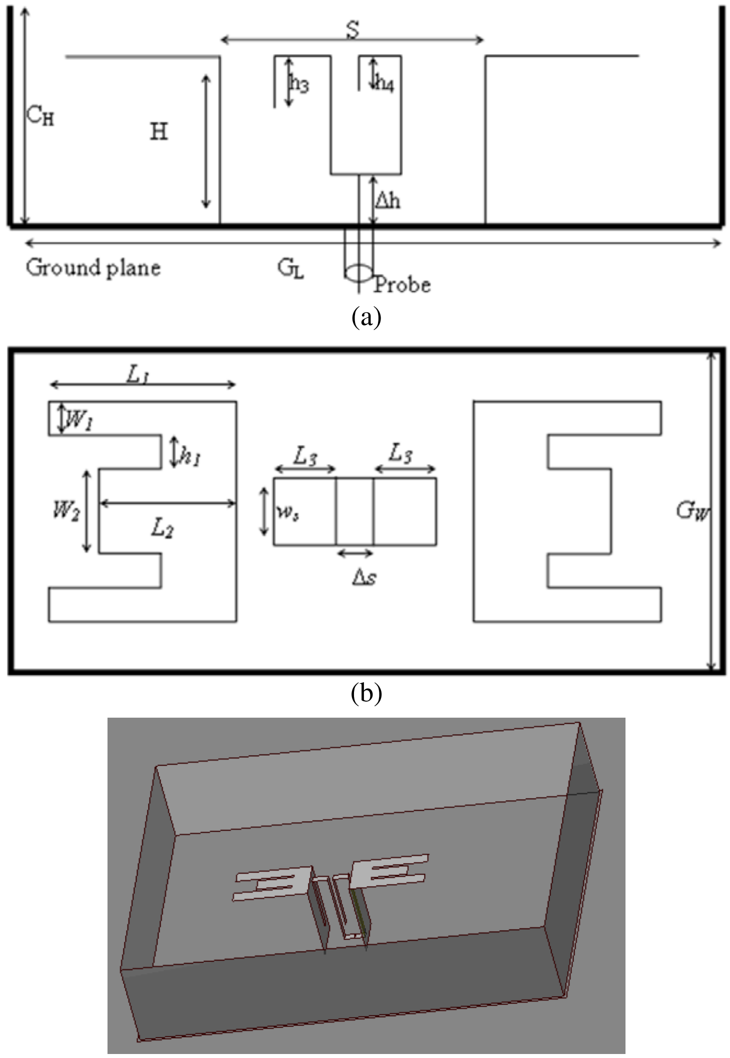


Figure 2. Schematic of proposed antenna. (a) Side view and (b) top view, (c) 3-D view of proposed antenna.

Table 1. Antenna specification.

Parameter	$\mathbf{G_L}$	$\mathbf{G_W}$	**H**	$\mathbf{L_1}$	$\mathbf{L_2}$	$\mathbf{L_3}$	$\mathbf{L_4}$	$\mathbf{W_1}$	$\mathbf{W_2}$
Value(mm)	**164**	**118**	**30**	**27.5**	**20**	**6**	**6**	**4.5**	**5**
Parameter	**Ws**	**S**	$\mathbf{h_1}$	$\mathbf{h_2}$	$\mathbf{h_3}$	$\mathbf{h_4}$	**Δh**	**Δs**	$\mathbf{C_H}$
Value(mm)	**2.5**	**16**	**1**	**1**	**22**	**22**	**1**	**2**	**34**

the broadside direction and suppressed in the back side, resulting in uniform unidirectional broadside radiation pattern. These two dipoles are excited one by one after $T/4$ time, where T denotes the time period to complete one cycle. Fig. 3 indicates the current distribution of the E-shaped antenna at different times.

At time $t = 0$, the horizontal current on the planar E-shaped electric dipole dominates, and the current on two vertically oriented shorted patches is negligible. Hence, the electric dipole mode is strongly excited at time $t = 0$.

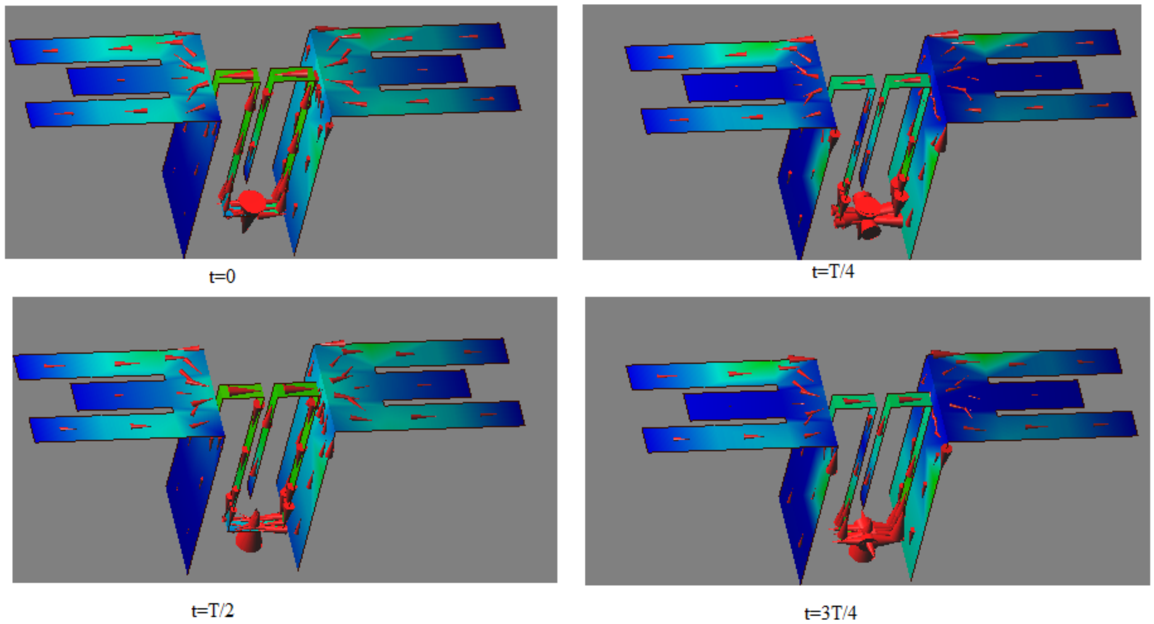


Figure 3. Current distribution of E-shaped antenna at 2.6 GHz.

At time $t = T/4$, the horizontal current on E-shaped patches is very weak, and the current on two vertically oriented shorted patches dominate. This behavior of current indicates that the current loop radiates as magnetic dipole, which is strongly excited at $t = T/4$.

For the next two cycles, the process repeats but in the opposite direction.

4. PERFORMANCE OF E-SHAPED ANTENNA

A prototype of the E-shaped antenna was made to verify and analyze the design. The measured results match with simulated ones within acceptable limit. Fig. 4 shows the predicted and measured return

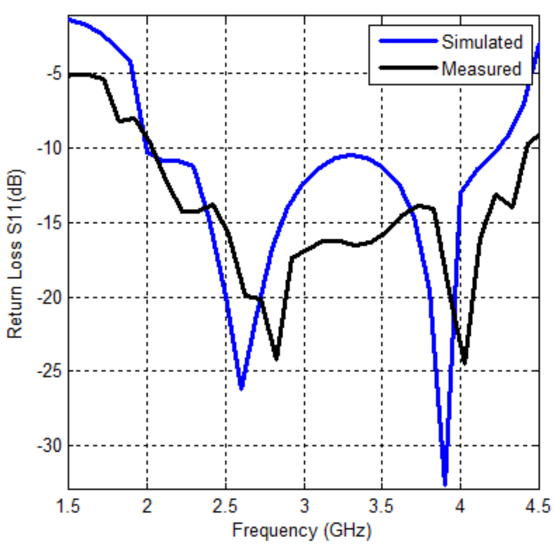


Figure 4. The simulated and measured return loss of E-shaped antenna.

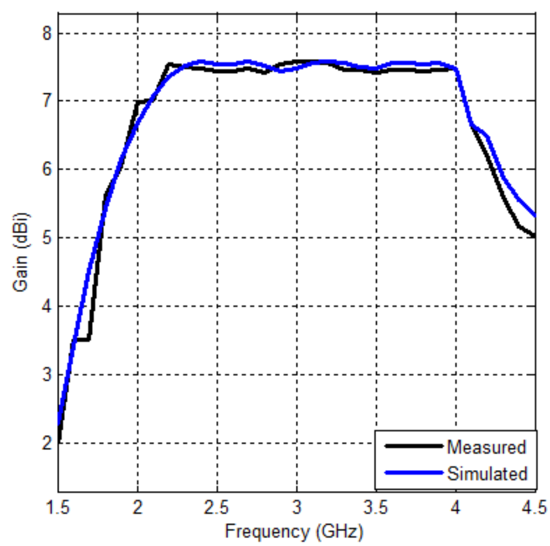


Figure 5. The simulated and measured gain of E-shaped antenna.

losses of the E-shaped antenna. It has been found that the simulated impedance bandwidth of the antenna was 2.2 GHz, ranging from 2.0 GHz to 4.2 GHz or 70.9%, hence making the antenna an ultra-wide band antenna. The variation of simulated and measured gains of the antenna with frequency of operation is shown in Fig. 5. It is clear from the figure that the antenna is able to provide a gain of 7.5 dBi and remains almost constant for the entire range of antenna bandwidth.

5. PROPOSED E-SHAPED ANTENNA WITH RECTANGULAR CAVITY REFLECTOR

Though the initial E-shaped antenna showed impressive and concrete results, there was still scope for improvement in gain. Hence, to improve the gain, a rectangular shaped cavity reflector with length C_L, breadth G_W and height C_H, as shown in Fig. 1, was inserted in the initial design of the E-shaped antenna. To gather more information regarding the effect of cavity reflector, the parametric study of C_L and C_H was done, and their impacts on gain and polarization radiation patterns were obtained. It is noted that while varying one parameter, all other parameters were kept constant.

5.1. Effect of Cavity Height, C_H

To analyze the effect of cavity height, different cavity heights of 32 mm, 34 mm and 36 mm were selected. As shown in Fig. 6, the impedance bandwidth is slightly influenced by the height of cavity. As the height increases, its impedance bandwidth starts decreasing, however very small. It has been observed that with an increment of 2 mm in cavity height, the impedance bandwidth reduces by 2.2%. The impact of change in cavity height has also been studied, and it has been found that the gain of antenna increases as the height of cavity increases, which is indicated by Fig. 7. Without rectangular cavity, the stable and peak gain of 7.5 dBi was obtained. But after inserting rectangular cavity, the simulated peak gains of 10.22 dBi, 10.4 dBi and 10.58 dBi were observed at cavity heights of 32 mm, 34 mm and 36 mm, respectively. This increase in gain with cavity height was observed because the side lobe radiation of the antenna concentrates in the broadside direction. Fig. 8 shows co-polar and cross-polar radiation patterns at 2.8 GHz for different cavity heights. Fig. 8 indicates co-polarization and cross-polarization radiation pattern in E-plane at 2.4 GHz for different cavity heights chosen for analysis. From Fig. 8(a), it is observed that co-polar radiation takes place at broadside of the antenna, and it is almost constant

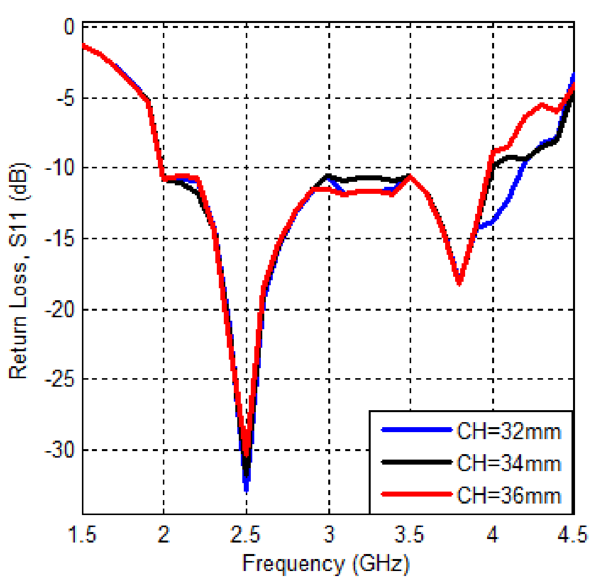


Figure 6. Variation of return loss with frequency for different cavity heights.

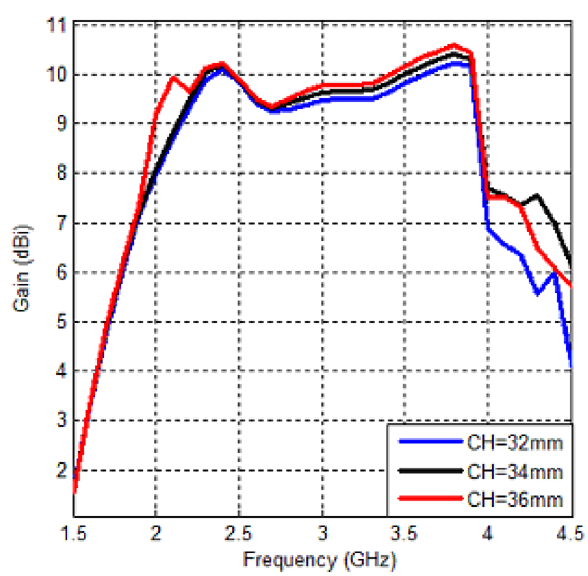
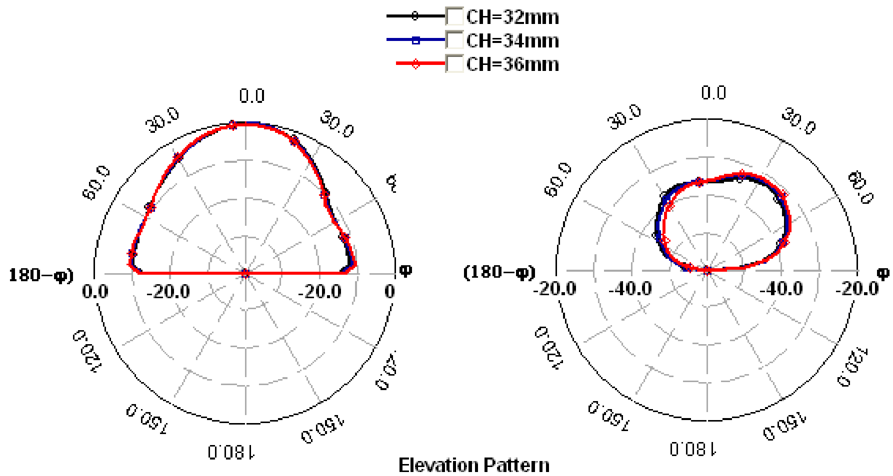


Figure 7. Variation of gain with frequency at different cavity heights.



(a) (b)

Figure 8. (a) Co-polar and (b) cross polar radiation patterns in E-plane for different cavity height at 2.4 GHz.

for various cavity heights. Fig. 8(b) indicates that the cross-polarization radiation pattern was decreased with the increase in height of cavity though the decremented value is very small. It is also observed that cross-polarization level lower than -32 dB is obtained for cavity height of 36 mm, which indicates more purity in radiations of antenna.

5.2. Effect of Cavity Length, C_L

The length of cavity was another parameter whose impact was analyzed for different cavity lengths of 164 mm, 166 mm and 168 mm. Fig. 9 indicates the variation of reflection coefficient with operating frequency for different lengths of cavity. It is observed that as the length increases, impedance bandwidth

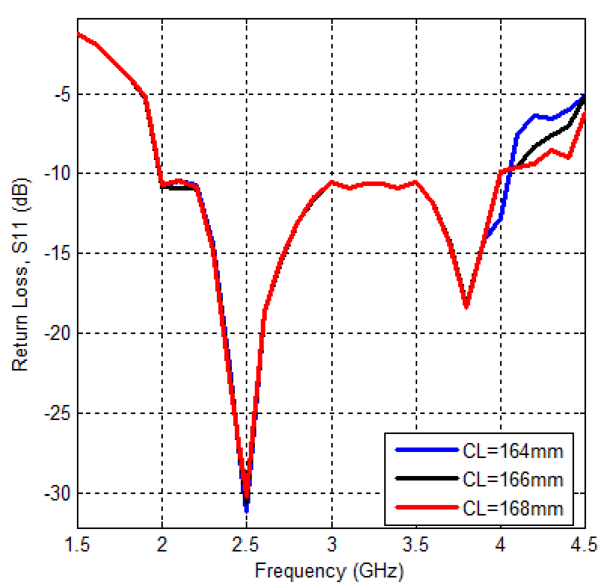


Figure 9. Variation of return loss with frequency for different cavity lengths.

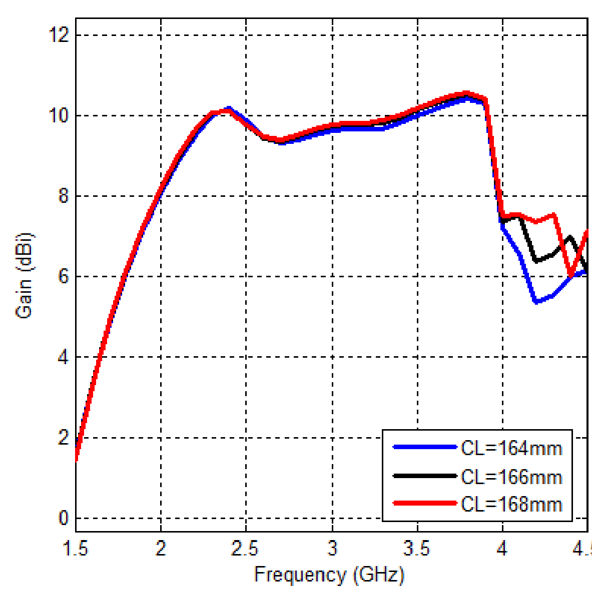


Figure 10. Variation of gain with frequency for different cavity length.

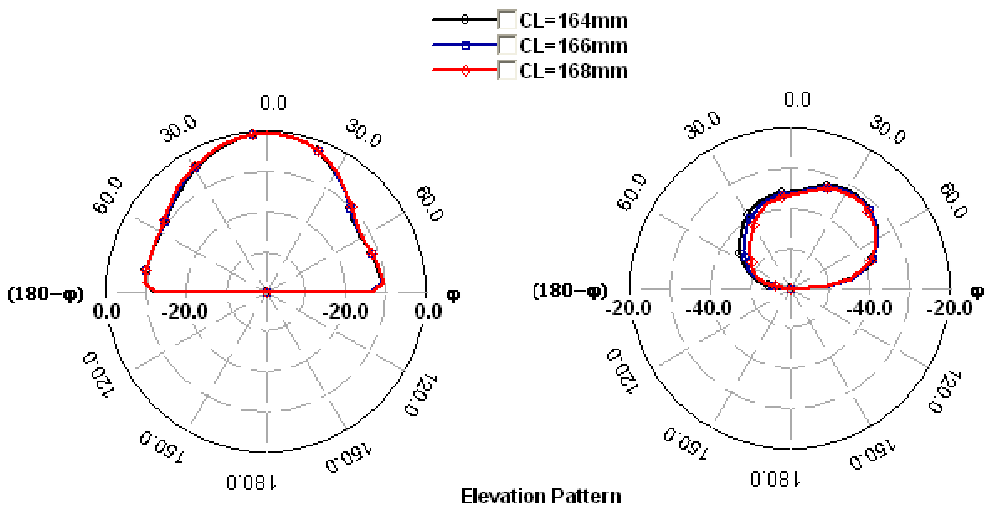


Figure 11. Simulated (a) co and (b) cross polarization radiation patterns in E-plane for different cavity length at 2.4 GHz.

decreases. Moreover, it is also noticed that with an increment of 2 mm in cavity length, the impedance bandwidth reduces by 2.2%. Fig. 10 shows the variation of antenna gain at broadside direction for different lengths of cavity. From the figure it is seen that gain increases as the cavity length increases because of increased ground plane size and reduced back lobe radiations. It was also observed that when the cavity size becomes comparable with the maximum antenna dimensions $(2L_1 + S)$, the gain of antenna decreases due to increased back lobe radiations. After inserting rectangular cavity, the simulated peak gains of 10.4 dBi, 10.51 dBi and 10.66 dBi were observed for cavity lengths of 164 mm, 166 mm and 168 mm, respectively. Fig. 11 indicates the variation of co-polarization and cross-polarization radiation patterns in E-plane at 2.4 GHz for different lengths of cavity. From Fig. 11(a) it is observed that co-polarization radiation pattern is nearly identical, and it does not vary much with the change in cavity length. Cross-polarization radiation pattern for different lengths of cavity is shown in Fig. 11(b), and it is observed that cross-polarization decreases with the increase in length, though the change is very small. It is also observed that the cross-polarization level better than −31 dB is obtained, which indicates that radiation of the antenna becomes purer.

6. RESULTS AND DISCUSSION

From the results obtained using parametric study of the E-shaped antenna for different cavity heights and lengths, a final prototype of the proposed antenna with rectangular cavity has been designed, fabricated and tested, shown in Fig. 1. The final prototype has been designed with cavity height of 34 mm and cavity length of 165 mm. The measured results match with the simulated ones within acceptable limit. Fig. 12 indicates the variation of return loss with frequency. From the figure, it is observed that return loss is less than −10 dB for the bandwidth 2.0 GHz to 4.1 GHz, which gives an impedance bandwidth of 68.8%, better than [3, 5]. Fig. 13 indicates the variation of measured and predicted gains with frequency. It is observed that the predicted peak gain of the antenna at broadside is 10.45 dBi, which matches well with the measured broadside gain of 10.2 dBi. It is also observed that gain of the antenna is almost constant within the entire range of operation.

Another important parameter is antenna efficiency which shows the effectiveness of antenna in terms of radiations of electromagnetic waves. Fig. 14 indicates the variation of antenna efficiency and radiation efficiency with respect to frequency. From the figure, it is clearly seen that antenna efficiency of more than 90% has been achieved, which shows that the antenna radiates well within the entire range of operation. It is also observed that radiation efficiency of antenna is greater than 95%, which shows that minimum losses are encountered while antenna is radiating.

The simulated and measured E-plane and H-plane radiation patterns at 2.4 GHz, 2.8 GHz and 3.2 GHz are shown in Fig. 15, which indicate that the antenna is unidirectional, hence identical E-plane and H-plane radiation patterns are observed in the range of operation.

To show the effectiveness of the antenna, cross-polarization radiation patterns in E-plane at 2.4 GHz, 2.8 GHz and 3.2 GHz are shown in Fig. 16. From the measured results, it is observed that cross-polarization levels better than −30 dB have been successfully achieved. It is also observed from the results that the antenna has back radiations, which can be decreased by increasing the size of ground plane.

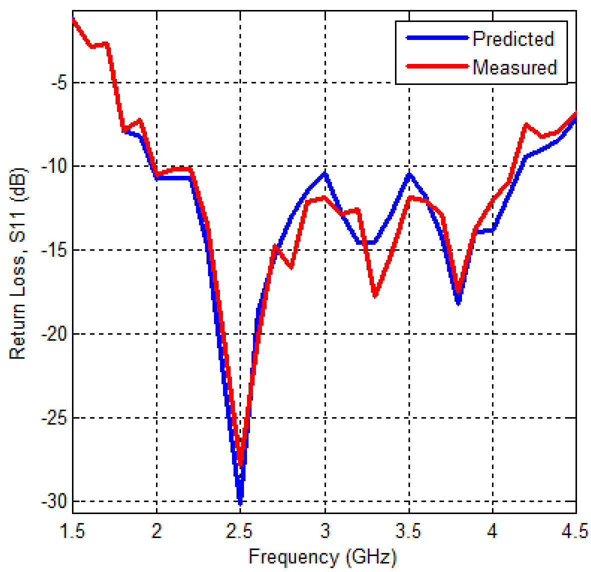


Figure 12. Simulated and measured return loss vs frequency of proposed antenna.

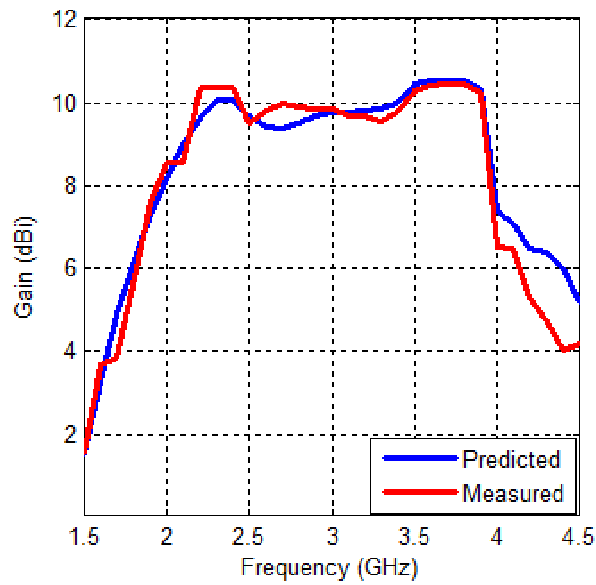


Figure 13. Simulated and measured gain vs frequency of proposed antenna.

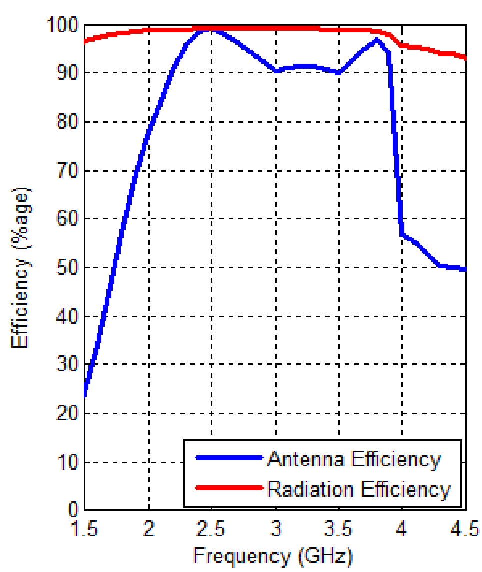


Figure 14. Simulated antenna efficiency and radiation efficiency vs frequency of proposed antenna.

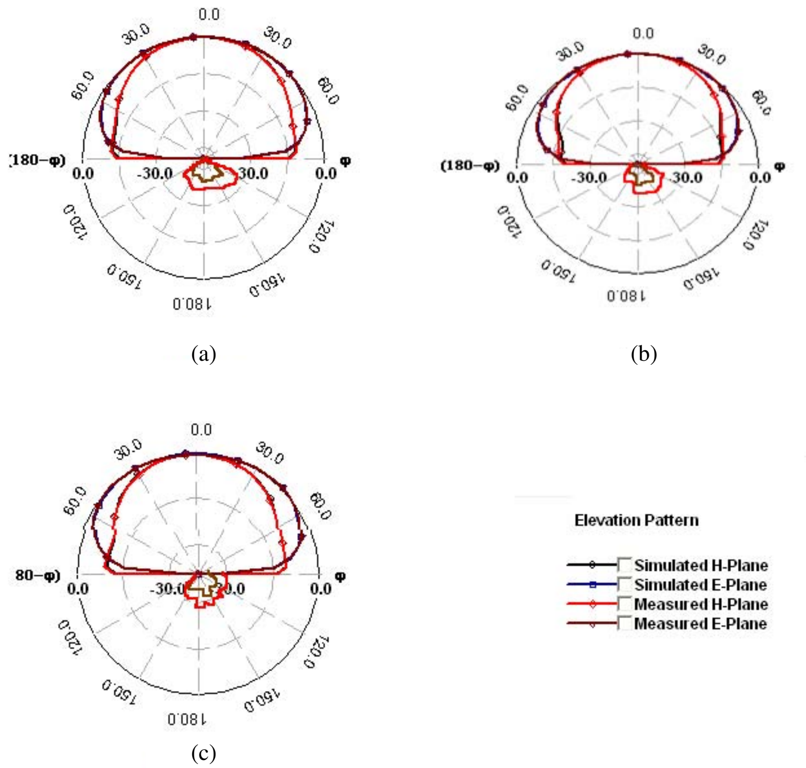


Figure 15. Simulated and measured E-plane and H-plane radiation patterns at: (a) 2.4 GHz, (b) 2.8 GHz and (c) 3.2 GHz.

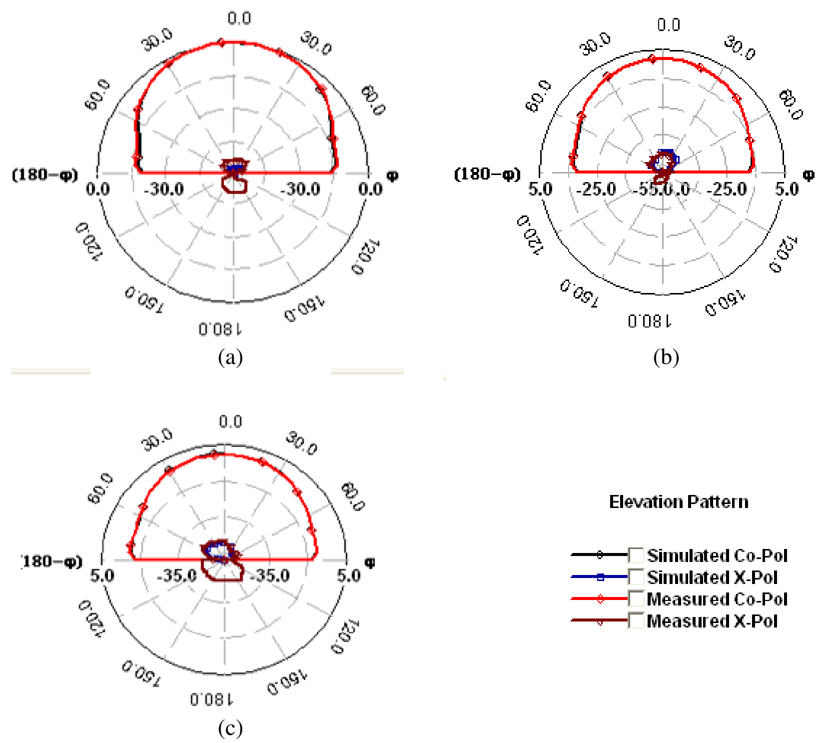


Figure 16. Simulated and measured co-polarization and cross polarization radiation patterns at: (a) 2.4 GHz, (b) 2.8 GHz, (c) 3.2 GHz.

7. CONCLUSION

A novel and simple E-shaped magneto-electric dipole antenna with novel feed design with rectangular cavity has been designed and fabricated. The measured and simulated results indicate that it possesses wide impedance bandwidth, which is 68.8% from 2 GHz–4.1 GHz. A stable unidirectional radiation pattern with more than 90% antenna efficiency has also been observed. The antenna exhibits equal E-plane and H-plane radiation patterns with stable peak gain of 10.45 dBi and low cross-polarization level less than -30 dB. Due to its good electrical characteristics, the antenna is suitable for various wireless communication applications in S-band.

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