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A Novel Magneto-Electric Monopole Antenna for C Band Wireless Applications

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Abstract—A new design of non-planar magneto-electric monopole antenna is proposed and presented. This antenna consists of a novel design of electric monopole with dual ꓶ shaped feed line design and possesses 61.5% impedance bandwidth, from 4.5 GHz–8.5 GHz. The antenna exhibits stable omnidirectional radiation pattern with almost identical E-plane and H-plane radiation patterns and also provides a peak gain of 7.4 dBi. Due to its good electrical characteristics and radiation parameters, the antenna has great capability to operate in C band, to overcome the challenges of multi-frequency applications.

1. INTRODUCTION

Ultra-Wide Band (UWB) communication system covering 3.1 GHz–10.6 GHz was released by FCC in 2002. It requires a compact antenna providing wide band characteristics over the entire range of operation. Due to their appealing characteristics of wide bandwidth, simple structures, omnidirectional radiation patterns, and ease of design, monopole antennas have been proposed. Broadband planar monopole antennas have all the advantages in terms of cost and ease of fabrication, but in terms of gain, directivity, stable radiation pattern, they definitely need improvement. In recent years with the development of the modern wireless techniques, the demand for low profile, light weight, easy design and fabrication, low cost broadband antennas have attracted researchers for short distance communication devices [1, 2]. Worldwide interoperability for microwave access (WiMAX) and wireless local area network (WLAN) have become very popular wireless communication systems and are widely studied, with their applications in mobile devices [1–4]. But it is also observed that to enhance the performance and make the antenna functional in a complicated and diversified environment as WLAN and WiMAX, the antenna should cover multiple frequency bands to provide stable omnidirectional radiation patterns and desired gain to justify its suitability for WLAN (2.4–2.484, 5.15–5.35, and 5.725–5.825 GHz) and WiMAX (3.3–3.69 and 5.25–5.85 GHz) communication systems. It is also possible to use WLAN and WiMAX simultaneously in the same system. Hence, it is necessary to design a single antenna to cover multiple bands. Several planar printed monopole antennas using slot structures and toothbrush patch have been proposed and designed by the researchers, to achieve either a wide-band property or a dual-band feature to meet wide-band communication system applications [5–8]. Some of these antennas were able to meet the ever-increasing multiple band communication requirements. So, in order to serve more to the communication systems, several multiband monopole antennas with meander lines have been presented in [9–12]. Some of these reported multiband antennas cannot be integrated into portable devices as an internal antenna because of their large sizes or complex structures. In addition to above, microstrip fed monopole antennas have been widely studied and applied to modern portable terminals as they have simple structures with ease of fabrication and debugging [10, 13]. However, most of these monopole antennas are large in size with low gain. The concept of equal E-plane and

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H-plane radiation patterns was proposed by Clavin et al. [14, 15], by exciting an electric dipole and a magnetic dipole simultaneously. But these antennas suffer a major disadvantages of unstable 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 [16] 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. In [17], a multiband planar monopole magneto-electric monopole antenna providing two wide bands for covering seven-band LTE/GSM/UMTS operation was presented and achieved impedance bandwidth of 38.5% for 704–1040 MHz and 44.7% for 1.56 GHz–2.46 GHz. To the authors' best of knowledge, no non-planar magneto-electric monopole antenna has been reported so far.

In this paper, the first non-planar magneto-electric monopole antenna is designed, fabricated and analyzed for UWB applications. The novel magneto-electric monopole antenna with dual Γ-shaped feed and truncated ground plane operates from 4.5 GHz to 8.5 GHz, having wide potential for satellite communication and radio navigation as well. The antenna has achieved peak gain of 7.4 dBi in the operating range of frequency. Almost identical radiation pattern for both E-plane and H-plane has also been shown by the antenna, indicating omnidirectional radiation pattern. Not only has this novel proposed antenna provided high peak gain with stable radiation pattern, as compared to various planar antennas designed and presented so far, but the cost of fabrication is also very low.

2. ANTENNA DESIGN

The geometry of the proposed antenna is given in Fig. 1(a) and Fig. 1(b). The length of ground plane, G_L, is 65 mm and width, G_W, is 98 mm. The optimized ground plane size of $G_L \times G_W$ has been taken for

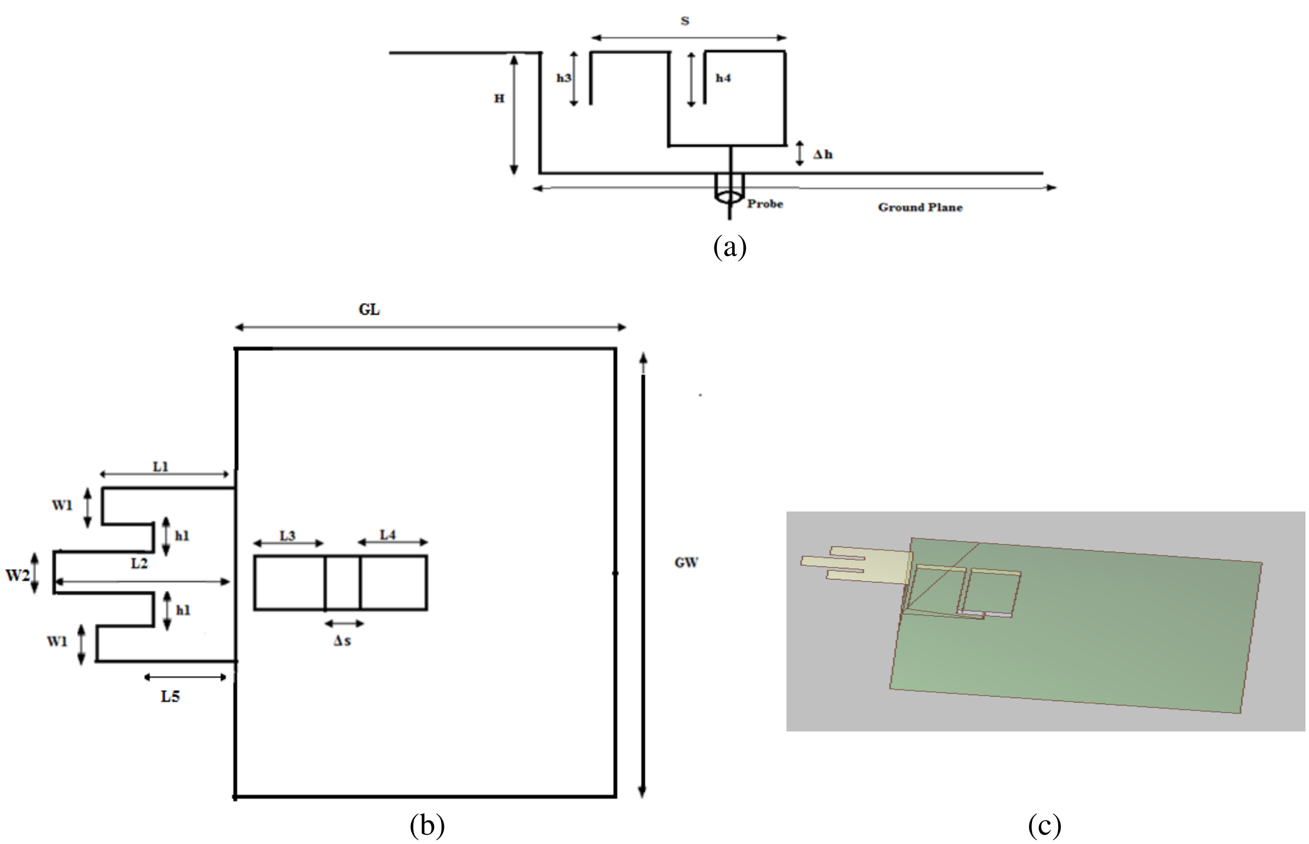


Figure 1. (a) Side view of the proposed antenna. (b) Top view of proposed antenna. (c) 3-D view of proposed antenna.

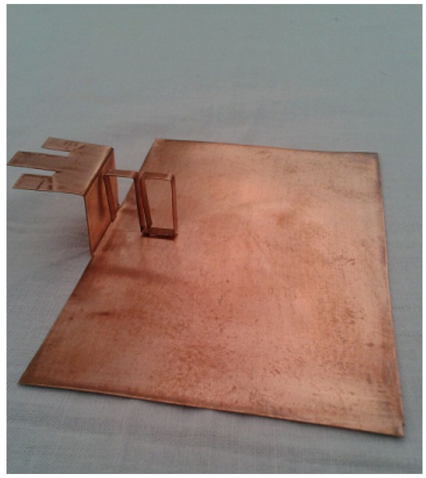


Figure 2. Prototype of proposed antenna.

Table 1. Antenna specification.

Parameter	G_L	G_W	L_1	L_2	$L_3 = L_4$	L_5	W_1
Value (mm)	65	98	20	15	7	8.5	5.5
Parameter	W_2	W_s	h_1	$h_3 = h_4$	$H = S$	Δh	Δs
Value (mm)	6.5	3	2	13	16	2	1

antenna design. The antenna consists of three parts — a radiating structure, a feeding structure and a ground plane. The radiating structure has vertically oriented shorted patch as magnetic monopole and a planar E-shaped patch as an electric monopole, with middle strip length greater than the length of upper strip as well as lower strip, hence giving it a unique shape. The height of the antenna (H) is 16 mm. To meet the low impedance of monopole, two ˥ feeding structures are connected in parallel which excite the magnetic monopole and electric monopole equally and provide wide impedance matching. The two ˥ shaped feeding structure are separated by $\Delta_s = 1$ mm. The longest vertical portion of each ˥-shaped feed behaves as a 50 ohms transmission line. A coaxial probe is connected to the center of two transmission lines via 8 mm long and 3 mm wide (W_s) copper strip. 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 is chosen as $\Delta_h = 2$ mm. With each transmission line, a coupled line is connected to couple the electromagnetic energy to electric and magnetic monopoles. 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. Ground plane and all other parts of the proposed antenna have been made of copper with 0.3 mm thickness. The designed antenna has been optimized and simulated on MOM based IE3D software. The 3-D view of proposed antenna is shown in Fig. 1(c). The purpose of optimization is to maximize the impedance, gain and bandwidth while maintaining unidirectional as well as stable radiation pattern throughout the range of operation. The prototype of the proposed antenna is shown in Fig. 2, and Table 1 represents the optimized geometrical parameters of the proposed antenna.

3. CURRENT DISTRIBUTION

To prove the operation of magneto-electric monopole antenna, the current distribution of the proposed antenna at 4.7 GHz is represented in Fig. 3. At time $t = 0$, the horizontal current on the planar E-shaped electric monopole dominates, and the current on vertically oriented shorted patch is negligible. Hence,

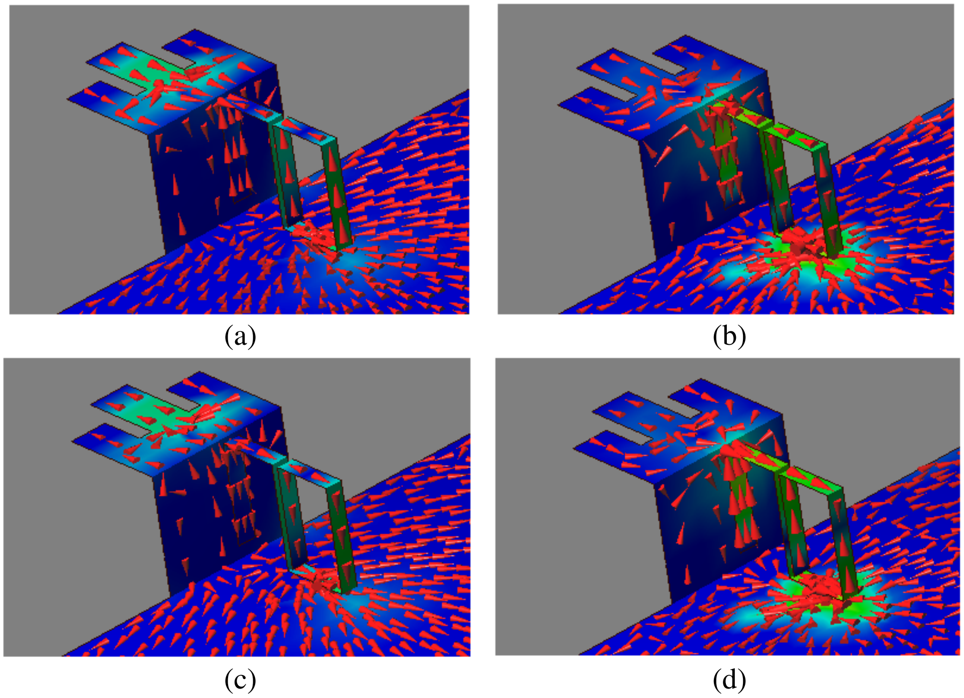


Figure 3. Current distribution of proposed antenna at 4.7 GHz. (a) $t = 0$. (b) $t = T/4$. (c) $t = T/2$. (d) $t = 3T/4$.

the electric monopole mode is strongly excited at time $t = 0$. At time $t = T/4$, the horizontal current on the E-shaped patch is very weak, and the current on vertically oriented shorted patch dominates. This behavior of current indicates that the current loop radiates as magnetic monopole, which is strongly excited at $t = T/4$. For another two cycles, the process repeats but in opposite direction.

4. ANALYSIS OF MAGNETO-ELECTRIC MONOPOLE ANTENNA

According to the structure and function of the ME monopole antenna, the input impedance of antenna Z_{in} can be expressed as follows:

$$Z_{in} = Z_L + Z_c(CD) + (Z_L(BD)||Z_c(DF)) + Z_c(BD') + \left(Z_L(B'D')||Z_c(D'F')\right) + Z_o/2 \tag{1}$$

where Z_o is characteristic impedance of transmission line; $Z_c(CD)$ and $Z_c(BD')$ are the open circuit impedances provided by points CD and BD', respectively; $Z_L(BD)$ and $Z_L(B'D')$ are the impedances provided by the horizontal part of coupling strip inductance; $Z_c(DF)$ and $Z_c(D'F')$ are the impedances provided by vertical portion of coupling strips, DF and $D'F'$, respectively; Z_L is the impedance of electric monopole. In the resonant process, the horizontal part of coupling strip and electric monopole behave as an inductor while magnetic monopole, vertical portions of feeding structure, and shorted wall behave as a capacitor. The schematic of the proposed magneto-electric monopole antenna along with its equivalent circuit is shown in Fig. 4.

To calculate the input impedance Z_{in}, the impedance of each part can be expressed as:

$$Z_L = j\omega L_{GC}$$
$$Z_c(CD) = -jZ_o \cot \beta l_{CD}$$
$$Z_c(BD') = -jZ_o \cot \beta l_{BD'}$$
$$Z_L(B'D') = j\omega L_{BD}$$
$$Z_L(B'D') = j\omega L_{B'D'}$$
$$Z_c(DF) = 1/j\omega C_{DF}$$

$$Z_c(D'F') = 1/j\omega C_{D'F'}$$

Here L and C represent inductance and capacitance, respectively, whereas l represents electrical length. On the basis of Equation (1), it can be observed that the input impedance is mainly affected by the parameters of the horizontal length and vertical height of electric dipole, and the horizontal length and vertical length of the coupling strip.

On the basis of the formula derived, using Equation (1) for input impedance, for the proposed magneto-electric monopole antenna, real and imaginary parts of input impedance are calculated and plotted using MATLAB. It is observed that the calculated real part of input impedance varies from 26.9 ohms to 37.7 ohms, and imaginary part varies from 3.8 ohms to 17.5 ohms, for the given frequency range of 4 GHz–9 GHz, which is indicated by Fig. 5. As the theoretical value of input impedance of any quarter wave monopole antenna is 37.5 ohms, the proposed antenna shows real part of input impedance

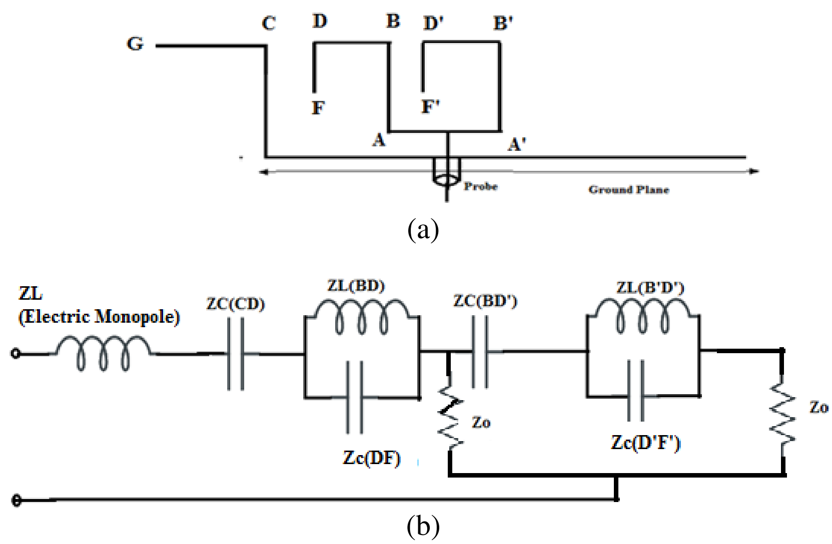


Figure 4. (a) Schematic of proposed magneto-electric monopole antenna. (b) Equivalent circuit of magneto-electric monopole antenna.

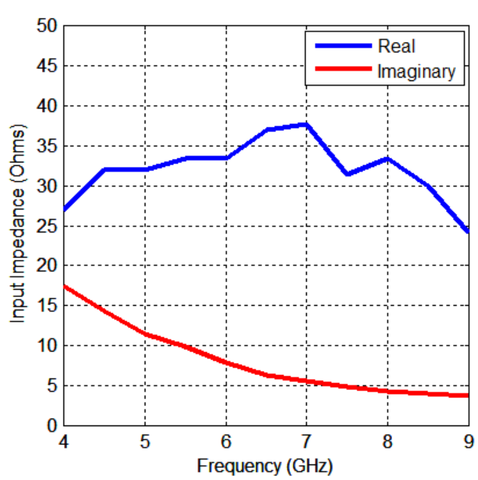


Figure 5. Real and imaginary parts of input impedance of proposed magneto-electric monopole antenna.

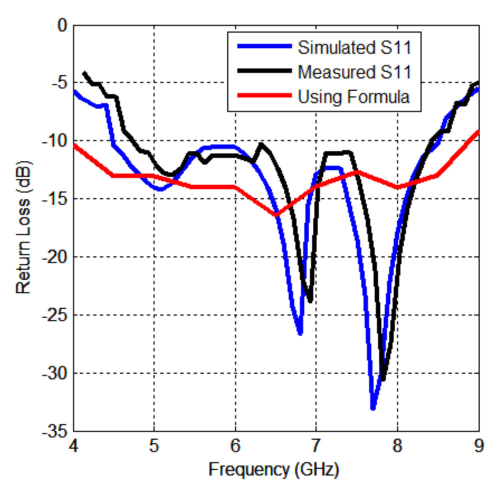


Figure 6. Measured, simulated and formula based return loss of proposed antenna.

variation from 32.5 ohms at 4.5 GHz, 37.7 ohms at 7 GHz and 30 ohms at 8.5 GHz.

Using Equation (1), the return loss has also been calculated and plotted, which is shown in Fig. 6. It is observed that the return loss calculated from the formula varies from −13.4 dB at 4.5 GHz, peak value of −16.2 dB at 6.5 GHz and −13.09 dB at 8.5 GHz.

In the light of above results, it can be concluded that the proposed magneto-electric monopole antenna works properly from 4.5 GHz to 8.5 GHz.

5. RESULTS AND DISCUSSION

The proposed magneto-electric monopole antenna is designed and analyzed using MOM-based full wave electromagnetic simulator IE3D. The antenna is fabricated using 0.3 mm copper sheet, and in

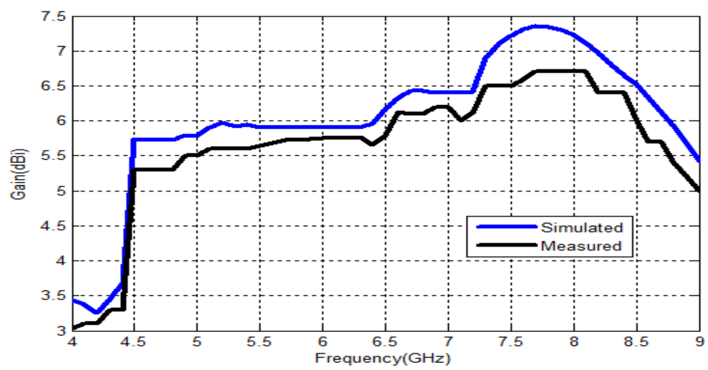
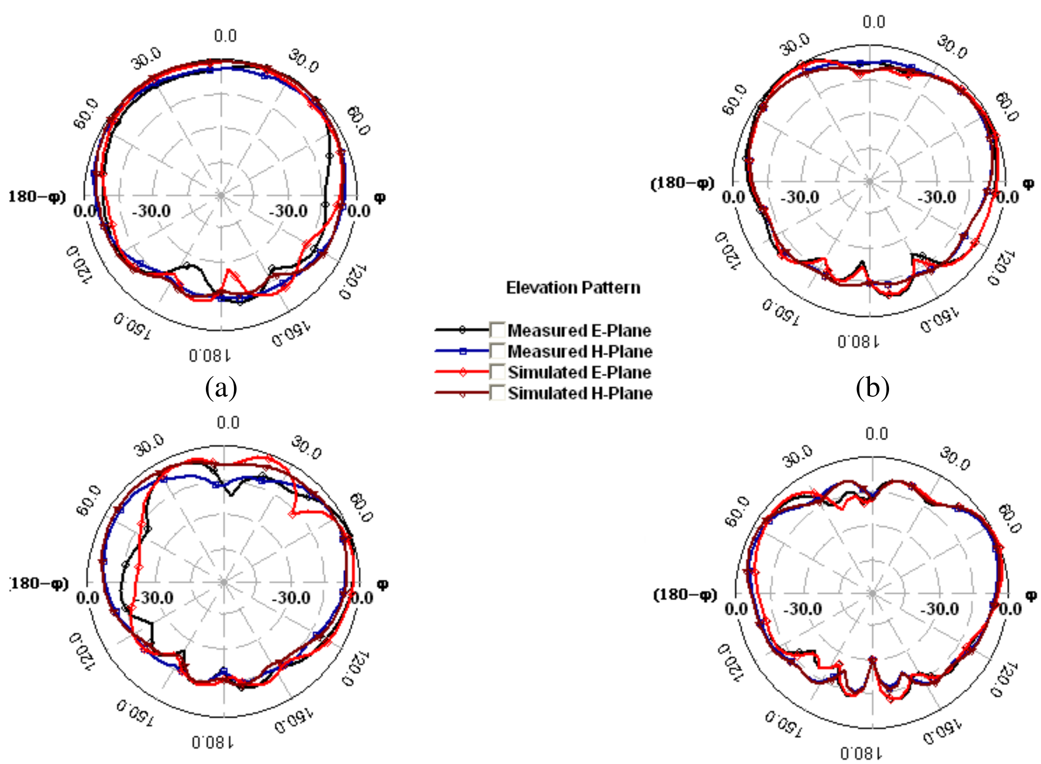


Figure 7. Measured and simulated gain of proposed antenna.



(a) (b) (c) (d)

Figure 8. Measured and simulated E-plane and H-plane radiation patterns at: (a) 5 GHz, (b) 6 GHz, (c) 7 GHz, (d) 8 GHz.

accordance with actual antenna, the same thickness is used for copper in simulations. Various antenna parameters, such as S_{11}, current distribution, radiation pattern and gain, are analyzed rigorously to get the optimum results. Variation of simulated return loss, measured return loss and the formula based return loss of the proposed antenna with frequency is depicted in Fig. 6. From the figure, it is clear that the measured results match well with the simulated one within the acceptable limit. The proposed antenna delivers impedance bandwidth of 61.5% ranging from 4.5 GHz to 8.5 GHz. Another important antenna parameter is gain, and the variation of simulated and measured gains with frequency is represented in Fig. 7, which shows the peak gain of 7.4 dBi. This high gain, which is confirmed from simulated results, is in contrast to electrical monopole antenna that provides low gain in the range of operation. One of the most desired characteristic of magneto-electric monopole antenna is to show identical E-plane and H-plane radiation patterns, shown in Fig. 8. From the figure it is shown that the proposed monopole antenna shows almost identical E-plane and H-plane radiation patterns, indicating the desired omnidirectional radiation characteristics. Cross polarization is another parameter which has to be analyzed to indicate purity of the signal. Fig. 9 represents the cross-polarization radiation pattern of the proposed monopole antenna. From the figure it is clear that the antenna possesses low cross-polarization level at 5 GHz, 6 GHz and 7 GHz, but at 8 GHz the cross polarization increases which may be due to the presence of back radiations. These back radiations may be reduced by increasing the size of ground plane.

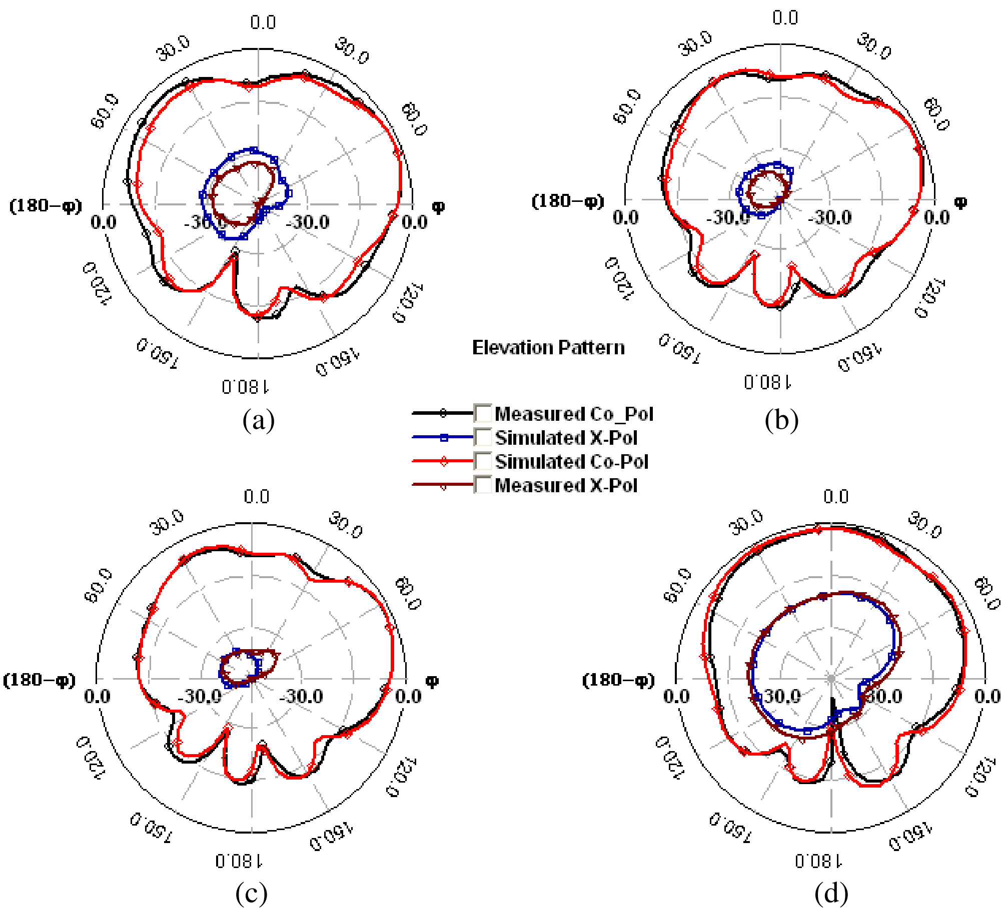


Figure 9. Measured and simulated co-polarization and cross polarization radiation patterns in E-Plane at: (a) 5 GHz, (b) 6 GHz, (c) 7 GHz, (d) 8 GHz.

6. EFFECT OF HEIGHT OF MONOPOLE ANTENNA

Height of the antenna plays an important role because designing an antenna and study of antenna parameters are closely associated with it. To analyze the impact of change in height of antenna on return loss and gain, the height of antenna has been changed to 17 mm and 15 mm, while maintaining 16 mm as the optimum one. Fig. 10 represents the variation of return loss with frequency at different heights of monopole antenna. It is observed that as the antenna height is reduced to 15 mm, antenna shows the presence of dual bands at 4.5 GHz–7.3 GHz and 7.6 GHz–8.7 GHz, which ultimately gives impedance bandwidth of 47.4% and 13.4%, respectively. On the other hand, when the height of monopole antenna is increased to 17 mm, the impedance bandwidth of 62.1% is shown by antenna in the frequency range 4.1 GHz–7.8 GHz. By analyzing the results obtained at 15 mm, 16 mm and 17 mm, it is concluded that as the antenna height is increased from 16 mm, the impedance bandwidth starts increasing, while impedance bandwidth is decreased drastically as the antenna height is lowered from 16 mm.

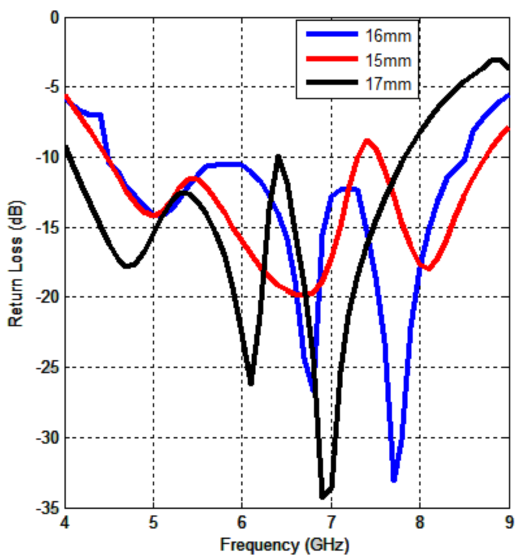


Figure 10. Simulated return loss of proposed antenna at different height.

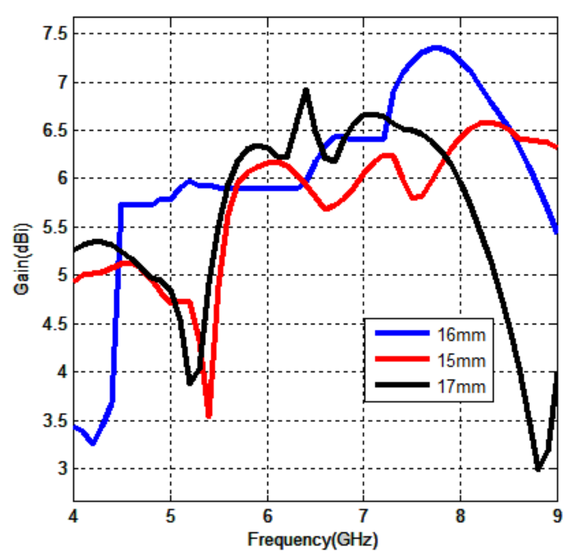


Figure 11. Simulated gain of proposed antenna at different height.

Variation of gain with the different heights of antenna is shown in Fig. 11. It is observed that as the height of antenna is decreased to 15 mm, the peak gain of 6.6 dBi is obtained, while a peak gain of 6.9 dBi is observed as the height of antenna is increased to 17 mm. The antenna at the height of 16 mm gives the peak gain of 7.4 dBi, which is higher than the results obtained at antenna heights of 15 mm and 17 mm.

Hence, it can be concluded that as the height of monopole antenna is decreased from 16 mm, the peak gain of antenna is reduced with decrease in impedance bandwidth whereas as the height of antenna is increased from 16 mm, higher impedance bandwidth but with lower peak gain is obtained.

7. EFFECT OF LENGTH OF FEED OF MONOPOLE ANTENNA

As observed from Equation (1), the length of feed is an important factor on which input impedance of the monopole antenna is closely associated. To study the impact of change in length of feed (L_3 and L_4) on antenna return loss and gain, the length of feed has been changed to 7.5 mm and 6.5 mm, while maintaining 7 mm as the optimum one. Fig. 12 represents the variation of return loss with frequency for different lengths of feed of monopole antenna. It is observed that as this length of feed is increased to 7.5 mm, the antenna starts showing dual bands at 4.1 GHz–6.6 GHz and 6.8 GHz–8.1 GHz, which

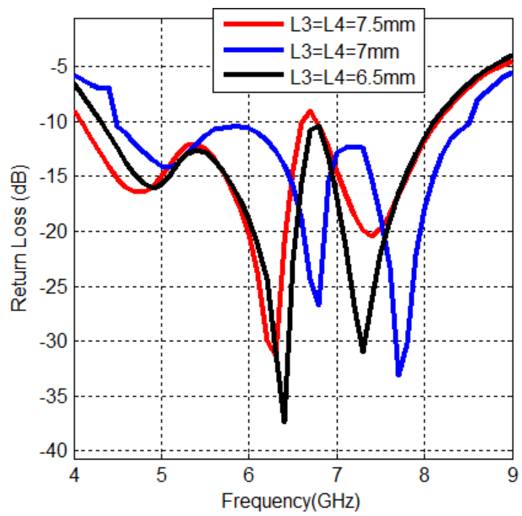


Figure 12. Simulated return loss of proposed antenna for different length of feed.

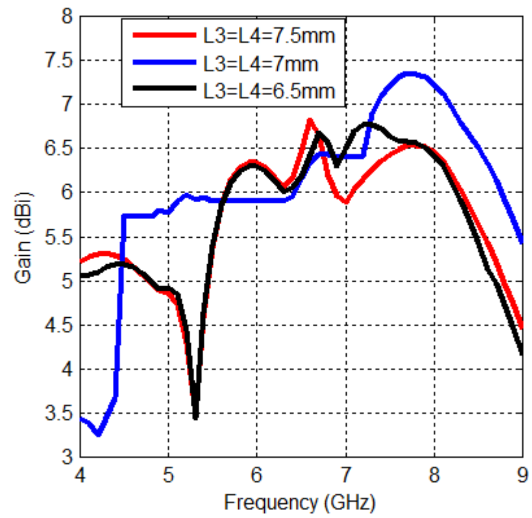


Figure 13. Simulated gain of proposed antenna for different length of feed.

provides an impedance bandwidths of 46.7% and 17.4%, respectively. On the other hand, when the length of feed of monopole antenna is decreased to 6.5 mm, the impedance bandwidth of 61.2% is shown by the antenna in the frequency band 4.3 GHz–8.1 GHz. It can be concluded that the impedance bandwidth starts decreasing, when the length of feed is either decreased or increased from 7 mm.

Variation of gain with the change in length of feed is shown in Fig. 13. It is observed that as the length of feed is decreased to 6.5 mm, the peak gain of 6.78 dBi is obtained, while a peak gain of 6.8 dBi is observed as the length of feed of antenna is increased to 7.5 mm. The antenna at the feed length of 7 mm gives the peak gain of 7.4 dBi, which is higher than the results obtained at feed length of 6.5 mm as well as 7.5 mm.

On the basis of above results, it can be concluded that as the feed length of monopole antenna is increased or decreased from 7 mm, the peak gain of antenna is reduced with decrease in impedance bandwidth.

8. EFFECT OF WIDTH OF GROUND PLANE OF MONOPOLE ANTENNA

The size of ground plane is a very important factor while designing an antenna, as gain, impedance bandwidth and back lobe radiations are closely related to it. To confirm its effect on a magneto-electric monopole antenna, width of ground plane, G_W, is changed to 88 mm and 108 mm, while maintaining the length of ground plane, G_L, 65 mm. In Fig. 14, the variation of return loss with change in width of ground plane is indicated. It is observed that as the width of ground plane is decreased to 88 mm, impedance bandwidth increases to 63.4% for the frequency range 4.2 GHz–8.1 GHz, whereas, as the width of ground plane is increased to 108 mm, the antenna shows possessing dual bands at 4.2 GHz–6.6 GHz and 6.9 GHz–8.0 GHz, which gives impedance bandwidths of 44.4% and 14.7%, respectively. The proposed antenna, with width of ground plane as 98 mm, gives an impedance bandwidth of 61.5% from 4.5 GHz to 8.5 GHz.

The impact of change in width of ground plane was next observed on gain of the monopole antenna, which is shown in Fig. 15. It is observed that peak gain of the antenna decreases for both the values of changed width of ground plane, which is 6.77 dBi and 6.4 dBi for width of ground plane, G_W, as 88 mm and 108 mm respectively. The proposed antenna shows the peak gain of 7.4 dBi for width of ground plane as 98 mm.

On the basis of above two results, it can be summarized that as the width of ground plane is decreased, the impedance bandwidth increases with fall in peak gain whereas for the increased width of ground plane, the impedance bandwidth as well as the peak gain of monopole antenna decreases.

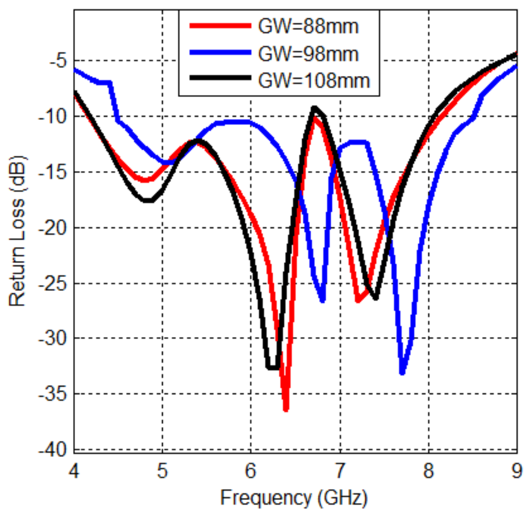


Figure 14. Simulated return loss of proposed antenna for different width of ground plane.

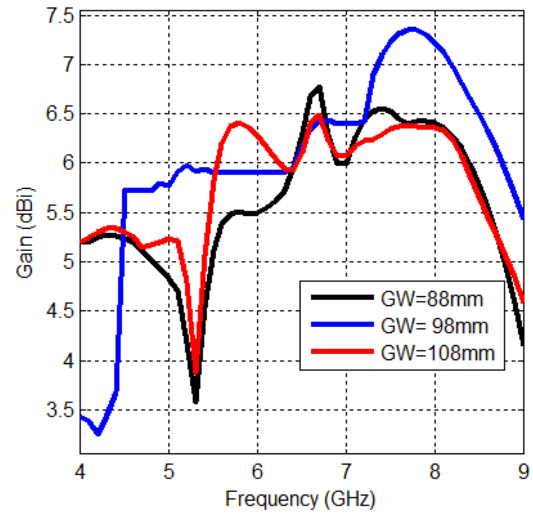


Figure 15. Simulated gain of proposed antenna for different width of ground plane.

9. EFFECT OF LENGTH OF GROUND PLANE OF MONOPOLE ANTENNA

The next parametric analysis was to study and analyze the impact of length of ground plane on the proposed monopole antenna. Hence the length of ground plane, G_L, was changed to 60 mm and 70 mm while maintaining width of ground plane, G_W, as 98 mm. The effect of change in length of ground plane on return loss is shown in Fig. 16. It is observed that as the length of ground plane is decreased to 60 mm, the antenna shows clear presence of dual bands at 4.2 GHz–6.6 GHz and 6.8 GHz–8.1 GHz, hence giving impedance bandwidths of 44.4% and 17.4%, respectively. But as the length of ground plane is changed to 70 mm, there is an increase in impedance bandwidth of 1.9%, which is 63.4% for 4.2 GHz–8.1 GHz, as compared to the proposed antenna at G_L at 65 mm.

The effect of change in length of ground plane has affected the gain too, which is shown by Fig. 17. It is observed that for both the changed values of length of ground plane, the peak gains of antenna are dropped, which are 6.47 dBi and 6.74 dBi for lengths of ground plane as 60 mm and 70 mm, respectively.

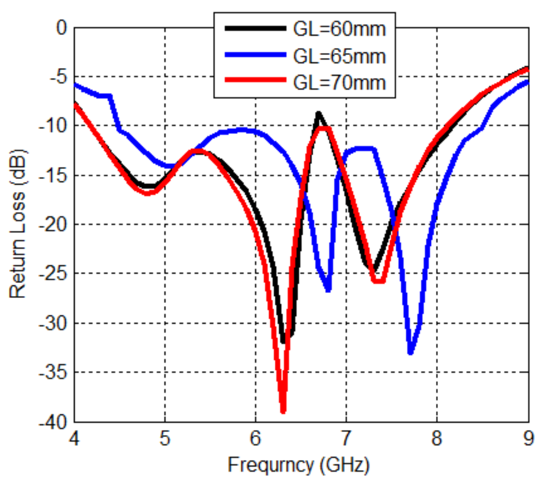


Figure 16. Simulated return loss of proposed antenna for different length of ground plane.

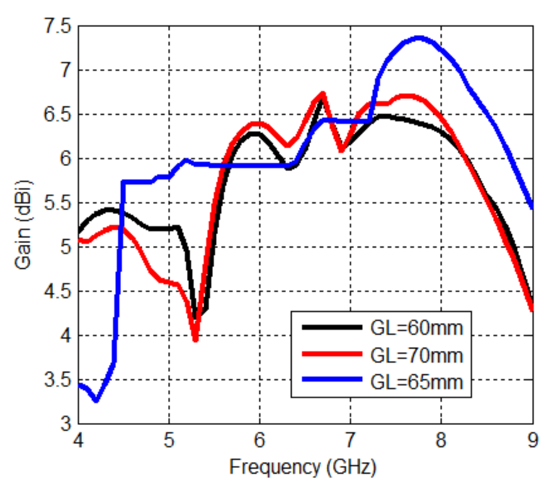


Figure 17. Simulated gain of proposed antenna for different length of ground plane.

The proposed antenna shows the peak gain of 7.4 dBi, while maintaining the length of ground plane as 65 mm.

It can be concluded that impedance bandwidth is proportional to the length of ground plane. When the length of ground plane increases, impedance bandwidth also increases and vice versa. But the change in length of ground plane, G_L, from 65 mm, also results in the fall of peak gain.

10. CONCLUSION

A simple non-planar magneto-electric monopole antenna with novel feed design is designed and fabricated. The measured and simulation results indicate that it possesses 61.5% impedance bandwidth, from 4.5 GHz to 8.5 GHz. The antenna exhibits a stable omnidirectional radiation pattern with almost identical E-plane and H-plane radiation patterns and provides a peak gain of 7.4 dBi. Due to its good electrical and radiation characteristics, the antenna has great potential to operate in C band to overcome the challenges of multi-frequency applications.

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