Progress In Electromagnetics Research C, Vol. 67, 21–29, 2016

Design of Circularly Polarized Planar Magneto-Electric Dipole Antenna

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Abstract—A new design of a circularly polarized planar magneto-electric dipole antenna is proposed and presented. This antenna consists of dual horizontal T-shaped electric dipole and an inverted U-shaped feed line. The antenna possesses 21.1% impedance bandwidth, from 8.9 GHz–11.0 GHz, provides 3-dB axial ratio bandwidth of 9.52% ranging 10.0 GHz–11.0 GHz, exhibits stable omnidirectional radiation pattern with almost equal E-plane and H-plane radiation patterns and provides a peak gain of 6.2 dBi. Due to its good electrical characteristics and radiation parameters, the antenna is suitable for satellite and RADAR communication in X-band.

1. INTRODUCTION

Circularly polarized (CP) antennas play an important role in RADAR, modern wireless communication, as they provide stable reception of the signal and better mobility. Either with single-feed or dual-feed designs, CP can be achieved. The single-feed design has the advantage of maintaining a simple structure without the need of polarizer (like hybrid and power divider), which is essentially required in dual-feed designs. In 2006, Luk et al. presented an improved version of complementary antenna and designated as magneto-electric Dipole antenna. This antenna can provide wide impedance bandwidth, identical E-plane and H-plane radiation patterns, stable gain and low back radiations [1, 2]. Despite the antenna has shown excellent performance with a staircase-shaped structure [3–6], where additional need of balun may be removed and antenna can provide dual-band with wide impedance bandwidth and high gain, with differential feeding structure [7, 8], where the originally single ended operation is converted into differential ended to provide ultra-wide band, theoretically infinite differential port to port isolation and to be directly connected to differential microwave circuits, and with dielectric material [8–10], where magneto-electric dipole antenna is printed on dielectric material, it suffers from disadvantages of being bulky and pertaining complex structures. In [11–13], circular polarization has been achieved with 3-dB axial ratio bandwidth of 42.9%, 61.5% and 82% respectively, but the magneto-electric dipole antenna structure is non-planar. To the best knowledge of the authors, no true planar magneto-electric dipole antenna with circular polarization has been designed or presented.

In this paper, the first planar circularly polarized magneto-electric dipole antenna is designed, fabricated and analyzed. The novel magneto-electric dipole with inverted U-shaped feed and truncated ground plane operates between 8.9 GHz–11.0 GHz while the circular polarization operation is achieved for 10.0 GHz to 11.0 GHz band. The peak gain of 6.2 dBi in the operating range of frequency has been achieved. Almost identical radiation patterns for both E-plane and H-plane have also been shown by the antenna.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed antenna. The proposed antenna has been printed on an RT duroid 5880 substrate, which has permittivity of 2.2, thickness of 0.78 mm and size of 80 mm × 40 mm

Received 23 June 2016, Accepted 26 August 2016, Scheduled 30 August 2016

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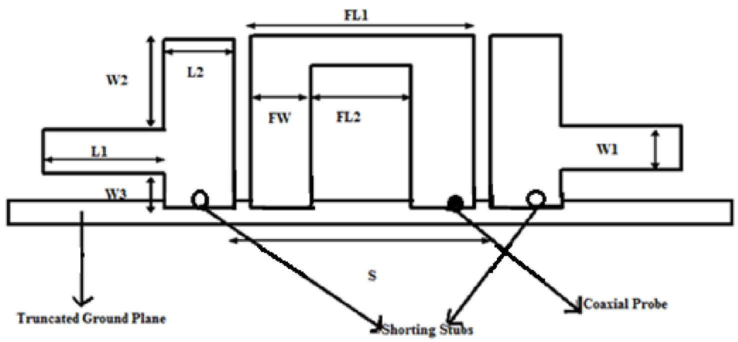
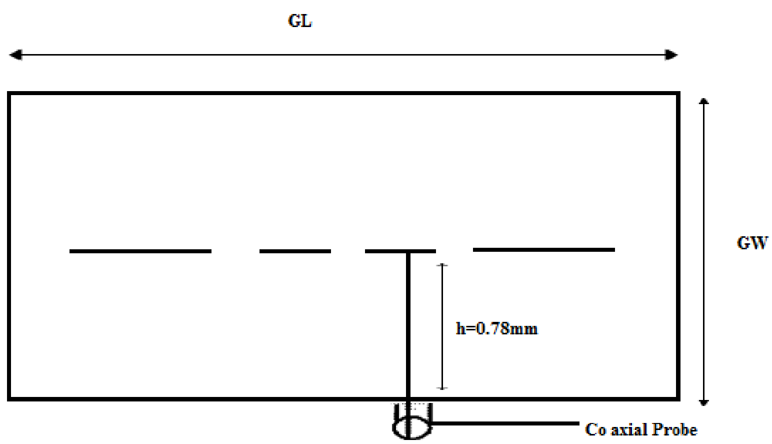
(CL × CW). The antenna consists of dual horizontal T-shaped electric dipole, an inverted U-shaped feeding structure, a pair of shorted stubs, and a truncated rectangle-shaped ground plane 48 mm × 2 mm (GL × GW). The two T-shaped patches work as an electric dipole whereas shorted stubs and truncated ground plane are combined to make a magnetic dipole. The electric dipole, feeding structure and shorted stubs are printed on the front side of the substrate whereas the ground plane is printed on the back side of the substrate. The shorted vias have been used to interconnect shorted stubs to the ground plane. These shorted vias are placed at the intersection of center of $L2$ and 0.5 mm below the upper side of ground plane. The right end of the inverted U-shaped feeding structure has been connected to SMA connector under the ground plane. The SMA connector is connected at the intersection of center of FW and 0.5 mm below the upper side of ground plane. Figure 2 shows the prototype of the proposed antenna according to dimensions given in Table 1.



(a)



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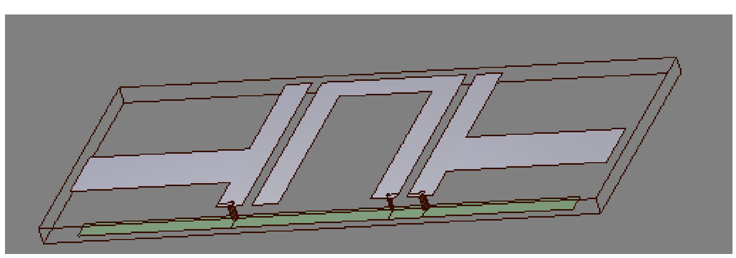
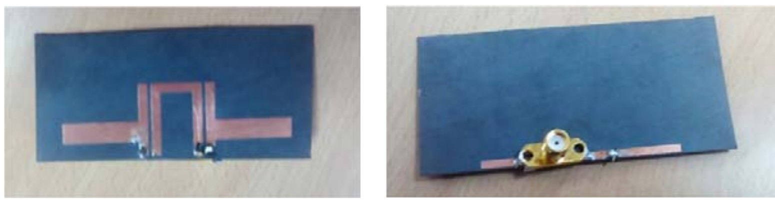


(c)

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

Table 1.

Parameter	$L1$	$L2$	$W1$	$W2$	$W3$	$FL1$	$FL2$
Value (mm)	15.5	2.5	5.5	10.5	4	14	9
Parameter	CL	CW	CH	GL	GW	FW	S
Value(mm)	80	40	10	48	2	2.5	16



(a) (b)

Figure 2. (a) Front side of the proposed antenna. (b) Back side of proposed antenna.

3. RESULTS AND DISCUSSION

The proposed circularly polarized magneto-electric dipole antenna is designed and analyzed using MOM based full wave electromagnetic simulator IE3D. The antenna is fabricated using 0.3 mm copper sheet, and to realize with actual antenna, the same thickness is used for copper in simulations. Various antenna parameters such as S_{11}, axial ratio, current distribution, radiation pattern and gain are analyzed rigorously to get the optimum results. The variation of simulated and measured return losses is presented in Figure 3. From the figure, it is clear that the measured results match well with the simulated ones within the acceptable limit. The proposed antenna delivers impedance bandwidth of 21.1% from 8.9 GHz to 11.0 GHz. Figure 4 presents the variation of axial ratio in broadside direction with frequency. The axial ratio taken at (0, 0) degree remains below 3 dB from 10.0 GHz–11.0 GHz hence giving axial ratio

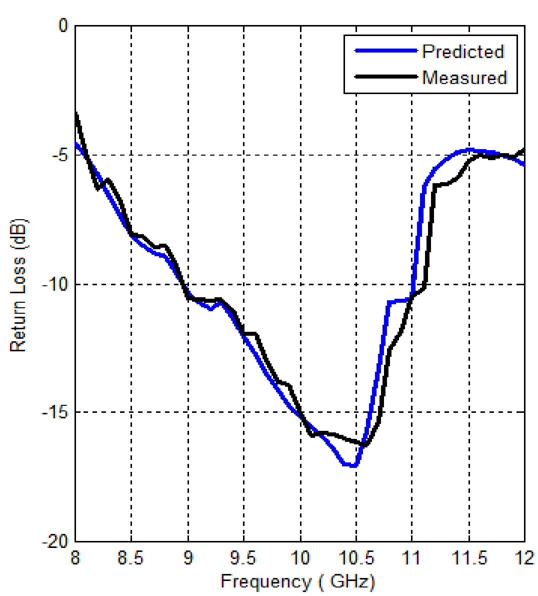


Figure 3. Measured and simulated return loss of proposed antenna.

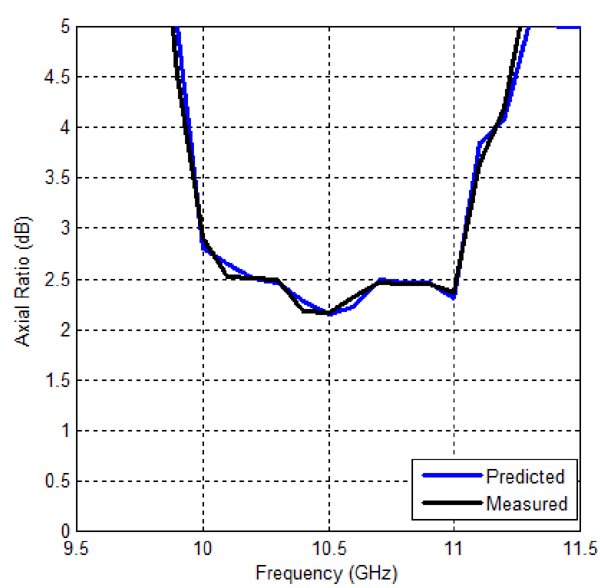


Figure 4. Measured and simulated 3-dB axial ratio of proposed antenna.

bandwidth of 9.52%. The peak gain of 6.2 dBi has been confirmed from simulated results, maintaining stable gain of almost 6 dBi in the entire operating range, indicated in Figure 5. To indicate the working of magneto-electric dipole antenna with circular polarization, current distribution is shown in Figure 6 at 10.5 GHz and at a quarter time period interval. The overall current in the structure at $t = 0$ moves towards left-hand side while it is in upward direction at $t = T/4$. Similarly, the vector current rotates in clockwise direction, suggesting right-handed circular polarization. The figure also depicts the working of magneto-electric dipole antenna, where first electric dipole is excited for $t = 0$, and then magnetic dipole is excited for $t = T/4$. For rest of the two cycles, process continues but in opposite directions. One of the important characteristics of a magneto-electric dipole antenna identical E-plane and H-plane radiation patterns. It is observed that almost identical E-plane and H-plane radiation patterns are shown by the antenna at 9.5 GHz, 10 GHz and 10.5 GHz, which is shown in Figure 7. To the best knowledge of the authors, no printed circularly polarized magneto-electric dipole antenna has been presented, and a comparison Table 2 has been drawn to indicate the novelty of the work.

Table 2.

Reference No.	Circularly Polarized	Planar/Non-Planar	Frequency Range	Impedance Bandwidth (IB)/ 3-dB Axial Ratio Bandwidth (ARBW)	Gain
[9]	No	Vertical Planar	2.36 GHz–2.8 GHz	17.1% IB	6.5 dBi
[10]	No	Planar	50 GHz–70 GHz	33% IB	7.5 dBi
[11]	Yes	Non Planar	1.1 GHz–1.7 GHz	42.9% ARBW	5.6 ± 0.6 dBi
[12]	Yes	Non Planar	2.7 GHz–5.1 GHz	61.5% ARBW	8.3 dBi (Peak)
[13]	Yes	Non Planar	1.28 GHz–3.05 GHz	82% ARBW	5 dBi
Proposed Antenna	Yes	Planar	10 GHz–11 GHz	9.52% ARBW	6.2 dBi

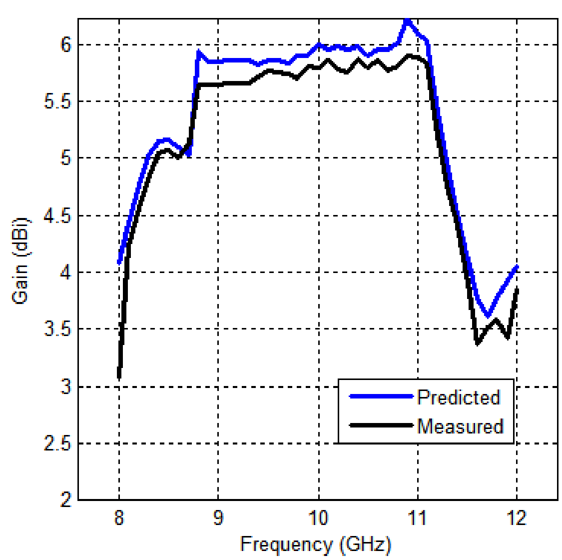


Figure 5. Measured and simulated gain of proposed antenna.

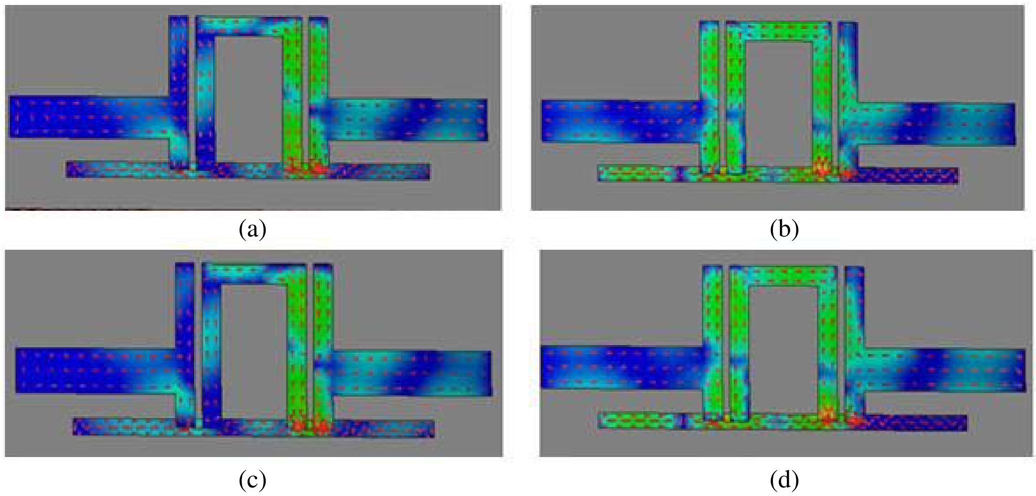


Figure 6. Current distribution indicating right-handed circular polarization at 10.5 GHz. (a) $t = 0$. (b) $t = T/4$. (c) $t = T/2$. (d) $t = 3T/4$.

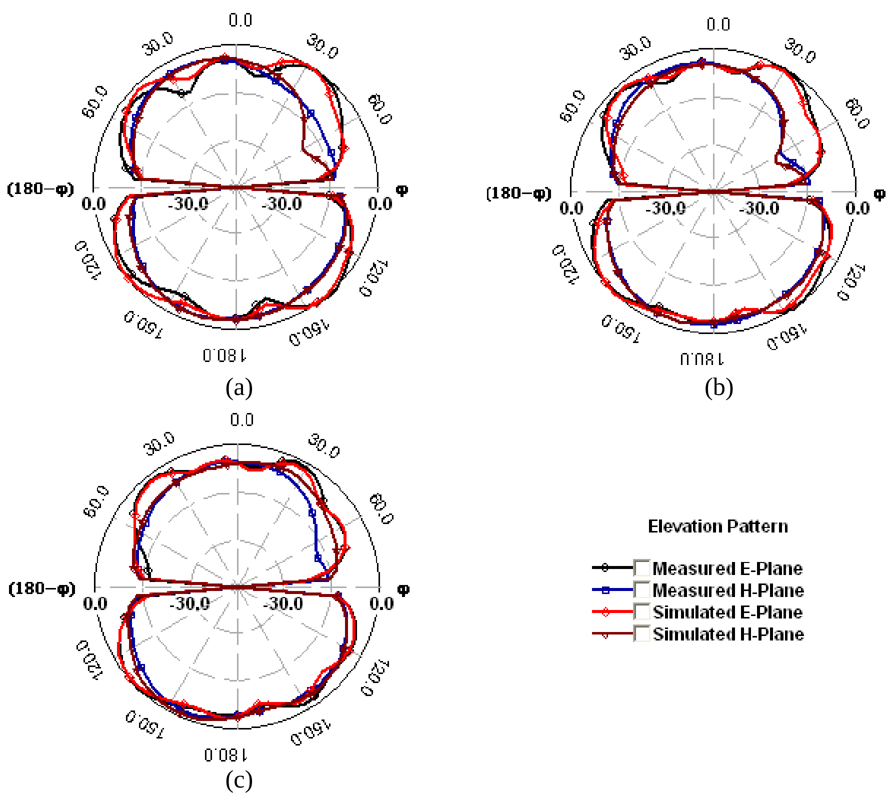


Figure 7. Measured and simulated E-plane and H-plane radiation patterns at: (a) 9.5 GHz (b) 10 GHz and (c) 10.5 GHz.

4. EFFECT OF LENGTH OF GROUND PLANE

As the truncated ground plane along with shorted stubs makes magnetic dipole, it was necessary to know the effect of length of ground plane on various antenna parameters. Hence a parametric study has been done taking different lengths of ground plane, and its impact on impedance bandwidth, gain and 3-dB axial ratio has been analyzed. It is worth to mention that all the other dimensions of antenna has been kept constant while changing the length of ground plane. The proposed antenna has the size of ground plane $48 \times 2\,\text{mm}^2$. To analyze the effect of length of ground plane, the length has been changed to 52 mm and 44 mm. Figure 8 indicates the variation of return loss with frequency. It has been observed that as the length of ground plane changes from 48 mm, the impedance bandwidth starts decreasing. The impedance bandwidth has been reduced to 14.9% and 16.5%, for 44 mm and 52 mm lengths of ground plane, respectively. It is also observed that lower cutoff frequency increases for both 44 m and 52 mm lengths, but upper cutoff frequency decreases for 44 mm and increases for 48 mm length of ground plane. Figure 9 indicates the variation of gain with frequency for different lengths of ground plane. The proposed antenna has the peak gain of 6.2 dBi. It has been observed that as the length of ground plane decreases or increases from 48 mm, the peak gain of antenna starts increasing. It changes to 6.68 dBi and 6.57 dBi for 44 mm and 52 mm, respectively. Figure 10 indicates the variation of axial ratio with frequency. It has been observed that with change in length of ground plane, 3-dB axial ratio

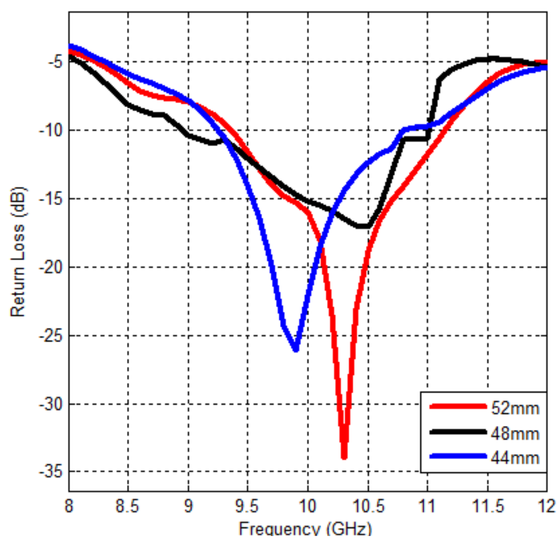


Figure 8. Variation of return loss with frequency for different length of ground plane.

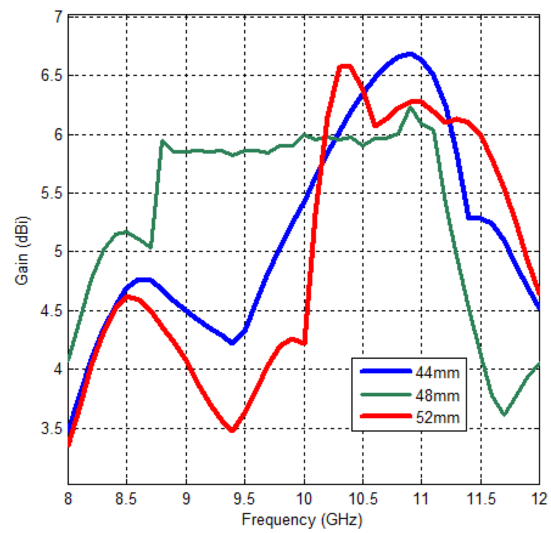


Figure 9. Variation of gain with frequency for different length of ground plane.

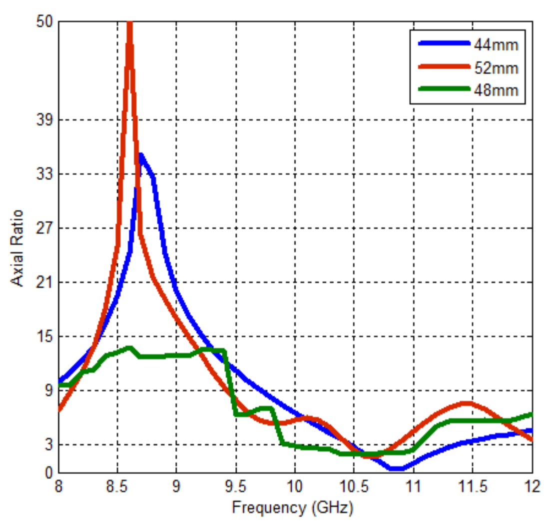


Figure 10. Variation of axial ratio with frequency for different length of ground plane.

bandwidth decreases drastically. It decreases to 7.3% and 3.75% respectively for 44 mm and 52 mm lengths of ground plane, respectively.

So the effect of length of ground plane results in increase in gain of antenna at the cost of decrement in impedance band and 3-dB axial ratio bandwidth. It is noticed that for 48 mm length of ground plane, the antenna gives stable gain, wide impedance bandwidth and 3-dB axial ratio bandwidth.

5. EFFECT OF WIDTH OF GROUND PLANE

The width of ground plane is an important factor on which various antenna parameters depend. To analyze its impact on impedance bandwidth, gain and axial ratio, the 2 mm wide ground plane has been changed to 1.5 mm and 2.5 mm. Figure 11 shows the variation of return loss with frequency for different widths of ground plane. It has been observed that lower cutoff frequency decreases by 500 MHz and 200 MHz respectively for 1.5 mm and 2.5 mm widths of ground plane while the upper cutoff frequency increases by 200 MHz for both the values compared to 2 mm width of ground plane. This results in

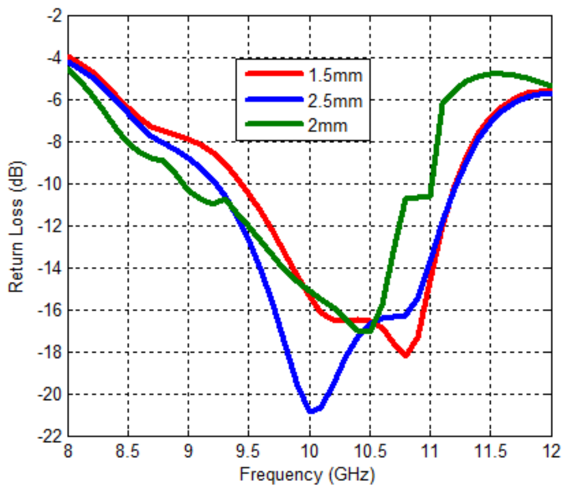


Figure 11. Variation of return loss with frequency for different width of ground plane.

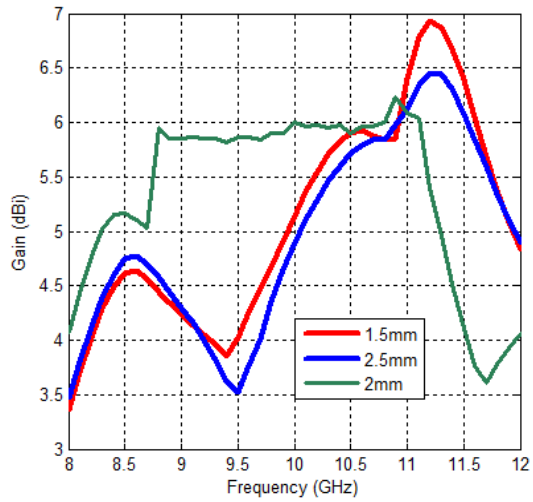


Figure 12. Variation of gain with frequency for different width of ground plane.

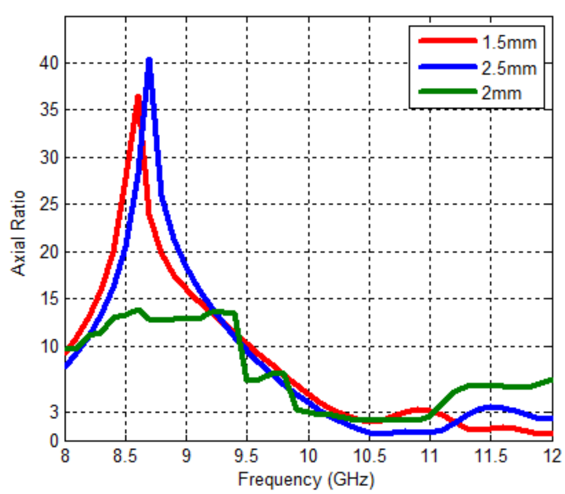


Figure 13. Variation of axial ratio with frequency for different width of ground plane.

decrease in impedance bandwidth to 16.4% and 19.6%, respectively. Figure 12 shows the variation of gain with frequency for different widths of truncated ground. For both widths, 1.5 mm and 2.5 mm, peak gain increases to 6.9 dBi and 6.45 dBi, respectively. From Figure 13, the impact of width of ground plane on axial ratio has been observed. It is noticed that 3-dB axial ratio decreases to 4.73% and 9.34% respectively for truncated ground widths of 1.5 mm and 2.5 mm, respectively.

Hence, the impact of change in width of truncated ground plane results in increase in gain but decrease in impedance bandwidth and 3-dB axial ratio.

6. EFFECT OF WIDTH OF FEED LINE

The width of feed plays an important role in designing an antenna, and antenna parameters are highly dependent on it. To analyze the impact of change in width of feed on return loss, gain and axial ratio, the width of feed has been changed to 2 mm and 3 mm, while maintaining 2.5 mm as the optimum one. It has been found from Figure 14 that return loss decreases to 20.1% and 18.18% for feed widths 2 mm and 3 mm, respectively. It has been observed that lower cutoff frequency and upper cutoff frequency for 2 mm feed width decrease by 500 MHz and 600 MHz respectively whereas for 3 mm feed width, lower

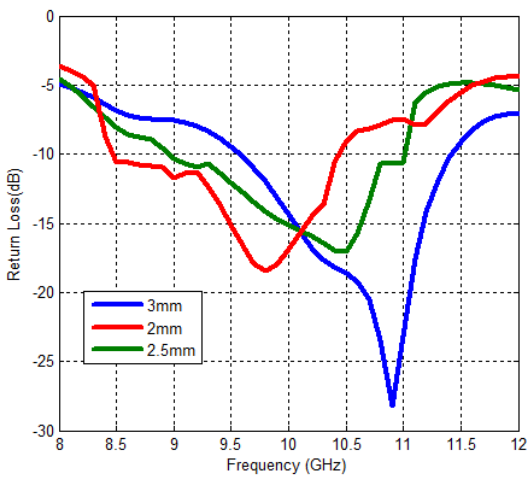


Figure 14. Variation of return loss with frequency for different width of feed.

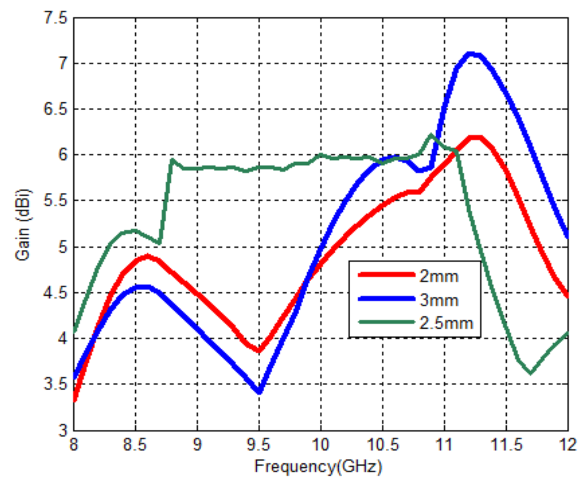


Figure 15. Variation of gain with frequency for different width of feed.

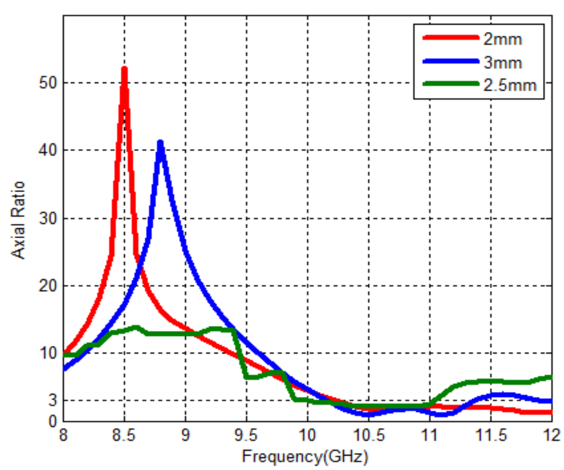


Figure 16. Variation of axial ratio with frequency for different width of feed.

cutoff frequency increases by 500 MHz, and upper cutoff frequency increases by 400 MHz respectively as compared to feed width of 2.5 mm. Figure 15 indicates the variation of gain with frequency for different feed width. It has been seen that peak gain falls to 5.3 dBi for 2 mm width and rises to 7.1 dBi for 3 mm width whereas it is 6.2 dBi for 2.5 mm width. Figure 16 shows the variation of axial ratio with frequency for different widths of feed. It is clearly evident that 3-dB axial ratio bandwidth falls drastically to 0.96% for 2 mm width and 9.3% for 3 mm, while maintaining 9.52% for 2.5 mm width.

On the basis of above results it can be concluded that as the width of feed either increased or decreased from 2.5 mm, its impedance bandwidth decreases; gain increases on the positive side of 2.5 mm and decreases on the negative side of 2.5 mm; 3-dB axial ratio falls remarkably on negative side and marginally decreases on positive side of 2.5 mm.

7. CONCLUSION

A novel and simple circularly polarized planar magneto-electric dipole antenna with inverted U-shaped feed design has been designed and fabricated. The measured and simulated results indicate that it possesses 21.1% impedance bandwidth, from 8.9 GHz–11.0 GHz and provides 3-dB axial ratio bandwidth of 9.52% covering 10 GHz–11.0 GHz. The antenna exhibits stable omnidirectional radiation pattern with almost equal E-plane and H-plane radiation patterns and provides a peak gain of 6.2 dBi. Due to its good electrical characteristics, the antenna is suitable for satellite and RADAR communication in X-band.

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