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Triple Band-Notched Square Monopole UWB Antenna with Enhanced Bandwidth using Novel Coupled M-shaped Strip

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Abstract—*In this paper we present a square monopole antenna with triple band-notched characteristics for ultrawideb and application. The proposed antenna consists of a micro strip feed stepped square radiating patch with W- and H-shaped slot, a partial ground plane with a protruded rectangular strip and a novel M-shaped coupled strip. By inserting a rectangular strip and coupled M-shaped strip with ground plane, fractional bandwidth of antenna increased up to 103%. By embedding W- and H-shaped slot in radiating triple band-notched performance is generated. By properly adjusting the dimension of these slots band-notched characteristics such as notch frequency and notch bandwidth can be control. The proposed antenna has size of 14×18 mm^2 and provides 10-dB return loss bandwidth between 2.55 GHz and 12 GHz (130%) with three notches, covering 3.5/5.5-GHz WIMAX, 5.2/5.8-GHz WLAN, 7.9–8.7 GHz ITU band. The simulated VSWR and return loss characteristics of proposed antenna are presented and investigated, which fulfill the criteria to use it for various UWB applications.*

1. INTRODUCTION

In the last few years, the ultrawideband (UWB) antenna designer face some challenges such as achieving wide bandwidth, removing interference from existing narrow band system, reducing cost and size of antenna. The development of UWB technology increases the demand of small low-cost antennas with omnidirectional radiation patterns and wide bandwidth. Therefore this demand greatly attracted towards printed monopole antennas to use for UWB application, because of their features such as small size, low cost, low profile, light weight, simple structure, wide impedance bandwidth, easy fabrication, and easy integration with other microstrip circuits. In the last century several printed monopole antennas have been designed [2], [3] to use for UWB applications in frequency band 3.1–10.6 GHz [1] defined by Federal communications commission (FCC). In the UWB frequency range 3.1 to 10.6 GHz, there are many narrow band wireless system such as WIMAX (3.3–3.6 GHz), WLAN for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands, 7.9–8.7 GHz ITU band, which causes interference. Therefore to reduce the interference caused due to these narrow band system UWB antennas with band-stop performance needs to design.

To generate frequency band-stop performance several planar monopole antennas have been reported [4]-[12].

Single band-stop characteristics can be achieved using with a pair of T-shaped strips protruded inside square ring radiating patch [4], two rod-shaped parasitic structures [5], H-shaped conductor-backed plane [6], two U-shaped slot [7], small rectangular patch [8], strip placed at the center of the patch [9]. UWB monopole Antenna with dual band-stop characteristics have been reported in [10]-[12].

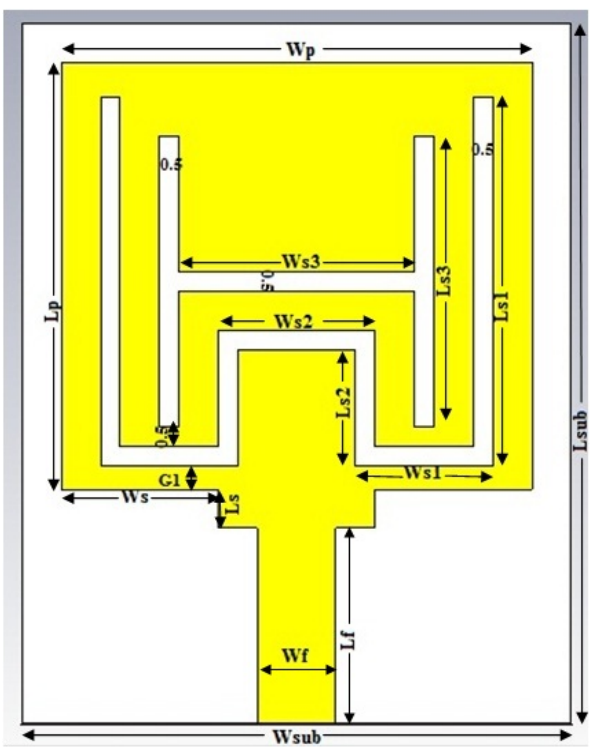
In this paper a simple triple band-notched stepped square monopole antenna with wide bandwidth using a novel coupled M-shaped strip is proposed. By using a rectangular strip and coupled M-shaped strip additional resonance are excited, hence impedance bandwidth of proposed antenna effectively increased at higher band whereas triple band-notched characteristics are realized with the help of W- and H-shaped slots cut in square radiating patch. The proposed antenna provides wide impedance bandwidth between 2.55–12 GHz with three notches around 2.68–4.06 GHz, 4.9–6.0 GHz and 7.78–9.0 GHz covering 3.5/5.5-GHz WIMAX, 5.2/5.8-GHz WLAN, and 7.9–8.7 GHz ITU band respectively. Simulated and measure results shows that proposed antenna has good return loss and radiation pattern characteristics which fulfill the requirement for UWB applications.

2. ANTENNA DESIGN AND CONFIGURATIONS

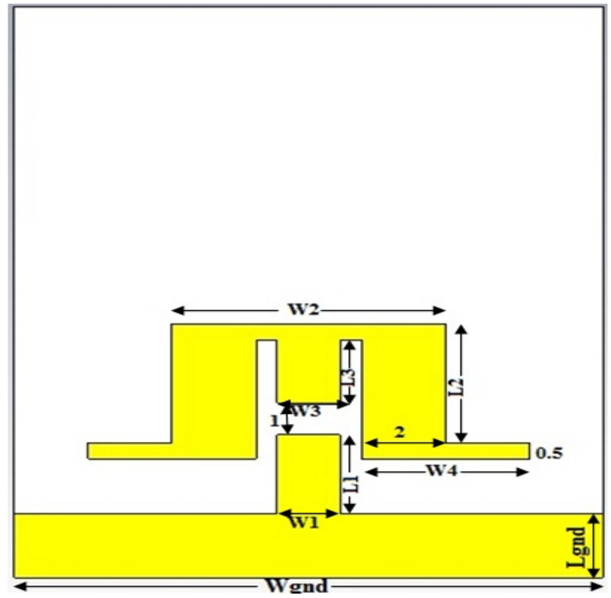
Fig. 1 shows the geometry of the proposed UWB monopole antenna. The proposed antenna is designed on a 14×18 mm^2 FR4 substrate of thickness of 1.6 mm, relative permittivity of 4.4 and loss tangent of 0.018. As shown in Fig. 1 basic structure of proposed antenna consists of a stepped square radiating patch with W- and M-shaped slots cut inside it, 50 Ω microstrip feed line printed on substrate, a partial ground plane with a protruded rectangular strip and M-shaped coupling strip printed on other side of substrate. The square patch has dimension of 12×12 mm^2 and width Wf of microstrip feed line is fixed to 2 mm to achieve 50 Ω characteristics impedance over operating frequency range 2.55–12 GHz.

In this structure, Firstly by creating a rectangular strip with ground plane impedance matching of simple monopole antenna is improved, hence bandwidth increases from 8.5 GHz to 10.18 GHz. Then with the help of a novel couple M-shaped strip additional resonance at 11.8 GHz is excited which provides the wide impedance bandwidth up to 12.2 GHz. To realize triple band-notched characteristics W-shaped and H-shaped slots are embedded in square radiating patch. At optimal parameter the proposed antenna operates over frequency range 2.55–12 GHz while showing three notches around frequency band 2.68–4.06 GHz, 4.9–6.0 GHz and 7.78–9.0 GHz GHz covering 3.5/5.5-GHz WIMAX, 5.2/5.8-GHz WLAN, and 7.9–8.7 GHz ITU band respectively.

The optimal dimensions of the proposed antenna are as follows: Wsub = 14 mm, Lsub = 18 mm, Wf = 2 mm, Lf = 5 mm, Wgnd = 14 mm, Lgnd = 2 mm, Lp = 11, Wp = 12, L1= 2.5 mm, W1= 1.5 mm, W2 = 6.5 mm, L2= 3.75 mm, W3 = 1.5 mm, L3 = 2 mm, W4 = 4 mm, Ls = 1 mm, Ws = 4 mm, Ls1 = 9.5 mm, Ws1 = 3.5 mm, Ls2 = 3 mm, Ws2 = 4 mm, Ls3 = 7.5 mm, Ws3 = 6 mm G1 = 0.6 mm. Moreover, the structure of the antenna is symmetrical with respect to the longitudinal direction.



(a) Front view



(b) Rear view

Fig. 1: Geometry of proposed antenna

3. RESULTS AND DISCUSSIONS

In this Section, the printed monopole antenna with various design parameters was constructed, and simulated VSWR, return loss and radiation characteristics are presented and discussed.

The effects of parameters variation on proposed antenna are studied by changing one parameter at a time and fixing the other. The designed antenna is simulated using CST Microwave Studio 2011 [13].

3.1. Full-Band UWB Monopole Antenna

In the proposed structure to increase impedance bandwidth of simple printed monopole antenna a rectangular strip and coupled M-shaped strip are inserted with ground plane as displayed in Fig. 1(b). In the proposed structure coupled M-shaped strip acts as conductor-backed plane and plays important role in enhancing impedance bandwidth of proposed antenna, because it can adjust the electromagnetic coupling between patch and ground plane, hence improved the impedance bandwidth without any cost of size.

The effect of protruded rectangular strip and coupled M-shaped strip on impedance bandwidth of simple monopole antenna is shown in Fig. 2. As displayed in Fig. 2, ordinary square monopole antenna have fundamental and next higher radiation band at 4.4 GHz and 7.4 GHz respectively and shows 10-dB return loss bandwidth from 3.7 GHz to 8.4 GHz in the absence of rectangular strip and coupled M-shaped strip. By inserting rectangular strip upper frequency of impedance bandwidth effectively increased up to 10.18 GHz. In addition by inserting coupled M-shaped strip with rectangular strip, an additional resonance is excited at frequency 11.8 GHz, Hence impedance bandwidth of ordinary monopole antenna increases up to 12.2 GHz.

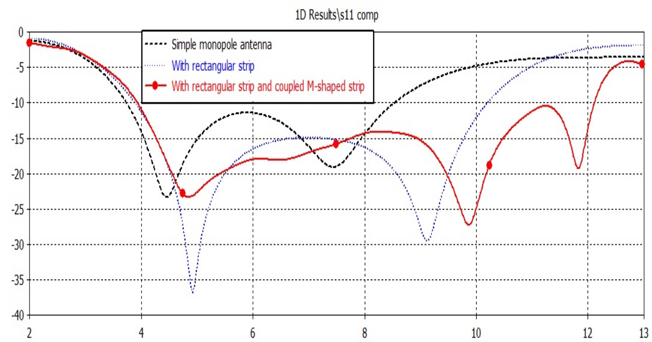


Fig. 2: Simulated return loss characteristics for simple square monopole antenna, Square monopole antenna with protruded rectangular strip and Stepped square monopole antenna with protruded rectangular strip and coupled M-shaped strip

In order to understand the phenomena behind additional resonance, current distribution at 11.8 GHz is shown in Fig. 3. As displayed in Fig. 3, the current concentrated on the edges of the interior and exterior of the coupled M - shaped strip at third resonance frequency (11.8 GHz). It can be observe from Fig. 3 that the current at third resonance 11.8 GHz does not change the direction along bottom edge of square radiating patch. Therefore, the antenna impedance changes at this frequency, that's why impedance bandwidth will increase.

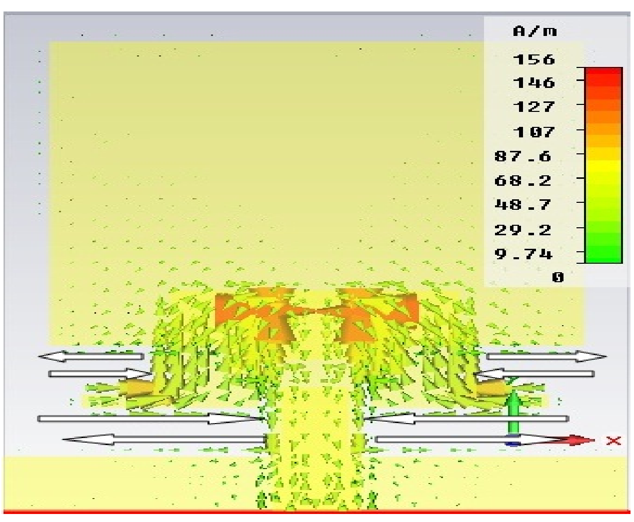
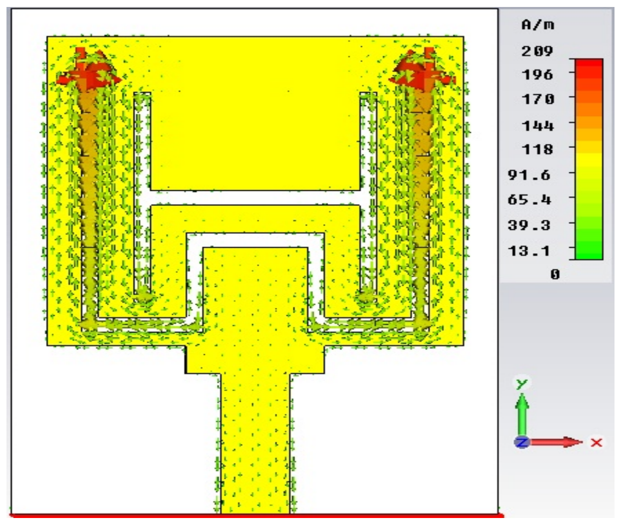


Fig. 3: Simulated current distribution with rectangular strip and couple M-shaped strip at resonant frequency at 11.8 GHz.

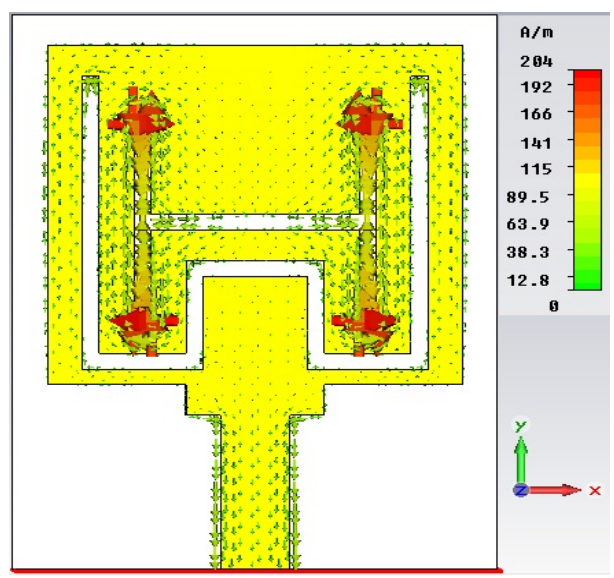
3.2. UWB Monopole Antenna with Triple Band-Notched Characteristics

In this paper in order to realize triple band-notched characteristics W- and H-shaped slots cut in radiating patch as shown in Fig. 1(a), which provides triple band-notch characteristics around 2.68–4.0 GHz, 4.9–6.0 GHz, 7.78–9.0 GHz that cover all 3.5/5.5-GHz WIMAX, 5.2/5.8-GHz WLAN and 7.9–8.7 GHz ITU band respectively.

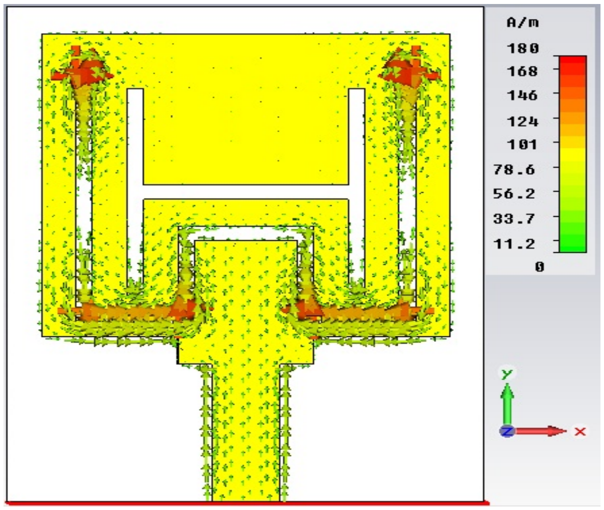
In order to understand the phenomena behind this triple band-notch performance, the simulated current distribution on the radiating patch for the proposed antenna at the notch frequencies of 3 GHz, 5.5 GHz and 8.2 GHz is presented in Fig. 4(a), 4(b) and 4(c) respectively. It can be observed from Fig. 4(a), 4(b) and 4(c), that the current concentrated on the edges of the interior and exterior of W-shaped slot at 3 GHz, on the edges of the interior and exterior of H-shaped slot at 5.5 GHz and on the edges of the interior and exterior of top and bottom side of W-shaped slot at 8.2 GHz. Therefore, the resultant radiation field becomes canceled out and proposed antenna does not radiate efficiently at these notch frequencies which results in notched band.



(a)



(b)



(c)

Fig. 4: Simulated current distributions on the radiating patch for the proposed antenna at (a) 3 GHz (first notch frequency) and (b) 5.5 GHz (second notch frequency), (c) 8.2 GHz (third notch frequency)

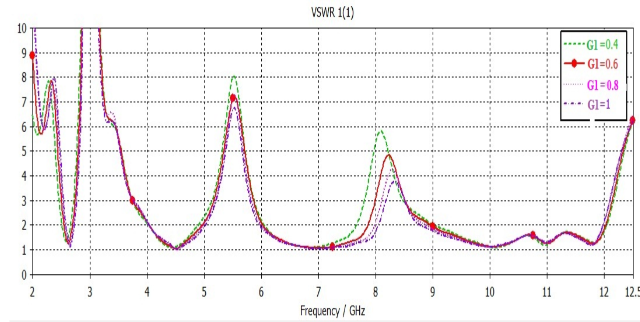
Notch frequency of these three notched band along with peak VSWR can be control with variation of length, width and position of W- and H-shaped slots, as described below.

3.2.1. Effect of G1 Variation: By varying gap G1 between W-shaped slots and lower edge of patch notch frequency for ITU band can be control. The effects of G1 variation on notch frequency for ITU band is shown in Fig. 5(a). It can be observed from Fig. 5 (a), as the G1 increases from 0.4 mm to 1 mm, the notch frequency for ITU band increases from 8.0 GHz to 8.34 GHz.

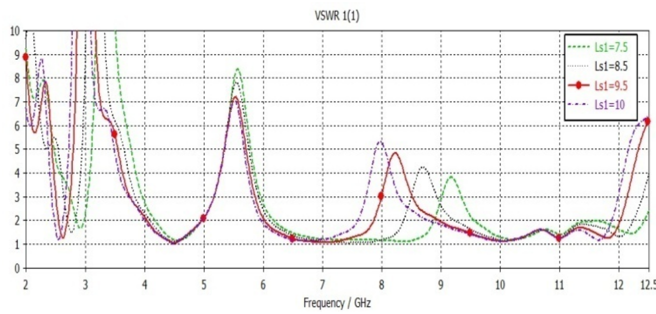
3.2.2. Effect of Ls1 Variation: The effect of length Ls1 variation on notch frequency for ITU band and WIMAX band is shown in Fig. 5(b). It can be observed from Fig. 5(b) as the length increases from 7.5 mm to 10 mm, the notch frequency decreases from 9.17 GHz to 7.9 GHz for ITU notch-band and from 3.32 GHz to 2.9 GHz for WIMAX notch-band.

3.2.3. Effect of Ls2 Variation: By varying length Ls3 of W-shaped slot notch frequency for ITU band and WLAN band can be control. The effects of Ls2 variation on notch frequency is shown in Fig. 5(c). It can be observed from Fig. 5(c), as the Ls2 increases from 1.5 mm to 3.5 mm, the notch frequency decreases from 9 GHz to 8 GHz for ITU notch-band and from 3.2 GHz to 2.9 GHz for WIMAX notch-band

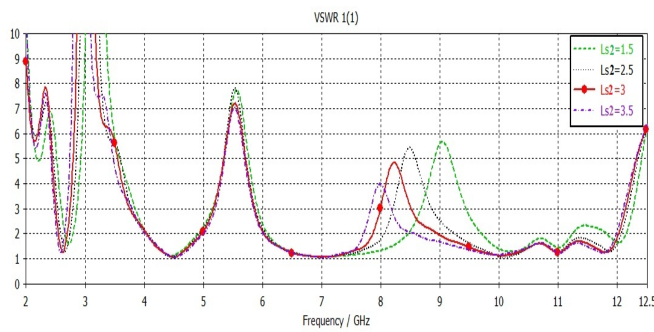
3.2.4. Effect of Ls3 Variation: The effect of length Ls3 of H-shaped slot variation on notch frequency for WLAN band is shown in Fig. 5(d). It can be observed from Fig. 5(d) as the length Ls3 increases from 6 mm to 8.5 mm, the notch frequency for WLAN notch band decreases from 6.18 GHz to 5.2 GHz.



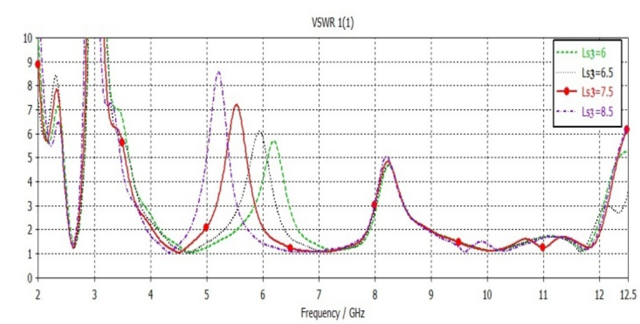
(a)



(b)



(c)



(d)

Fig. 5: Simulated VSWR curve for different value of (a) G1, (b) Ls1, (c) Ls2 and (d) Ls3 while fixing other parameter.

Simulated return loss characteristics for S11 ≤ -10 dB of proposed antenna in comparison of same antenna without W- and H-shaped slots is displayed in Fig. 6. From Fig. 6, it can be observed that proposed antenna operates over frequency for UWB system 2.55–12.0 GHz (130%) while showing three rejection band around 2.68–4.06 GHz, 4.9–6.0 GHz and 7.78–9.0 GHz which cover the 3.5/5.5-GHz (3.4–3.69/5.25–5.85 GHz) WIMAX bands, 5.2/5.8-GHz (5.15–5.35/5.725–5.825 GHz) WLAN bands and 7.9–8.7 GHz ITU band respectively. It is also observed in proposed antenna that the lowest operating frequency highly affected with the filtering structure, hence it is significantly decreased from 3.9 to 2.55 GHz.

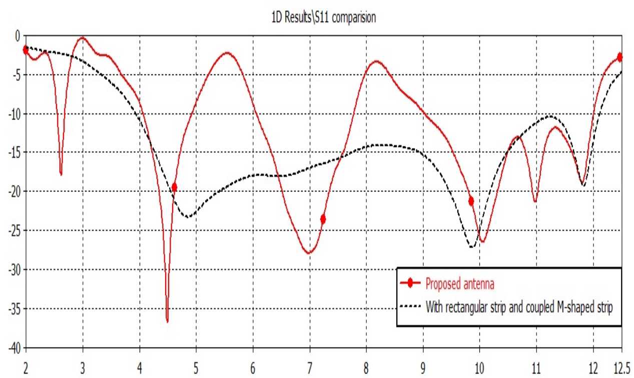


Fig. 6: Simulated return loss curve of proposed antenna in comparison of same antenna without W - and H - shaped slots.

Fig. 7 shows the measured maximum gain comparison with and without band-notch function. As shown in Fig. 7, gain decreases at the frequency bands of 3 GHz, 5.5 GHz and 8.2 GHz. Outside the notched band, proposed antenna gain decreases negligible as compared to simple monopole antenna without notch function.

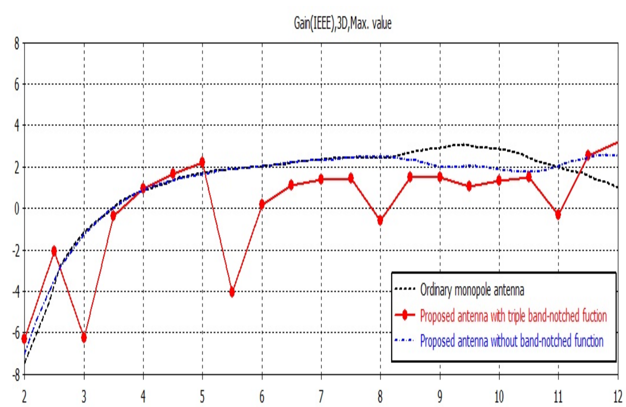


Fig. 7: Maximum gain comparison of proposed antenna

Fig. 8 shows the simulated radiation pattern at 4 GHz, 7 GHz, and 10 GHz in two principle planes known as plane y-z (E-plane) and plane x-z (H-plane). It can be observed from Fig. 7, that the proposed antenna actually radiates over a wide frequency band. The simulated results of these radiation patterns shows that the antenna behaves quite similarly to the typical printed monopoles in E-plane at low operating frequency and start to destroy its radiation pattern at high frequencies. It can also be observed that proposed antenna has nearly omni-direction radiation pattern in H-plane.

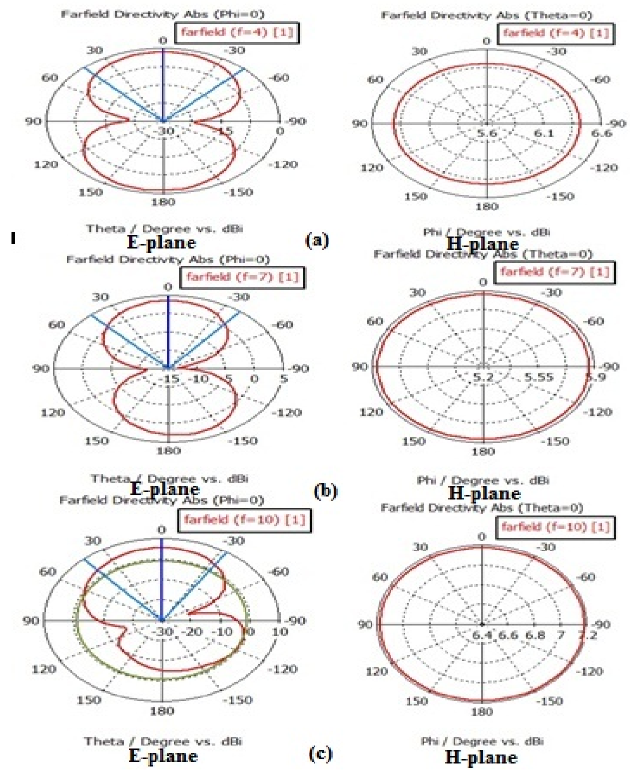


Fig. 8: Simulated radiation pattern of proposed antenna at (a) 4 GHz, (b) 7 GHz, (c) 10 GHz

4. CONCLUSION

A microstrip-fed printed stepped square monopole antenna with triple band-notched characteristic for UWB applications has been presented and investigated. We observe that by embedding a protruded rectangular strip and novel coupled M-shaped strip with ground plane, impedance bandwidth of ordinary square monopole antenna can be increased to higher band and also the triple band-notched function can be achieved using W- and H-shaped slots cut in radiating patch. The proposed antenna offers wide impedance bandwidth between 2.55 to 12.0 GHz with three rejection band around 2.68–4.06 GHz, 4.9–6.0 GHz and 7.78–9.0 GHz which filter the interference caused by existing 3.5/5.5-GHz (3.4–3.69/5.25–5.85 GHz) WiMAX bands, 5.2/5.8-GHz (5.15–5.35/5.725–5.825 GHz) WLAN bands and 7.9–8.7 GHz ITU band respectively. It is also seen that by employing these slots, the lowest operating frequency can be remarkably decreased by 1.35 GHz.

5. ACKNOWLEDGEMENTS

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