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Compact UWB Planar Antenna with Triple Band EMI Reduction Characteristics for WiMAX/WLAN/X-Band Satellite Downlink Frequency

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Abstract—A new compact and simple design of UWB antenna with triple band-notched characteristic is proposed in this paper. The first band notch for 3.3–3.8 GHz (WiMAX) is created by cutting a line slot in the radiating patch. The second band rejection for 5.1–5.8 GHz (WLAN) is achieved by etching out an elliptical split ring resonator (ESRR) from the patch placed just above the feed line and patch junction. And the third notch for 7.25 GHz–7.75 GHz (X-band satellite downlink frequency) is created using rectangular split ring resonator (RSRR) in the feed line. Each notch can be adjusted without disturbing the others. A 10 dB return loss wide bandwidth (3.1–10.6 GHz) and VSWR > 2 for the stopbands has been measured.

1. INTRODUCTION

The US Federal Communications Commission (FCC), in the year 2002, allocated the ultra-wideband (UWB) spectrum (3.1 to 10.6 GHz) for commercial communication purposes [1]. Since then, the problem of in-band electromagnetic interference (EMI) occurring due to co-existing narrowband communication systems such as WiMAX (3.3–3.8 GHz), WLAN (5.15–5.85 GHz), or X-band satellite downlink frequency (7.25 GHz–7.75 GHz) which occupy frequency bands within the designated UWB bandwidth has become the topic of major concern. To keep the antenna footprint unaltered, effective ways to achieve band rejection behavior are inserting strips or slots of various shapes and sizes in the radiating patch/ground plane [2, 12] or embedding a tuning stub within a large slot on the patch [4]. Methods using open loop or split ring resonator [3, 5, 6], inserting the band-rejecting elements integrated in the feed line [7, 13], capacitance loaded loop resonator [8], triple-mode resonator [9], electromagnetic band gap structures [10], and triple mode stub loaded resonator [11] have also been presented.

The design and parametric study of the proposed optimal UWB antenna (3.1 to 10.6 GHz) providing single, double and triple reject notch function that effectively reduces the in-band electromagnetic interference due to the existing narrowband systems operating at higher power levels are presented in this paper.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed antenna designed using ANSYS High Frequency Structural Simulator (HFSS). It is fabricated on an FR4 substrate with dielectric constant of 4.4 and thickness of 1.6 mm. The proposed antenna is ultra-wideband and compact in size ($26 \times 27 \times 1.6\,\mathrm{mm}^3$). The radiating patch of antenna is half-elliptical having major axis of 14 mm and minor axis of 13 mm. A $50\,\Omega$ microstrip line of 3.13 mm width and 12.5 mm length is used for feeding the radiating patch. Upper

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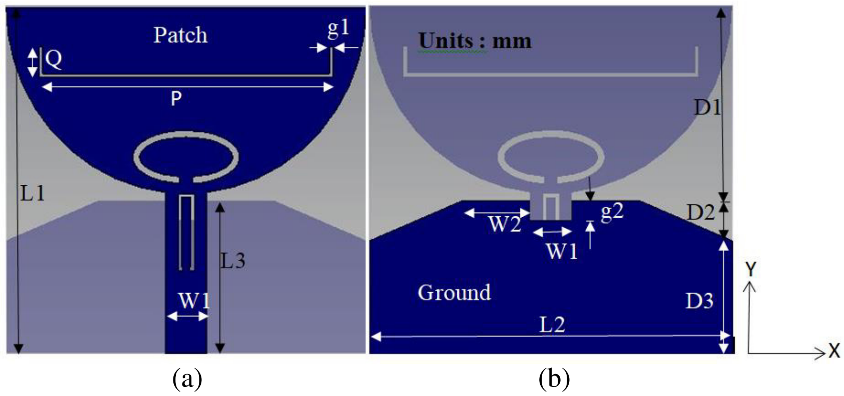


Figure 1. (a) Front and (b) back view of proposed antenna.

Table 1. Optimized antenna parameters.

Parameter	Value (mm)	Parameter	Value (mm)
$L1$	26	$g2$	1.5
$L2$	27	$D1$	14.5
$L3$	11.5	$D2$	3.5
P	22	$D3$	8.5
Q	1.75	$W1$	3.13
$g1$	0.25	$W2$	5

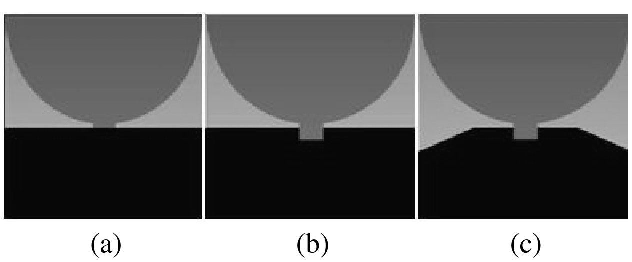


Figure 2. Reference antenna ground, (a) without slot and tapering, (b) with slot and (c) with slot and tapering.

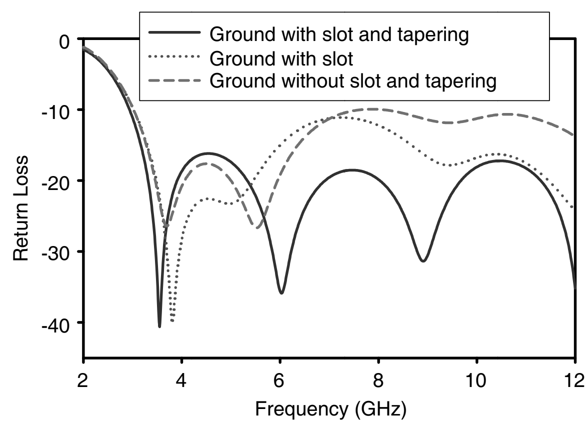


Figure 3. Effect of ground modification on bandwidth.

$14.5 \times 27\,\text{mm}^2$ of the ground plane of the reference antenna is etched out, and remaining $11.5 \times 27\,\text{mm}^2$ is modified by tapering its side edges and cutting a rectangular slot [4] of $1.5 \times 3\,\text{mm}^2$ to enhance the antenna's broadband performance. The values of all antenna parameters are given in Table 1.

Figure 2 shows the ground modifications in the simulated reference antenna structure in three stages, and Figure 3 shows the effect of these modifications on the return loss of reference antenna. After the modification, $-10\,\text{dB}$ return loss improves to $-16\,\text{dB}$ throughout the broadband, and we get wide bandwidth of 9.10 GHz (2.9–12 GHz) that covers frequency band for UWB systems specified by FCC. Our objective is to get the desired single, double and triple band-rejection by using the slots and split ring resonators on the reference UWB antenna. Initial estimates for the dimensions of the notching element, full-wave simulation and measured results are addressed in Section 3 for all the cases of antenna design.

3. DESIGN METHODOLOGY AND RESULT DISCUSSION

The structure of the proposed antenna is designed in five stages as shown in Figure 4.

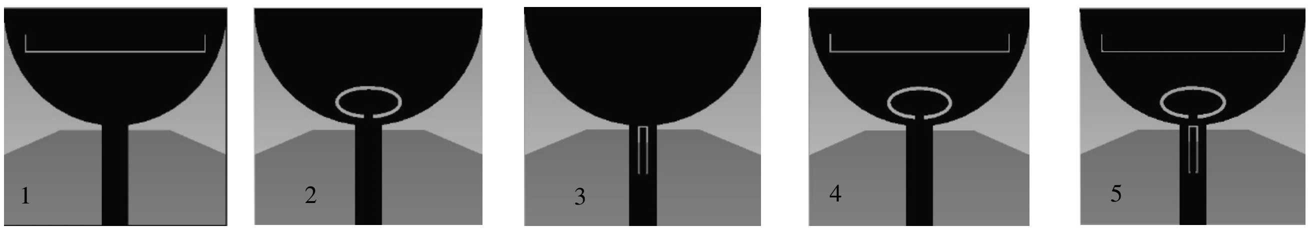


Figure 4. Different stages of antenna design.

Antenna 1: Antenna structure with U-shaped line slot for single band WiMAX rejection. **Antenna 2:** Antenna structure with ESRR for single band WLAN rejection. **Antenna 3:** Antenna structure with RSRR for single X-band satellite downlink frequency rejection. **Antenna 4:** Antenna with dual band-notched characteristics by use of U-shaped line slot and ESRR. **Antenna5:** proposed triple band-notched antenna using U-shaped line slot, ESRR and RSRR.

3.1. Antenna with Notch Frequency for WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) operating in the range of 3.3 GHz to 3.8 GHz may cause interference with UWB devices. So instead of using a band-stop filter at the receiver antenna we have etched a U-shaped line slot. Total length of the line slot is $L = P + 2 \times Q$ as shown in Figure 1. Initial calculated length by Eq. (1) [2] of the line slot is $L = 26\,\text{mm}$ for 3.5 GHz, and the optimized length is 25.5 mm. Here $c = 3 \times 10^8\,\text{m/s}$, $f_{\text{notch}} = 3.5\,\text{GHz}$ and $\varepsilon_r = 4.4$.

$$L = \frac{c}{2 \times f_{notch}\sqrt{\dfrac{\varepsilon_r + 1}{2}}} \tag{1}$$

$L = 16$ to $L = 28$ variation as plotted in Figure 5 shows that by increasing the length of the slot the center frequency is shifting towards lower values, and rejection is also improving, hence this slot

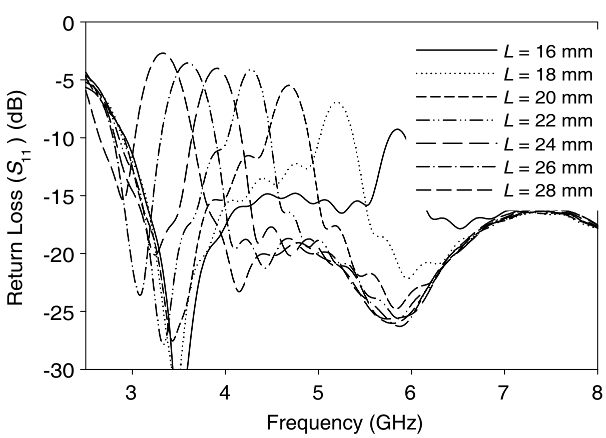


Figure 5. Variation of Return Loss of Antenna 1 for $L = 16\,\text{mm}$ to $L = 28\,\text{mm}$.

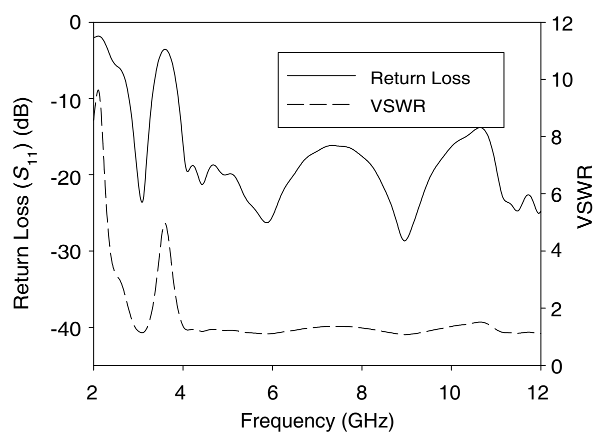


Figure 6. Return Loss and VSWR of Antenna 1 for $L = 26\,\text{mm}$.

is a good candidate for getting notch frequency at lower frequency band, i.e., for WiMAX band. The simulated return loss for $L = 26$ mm is shown in Figure 6. We get rejection with Voltage Standing Wave Ratio (VSWR) reaching 5 and less than -15 dB return loss for the remaining band.

3.2. Antenna with Notch Frequency for WLAN

To reject WLAN (5.15 GHz to 5.825 GHz) communication signals, an ESRR having minor axis inner radius 2 mm and major axis outer radius 4.5 mm with a split of 1 mm is etched out of the patch just above the feed as shown in Figure 7. The calculated inner circumference of the ellipse by Eq. (2) [6] is $S = 14.9$ mm for $f_{\text{notch}} = 5.5$ GHz.

$$S = \frac{\lambda_g}{2} = \frac{c}{2 \times f_{\text{notch}} \sqrt{\varepsilon_{\text{reff}}}} \tag{2}$$

Variation of return loss due to change in $X = 2$ mm to 5 mm plotted in Figure 8 and $Y = 1$ mm to 2.5 mm plotted in Figure 8 and Figure 9 respectively shows that this structure can be effectively used for creating notch in middle frequency range of UWB. Circumference of ESRR is optimized to 16.34 mm to get notch band of 5.1–5.9 GHz with high rejection having VSWR > 5 and return Loss < -15 dB for the remaining band as shown in Figure 7.

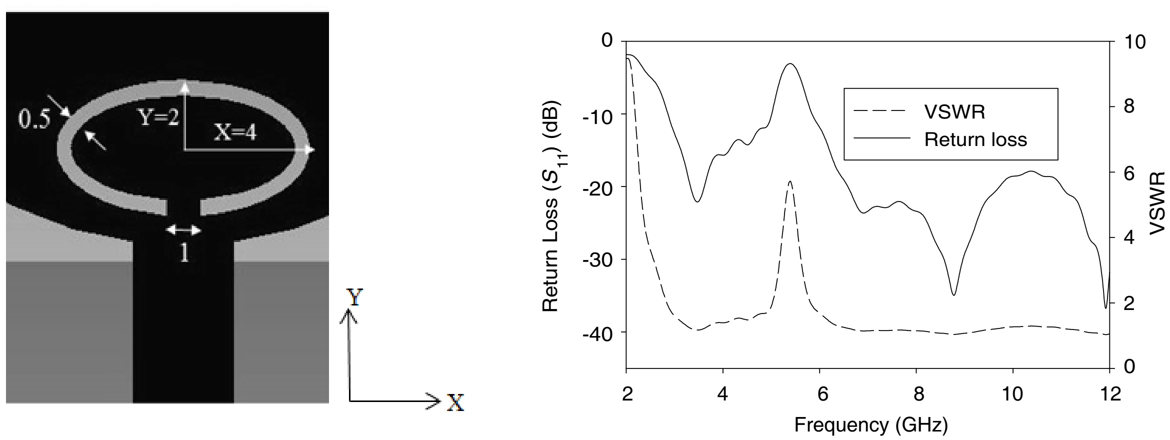


Figure 7. Elliptical split ring resonator dimensions and Return Loss and VSWR of Antenna 2 for $X = 4$ and $Y = 2$.

3.3. Antenna with Notch Frequency for X-Band Satellite Downlink

X-band Satellite downlink frequency band, which occupies frequency band within the designated UWB bandwidth, operates from 7.25 GHz to 7.75 GHz. To reject this interference an RSRR has been etched out of feed line. Calculated value for inner perimeter of the RSRR by Eq. (2) [6] is $S = 11$ mm for $f_{\text{notch}} = 7.5$ GHz. Length and width of the structure are optimized to get perimeter of 12.9 mm as shown in Figure 10. Simulation of the antenna for variation of Length 'm' = 1.1 to 2.5 as plotted in Figure 11 and width 'n' = 4 to 8 mm as plotted in Figure 12 shows that this RSRR is good for creating notch at higher frequency, i.e., for satellite downlink frequency rejection. We get less than -15 dB return loss and a rejection band of 7.724–7.78 GHz having VSWR > 2 for $m = 1.2$ mm and $n = 5.75$ mm.

3.4. Antenna with Double Notch Band

A double notch-band characteristic has been achieved by combination of a U-shaped line slot of $L = 26$ mm and the ESRR of $X = 4$ and $Y = 2$ on a single substrate as shown in Figure 4 as Antenna 4. We get VSWR approaching 13 for 3.08–4.14 GHz (WiMAX) and peak VSWR > 5 for 5.03–5.9 GHz (WLAN) and -10 dB return loss for remaining band as plotted in Figure 13.

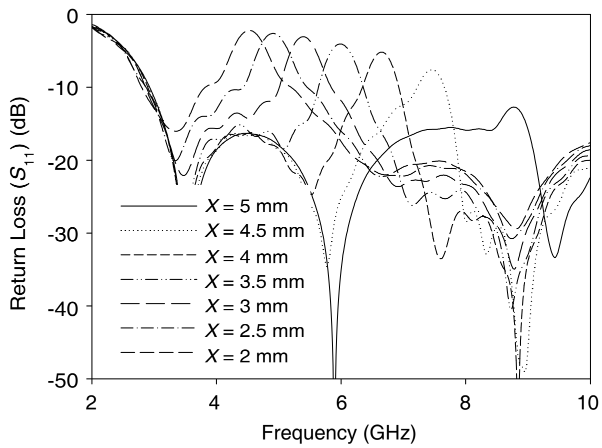


Figure 8. Variation of Return Loss of Antenna 2 for $X = 2$ mm to 5 mm.

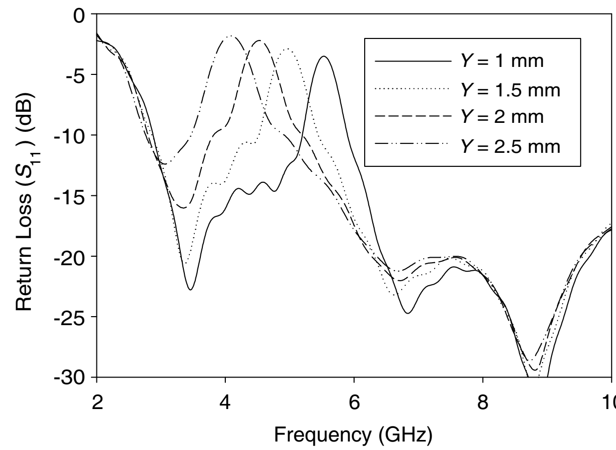


Figure 9. Return Loss variation of Antenna 2 for $Y = 1$ mm to 2.5 mm.

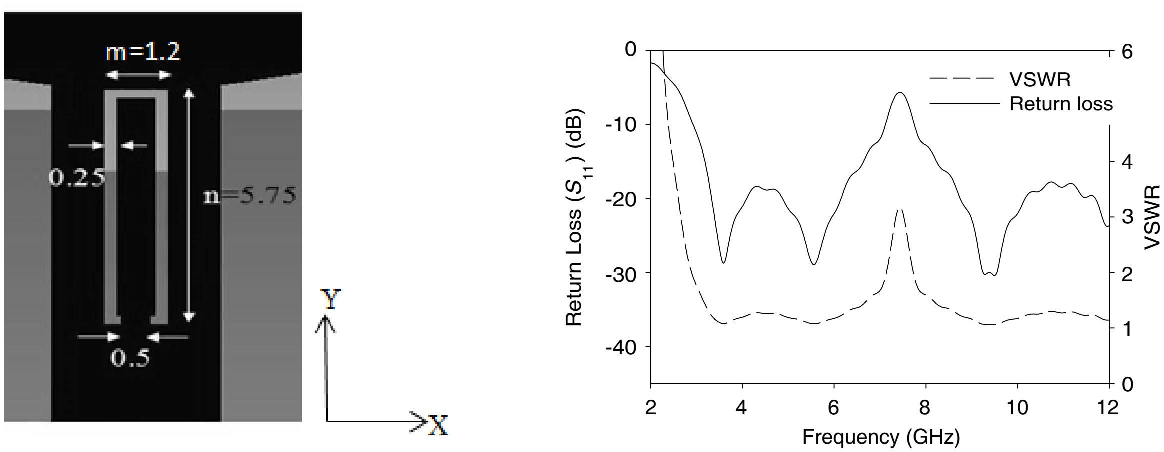


Figure 10. Rectangular split ring resonator dimensions and plot of Return Loss and VSWR of Antenna 3 for $m = 1.2$ and $n = 5.75$ mm.

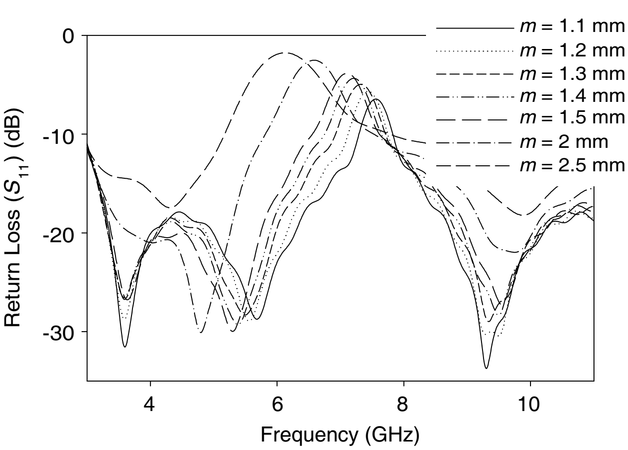


Figure 11. Variation of Return Loss of Antenna 3 for $m = 1.1$ mm to 2.5 mm.

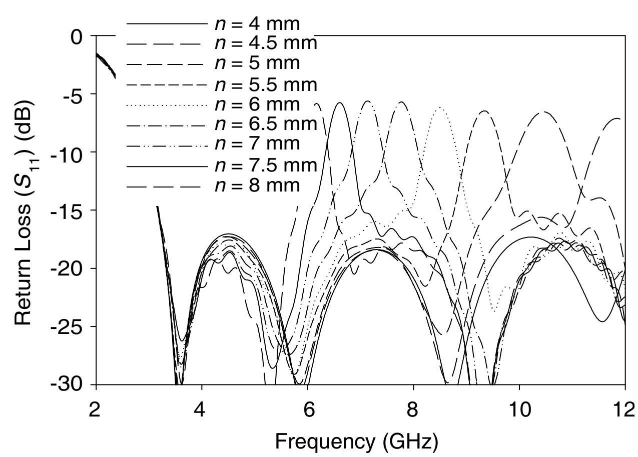


Figure 12. Variation of Return Loss of antenna 3 for $n = 4$ mm to 8 mm.

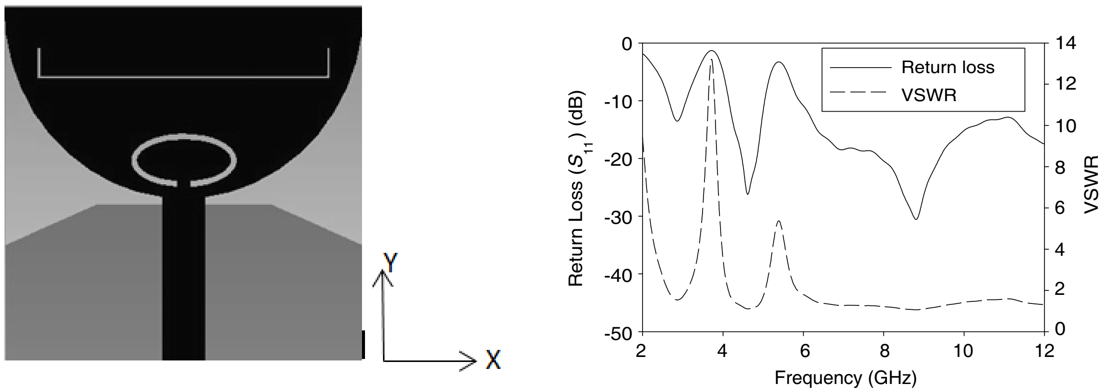


Figure 13. Dual notch band antenna structure and Return Loss and VSWR of Antenna 4 with dual band-notched characteristics by use of U-shaped line slot and ESRR.

3.5. Antenna with Triple Notch band Characteristics

Triple notch band antenna is created by combination of all three notch elements, i.e., using U-shaped line slot, ESRR and rectangular SRR on the primitive UWB antenna as shown in Figure 1 and as antenna 5 in Figure 4. The simulated current distributions of the designed antenna at the notched frequencies in Figure 14 clearly indicate the respective elements responsible for the band-notch characteristics. Front and back sides of the fabricated antenna prototype and measurement setup in anechoic chamber are shown in Figure 15.

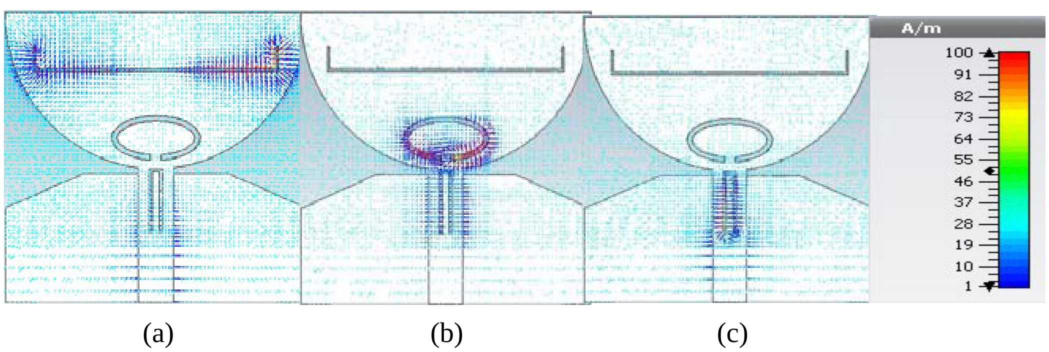


Figure 14. Relative concentration of surface current at notched frequency, (a) 3.5 GHz, (b) 5.5 GHz and (c) 7.5 GHz.

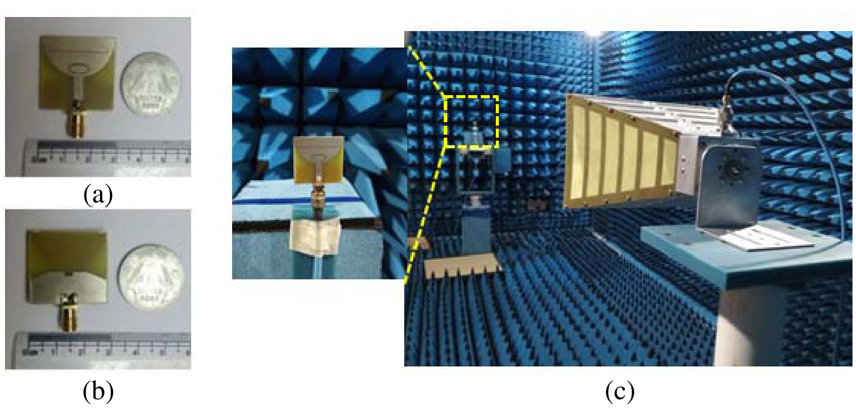


Figure 15. Photograph of the (a) front view, (b) back view of triple band-notched fabricated antenna, (c) measurement set-up in anechoic chamber.

Comparisons of simulated and measured results of return loss and VSWR are shown in Figure 16. We get -10 dB return loss throughout the band and VSWR $>$ 5 for 3.3–3.8 GHz and 5.1–5.9 GHz and VSWR $>$ 3 for 7.24–4.78 GHz frequency bands after simulation. The fabricated antenna has an impedance bandwidth of 2.7 to 12 GHz having notch-bands in the frequency ranges 3.14–3.9 GHz (Peak

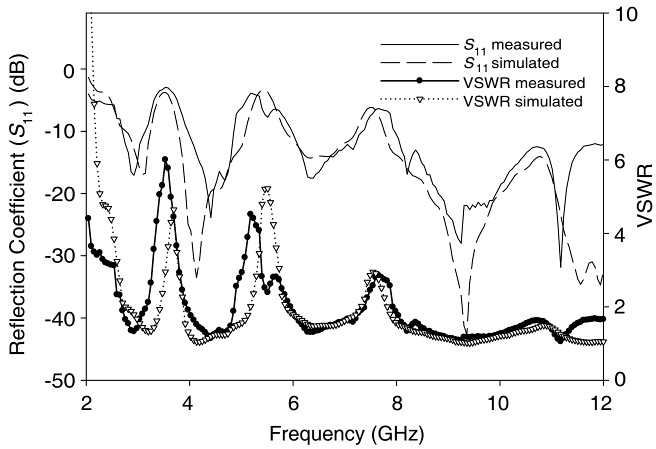


Figure 16. Measured and simulated Return Loss and VSWR variation of proposed triple band notched antenna.

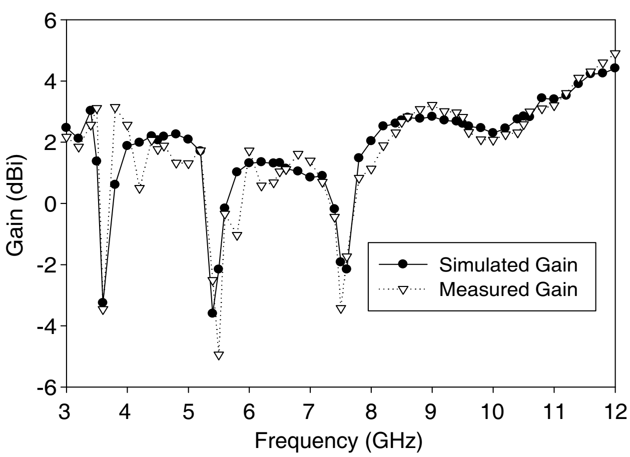


Figure 17. Measured and simulated gain of proposed triple band notched antenna.

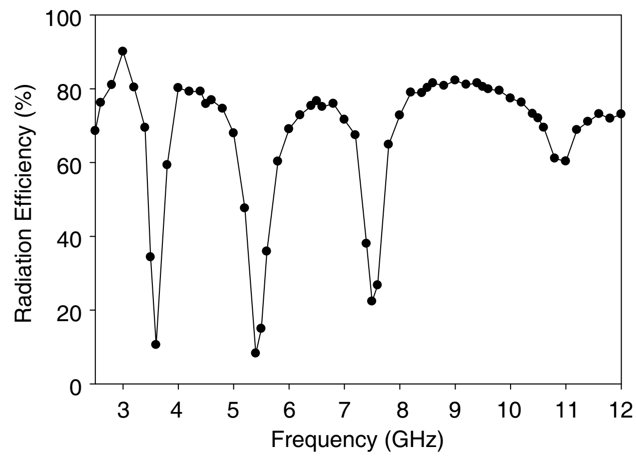
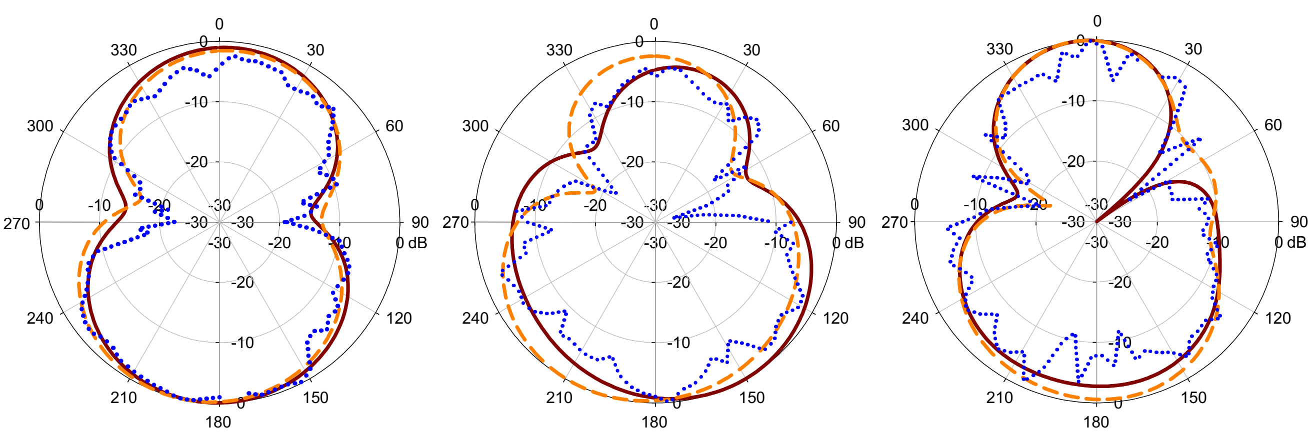


Figure 18. Radiation efficiency of the proposed triple band notched antenna.



(a) (b) (c)

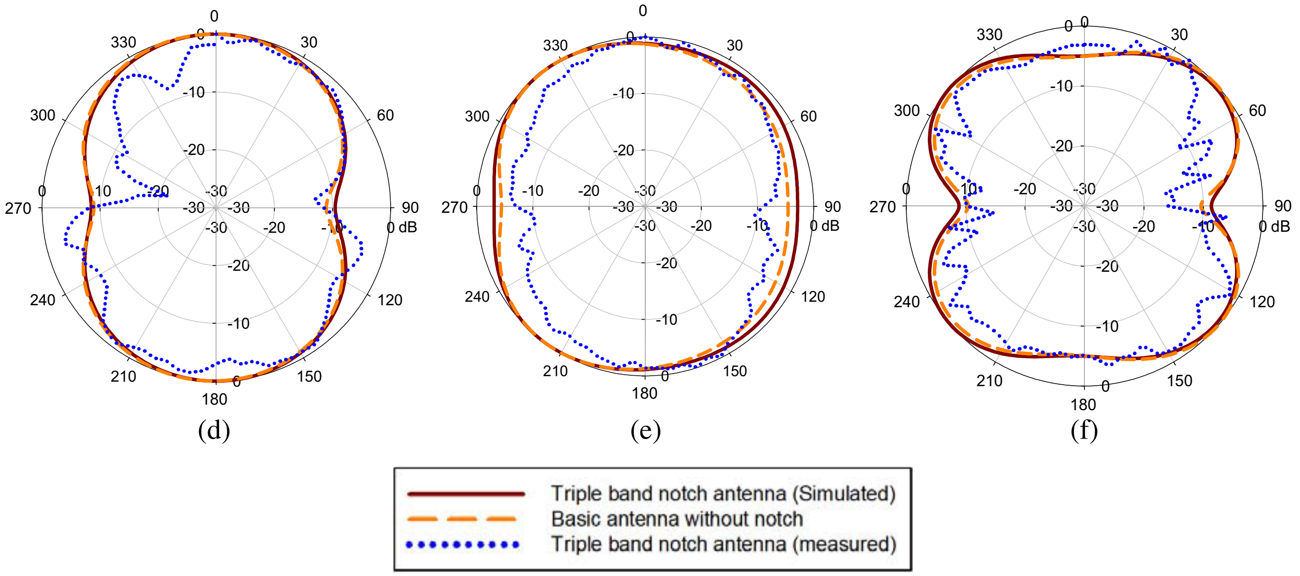


Figure 19. Simulated and measured 2-D radiation patterns of basic antenna without any notch and triple band notched antenna. Elevation plane pattern at (a) 4.5 GHz; (b) 6.5 GHz; (c) 8.5 GHz and azimuth plane pattern at (d) 4.5 GHz; (e) 6.5 GHz; (f) 8.5 GHz.

Table 2. Comparison of the proposed antenna with several existing designs.

Antenna Structure	Antenna Dimensions (mm)	No. of notching elements	Rejection Bands $f1/f2/f3$ (GHz)	Max. Gain (dBi)
[2]	$20 \times 27 \times 1$	2	3.5/5.5	5.5
[3]	$31 \times 40 \times 0.635$	1	5.2	6.5
[4]	$28 \times 24 \times 1.524$	1	3.5–6.8	6
[5]	$27 \times 34 \times 0.787$	3	3.5/5.2/5.7	5
[6]	$35 \times 35 \times 1.6$	4	3.5/5.5/8.3	6.1
[7]	$28 \times 28.5 \times 0.635$	4	3.5/5.2/5.8	4
[8]	$26 \times 36.6 \times 1$	2	3.5/5.5/7.5	6
[9]	$20 \times 38 \times 0.508$	1	5/6.5/8	3.7
[10]	$42 \times 50 \times 1.6$	3	3.5/5.5/7.5	5.9
[11]	$20 \times 40 \times 0.508$	1	3/5.5/8	5.3
[12]	$19 \times 24 \times 1.2$	3	3.5/5.5/7.5	4
[13]	$40 \times 42.2 \times 0.762$	2	3.5/5.5/8.2	5
Proposed	$26 \times 27 \times 1.6$	3	3.5/5.5/7.5	4.4

VSWR = 6), 4.9–5.9 GHz (Peak VSWR = 4.5) & 7.3–7.9 GHz (Peak VSWR = 2.8). Measured VSWR and return loss are similar to the simulated values with small shifts due to fabrication imperfections and slight misalignment in measurement process.

Gain and radiation efficiency of antenna plotted in Figure 17 and Figure 18 respectively show that in the working band, the antenna has stable efficiency and gain, and both decrease drastically at notched frequencies. Measured gain is in good match with simulated gain. Figure 19 depicts that the nearly omnidirectional radiation patterns are obtained in the azimuth-plane over the whole UWB frequency range.

Furthermore, as compared in Table 2, the proposed antenna has three notch bands which are more than that of [2, 3] and [4]. In [9] and [11], minimum number of notching elements used for creating triple band notches is one, but sizes of the antennas are bigger than the proposed antenna. The proposed design uses three notching elements and has dimensions $26 \times 27 \times 1.6\,\mathrm{mm}^3$ equivalent to $0.24\lambda \times 0.23\lambda \times 0.01\lambda$ with respect to the first resonance frequency at 2.7 GHz which is compact in size as compared to all the references taken, and hence, is a good candidate to be integrated in miniature UWB portable devices.

4. CONCLUSION

A compact triple band-notched omnidirectional UWB antenna with high radiation efficiency and stable gain over the desired frequency is achieved by embedding line slot, elliptical split ring and rectangular split ring in the antenna structure for reducing the EMI with the existing WiMAX, WLAN, and X-band satellite downlink frequency bands. Impedance bandwidth of the antenna is enhanced by using tapered ground structure and embedding a rectangular slot in it. A low-cost FR4 substrate is used for fabrication. Measured return loss, VSWR, gain and radiation patterns of the fabricated antenna show good match with simulated results. The proposed antenna can be used as single, double or triple band notch antenna by using the three integrated shapes separately or together on the reference antenna.

REFERENCES

1. Federal Communications Commission, "Federal Communications Commission revision of Part 15 of the Commission's rules regarding ultra-wideband transmission system from 3.1 to 10.6 GHz," Washington, DC, USA, 2002.
2. Gao, P., L. Xiong, J. Dai, S. He, and Y. Zheng, "Compact printed wide-slot UWB antenna with 3.5/5.5-GHz dual band-notched characteristics," *IEEE Antennas Wireless Propag. Lett.*, Vol. 12, 983–986, 2013.
3. Kelly, J. R., P. S. Hall, and P. Gardner, "Band-notched UWB antenna incorporating a microstrip open-loop resonator," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 8, 3045–3048, Aug. 2011.
4. Abbas, S. M., Y. Ranga, A. K. Verma, and K. P. Esselle, "A simple ultra wideband printed monopole antenna with high band rejection and wide radiation patterns," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 9, 4816–4820, Sep. 2014.
5. Lin, C.-C., P. Jin, and R. W. Ziolkowski, "Single, dual and tri-band-notched ultrawideband (UWB) antennas using capacitively loaded loop (CLL) resonators," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 1, 102–109, Jan. 2012.
6. Sarkar, D., K. V. Srivastava, and K. Saurav, "A compact microstrip-fed triple band-notched UWB monopole antenna," *IEEE Antennas Wireless Propag. Lett.*, Vol. 13, 396–399, 2014.
7. Zhu, F., S. Gao, A. T. S. Ho, R. A. Abd-Alhameed, C. H. See, T. W. C. Brown, J. Li, G. Wei, and J. Xu, "Multiple band-notched UWB antenna with band-rejected elements integrated in the feed line," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 8, 3952–3960, Aug. 2013.
8. Wang, J., Z. Wang, Y. Yin, and X. Liu, "UWB monopole antenna with triple band-notched characteristic based on a pair of novel resonators," *Progress In Electromagnetics Research*, Vol. 49, 1–10, 2014.
9. Peng, H., Y. Luo, and Z.-X. Shi, "Triple band-notched UWB planar monopole antenna using triple-mode resonator," *Progress In Electromagnetics Research C*, Vol. 57, 117–125, 2015.
10. Jaglan, N., B. K. Kanaujia, S. D. Gupta, and S. Srivastava, "Triple band notched UWB antenna design using electromagnetic band gap structures," *Progress In Electromagnetics Research C*, Vol. 66, 139–147, 2016.
11. Wang, S., "A new compact printed triple band-notched UWB antenna," *Progress In Electromagnetics Research Letters*, Vol. 58, 67–72, 2016.
12. Nguyen, D. T., D. H. Lee, and H. C. Park, "Very compact printed triple band-notched UWB antenna with quarter-wavelength slots," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 411–414, 2012.
13. Xu, F., Z. Wang, X. Chen, and X. Wang, "Design of ultrawideband antenna with triple band-notched functions based on non-uniform width slots," *International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, 2012, DOI: 10.1109/ICMMT.2012.6230198.