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A Multi-Slot Rectangular Monopole Antenna with Inverted L-Shaped Stub and Defected Ground Structure for Multiband Wireless Applications

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Abstract— *This paper introduces a triple-band antenna suitable for UMTS, 4G-LTE, IEEE 802.11 b/g WLAN for S-band, WiMAX, C-band and X-band applications. The proposed design is based on a modified and miniaturized printed monopole antenna, which incorporates multiple slots onto the rectangular patch with an inverted L-shaped stub towards the right of the patch and also a defect in the ground plane to achieve resonance in three frequency bands. The antenna operates in three bands with excellent impedance matching within these frequency ranges. To validate the proposed design, a prototype of the antenna has been fabricated and tested, and the measured results are provided. The radiation pattern exhibited nearly omnidirectional and directional characteristics, a reasonable gain across the three operating bands are achieved. The fabricated prototype verified the accuracy of the simulated results through measurements.*

Keyword— *UMTS, LTE, WiMAX, WLAN, monopole, omnidirectional.*

I. Introduction

The rapid advancement of wireless communication technology in the past decade has led to the development of various wireless communication standards such as PCS, DCS, UMTS, WLAN, WiMAX, UWB, Satellite Communication applications, etc. These standards operate in different frequency bands, sparking a growing interest in the research of antennas capable of supporting multiple bands or broadband communication [1–10]. There is an increasing demand for portable wireless communication devices that can integrate multiple communication standards into a single system [1]. For example, dual-band antennas are designed to cater to WLAN services, which require operation in the 2.4/5.2/5.8 GHz bands. Triple-band antennas are used for WiMAX applications, covering the 2.5/3.5/5.8 GHz bands, while UWB antennas cover a wide range from 3.1 to 10.6 GHz [2]. In these modern communication systems, reducing the antenna's size while achieving wide bandwidth and multiband operation has become crucial for practical applications. This research proposes an antenna design utilizing microstrip-feed technology to achieve multiband operation across WLAN, WiMAX, and UWB bands.

Various studies have described different types of dual-band/multiband antennas, including the slotted monopole antenna [3], cavity backed annular slot antenna [4], high directivity electromagnetic bandgap resonator [5], W-slot loaded patch antenna [6], single slotted patch and ground slot antenna [10], and so on so forth. These antennas face challenges such as size limitations, design complexity, limited gain/bandwidth, and unstable radiation patterns. Nevertheless, there are on-going research opportunities to enhance antenna performance by exploring and utilizing various techniques.

A reconfigurable sickle-shaped slotted antenna was developed with switchable frequencies, targeting Bluetooth, WiMAX, and WLAN applications has been proposed in [7]. In [8], a direct-fed slot antenna for similar applications has been proposed, utilizing a metal cover of a notebook computer instead of a substrate. To achieve higher gain and improved polarization, an antenna design incorporating asymmetrical multiple V slits in the patch outline and a central circular slot was employed in [9]. A compact dual-band microstrip patch antenna was designed by the researchers in reference [10]. The antenna featured two unequal rectangular slots on the patch and a ground slot. The researchers in [11] presented several designs of compact multi-frequency microstrip patch antennas that incorporated unequal slots on the patch at arbitrary positions. The miniaturization of a microstrip patch antenna was also explored in previous works, specifically by introducing slots on the ground plane with and without the slots on the patch, as discussed in [12] and [13]. Multiband slotted antennas which are focussing on various applications such as WLAN, C band, WiMAX, and digital broadcasting have been introduced in the previous studies [14–16].

In this research paper, a rectangular patch antenna which is slotted and fed by microstrip feeding structure having inverted L-shaped stub with defect in the ground plane has been introduced. This antenna exhibits three operating bands with better impedance bandwidth and supports UMTS, 4G-LTE, IEEE 802.11 b/g WLAN for S-band, WiMAX, C-band and X-band applications. The antenna comprises of the slotted structure on the rectangular patch with defecting ground plane and an inverted L- stub at right of the patch. The overall dimensions of the proposed antenna are 47x38x1.6 mm3. The comparison with the reference antennas has also been presented with respect to size and bandwidth.

II. Antenna Structure

Fig. 1. demonstrates the microstrip fed slotted rectangular patch antenna with DGS and an inverted L-shaped stub from

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patch. The antenna is fabricated on the FR4 substrate with the thickness of 1.6 mm. Upon selecting and optimizing the antenna dimensions carefully, the good impedance matching for all the three bands is shown which supports UMTS, 4G-LTE, IEEE 802.11 b/g WLAN for S-band, WiMAX, C-band and X-band applications. The feeding structure of 50 Ω is introduced of width WF and length LF on the top of substrate where the SMA connector is interfaced so that power transfer achieved should be maximum. The width and length of the substrate used are denoted by Wsub and Lsub. The patch is having the length and width denoted as Lp and Wp, respectively. The portion of the patch is protruded downward with the dimensions of L1xW1. The eight slots introduced on the rectangular patch in which four slots are on left side and the other four on the right are having the same structure with length and width denoted as Lslot and Wslot. All four slots on left hand and right hand side are equispaced by ‘t1’ which are apart by t2 as demonstrated in Figure 1. The inverted L-shaped stub structure is having the dimensions of Lstub1 and Lstub2 with the width of Wstub. The ground structure is defected and the cut-out structure is having the dimension of G1xG2 with the ground length of Lg and width Wg. All the dimensions are shown in the figure and the values (in mm) are illustrated in Table 1.

TABLE I. dimensions of the proposed antenna.

Lsub	**Wsub**	**Lp**	**Wp**	**Lg**	**Wg**	**L1**	**W1**	**LF**	**WF**
47	38	18	21	26	38	2	11	26	2
Lslot	**Wslot**	**Lstub1**	**Lstub2**	**Wstub**	**t1**	**t2**	**G1**	**G2**	
17	1	5.5	12	1	1	5	2	11	

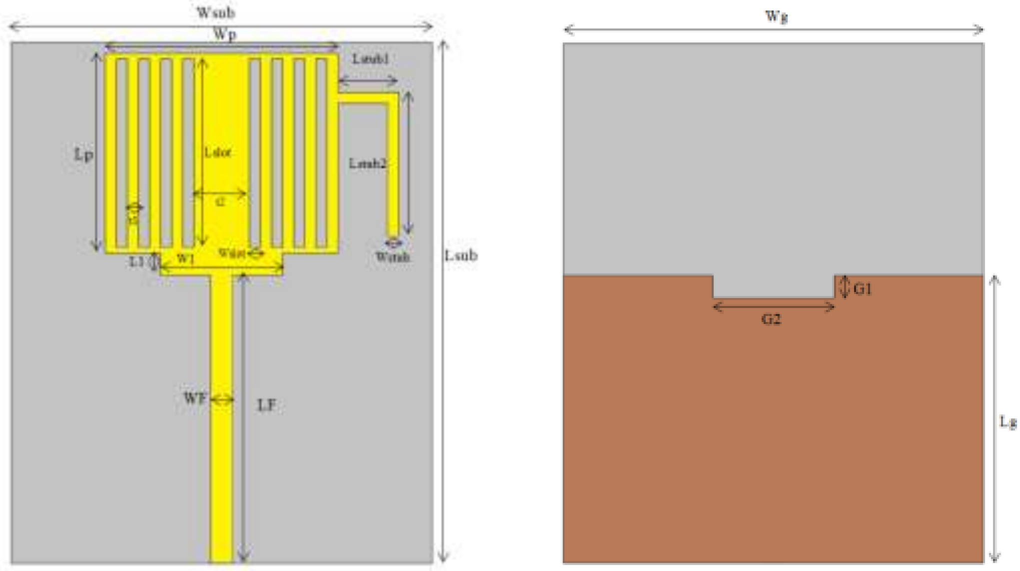

Fig. 1. Geometry of the proposed antenna. Top view and bottom view.

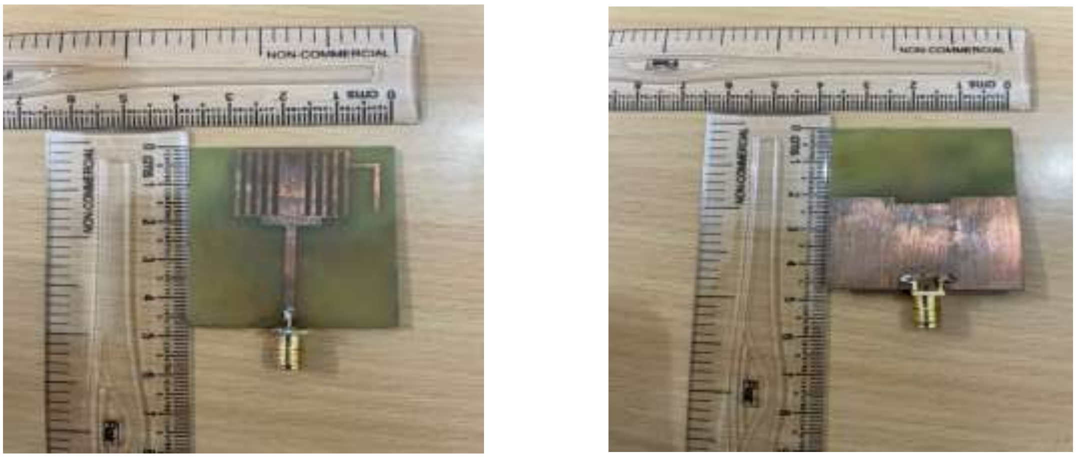

Fig. 2. Fabricated top view and bottom view of proposed antenna.

III. DESIGN EVOLUTION

The proposed antenna has been designed by four consecutive steps, as shown in the Fig. 3. The design is started with the Antenna 1, in which only rectangular patch which is protruded downward and a microstrip feedline is shown. The reflection coefficient has been presented in the same figure in

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which it is resonant at 5.9 GHz covering the bandwidth having the range of 5.1- 7.3 GHz. Antenna 2 in the figure shows that when incorporated with four slots in the left of the patch with same dimensions has been resonant at 3.3, 6.9 and 9.3 GHz with the frequency range of 2.8- 4 GHz, 4.9- 7.6 GHz and 8.9- 9.7 GHz but with very low return loss value at first and third resonance but very good at the second resonance frequency with good bandwidth. Now, Antenna 3 as shown has the four more slots on to the right of the patch which exhibits two bands resonant at 4.8 GHz and 7 GHz with frequency coverage of 2.8- 4.9 GHz and 5.6- 7.6 GHz, respectively. Finally, when the inverted L-shaped and the defect in ground plane as shown in figure as Antenna 4 (proposed antenna), are incorporated, then the antenna resonates at three frequencies with proper and good impedance matching and a better bandwidth at all the three resonant frequencies. The triple- band values are (1.9- 3.8 GHz)/2.3 GHz, (4.9- 5.9 GHz)/5.3 GHz and (7.4- 9.0 GHz)/8.1 GHz.

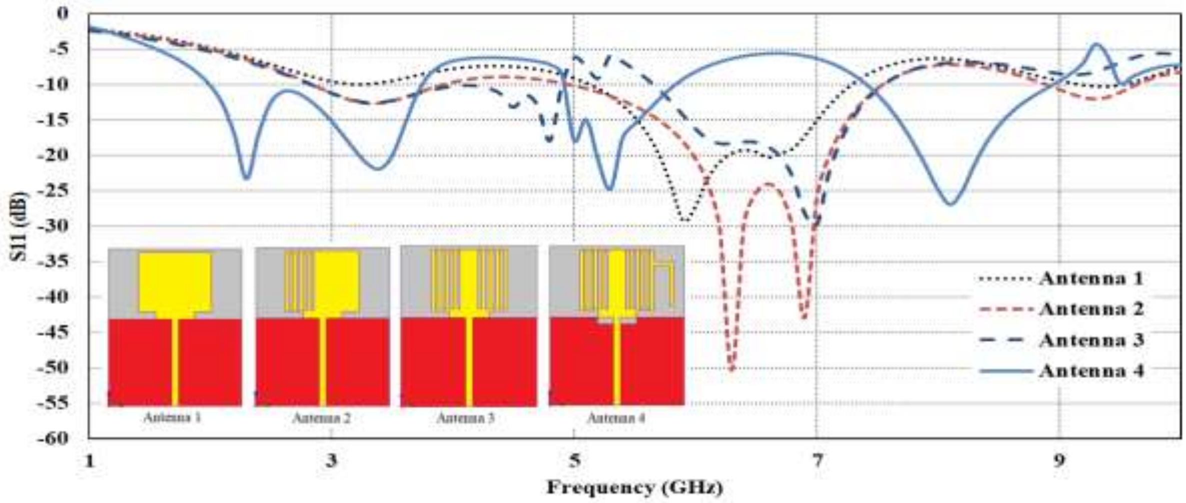

Fig. 3. Evolution of the prototype.

IV. Results and Discussions

A. Parametric Analysis

To investigate the effect by varying the width of the feeding structure 'WF' on the return loss and bandwidth, the value of the width is varied from 1 mm to 4 mm with the step size of 1 mm. it is very much evident from the Fig. 4. that variation in WF has got major effect on all the three bands. The figure also concludes that the value WF = 2 mm, is the optimum intake as it provides the desired return loss and good bandwidth. However, when the value of 1 mm is taken, there is a decrease in the return loss of band 1 and band 2 but increased return loss at band 3 with increased bandwidth and there are shifts in the return losses of band 2 and 3 and also in the resonance. When selected value is 3 mm, three bands are achieved with good return loss in band 1 but less in band 2 and least in band 3 with some enhanced bandwidth at band 1 but less in band 2 and 3. At last, when WF is taken as 4 mm only two bands are obtained with tremendous return loss and good bandwidth at band 1 and less return loss and bandwidth at band 2 as can be seen in the figure.

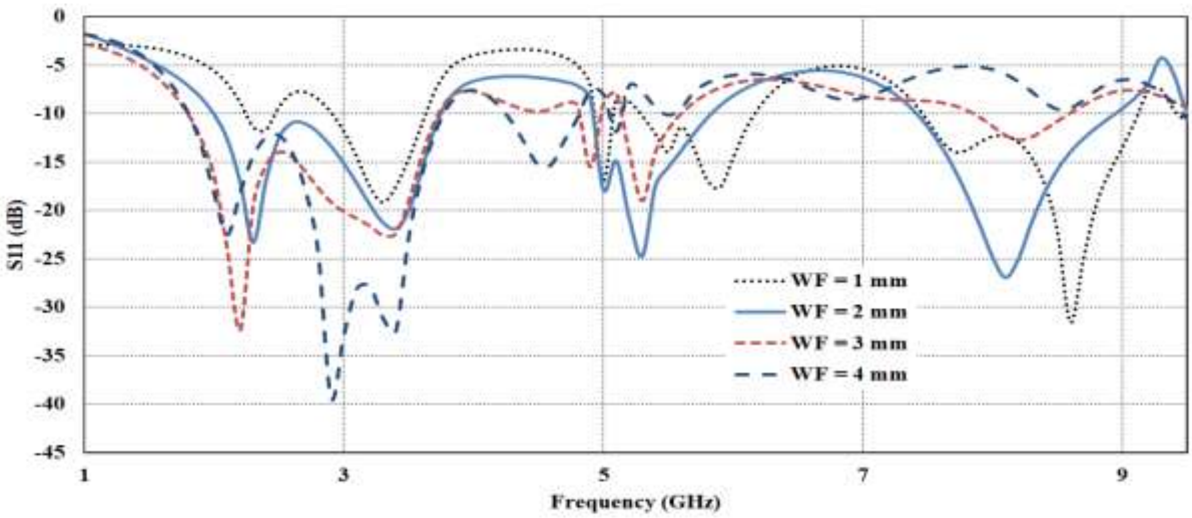

Fig. 4. Parametric analysis of the width of the feed WF.

Now, to understand the outcome of varying the length 'Lstub2' of the inverted L-shaped stub on the resonant frequencies, no. of bands and the bandwidth, the length is varied in the step size of 1 mm from 11 mm to 13 mm. Fig. 5. depicts that the 'Lstub2' is having the major effect on all the three bands. The optimum value of the Lstub2 is 12 mm as it provides the optimal bandwidth and return losses at all the three resonant frequencies as can be viewed in the figure. However, the value 11 mm taken generates only two bands and provides the shift in the resonant frequency in the band 1 and 2 both towards the right with slight increase in the return loss of band 2. Now, when the value is taken as 13 mm, this also generates two bands but slightly more return loss in band 1 and less in band 2 as can be seen from the figure.

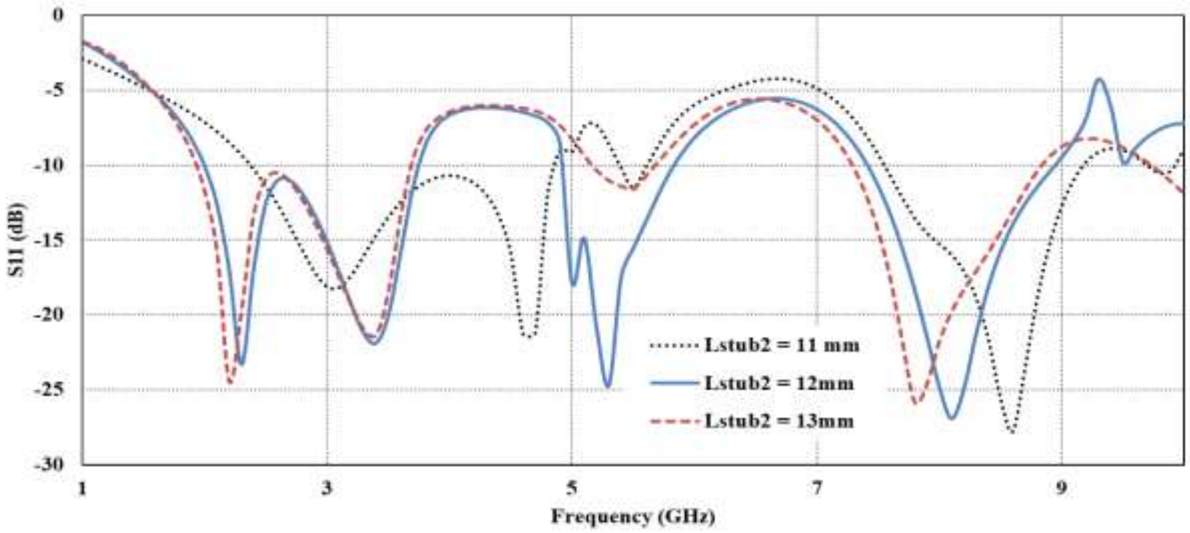

Fig. 5. Parametric analysis of the length of the stub of inverted-L shaped Lstub2.

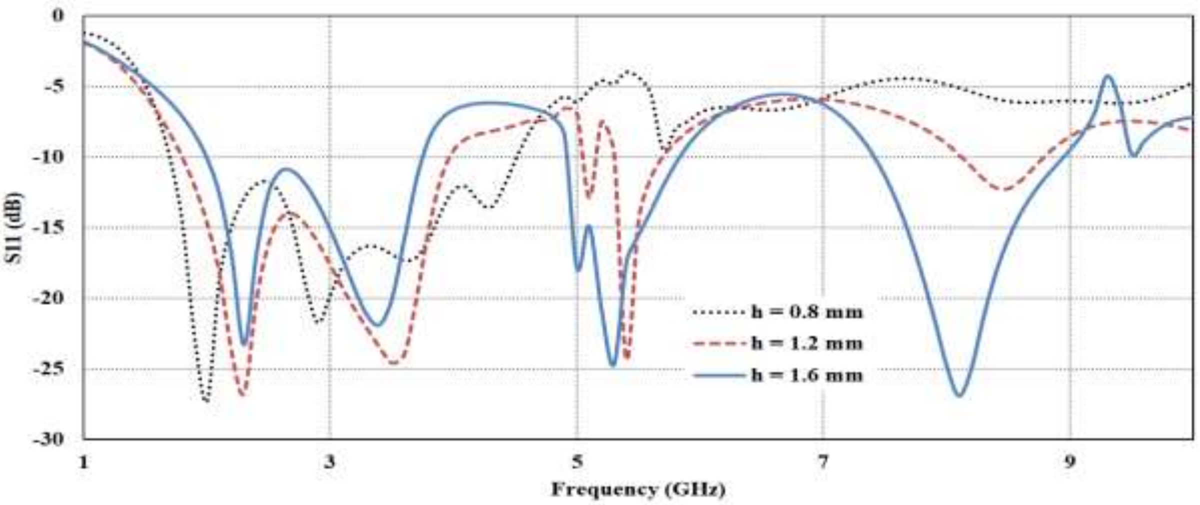

Fig. 6. Parametric analysis by varying thickness h.

Fig. 6. demonstrates the effect of varying the thickness of the substrate 'h' from the value 0.8 mm to 1.6 mm with the step of 0.4 mm. It is evident form the figure that when the value of thickness is taken as 0.8 mm, the antenna resonates only once with good bandwidth and return loss. Now, when the value is taken as 1.2 mm then, the antenna generates two bands of which band 1 provides good bandwidth and return loss but band 2 is giving out less bandwidth. Finally, value of 1.6 mm thickness provides the desired bandwidth with good impedance matching at all the three bands that are generated. Hence, h = 1.6 mm provides the optimum solution.

B. *Surface Current Distribution, Radiation Pattern and Gain:*

The surface current distribution of the proposed antenna has been shown in the Fig. 7. The surface current at 2.3 GHz is mainly distributed through the feeding structure towards the right side of the slotted radiator and the inverted L-shaped stub. It is evident from the figure that at the resonant frequency of 5.3 GHz, the surface current is mainly travelling through the feeding structure toward all the slots and the right edge of the radiator. The current is also distributed towards the truncated ground structure. Again, at the resonant frequency of 8.1 GHz,

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it is evident that the surface current is mainly distributed through the feed line towards the lower edge of the left side of the radiator and also through the truncated ground plane.

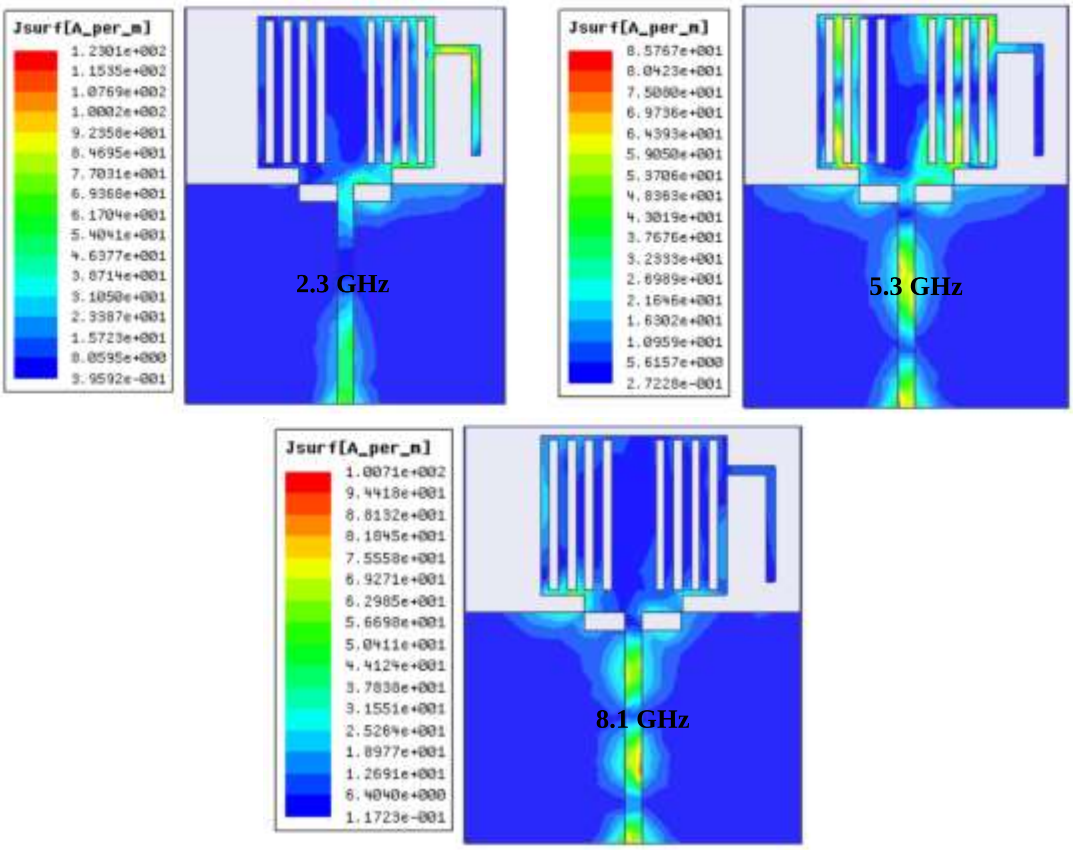
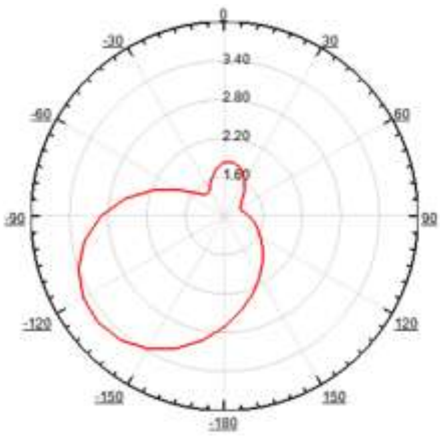
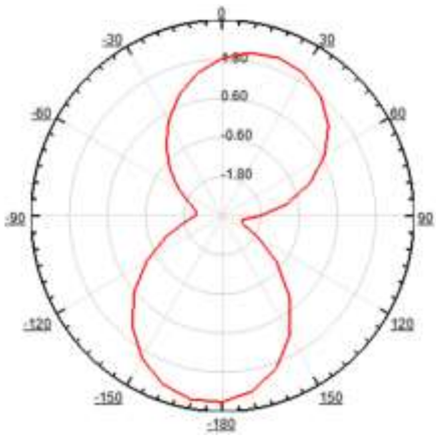


Fig. 7. Surface current distribution at 2.3 GHz, 5.3 GHz and 8.1 GHz.

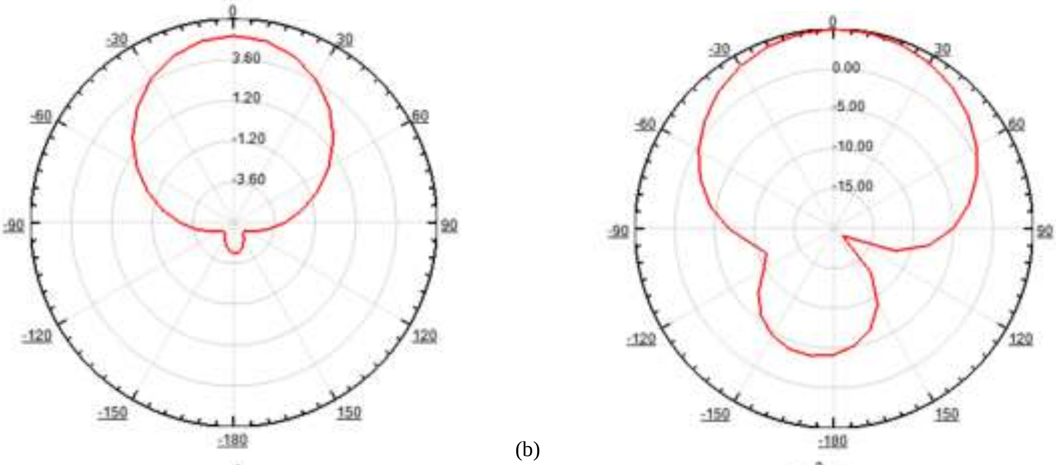
Fig. 8. illustrates the far-field simulated radiation pattern along E-plane and H-plane for the proposed antenna at 2.3 GHz, 5.3 GHz and 8.1 GHz. It is evident from the figure that antenna radiation pattern is directional at 2.3 GHz and 5.3 GHz and nearly omnidirectional at 8.1 GHz in E-plane shown in figure in the left hand side. Further in H-plane, antenna exhibits bi-directional type radiation pattern at 2.3 GHz and 5.3 GHz and omni-directional at 8.1 GHz as shown in figure in right hand side.

The gain plot of the proposed antenna has been presented in the Fig. 9. at all the three resonant frequencies. The simulated gains at 2.3 GHz, 5.3 GHz and 8.1 GHz are 3.94 dBi, 4.99 dBi and 3.75 dBi, respectively.

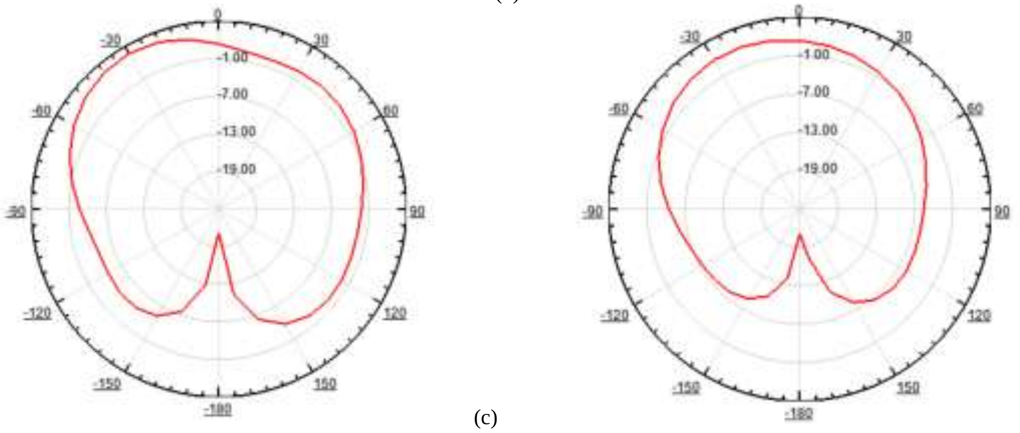




(a)



(b)



(c)

Fig. 8. Radiation pattern at (a) 2.3GHz, (b) 5.3 GHz and (c) 8.1 GHz.

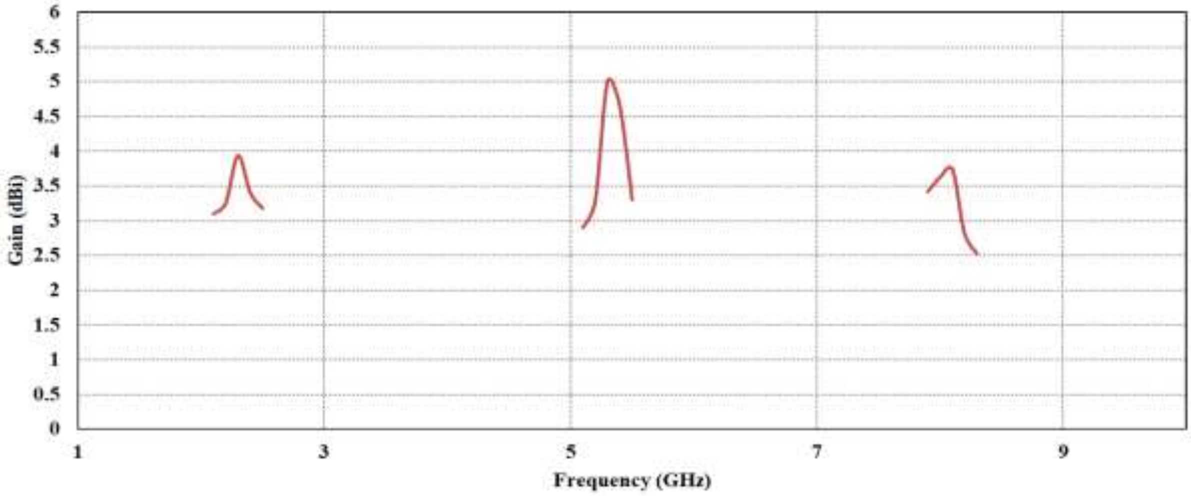


Fig. 9. The gain plot of prototype antenna.

C. *Measured Results:*

The fabricated antenna prototype is shown in Fig. 2. The simulated and the measured reflection coefficient versus the frequency graph are shown in the Fig. 10 (a). It can viewed from the figure that the according to the simulated results of S11, the proposed antenna demonstrates the impedance matching property for (1.9- 3.8 GHz)/2.3 GHz with -23.3 dB return loss, (4.9- 5.9 GHz)/5.3 GHz with -24.7 dB return loss and (7.4- 9.0 GHz)/8.1 GHz with -27 dB return loss, respectively. The simulated impedance bandwidths at the respective resonant frequency are 82.6 %, 19% and 19.8% respectively. According to the measured results, the operating bands achieved are (1.96- 4.64 GHz)/2.26 GHz with -22.3 dB return loss, (4.79- 5.76 GHz)/5.32 GHz with -20.25 dB return loss and (7.33- 8.74 GHz)/8.15 GHz with -28.59 dB return loss. The measured impedance bandwidths at each resonant frequency are 118.6%, 18.23% and 17.3% respectively. Fig. 10 (b) shows the return loss measured using Vector Network Analyser in an anechoic chamber.

Fig. 10 (c) demonstrates the simulated and the measured VSWR of the proposed antenna. The simulated VSWR at 2.3 GHz, 5.3 GHz and 8.1 GHz are 1.2, 1.01 and 0.78. According to measured results of VSWR at 2.26 GHz is 1.17, 5.32 GHz is 1.22 and at 8.15 GHz it is 1.08. Fig. 10 (d) demonstrates the measured VSWR using VNA Master by Anritsu in an anechoic chamber.

The parameters that are measured like return loss and VSWR, are tested on Anritsu VNA Master MS2037C/2 and both the results, i.e., simulated and measured are compared. The discrepancies occurred are due to the fabrication and tolerance factors during measurements.

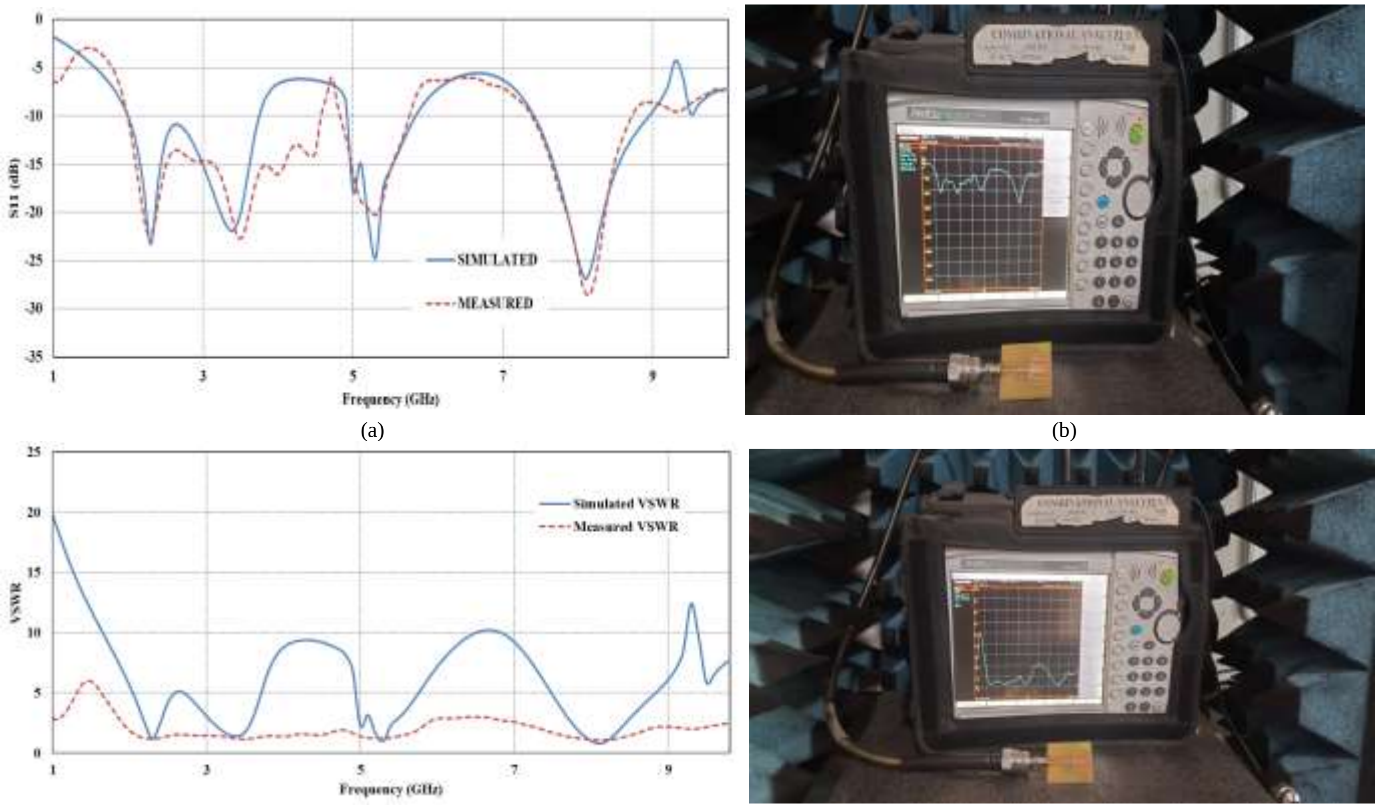


Fig. 10. (a). Simulated and measured reflection coefficient, (b). measurement picture using VNA, (c). simulated and measured VSWR and (d). measurement picture of VSWR using VNA.

TABLE 2. Comparison between the antennas existing in the literature and proposed antenna.

References	Antenna Size (mm^3)	Frequency Bands	Bandwidth (%)
[17]	49x38x1.6	three	25, 13 and 5.7.
[18]	65x85x0.78	two	17.3 and 26.5.
[19]	135x135x1.2	three	40.
[20]	40x40x1.905	two	52.7 and 21.75.
[21]	42.5x42.5x1.6	Single	83.08.
[22]	50x35x1.6	two	34.52 and 18.39.
Proposed Antenna	**47x38x1.6**	**three**	**118.6, 18.23 and 173.**

The antenna proposed in this paper has been compared with the existing literature in the Table 2. When the size, bandwidth offered, gain and multiband behaviour come into picture then, this antenna is very much advantageous. The design is simple and shows great promise as a potential choice for wireless communication appliances.

V. Conclusions

A triple-band antenna design suitable for UMTS, 4G-LTE, IEEE 802.11 b/g WLAN for S-band, WiMAX, C-band and X-band applications is presented in this study. The antenna incorporates multiple slots engineered into the patch of the radiating element with an inverted L- shaped stub protruding from right of the patch and a defect in the ground plane. Through careful analysis and optimization of the antenna dimensions, the impact of various factors on its performance parameters is considered. To evaluate the performance of the fabricated antenna prototype, measurements are conducted on return loss and VSWR. The results demonstrate that the antenna meets the required performance parameters for UMTS, 4G-LTE, IEEE 802.11 b/g WLAN for S-band, WiMAX, C-band and X-band applications across the frequency bands of (1.9- 3.8 GHz)/2.3 GHz with -23.3 dB return loss, (4.9- 5.9 GHz)/5.3 GHz with -24.7 dB return loss and (7.4- 9.0 GHz)/8.1 GHz with -27 dB return loss. The radiation pattern clearly indicates the

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average gain values, solidifying the suitability of the proposed slotted antenna for these triple-band applications.

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