Design, Development and Analysis of Aperture monopole patch Antenna for UWB Communication with multiple notched capabilities

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Research Article

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Design, Development and Analysis of Aperture monopole patch Antenna for UWB Communication with multiple notched capabilities

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Abstract— Present work illustrate CPW fed apertured monopole patch antenna having multiple interfering bands filtering capabilities. The proposed antenna contains three complementary improved inverted U-shaped slots on the radiating patch to filter out interfering signals namely WiMAX (3.3 to 3.6 GHz), C-band now extended for 5G application (3.7 GHz to 4.2 GHz) and WLAN (5.15 to 5.85 GHz) (combined lower 5.15-5.35 GHz and upper 5.725-5.825 GHz, WLAN). The ground plane is surrounded over the radiator with few modifications on the top corner to enhance impedance matching and hence to obtain optimized overall bandwidth. The projected antenna is made up on substrate of FR-4 ($\varepsilon_r = 4.4$) with height of 1.6mm and all the characteristics has been studied with VNA in anechoic chamber environment. The simulated and physically verified responses are in very close treaty to each other. Filtering capability is cross verified with ADS systematic software and lumped-equivalent circuit model also proposed with respective values of all the elements used. Time domain and current distribution analysis has also been undertaken to strengthen the functioning of antenna.

Keywords— ADS, CPW Fed multi-notch UWB Aperture monopole patch antenna, Defected Ground Structure (DGS) , Genetic Algorithm(GA), Lumped equivalent circuit, Time domain analysis

1. INTRODUCTION

Ultra-wideband (UWB) play a remarkable role in the development of communication system and its technologies in the last decade. As a result, several UWB antennas were proposed as they are good candidates for high data rate in indoor short-range communication systems. These UWB antennas find applications in communication systems; ground penetrating radar, medical imaging and precision location system. This revolution compelled the Federal Communications Commission (FCC) to release the band of frequency between 3.1 up to 10.6 GHz for UWB communication [1]. Initially and recently also some researchers have suggested wideband monopole patch antenna for UWB applications using different shapes and techniques. [2- 6]. However, this range is interfered by several unlicensed ranges (like WiMAX, C-band, WLAN, X-band etc) which introduced an interference with UWB and degrade the overall operations. Hence introduction of the different shape of notches and different technology were proposed to introduce some filtering capability at those ranges so that interference can be overcome, and malfunctioning of the antenna can be reduced. Initially, single notch patch antenna after that dual notch antennas was proposed using different shaped and sized slot, stub etc. in radiator or ground plane [7-10]. Due to the development of WLAN,WiMAX techniques , researchers have paid their concentration to reject any of the bands mainly WLAN initially [7]. After due development of technologies like WLAN and WiMAX , they have to sustain simultaneously with UWB, for that different researchers has proposed there respective work mainly making slots of different size and shape either in radiator or ground to filtering out WLAN and WIMAX from UWB range [8-10]. To reject WLAN and WiMAX two thin bent slots in radiator [8], two L-shaped conductor baked plane in ground [9], two modified complementary inverted U-shaped in radiator [10] and combination of U and inverted U shape in patch [11] are used in literature.

Now a day’s triple notching UWB antennas are being investigated as they are capable to discard three different interfering bands from UWB frequency range [12-18].In [12] a good attempt to reject different interfering unlicensed band like WiMAX, WLAN and downlink- X band has proposed but lacking in the proper bands of rejection (more wider). In [13] some arrangement has been applied to reject sharper rejections among WLAN lower and upper frequencies, but care has not been taken for WiMAX range as they are wider than required also having bigger and complex size. In [14] triple notch characteristics has been arise at WLAN,WiMAX, and satellite service band by introducing c-shaped slot in radiator, CSRR in ground plane and inverted U slot in middle radiator near to fed line respectively. In [15-19] an improved technique has taken for band rejection purpose but due to this some complexity has also arrived, some are lacking in gain too. A detailed compared table for our work to those reported work is shown in the preceding section.

In the present paper, a compact inset fed co-planar rectangular aperture patch antenna with three complementary improved inverted U-shaped slots in the radiating patch for achieving the desired band rejection is projected. To enhance the overall impedance matching the ground plane is improved accordingly. The projected structure is made-up on a low-cost FR4 substrate of size 33 x 26 x 1.6 mm^3, covers UWB range of 3.1 to 10.7 GHz with band refusal capacity at 3.3 to 3.57 GHz, 3.66 to 4.35 GHz and 5.01 to 5.85 GHz ,combinedly lower (5.15-5.35 GHz) and upper(5.725-8.825 GHz) WLAN, which are licensed band and interfere with UWB communication. For the prescribed rejection of bands the slots are optimized with Genetic Algorithm (Integrated module with IE3D)

2. APERTURE MONOPOLE ANTENNA DESIGN AND DISCUSSION

Fig.1 illustrates the geometry and arrangement of the projected Aperture patch antenna with multiple notch characteristics and its fabricated prototype. All the dimensions are illustrated in Table I. Primarily, a CPW inset fed monopole apertured patch antenna with aperture configuration for UWB application has been designed by using the basic equation of antenna design and also optimized by Genetic Algorithm method (integrated module in IE3D). The projected apertured monopole patch antenna is made-up on the FR 4 substrate with a specification like thickness 1.6 mm, loss tangent 0.017 and dielectric const. of 4.4. Three consecutive slots namely S1, S2 and S3 are integrated on the patch of the antenna, to achieve notching capability at complete WLAN (5.101 to 5.85 GHz), downlink C-band now extended to 5G communication (3.66 to 4.35 GHz) as well as Wi-MAX (3.3 to 3.56 GHz) respectively. The ground plane is up graded by introducing DGS near the feed line and by inserting upper corner slots to improve the impedance matching. The electromagnetic (EM) software IE3D which is obeying Method of Moment (MoM) from Zeeland [20] has been consider to design the projected aperture antenna. Dimensions of the antenna along with their respective slots are tabulated in the Table1 (a) and (b).

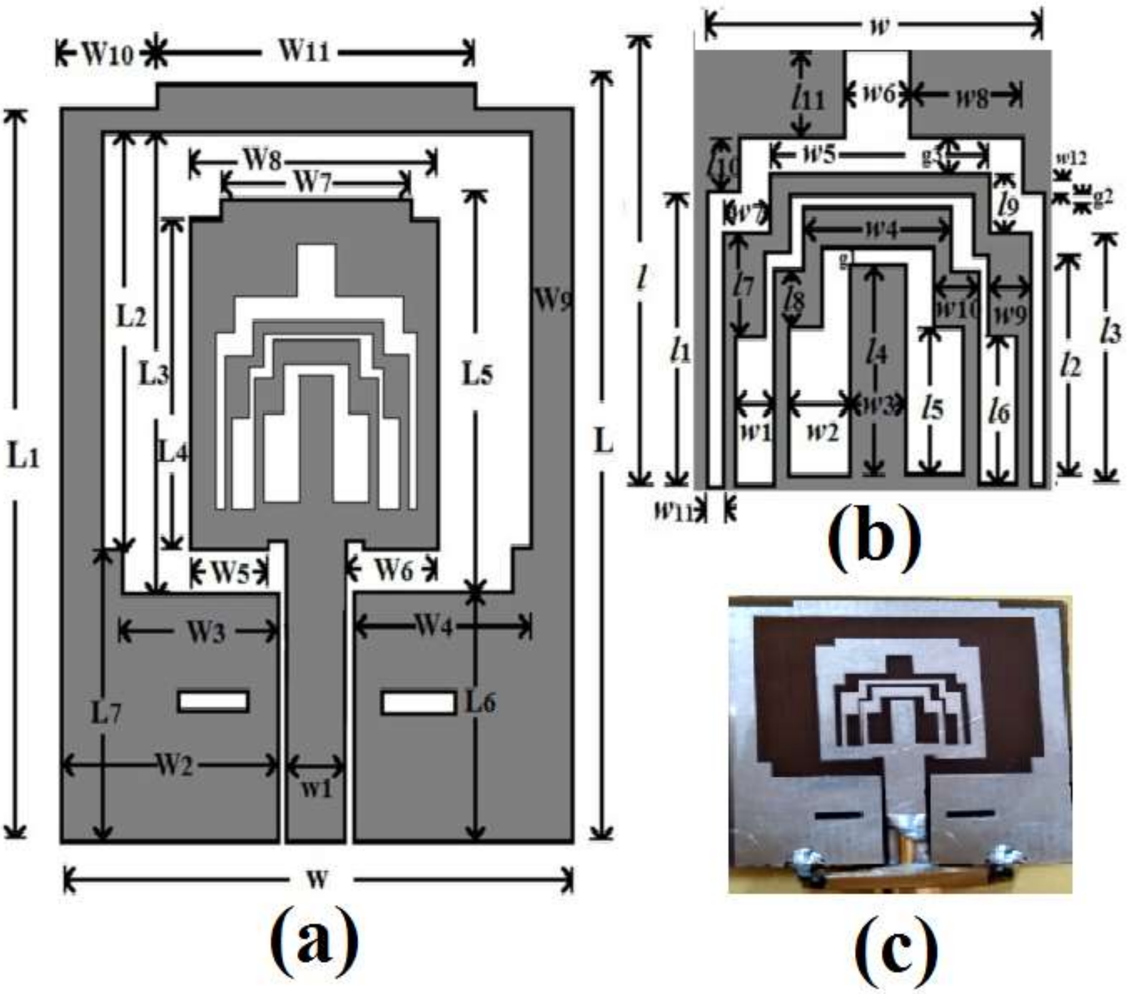


Fig. 1. (a) Geometry and its configuration (b) slots details (c) Fabricated Prototype

Table I Dimensions of antenna and slot (in mm).

(a) *For antenna*

W	26	W_5	4.025	W_{10}	5	L_3	20.5
W_1	3	W_6	5.025	W_{11}	16.7	L_4	14.5
W_2	15.3	W_7	10.1	L	33	L_5	17.45
W_3	8.35	W_8	13	L_1	32	L_6	11
W_4	9.35	W_9	2.075	L_2	18.575	L_7	12.5

(b) *For Slots*

SLOT S_1 (Inner Slot)				SLOT S_2 (Middle Slot)				SLOT S_3 (Outer Slot)			
w_2	*1.85*	l_2	*6.2*	w_1	*1.15*	l_3	*6.275*	w	*10.6*	L	*11.8*
w_3	*1.75*	l_4	*5.675*	w_5	*4.5*	l_6	*4.075*	w_6	*2*	l_1	*7.925*
w_4	*4.5*	l_5	*4*	w_7	*1*	l_7	*2.775*	w_9	*3.3*	l_{10}	*1.5*
w_{10}	*1.5*	l_8	*1.5*	w_9	*1.5*	l_9	*1.55*	w_{11}	*0.525*	l_{11}	*2.375*
g_1	*0.575*			g_2	*0.375*			w_8	*3.55*	g_3	*1*

2.1 Determination of Slot Dimensions

Initially, length of slots responsible for notching capabilities are calculated from the equation (i), however, after applying the Genetic Algorithm (a module available with IE3D) the calculated size got altered resulting better rejection frequency bands. In Genetic Algorithm always the old generation is replaced with advanced new generation they are working on the basic principal of mutation, cross over and finally selection. Hence after each mutation a new advanced population generated. Finally an optimized population got generated. Calculated and finally optimized size of slots are tabulated in Table-II [21].

$$L_{Slot} = \frac{0.45c}{f_{notch}\sqrt{\varepsilon_{eff}}} \quad \text{-----------------------------} \quad \text{(i)}$$

Here, c =1.6x10^8 m/sec (velocity of the light in vacuum)

ε_{eff} = The effective dielectric constant material used,

f_{notch} = The mean of uendesired notching frequency

L_{eff} = Effective length of slot used for filtering any frequency.

For monopole patch antenna effective dielectric constant can be given by equation (ii).

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \qquad \text{----------------------------------} \text{ (ii)}$$

Table II Formulated and optimized dimensions of the slots

Slot	Rejecting Frequencies (GHz)	Calculated Effective Slot Length (mm)	Optimized Effective Slot Length with Genetic Algorithm (mm)

S_1	5.01-5.85	17.6	14.4
S_2	3.66-4.35	20.5	22.4
S_3	3.3-3.57	25	33

Initially, slot S1 is introduced for WLAN filtering capabilities, a degradation in reflection coefficient is observed, to improve that a degradation a slot of dimension 3.75x1mm^2 in the ground plane near to both side feeding line is introduced.

The reflection coefficient characteristics of the structure with and without a modified ground plane for slot (S_1) are compared in Fig. 2, an improvement in the S_{11} characteristics towards a higher range of frequency is observed. Finally, the second (S_2) and third (S_3) slots are inserted in improved ground plane to obtain triple notch characteristic. A parametric study to achieve optimal values of g1, g2 and g3 are carried out by varying their values respectively as 0.5-1.25mm, 0.1-0.4 mm and 0.5-1 mm, shown in Fig.3 to Fig.5. The optimized values for all the gaps namely g1, g2 and g3 after parametric studies are found to be respectively 0.5, 0.4 and 1mm. It can be clearly observed that gap g1, g2 and g3 are responsible for filtering WLAN, C-band (Extension to 5G) and WiMAX respectively and none of the other bands is disturbed.

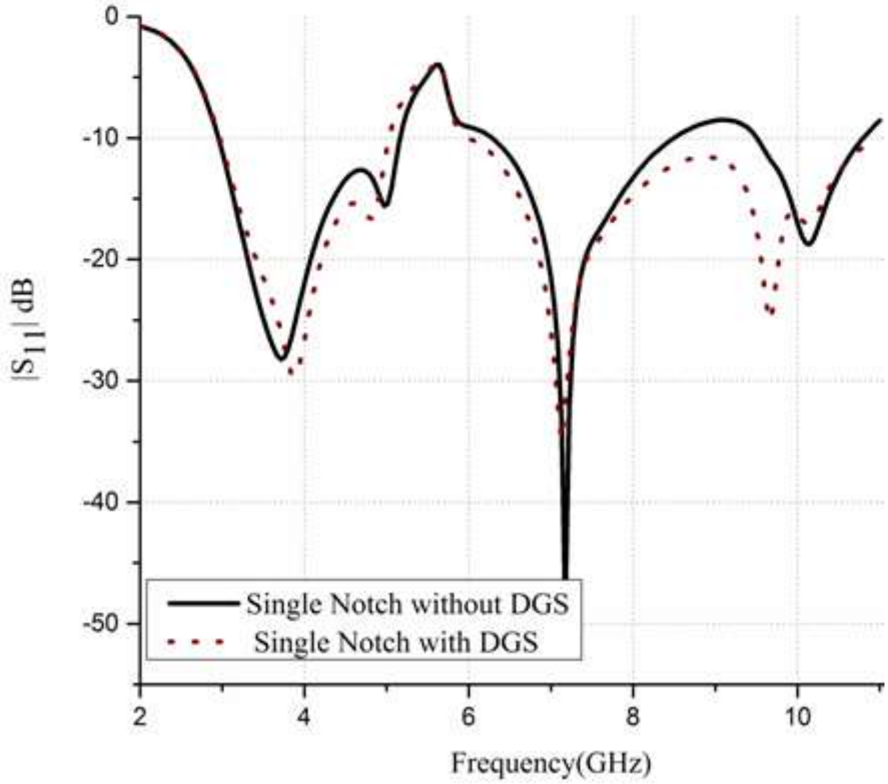


Fig. 2 Compare of Reflection coefficient with and without DGS for a single notch Antenna.

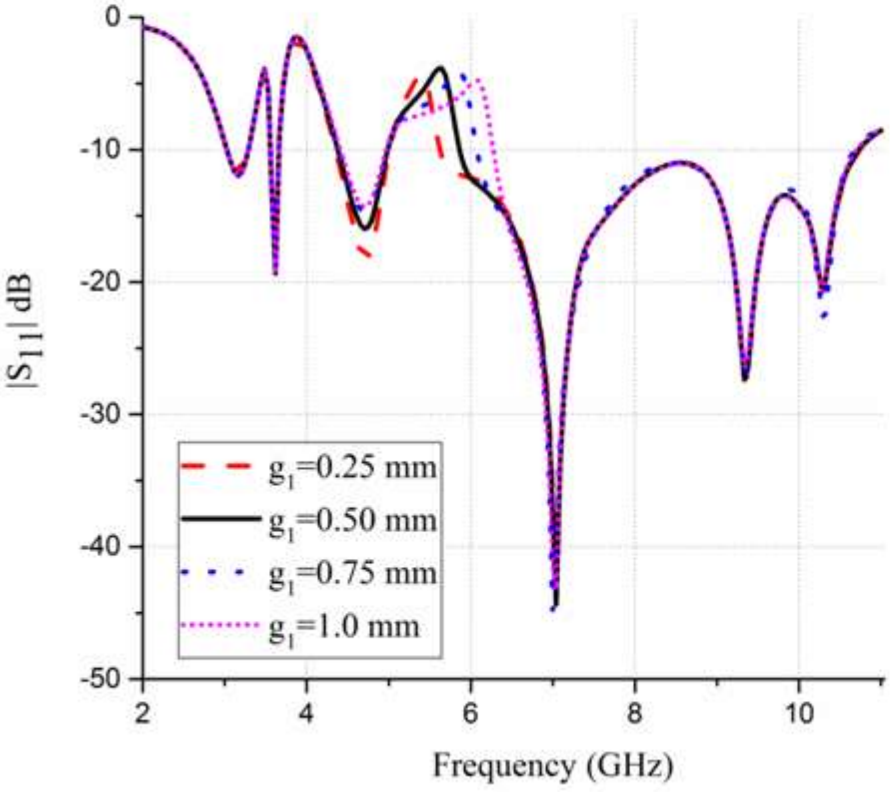


Fig. 3 Parametric Study of reflection coefficient at varying gap g_1.

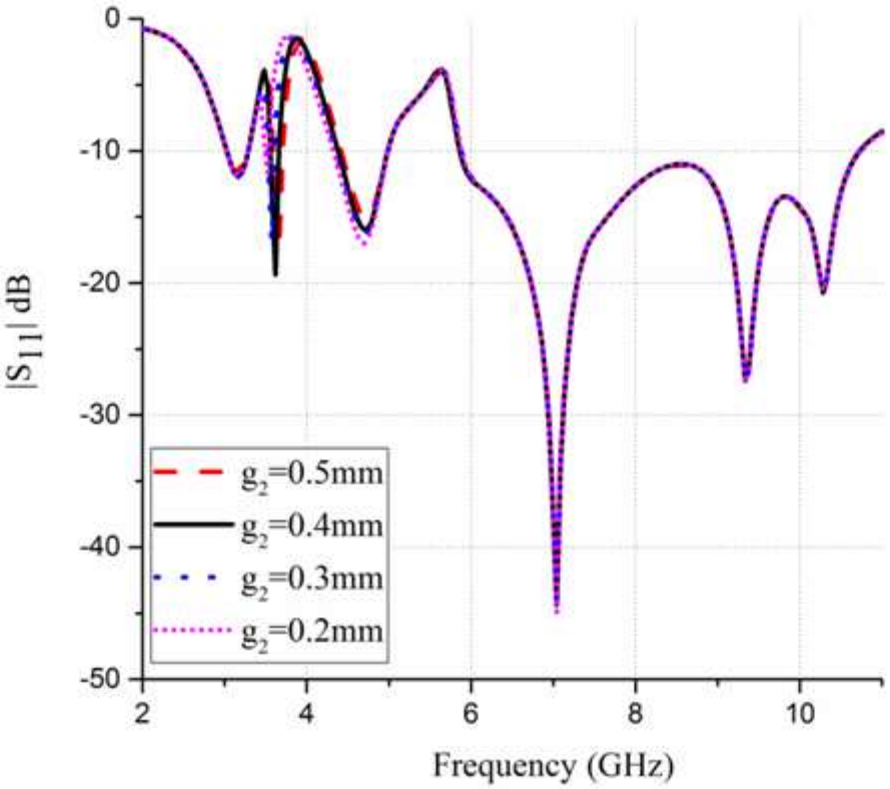


Fig. 4 Parametric Study of reflection coefficient at varying gap g_2

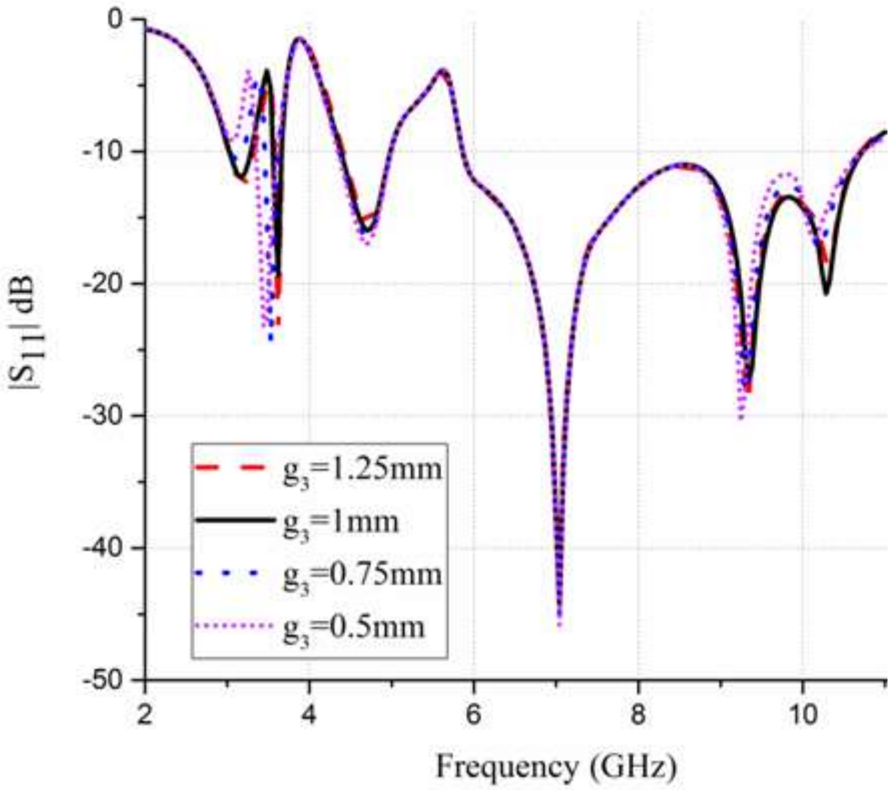


Fig. 5 Parametric Study of reflection coefficient at varying gap g_3.

2.2. Lumped Equivalent Circuit Model Analysis

As it is one of the facts that at notching frequencies either resistive values got increased too much or decreased too much. So that an impedance mismatching takes place and transmission of signal degraded. This behavior can be visualized by using RLC circuit. As in the present work, three different notching frequencies are present, each of the notching frequencies is represented by different parallel RLC circuit connected in series as shown in Fig.6. The selection of series or parallel combinations of R, L, C circuit to represent filtering frequencies depends upon the input impedance at the respective frequencies. If the input impedance is lower (less than 50 Ohm) at the filtering frequency than the circuit is represented through a series combination of R, L, C. Whereas it is represented through parallel combination if the input impedance is higher at the filtering band. Also, a combination of series as well as parallel R, L, C is used to denote a filtering frequency where input impedance is changed from lower to higher value in a rapid manner [22-24].

The initial set of RLC values are determined by formula denoted below [24]. However final values of RLC is determined through titrating each value of components (In ADS systematic) in such a fashion that upcoming input impedance curve fitted to the graph through IE3D as shown in Fig. 7. As it is very much evident from Fig. 7 that graph through IE3D and that through ADS is very much like each other hence the final values of R, L, C are tabulated in Table III.

Quality factor $Q_0 = \frac{f_0}{BW}$ -------------------------------------- (ii)

$Q_p = 2\pi f_p R_p C_p$ for parallel combination-------------------- (iii)

$Q_s = \frac{1}{2\pi f_s R_s C_s}$ for series combination---------------------- (iv)

$f_0 = \frac{1}{2\pi\sqrt{CL}}$ --(v)

f_0 ---- notching frequency.

Table III Optimised components values of the Lumped Equivalent circuit

Circuit	Filtering Band width (MHz)	Quality Factor	Resistance (Ω)	Inductance (pH)	Capacitance (pF)
1	23.3	144	110	36.32	62.2
2	27.4	142	220	63.6	26.48
3	38.8	144	190	38.75	21.63

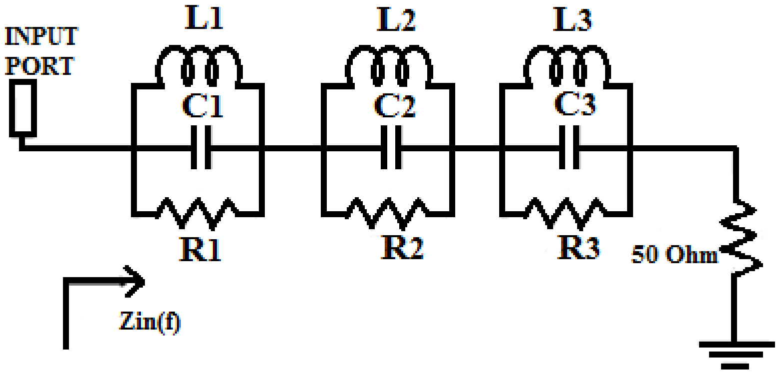


Fig. 6 Lumped equivalent circuit model of multi band-rejected apertured UWB antenna

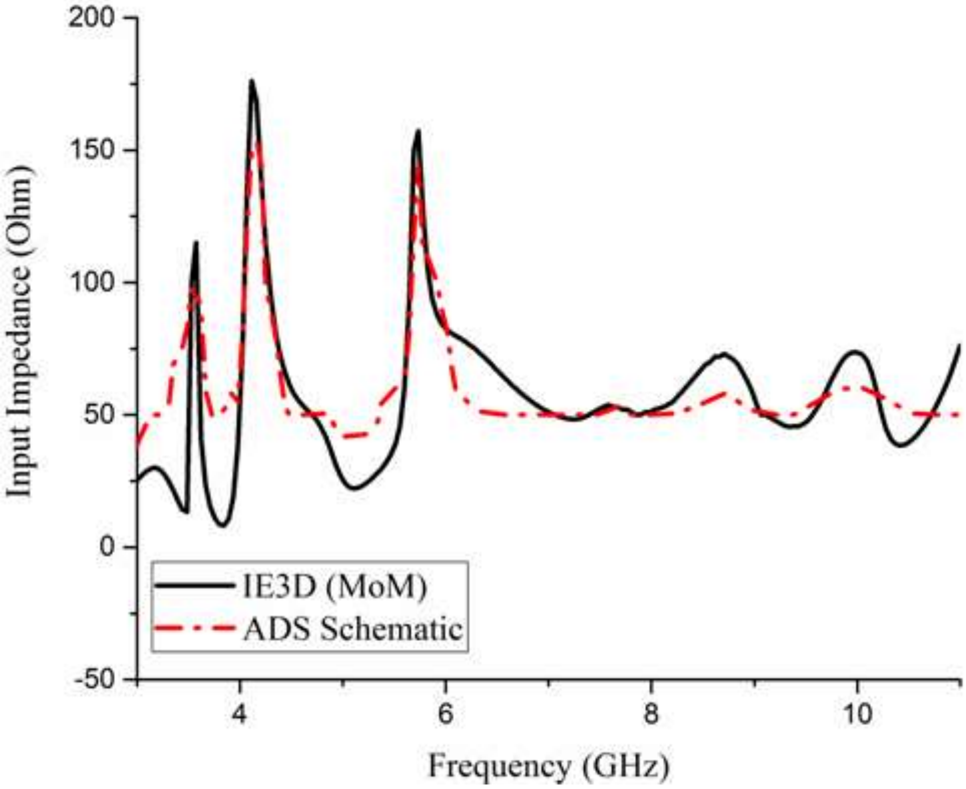


Fig. 7 Input Impedance comparison of multi notched Aperture patch antenna using IE3D and ADS Schematic.

2.3 Time Domain Analysis

For the optimal flow of signal in a higher bandwidth antenna group delay between transmitter and receiver is required. Generally, group delay indicates pulse distortion at any frequency among the bandwidth of operation. For the optimal operation of antenna, the group delay should be flat throughout the operating band whereas some distortion may be encountered at non-operating band of frequency. In the present work after finding the group delay in respective two orientation namely face to face and then side to side through the software, an arrangement has been by keeping a distance of 40 cm between transmitter and receiver, and its values was measured with VNA. From Fig.8 and Fig.9 it can be clearly observed that firstly, the observed and simulated response are in handshaking mode and secondly, that there is a flat variation of approx. 1 nano-sec in working frequencies and a variation of approx. 2.5 nano-sec in the non-operating frequencies. Hence through time domain analysis it is justified that projected antenna is optimal for any its practical utilization.

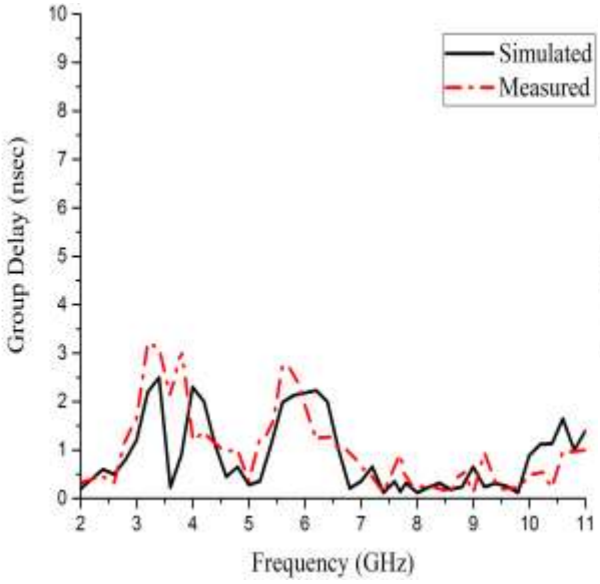


Fig.8 Group Delay Face to face

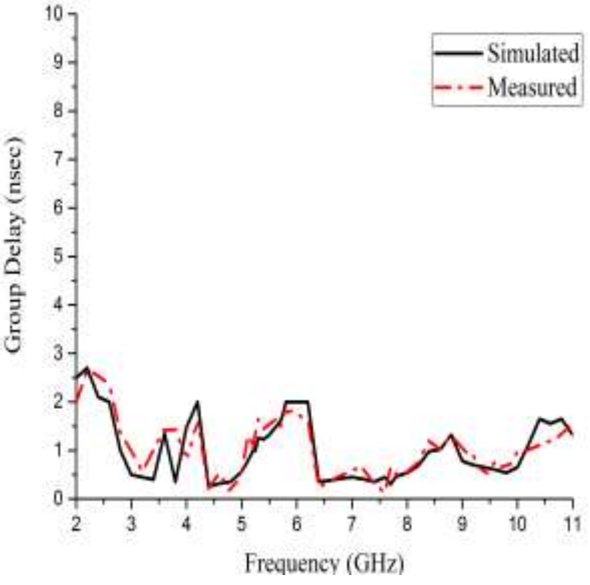


Fig. 9 Group Delay side to side

2.4 Current Distribution Analysis

Current distributions of proposed multi notched aperture UWB patch antenna at the non-operating center frequency of WLAN at 5.5 GHz and the operating (resonant) frequency of 7.04 GHz are presented respectively in Fig 10 (a) and (b). It is evident through the pattern that at filtered frequency, the current is flowing through the slots are out of phase that of the patch, as a result, suppression of radiation takes place. while at the operating frequencies, the flow of current in all different slots are in-phase to the patch, so enhancing overall radiation.

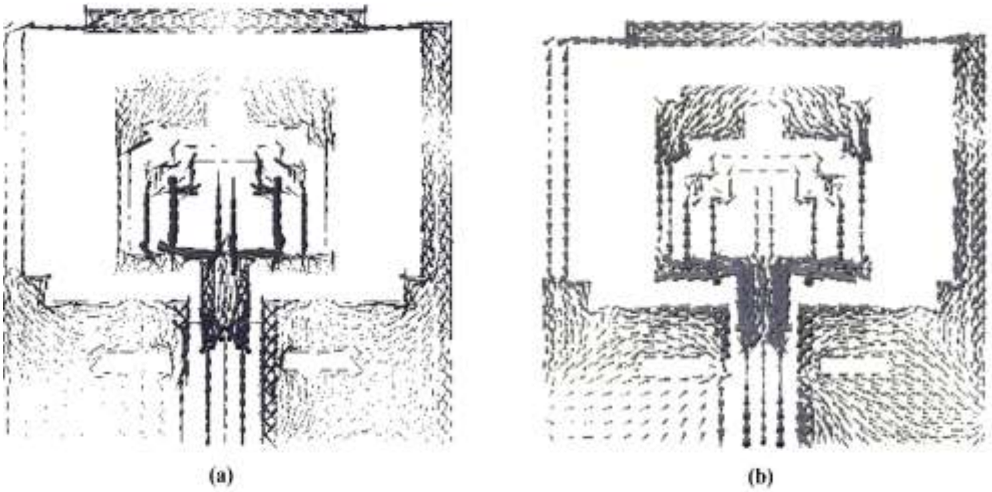


Fig. 10 (a) Current distribution at 5.5 GHz (Filtering frequency) (b) Current Distribution at 7.04 GHz (Operating frequency)

3 RESULTS WITH DISCUSSION

The performance characteristics like reflection coefficient, gain, radiation pattern, group delay etc were physically observed using Vector Network Analyzer (VNA) and spectrum analyzer in anachronic chamber environment. Comparative graph for simulated and measured responses for return loss, gain and radiation patterns are shown respectively from Fig.11 to Fig.13. From all the graphs above mentioned it is obvious that the simulated and physically observed results are very near to each other. A minor difference in the measured and simulated responses are due to the substrate under consideration (FR 4), which is frequency dependent and its permittivity varies in accordance with frequency. However, during simulation, a constant permittivity of 4.4 was considered. Apart from this fabrication tolerance may also be one of the reasons.

Fig. 7 and Fig. 11 show that the three bands have been successfully notched out with the help of three slots. Fig. 7 reflects higher impedance at the non-operating frequencies to be rejected out, confirming non-matching hence frequency filtering capability. It is also evident from the responses that the designed antenna shows high selectivity. From Fig 12 it is observed that the gain of antenna is more than 2.2 dBi at the operating frequencies and it is lowered to -1.15 dBi at the non-operating frequencies and having a peak gain of 7.9 dBi at the resonating band of frequency. The antenna is reflecting an omnidirectional behavior as shown in Fig. 13. Also, the measured response of the radiation pattern is very close to that of the observed pattern. From the radiation pattern curve, an omnidirectional behavior can be observed which is necessary for the UWB applications.

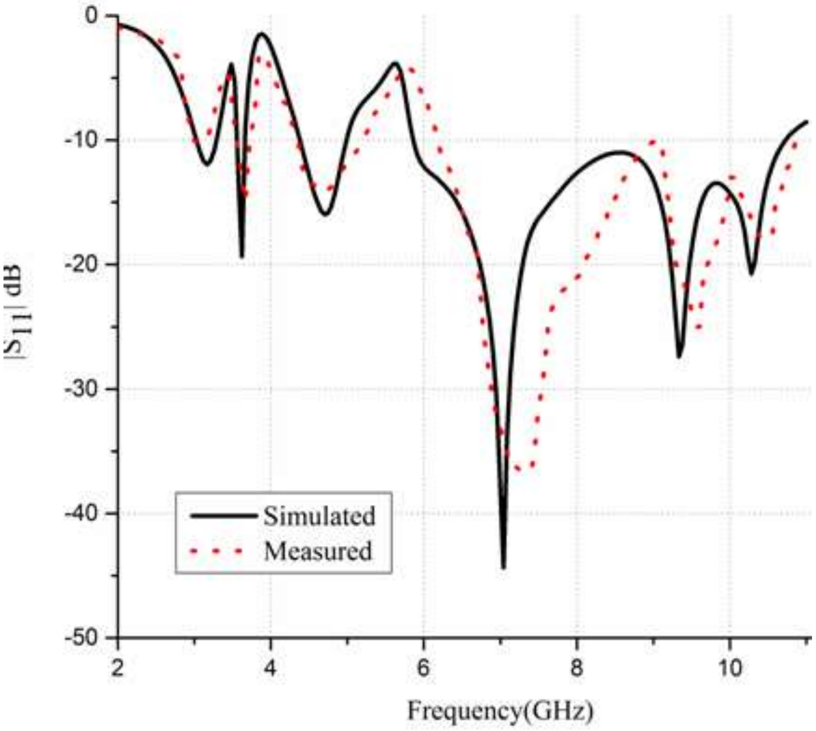


Fig. 11 Reflection coefficient evaluation between simulated and measured results

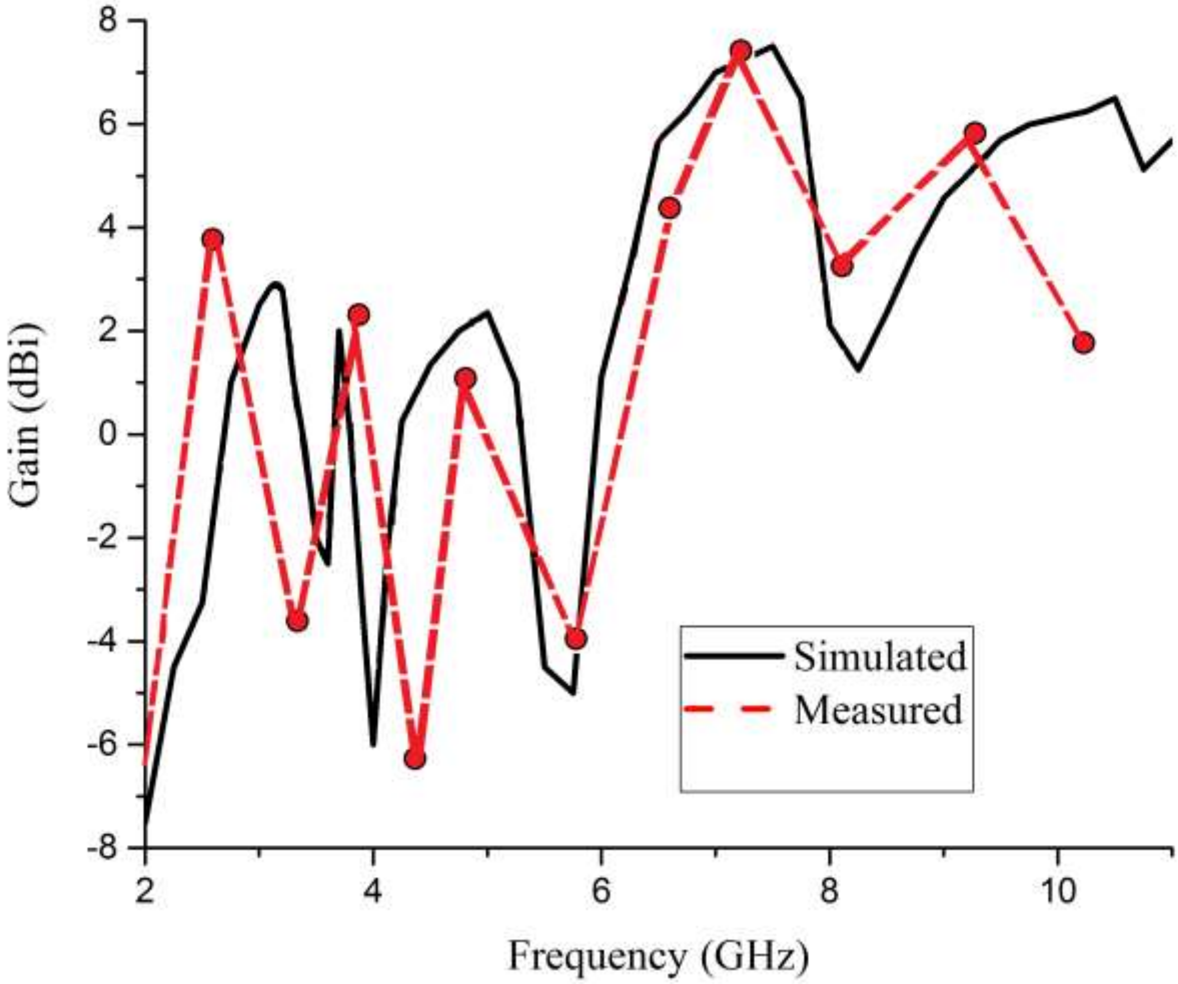
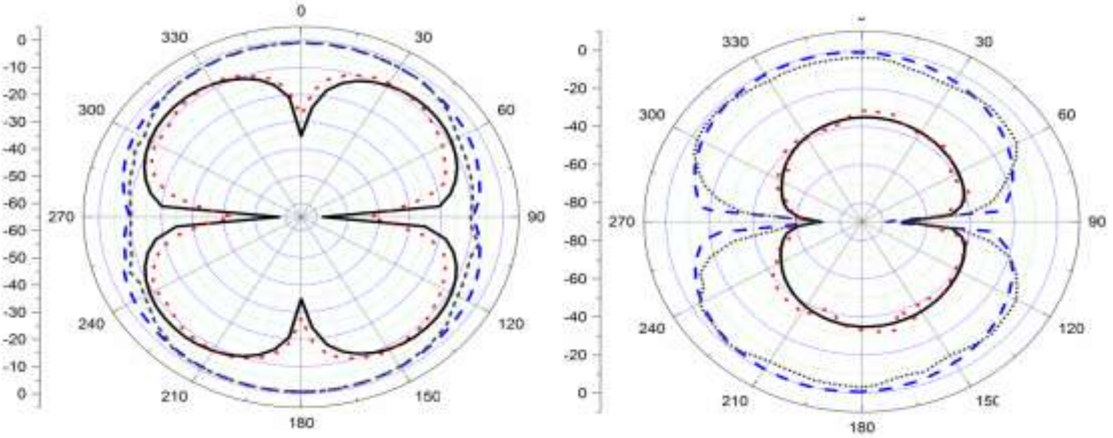
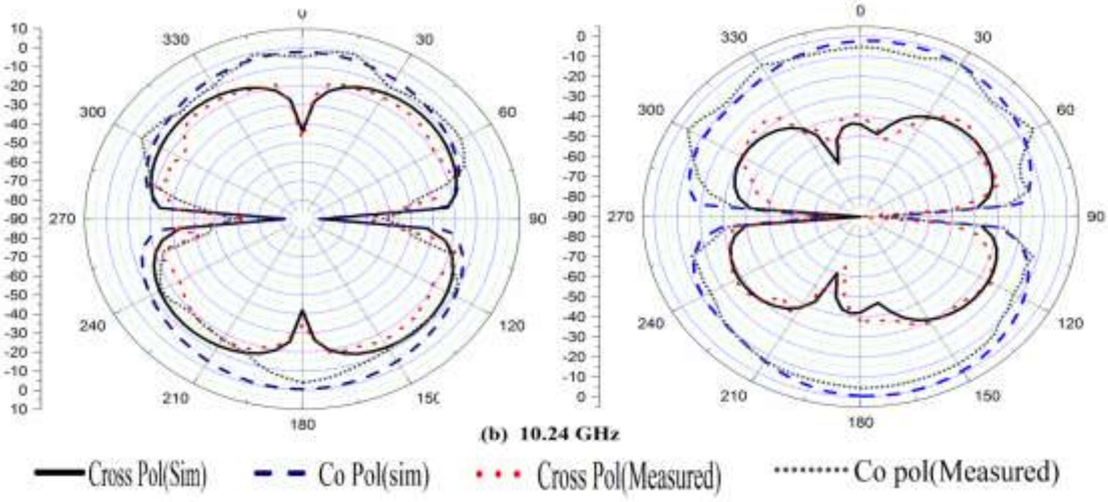


Fig. 12 Peak gain evaluation between simulated and measured results



(a) 4.7 GHz



(b) 10.24 GHz

Fig. 13 Radiation Patterns at 4.7 and 10.24 GHz in Elevation and Azimuth Plane respectively

4. CONCLUSION

In this research paper, a CPW fed aperture antenna for UWB communication having multiple notched capabilities is successfully presented. The proposed aperture patch antenna strictly covers the entire 3.1 to 10.6 GHz range of frequencies. The integrated slots reject the frequency band from 3.3-3.56 GHz,3.66-4.35 GHz and 5.01-5.85 GHz enabling the antenna compatible with the environment of WLAN, Wi-MAX and C-Band (now extended for 5G applications). The rejection in the desired band is quite sharp, which strengthen the novelty of antenna. The aperture antenna proposed is unilateral, conformal, having a squat gain at the non-operating frequencies and promising gain at operating frequencies. The design and notching of the purposed antenna are also supported by ADS software by giving its lumped element equivalent circuit. In Table IV a comparison of present work is done with different proposed work earlier. Present antenna is strictly following the UWB range also filtering very closed interfering frequencies in UWB. A peak gain of 7.9 dBi with better current distribution and radiation patterns are also observed.

Table IV Comparative analysis with other recent published papers

Reference	Size(mm^3)	BW (GHz)	Notching capability (GHz)	Return loss	Peak Gain(dBi)	Antenna Configuration
12	19x24x1.2	2.45-10.65	3.2–3.7, 4.8–6.3, 7.0–8.15	moderate	4	Non Apertured Single sided
13	24x30x1	2.6-12	3.3-4 ,5.1-5.4, 5.8-6.1	moderate	4.25	Apertured Dual-sided
14	31x30x1.6	2.4-11	3.3–3.67, 4.9–5.8 and 7.9–8.4 GHz,	moderate	5.5	Non Apertured Single sided
15	33x28x1.6	2.5-11.8	3.3–3.6, 3.7–4.4, and 5.1–5.85 GHz	good	4	Non Apertured Single sided
16	47x38x0.83	2.7-11	3.4-3.8,5.15-5.35,5.725-5.85	moderate	5.5	Non aperture Dual sided
17	38.3x34.3x0.	2.6-10.58	3.3-3.92, 5.1-5.4,5.68-6.02	N.R.	6	Non aperture Dual sided
18	40x29x1.6	2.7-11.06	3.22–3.83, 4.49–5.05 7.49–8.02	Moderate	4.7	Non aperture Dual sided
19	27x27x1.6	2.12-14	3.16-3.76,5.26-5.87,7.3-7.68	good	8	Non-Apertured Single Sided
Proposed Work	33x26x1.6	3.1-10.7	3.3-3.56,3.66-4.35,5.01-5.85	good	7.9	Apertured Single Sided

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