A Compact Printed UWB Notch Antenna with a slotted Radiating Element and Split Ring Resonator for Application in Wireless Communication

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Abstract

The design of a compact notch monopole antenna for application in ultra-wide band frequency domain is presented. The enhanced impedance bandwidth of the proposed antenna and a preliminary notch at 4.7 GHz are obtained by creating the square slot in the circular radiating element, an open ended slot is also created in the ground plane just below the microstrip feed-line and an open ended slit ring in the thick protruded stub erected from the upper portion of the square slot in the circular radiating element. The tuning of the notch frequency of 5.5 GHz in the WLAN band of 5-6 GHz as well as the further enhancement of notch is obtained by embedding a split ring resonator (SRR) in the left side of the microstrip feed line. The proposed UWB notch antenna provides the impedance bandwidth of 3.097GHz to 13.326 GHz (fractional bandwidth of 125%). The average measured gain of the proposed antenna is 7.1 dBi which covers the entire UWB band of operation except the notch band of WLAN. The group delay is consistent at around 0.2ns in whole of the UWB operating system except at the WLAN band where the measured group delay is around 2.8ns.

INTRODUCTION

On 14th February in the year of 2002 the Federal Communication Commission (FCC) in the United States had released a bandwidth of 7.5 GHz i.e. from 3.1GHz to 10.6 GHz for Ultra-wideband (UWB) wireless communication [1] which is currently a rapidly growing advancement as a high data rate wireless communication technology. This UWB is the defined radio system having a bandwidth of 10dB which is larger than 25 percent of its center frequency. Since 2002 the researchers have designed and also proposed so many antennas for UWB applications by taking care of the various requirements such as compactness, less fragile, light weight, low cost and portability in hand held devices in the UWB system. To achieve good impedance band-widths, Omni-directional far field beam patterns and radiation efficiencies the strongest contenders are elliptical and circular disc monopoles [2]. The designs for these antennas can be made printed and also can be allowed for simple integration and low-cost fabrication with the association of UWB electronics.

Like the conventional wireless communication system UWB antennas also face some challenges in broadband impedance matching, gain characteristics which need to be appropriate and also in getting stable radiation patterns. But over this UWB frequency band, there also exist some narrowband wireless local area network (WLAN) operating bands such as the 5.2 GHz (5150–5350 MHz) and 5.8 GHz (5725–5825 MHz) band.

World Interoperability for Microwave Access (WiMAX) service from 3.3-3.6 GHz also occupies in the UWB band [1],[3], [7]. So, the interference may be caused with these bands with UWB operations. In some UWB antenna designs, filters can also be used to notch out the interfering bands. But the demerit is that it increases the weight and complexity of the UWB system. Hence to overcome this problem, various UWB antennas with notch functions have been developed to mitigate the interference between the narrowband wireless systems and UWB systems. Incorporation of various shaped slots of different sizes into the main radiator is the most preferable simple and common approach. Band notch characteristics are achieved by using different shapes of slots with coupling strips. By varying the width and position of the slot we can control the band width and Centre frequency of the notched band. Two band notches can be introduced in a planar monopole UWB antenna using two different types of slots [4-5]. Especially at higher frequencies to improve the impedance matching the patch radiators are slotted. The current distribution at the radiators gets changed by the radiator cut slots with the change in input impedance and current path. A notch band of 5.12 GHz to 5.99 GHz can be realized by inserting a slot of U-shape in the radiating patch of half elliptical ring. Similarly, by loading two approximate half-wavelength slots of U-shape the band notch functions can be realized. These functions change the distribution of current on the y-shaped patch [6-7]. For annular ring UWB antennas with microstrip feed, WLAN and DSRC (dedicated short-range communication) band notch property can be achieved simply by inserting a partial annular slot in the radiator of antenna. To construct the left- hand materials, Pendry was developed Split ring Resonator (SRR). In these materials electromagnetic waves behave in the reverse direction in comparison to conventional rule of right-handed materials [8]. The SRR gives interest in its resonant behavior specifically. SRRs are generally considered as the electronically small resonator having a very high Q. The SRRs are very useful where sharp notch is required in the construction of filters and also to pass a band of certain frequency range [9]. The SRRs provide two types of properties such as resonance and anti-resonance properties. Inherently due to these properties the flow of the electromagnetic field can be passed or stopped which are localized and polarized along the SRR array. This is due to the resonance permeability and anti-resonance permittivity of the SRR [10-13]. Comparing UWB antennas with narrow band antennas it is found that due to the optimization in its wide bandwidth UWB system has greater impact and instead of continuous signals these UWB antennas transmit pulsed signals [14]. For narrow band antennas the standard parameters such as return loss, gain, radiation efficiency, etc. have been defined in frequency domain. Therefore, it is not enough to analyze the UWB antennas only in the frequency domain since it is needed to control the pulse distortion which is an important parameter [15-16]. Hence also in time domain these antenna characteristics must be studied. As the antennas behave differently during transmission and reception due to the involvement of large fractional bandwidth pulses the time domain analysis is equally important in the UWB antenna design used for high speed pulse communication [17-19]. Equivalent circuit of the patch antenna had been also derived by using lumped elements. So, for the applications of UWB frequency band several antenna configurations have been studied [1]-[24].

Based on the different kinds of designs of UWB notch-antennas mentioned above in literature survey, a simple, compact microstrip line fed notch antenna is proposed. The proposed antenna has a circular radiating element. For the proper impedance matching, a square shaped slot is created symmetrically in the circular radiating element, an open-ended slot is created in the middle of the ground plane and an open-ended slit ring created in the thick protruding stub from the upper portion of the square shaped slot created in the circular radiating element. The thick protruding stub helps in creation of a preliminary notch at the notch frequency centered at 4.7 GHz, which is not appropriate center of the notch frequency for the WLAN band of operation. Hence for the appropriate creation of the center of the notch frequency at 5.5 GHz (5 GHz to 6 GHz, WLAN), a split ring resonator SRR is embedded in the left portion of the microstrip line. Because of this SRR, the center of the notch frequency is tuned properly to 5.5 GHz from 4.7 GHz. The proposed antenna provides the bandwidth from 3.097GHz to 13.326GHz which is the operating bandwidth for the UWB system and a notch band from 5 GHz to 6 GHz (WLAN) with a center notch frequency of 5.5 GHz. This proposed notch antenna provides the average gain of 7.1 dBi which is suitable for operation in UWB system. The consistent average group delay is around 0.2 ns in the UWB band of operation and around 2.8 ns in the notch band of operation. The proposed antenna provides stable radiation patterns in the UWB band of operation with the appropriate level of cross-polar radiation. The equivalent circuit is developed for the proposed UWB notch antenna. The time domain analysis is performed for this proposed antenna. The proposed UWB notch antenna exhibits tremendous capability of handling the UWB short pulses. The proposed antenna is fabricated and all the antenna parameters are effectively measured. The measured results are in highly accordance with the simulation results.

The structural configuration, chronological development, conceptual analysis of the proposed UWB antenna are described in section I. Section II depicts the equivalent circuit analysis of the proposed antenna. Section III includes the comparative analysis of simulated and measured results of the proposed antenna. Section IV examines the time domain behavior of the proposed antenna, which is followed by the conclusion in section V.

Antenna design

The geometry and configuration of the proposed UWB notch antenna with the notch at 5.5 GHz is shown in the figure 1 (a) and (b). The antenna is simulated and fabricated on a FR4 epoxy substrate with the dielectric constant ϵ_ρ =4.4 and height h =1.6 mm. It has a circular radiating element of radius R_{patch}=5.25 mm on the front surface of the rectangular substrate of dimension (L_{sub}xW_{sub}) 15x17 mm^2. This radiating element is fed by a 50-Ω

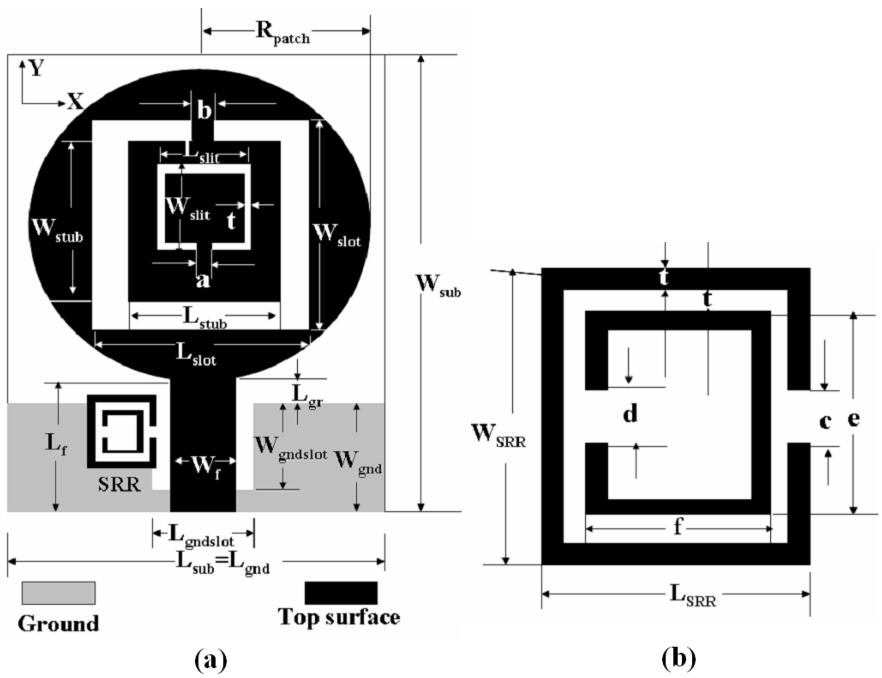

Fig.1 (a) Geometry and configuration of proposed antenna, (b) geometry of unit cell split ring resonator (SRR)

microstrip transmission line of length L_f=5 mm and width W_f=3 mm which is terminated with a sub miniature version A (SMA) connector for the measurement purpose. On the back surface of the substrate a ground plane of dimension (L_{gnd}xW_{gnd}) 15x2.75 mm^2 is printed. An open-ended rectangular slot is created at the middle of the ground plane of dimension ($L_{gndslot}$x $W_{gndslot}$) 4.5x2.5 mm^2.The distance between the circular radiating element and the ground plane is L_{gr}=2.25 mm. A square shaped slot is cut at the middle of the circular radiating patch of dimension (L_{slot}xW_{slot}) 7x7 mm^2. A rectangular stub of dimension

(L_{stub}xW_{stub}) 4x5mm^{2}is protruding down from the top middle edge of the square slot towards the center of the square slot created in the circular radiating patch. An open-ended square slit (slot with small thickness) ring of dimension (L_{slit}xW_{slit}) 1x1 mm^{2}is created on the top of the protruding stub. On the left side of the feed line on the front surface of the substrate, a SRR is embedded. The magnified version of unit cell split ring resonator (SRR) is also shown in the figure1 (b). The dimension of the outer side of the SRR is (L_{SRR}xW_{SRR}) 2x2 mm^{2}and the dimension of the inner side is (fxe) 1x1mm^2. Both the sides are open ended. The Ansoft HFSS [25] is employed to perform the design and optimization process of this antenna. The design parameters are mentioned in the table I.

TABLE I: Design parameters of proposed antenna

Symbol	**Size(mm)**	**Symbol**	**Size(mm)**
W_{sub}	17	L_{gnd}	15
L_{sub}	15	$W_{gndslot}$	2.5
R_{patch}	5.25	$L_{gndslot}$	4.5
W_f	3	W_{SRR}	2
L_f	5	L_{SRR}	2
W_{slot}	7	a	0.25
L_{slot}	7	b	0.5
W_{stub}	5	c	0.5
L_{stub}	4	d	0.25
W_{slit}	1	e	1
L_{slit}	1	f	1
W_{gnd}	2.75	L_{gr}	2.25
t	0.25		

The design of this proposed antenna has two sections. In section one UWB antenna with preliminary notch characteristics generation is configured where as in section two the enhancement of bandwidth and the tuning of the notch character are described by embedding open-ended slit ring in the protruding stub in the square slot cut from the circular radiating element and embedding a SRR in the left side of the microstrip feed line.

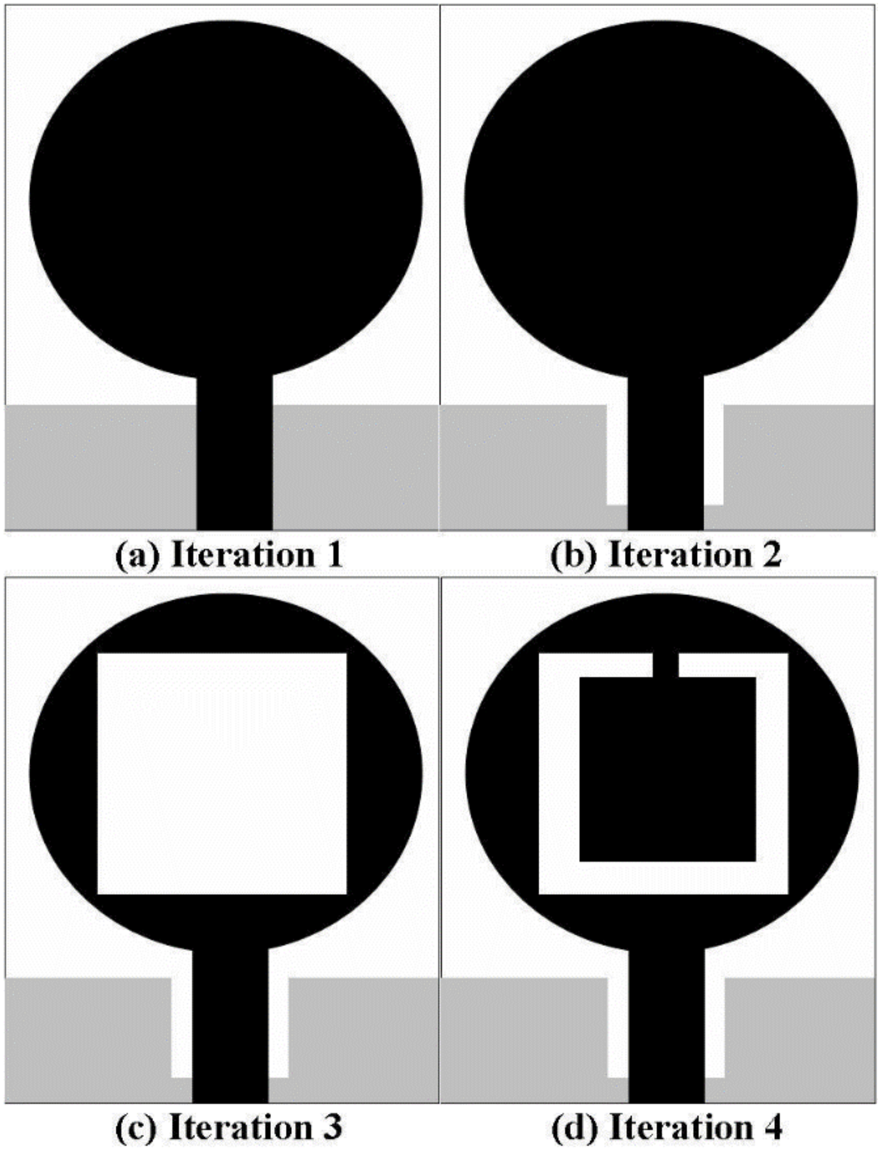

Fig. 2 Chronological developenent of the proposed antenna with first four iterative processes.

In section one preliminary design of the UWB notch antenna is presented with four iterative processes. The chronological developenent of the proposed antenna with first four iterative processes is shown in figure2. Figure 3 shows the simulated reflection coefficient ($|S_{11}|$) of all the first four iterations of the preliminary design of the UWB notch antenna. In first iteration shown in top and bottom view of figure2 (a), a simple circular radiating patch is created which is fed by the microstrip feed line with a partial ground plane as shown. With these configurations a poor impedance matching is obtained as the impedance bandwidth obtained as 6.6 GHz (bandwidth from 3.1 GHz to 9.7 GHz). In the second iteration shown in figure 2 (b), an open-ended rectangular slot is created at the middle of the ground plane just below the microstrip feed line. The open-ended rectangular slot in the middle of the ground plane enhances the bandwidth from 3.1 GHz to 11 GHz with impedance bandwidth 7.9 GHz. The enhancement of bandwidth due to the creation of an open-ended slot in the ground plane helps in proper impedance matching between the microstrip feed line and the circular radiating patch. In the third iteration a square slot is created for more enhanced impedance matching purpose which is shown in the figure 2 (c). After the simulation of the third iteration the bandwidth extended from the 4 GHz to 12 GHz with the impedance bandwidth 8 GHz. Though the impedance bandwidth increases from 7.9 GHz (second iteration) to 8 GHz (third iteration) but the lower frequency is increased to 4 GHz which is not acceptable for UWB operation point of view. To address this problem and for the creation of notch at f_n =5.5 GHz to mitigate out the WLAN operation in the UWB band, a thick rectangular stub is erected which is protruding down from the top middle edge of the square slot towards the center of the square slot created in the circular patch which is the fourth iteration as shown in the figure 2 (d). Due to this rectangular thick stub the bandwidth is extended from the 2.8 GHz to 12.4 GHz which has the impedance bandwidth 9.6 GHz which is 1.6 GHz more than the impedance bandwidth obtained in third iteration. But at the same time the protruding rectangular stub creates a notch centered atf_{ns1} =4.7 GHz which is having the notch band extended from 4.1 GHz to 5.3 GHz. The theoretical notch frequency (f_{nt1}) can also be expressed in terms of the effective physical electrical current path length (L_{eff1}) around the protruding rectangular stub and is given by

$$f_{nt1} = \frac{c}{2L_{eff1}\sqrt{\varepsilon_{\text{eff}}}} \text{——————————} (1)$$

where is the effective permittivity of the substrate whose expression is given by

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12\frac{h}{W_f}}} \text{——————————} (2)$$

ϵ_ρ =4.4 is the permittivity of the substrate and$c$ is the speed of light in vacuum. Putting all the numerical above in the above expression, the effective dielectric constant$\epsilon_{\epsilon\varphi\varphi}$ was found to be $\epsilon_{\epsilon\varphi\varphi}$=3.324. The effective physical electrical current path length (L_{eff1}) around the protruding rectangular stub is found to be 18 mm. Hence applying the equation (1) the theoretical notch frequency is found to be 4.6 GHz, which is very close to the simulated value of the center of notch frequency f_{ns1} =4.7 GHz. The difference between the theoretical $f_{nt1}$and simulational f_{ns1} is due to the different simulation environment adopted for simulation. Though with the introduction of protruding rectangular stub enhances the band but creates a notch with the center notch frequency off_{ns1} =4.7 GHz which is not the required notch center frequency for WLAN which is f_n =5.5 GHz. From figure 3, the sufficient enhancement of the impedance bandwidth is depicted with a notch characteristic at aroundf_{ns1} =4.7 GHz. Hence to obtain the required notch frequency at f_n =5.5 GHz and also extended impedance bandwidth, an open-ended slit ring and a SRR is embedded in the proposed antenna structure which is described in section two.

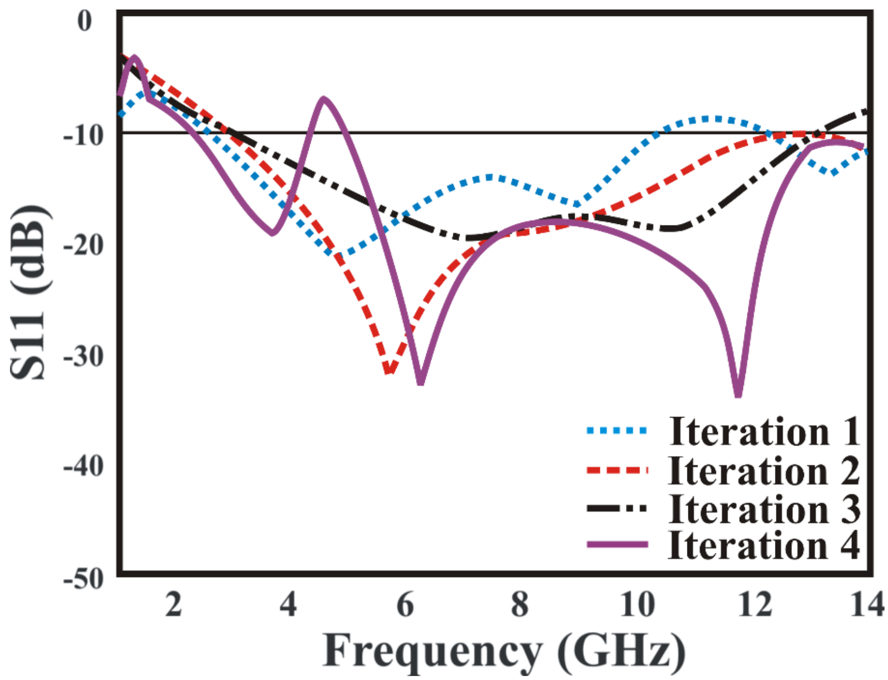

Fig. 3 Comparative analysis of the simulated reflection coefficients ($|S_{11}|$) of first four iterations

In section two the chronological developenent of the final UWB notch antenna is proposed through two iterative processes namely iteration five and six as shown in figure 4.

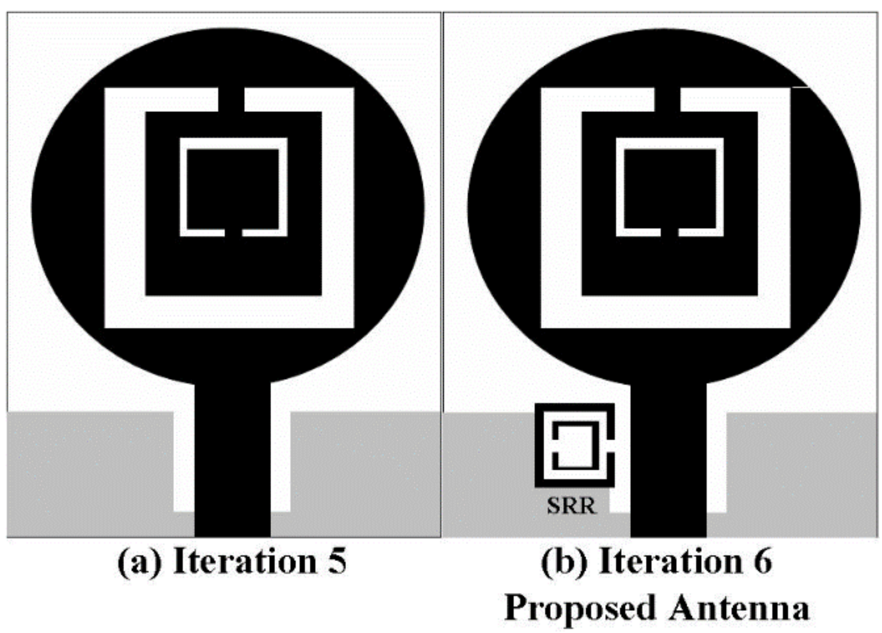

Fig. 4 Chronological developenent of the proposed antenna with last two iterative processes.

Figure 5 shows the simulated reflection coefficient ($|S_{11}|$) of iteration five and six of the final proposed design of the UWB notch antenna. In iteration five shown in figure 4 (a), an open-ended slit ring is created on the top of the protruding stub in the square slot of the circular radiating element. Due to the open-ended slit ring in the top portion of the protruding stub, the operation band is extended from 2.8 GHz to 12.8 GHz with impedance bandwidth 10 GHz which is 0.6 GHz more than the impedance bandwidth obtained in iteration four. The reason for the enhancement of the impedance bandwidth is due to creation of the extra current paths through open ended slit ring. This enhanced current path helps in the constructive addition of currents in the edges of the open-ended slit ring and the protruding stub. But in this iteration the position of the center of notch frequency is unmoved at f_{ns1}= 4.7 GHz as in fourth iteration. Hence there is no improvement of the position of the center frequency of the notch i.e.f_{ns1}= 4.7 GHz.

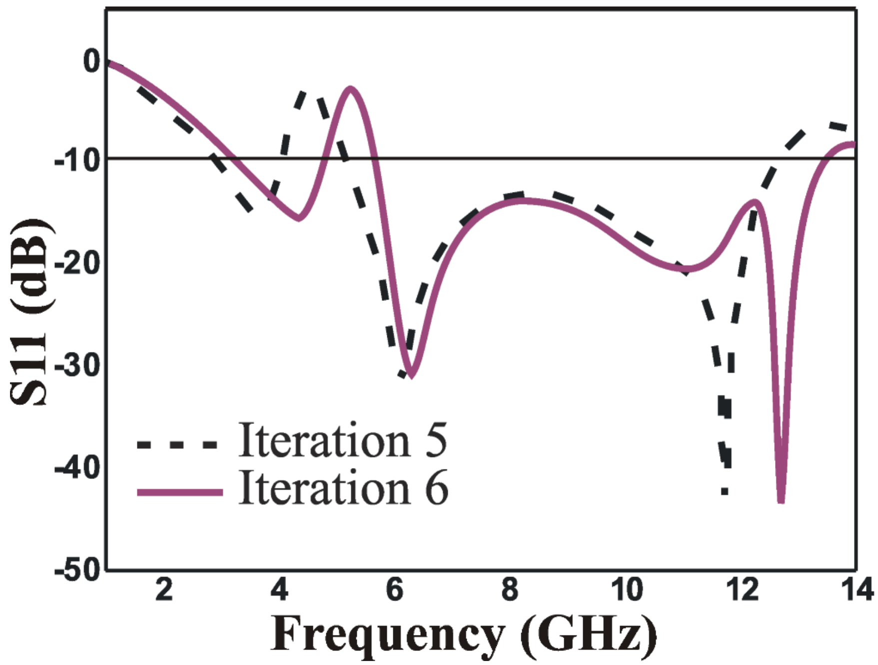

Fig. 5 Comparative analysis of the simulated reflection coefficients ($|S_{11}|$) of iteration five and six.

Hence, to move the center of notch frequency fromf_{ns1}= 4.7 GHz to f_n =5.5 GHz with the notch band from 5 GHz to 6 GHz, an SRR is introduced in the left side of the microstrip feed line in the iteration six depicted in figure 4 (b). After introduction of the SRR in the left side of the microstrip feed line the bandwidth is enhanced from 3.097GHz to 13.326GHz with the impedance bandwidth of 10.23 GHz which is highest among all the impedance bandwidths of previous five iterations. The percentage of bandwidth of the proposed UWB notch antenna is 125%. At the same time the center of the notch frequency of iteration fivef_{ns1}= 4.7 GHz is shifted right tof_n =5.5 GHz with notch band from 5 GHz to 6 GHz which is the desired center of the notch frequency for mitigation of interference between the WLAN and UWB band of operation.

The shifting of notch frequency f_{ns1}= 4.7 GHz tof_n =5.5 GHz is due to the presence of the SRR on the left side of the microstrip feed line. As we know that the SRR is a resonating structure, the resonance characteristics of a unit cell split ring resonator (SRR) are shown in figure 6.

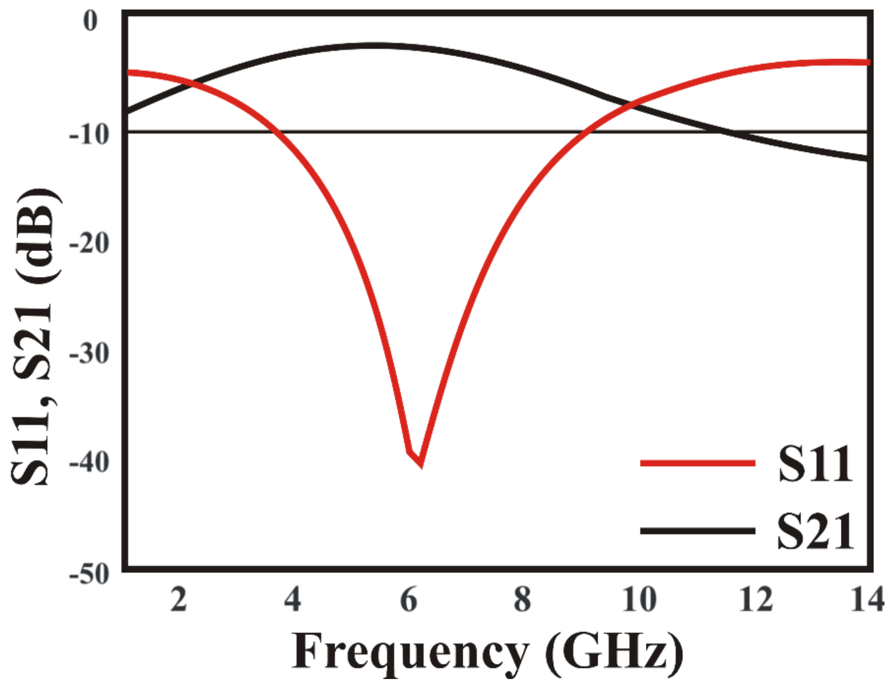

Fig. 6 Simulated reflection coefficients ($|S_{11}|$, $|S_{21}|$,) of unit cell split ring resonator (SRR).

From the graph it is clear that the SRR resonates at resonating frequency of f_{ns2}= 6.1 GHz. Because of the presence of the SRR in its position in the proposed UWB antenna, the actual simulation notch frequency is found to be

$$f_{\text{ns}} = \frac{f_{ns1}+f_{ns2}}{2} = \frac{4\cdot 7GHz+6\cdot 1GHz}{2} = 5\cdot 4GHz \text{————————} (3)$$

But in simulation of the proposed UWB antenna the notch frequency f_{n} is found to be 5.5 GHz which is close to the desired notch frequency f_{n} =5.5GHz obtained in iteration six. Hence the difference of f_{ns} and f_{n} is due to the different simulation environment adopted for SRR in the proposed notch antenna as single unit cell. Apart from this, the difference of f_{ns} and f_{n} may be due to the extra electromagnetic coupling between the SRR and microstrip feed line. In overall it is clear that the presence of SRR in the left side of the proposed antenna the notch frequency of iteration six, the initial notch frequency i.e. f_{ns}= 4.7GHz obtained at iteration four is shifted to the notch frequency of the proposed UWB notched antenna i.e. f_{n}=5.5GHz which is shown in the figure 6 (iteration six).

ii. Equivalent Circuit Model

The equivalent circuit for the proposed UWB notch antenna is exhibited in figure 7. Conceptually, a microstrip feed-line is represented as a planar transmission line with characteristic impedance of 50Ω and the ground plane behaves as the impedance matching network. The radiating patch with one thick slot created by a protruding stub in the square slot and open-ended slit ring represented by a cluster of RLC arrangement (L_4-R_1-C_3) and (L_5-R_2-C_4) respectively as shown in figure 7. Here L_1 represents the copper portion of radiating element of iteration 1or 2, L_2 represents the copper element of the protruding stub of iteration 4 and L_3 represents the inner copper portion of the open- ended slit-ring in iteration 5 and 6. L_2, L_3 and C_2 connected as a T-circuit represents the coupling of SRR.

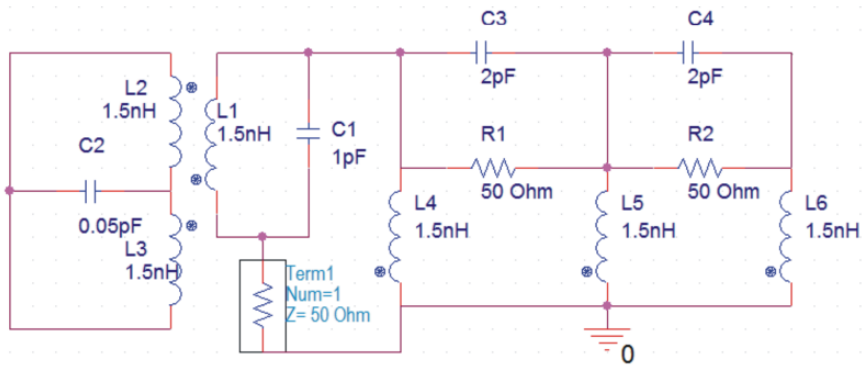

Fig.7 Equivalent circuit model of the proposed antenna

When this configuration of the equivalent circuit is simulated, the simulated reflection coefficient (| S_{11}|) due to the equivalent circuit of the proposed antenna is very much similar to the simulated reflection coefficient of the proposed antenna which is shown in figure 9. This close resemblance of the simulated reflection coefficient (|S_{11}|) of equivalent circuit and the full wave simulated reflection coefficient (|S_{11}|) Ansoft HFSS signifies the correctness of the lumped circuit description or the equivalent circuit analysis of the proposed antenna shown in figure 7.

results and discussion

Figure 8 shows the fabricated prototype of the proposed UWB notch antenna. The proposed UWB notch antenna is fabricated on the FR4_epoxy substrate with dielectric constant ϵ_ρ =4.4 and height h =1.6 mm. The antenna parameters such as reflection coefficient (|S_{11}|) and gain of the proposed antenna is measured with the help of a Rohde & Schwarz vector network analyzer (VNA) of range 1GHz to 20GHz.

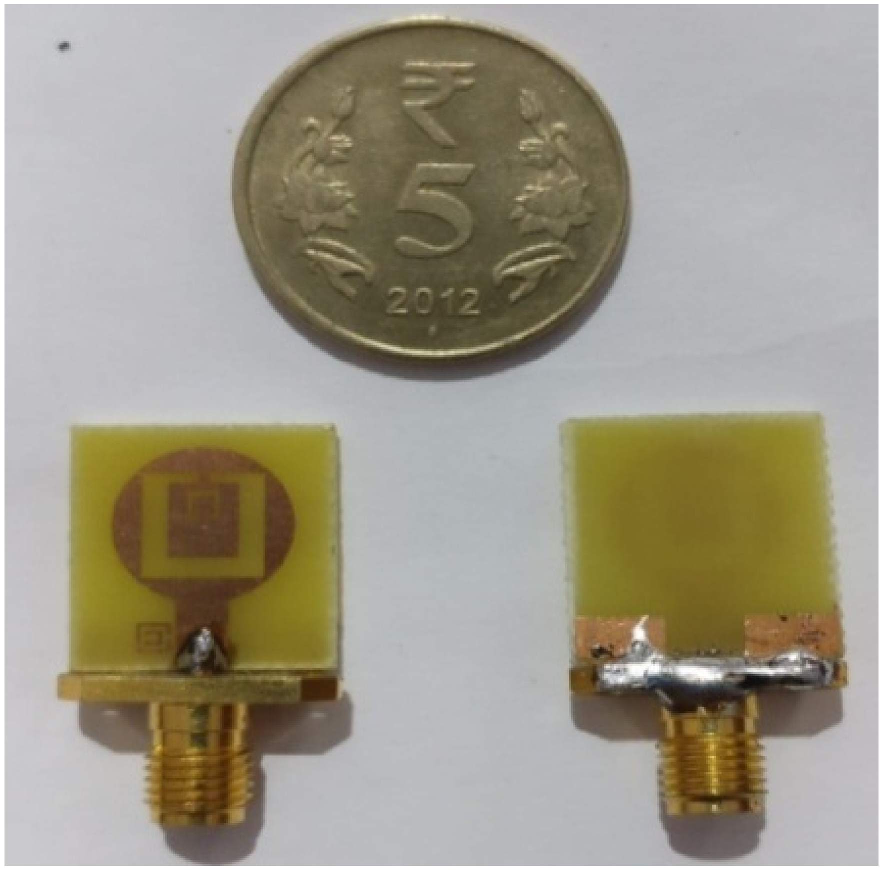

Fig. 8 Fabricated prototype of the proposed antenna.

Figure9 shows the simulated, measured and equivalent circuit simulated reflection coefficient ($|S_{11}|$) of the proposed UWB notch antenna. The simulated bandwidth of the proposed UWB notch antenna extends from 3.09 GHz to 13.32 GHz with the impedance bandwidth of 10.23 GHz. The measured reflection coefficient ($|S_{11}|$) of the proposed UWB notch antenna is in very much accordance with its simulated counterpart. The measured bandwidth of the proposed antenna extends from 2.7 GHz to 13.4 GHz with the impedance bandwidth of 10.7 GHz. This high impedance bandwidth of the measured reflection coefficient ($|S_{11}|$) of the proposed antenna depicts the proper impedance matching of the appropriate fabricated prototype of the proposed antenna. In figure 9 the reflection coefficient ($|S_{11}|$) due to the equivalent circuit is also compared with the simulated and measured reflection coefficient ($|S_{11}|$) of the proposed antenna. The reflection coefficient ($|S_{11}|$) due to the equivalent circuit is matched highly with the simulated and measured reflection coefficient having the bandwidth extending from 3.10 GHz to 13.3 GHz with the impedance bandwidth extended from 10.2 GHz. Hence in overall reflection coefficients ($|S_{11}|$) of the simulated, measured and equivalent circuit simulated are in excellent correlation with each other exhibits proper simulation, fabrication of the proposed UWB notch antenna.

Fig.9 Simulated, measured and the equivalent circuit generated reflection coefficient ($|S_{11}|$) of the proposed UWB notch antenna

Variation of the simulated and measured gain vs. frequency in GHz of the proposed UWB notch antenna is shown in figure 10. From the graph it is clear that the simulated gain increases almost linearly with frequency and the range of simulated gain variation is around 5 dBi to 9.5 dBi. But on the way of linear increase of the simulated gain there is a sharp drop of gain is exhibited in the graph. At around 5 GHz the gain decreases at rapid rate and reached peak at 5.5 GHz. After this event the gain increases and reaches the linearly increasing graph at 6 GHz. At this notched frequency band of 5 GHz to 6 GHz (WLAN), the proposed antenna become non-responsive because proposed antenna does not radiate because of the conjugate effect of the protruding stub and the SRR in the proposed notch band. The value of the simulated gain at 5.5 GHz is around -5 dBi. However, for the other frequencies outside the notched band, the proposed antenna gain is appropriately consistent and almost stable in the whole of the UWB band. On the other hand, the measured peak gain is in accordance with the simulated gain and the value of the measured gain at the 5.5 GHz is around -10 dBi. Hence from this gain vs. frequency graph it is clear that the proposed UWB notch antenna is suitable for the operation in the UWB frequency band but simultaneously notching out the WLAN band for appropriate coexistence.

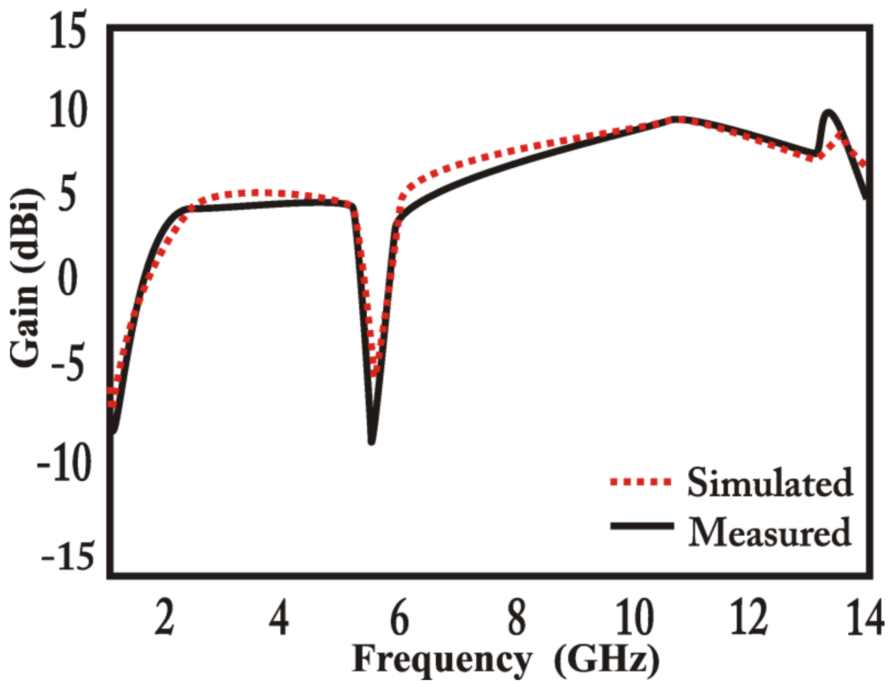

Fig. 10Simulated and measured gain (dBi) of the proposed antenna

The stability of radiation pattern, gain, polarization, reflection coefficient etc, when radiated at different frequencies, the phase difference is not taken into account. At the same time all the frequency components of the UWB system are radiated. In order to reconstruct the phase on reception for different components, the stability must take into account the phase difference. The group delay is considered as the figure of merit. In the UWB communication system, UWB pulse distortion by an antenna is an important issue as the UWB system helps in pulse transmission. A constant group delay (linear phase response) is needed in the UWB system in true sense. The simulated and measured group delay of the proposed UWB notch antenna is shown in figure 11. The simulated group delay for the UWB notch antenna is around 2 ns at the notch frequency of 5.5 GHz. This disturbance of phase response as group delay occurs due to notch characteristics of the proposed UWB notch antenna at 5.5 GHz. At this frequency of 5.5 GHz, linear phase response of the UWB notch antenna is disturbed. On the other hand, the measured group delay of the proposed antenna is in accordance with the simulated one. The measured group delay of the proposed antenna is around 2.8 ns. Apart from this notch band the phase response of the proposed antenna in the UWB frequency range for simulation and measurement are consistent and are at the approximate average value of 0.2 ns from 3.097GHz to 13.326 GHz. Hence from figure 10 it is clear that the proposed antenna exhibits excellent linear response in the UWB range of 3.097GHz to 13.326 GHz except at the notch band centered at 5.5 GHz.

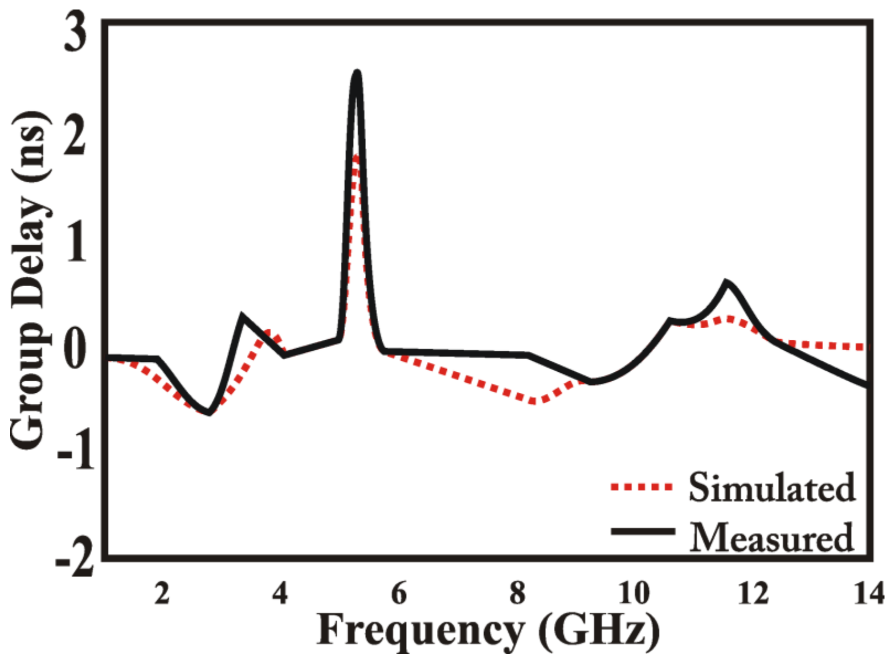

Fig.11Simulated and measured group delay of the proposed antenna

Figure 12 exhibits the surface current distribution of the proposed antenna at 3.5 GHz, 4.4 GHz, 5.5 GHz, 8.8 GHz, and 12 GHz. At 3.5 GHz and 4.4 GHz shown in the figure 12 (a), (b) respectively, the increased current density is visible in the microstrip feed-line and inner edges of the square slot in the circular radiating element. Because of this amount of current density, proper radiation is possible by the proposed UWB antenna that radiates properly in these operating frequencies. At notch frequency 5.5 GHz because of the thick rectangular protruding stub and a SRR printed in the left side of the microstrip feed-line the proposed UWB notch antenna cannot able to radiate considerably as depicted in figure 12 (c). At this operating frequency of 5.5 GHz the current density is very low in the whole structure of the proposed UWB notch antenna. Similarly, at other frequencies of 8.5 GHz and 12 GHz as in figure 12 (d), (e) proper radiation happened as the enhanced current density is visible again in the inner edges of the square slot and around the edges of the open-ended slit ring.

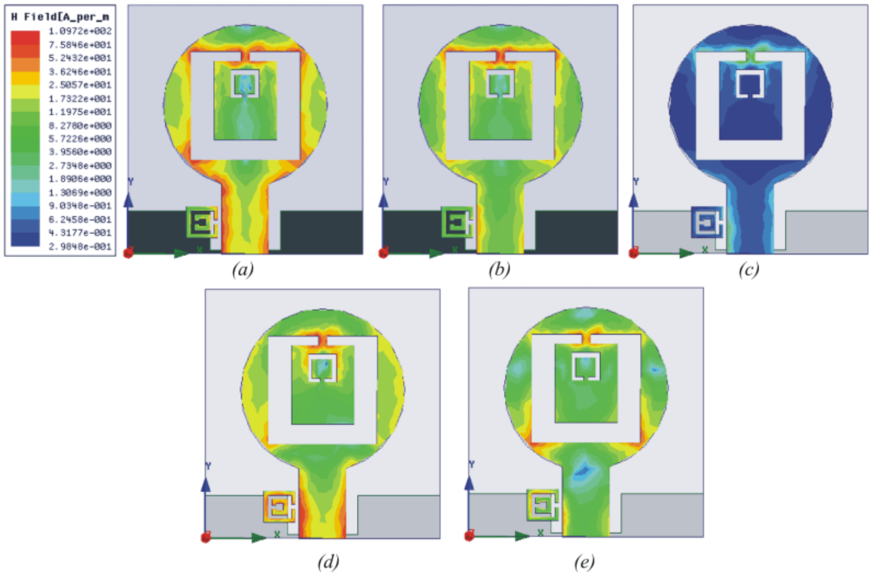

Fig. 12Simulated surface current density (A/m^2) of the proposed antenna at (a) 3.5GHz (b) 4.4GHz (c) 5.5GHz the notch frequency (d) 8.8GHz (e) 12GHz

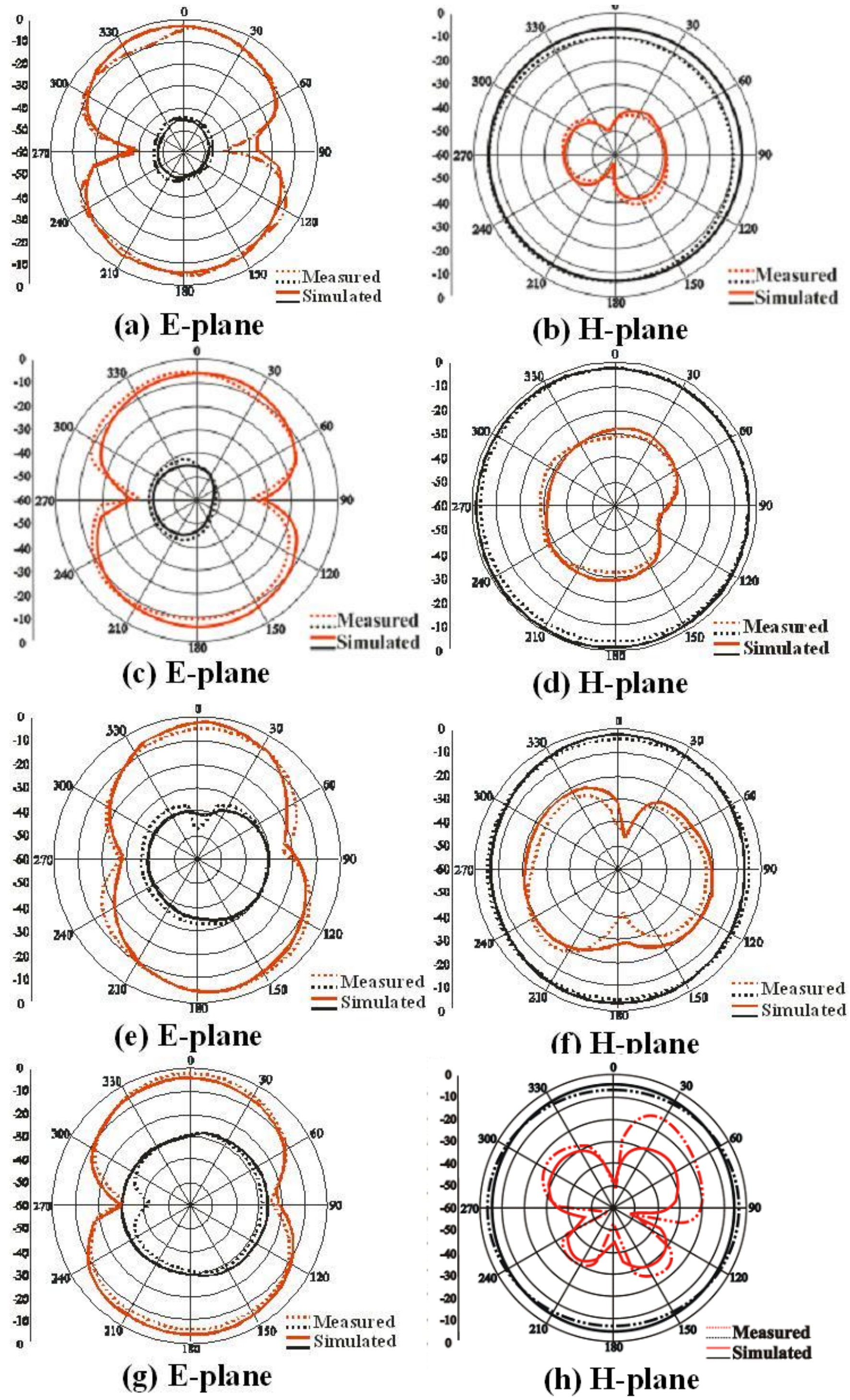

Fig. 13 Simulated and measured E-plane and H-plane radiation pattern of the proposed antenna (a, b) 3.5 GHz, (c, d) 4.4 GHz, (e, f) 8.8 GHz, (g, h) 12.0 GHz.

Figure 13 (a), (c), (e), (g) shows the simulated (red solid line) and measured (red dotted line) normalized co-polar, simulated (black solid line) and measured (black dotted line) cross-polar E-plane (xy-plane) radiation pattern of the proposed antenna at 3.5, 4.4, 8.8, and 12 GHz respectively. Similarly figure 13 (b), (d), (f), (h) shows the simulated (black solid line) and measured (black dotted line) normalized co-polar, simulated (red solid line) and measured (red dotted line) cross-polar H-plane (xz-plane) radiation pattern of the proposed antenna at 3.5, 4.4, 8.8, and 12 GHz respectively From the simulated as well as measured co-polar H-plane radiation patterns of the proposed antenna at 3.5, 4.4, 8.8, and 12 GHz shown in figure 13 (b), (d), (f) and (h) it is clear that there is purely Omni-directional radiation pattern of co-polar H-plane at all the simulated and measured operating frequencies and it is highly consistent in all the operating frequencies. H-plane cross-polar radiation pattern at the operating frequencies of 3.5, 4.4, 8.8, and 12 GHz reveal that there is significant increase of the level of average simulated H-plane cross-polar radiation from -35 dB at 3.5 GHz to -20 dB at 12 GHz. This increase of the level of H-plane cross-polar radiation as the frequency increases is due to the destructive scattering of the radiation from the different edges of the constituent structures such as open-ended slit ring, SRR etc. On the other hand, the co-polar E-plane radiation patterns of the proposed antenna shown in figure 13 (a), (c), (e), (g) are directional along 0^0 and 180^0, respectively. The co-polar E-plane radiation pattern at the operating frequencies of 3.5, 4.4, 8.8, and 12 GHz are roughly a dumbbell-shape or of the shape of English letter “8”. This shape of co-polar E-plane radiation pattern is highly consistent with all the operating frequencies of 3.5, 4.4, 8.8, and 12 GHz which shows that the proposed UWB notch antenna is well suitable for application in entire UWB system except in the operating band of WLAN. Regarding the simulated cross-polar radiation pattern of the E-plane radiation pattern, the level of average E-plane cross-polar radiation varies from -45 dB at 3.5 GHz to -30 dB at 12 GHz. The measured E-plane and H-plane radiation patterns of all the aspects such as co-polar and cross-polar radiation, the measured radiation patterns of E–plane and H-plane are in accordance with their simulated counterpart signifies accurate fabrication of the proposed antenna prototype.

TIME DOMAIN CHARACTERISICS

One of the important characteristics of UWB antenna is its time domain behavior in the UWB operating frequency. Maintenance of high degree of correlation between the transmitted and received pulse is required to avoid the distortion in both transmitting and receiving modes. Fidelity factor is used to calculate the correlation between the transmitted and received pulses is a well-defined parameter whose expression is given by

$$F = max_{\tau}\left|\frac{\int_{-\infty}^{\infty} s(t)r(t-\tau)dt}{\sqrt{\int_{-\infty}^{\infty} s(t)^2dt*\int_{-\infty}^{\infty} r(t)^2\mathrm{d}t}}\right| \text{———————————}(3)$$

Where *s(t)* and *r(t)* are the transmitted and received pulses respectively. The incorrect reception of the output signal*r(t)* results from the non-ideal behavior of the channels and antennas. Hence the UWB antenna should be properly designed to avoid any loss of information to fit a set of time domain characteristics. As frequency domain, the time domains characteristics in UWB antennas are equally essential. In transmitting as well as receiving mode the UWB antenna must have the minimum distortion. For the investigation of the time-domain behavior of the proposed UWB notch antenna, two identical replicas of the proposed UWB notch antenna are kept face-to-face maintaining the distance of 65 cm between the two identical proposed UWB notch antennas as shown in the figure 14.

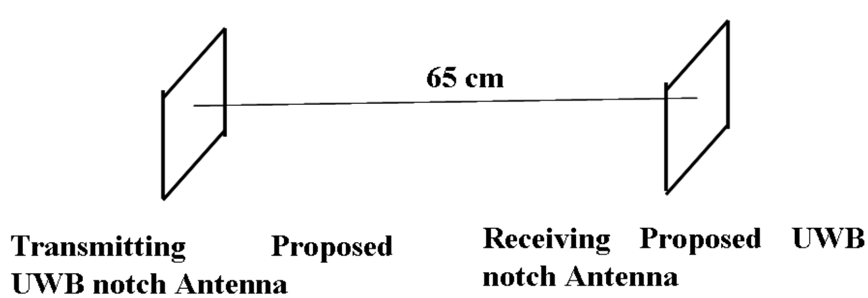

Fig. 14 Time domain simulation set up for the proposed UWB notch antenna in face-to-face configuration.

In this simulation set up for the simulation of the time domain behavior of the proposed antenna, proposed UWB notch antenna in the transmitting side is excited with a Gaussian pulse as the input signal shown in the figure 15. At the receiving side, the output pulse at the replica of the proposed antenna is captured and is shown in the figure 15. In the figure 15 the comparison of the input pulse (transmitted pulse) and output pulse (received pulse) is thus accomplished. The tail of the received pulse is disturbed and considerable amount of ringing is visible in the graph from 0.4 ns to 2 ns. The ringing or the received pulse distortion is more at around 0.4 ns and decays down slowly towards as the time increases. This ringing or the distortion of the pulse is due to the presence of the notch band from 5 GHz to 6 GHz. Because of the presence of notch centered at 5 GHz the received pulse is obstructed heavily leading to appreciable ringing as compared to the transmitted pulse as there is absolutely no ringing in the tail of the input pulse. Fidelity factor of the proposed UWB notch antenna is 0.92 or 92% as calculated by mathematical formula furnished by the equation (3). The fidelity factors of the proposed UWB notch antenna, calculated when it is configured in face-to-face reveals the similarity between the transmitted pulse and the received pulse. Good correlation between the transmitted pulses and received pulses by proposed UWB notch antenna can be identified from the fidelity factor value. From this fidelity factor value of the face-to face configuration of the proposed antenna, a conclusion can be drawn that the excellent pulse handling capability is exhibited by the proposed UWB notch antenna as required by the UWB communication system.

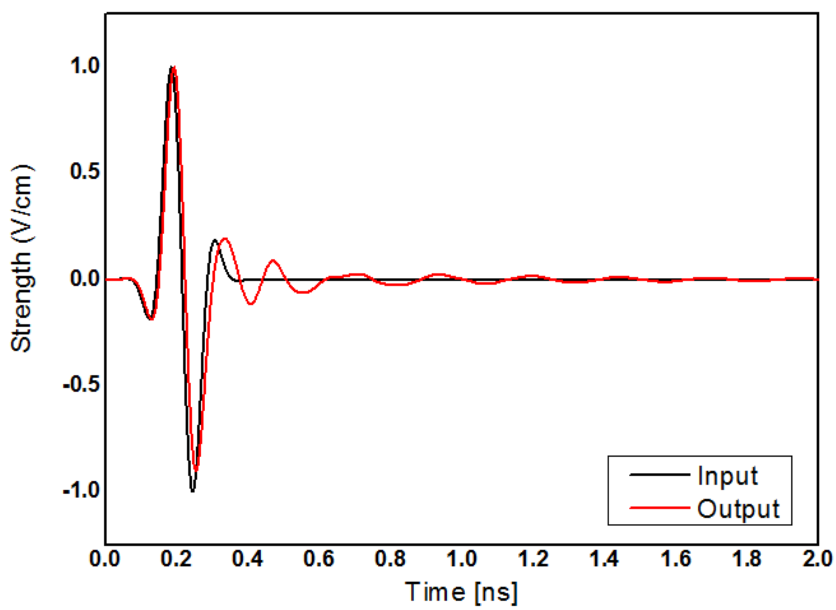

Fig.15 Comparison of input and output Gaussian pulse at the transmitting and receiving side in time-Domain Analysis of the proposed antenna

Table II shows the comparison of the performance of the proposed UWB notch antenna with some contemporary UWB notch antennas. From table-II it is clear that the proposed antenna exhibits superior performance in several antenna performance characteristics such as operating band, impedance bandwidth and gain in the UWB range of operation.

TABLE II Comparison of the proposed UWB Antenna Structure with other Similar Structures Reported in Literature

Sl. No.	Reference	Size (mm^2)	Operating Band (GHz)	Percentage Bandwidth (%)	Average Gain (dBi)
1	[13]	25x20	3.6-9.20	87.5	-
2	[20]	50x50	2.8-11.0	118	2.8
3	[10]	50x50	2.6-10.8	122	6.5
4	Our Work	17x15	3.09-13.32	125	7.1

V. CONCLUSION

A new compact microstrip line fed printed UWB notch monopole antenna of dimension 15x17 mm^2 having a circular radiating element with a square slot is proposed. For generation of a WLAN notch band of 5 GHz to 6 GHz with notch frequency center 5.5 GHz a thick protruding stub is erected down from top portion of the square slot in the circular radiating patch. For the purpose of impedance matching an open-ended slot etched out in the middle portion of ground plane just below the microstrip feed-line and an open-ended square slit ring is printed in the upper portion of the protruding stub. For the proper tuning of the center of the notch frequency and also proper impedance matching, a SRR is printed on the left side of the microstrip feed-line. Hence this antenna structure configuration is simulated and the bandwidth obtained is from 3.09 GHz to 13.32 GHz having the percentage bandwidth of 125 which covers the entire UWB frequency band. Along with this band a deep notched band is obtained from 5 GHz to 6 GHz with notch frequency center 5.5 GHz to mitigate the interference of the WLAN band (5-6 GHz) with the UWB operating system for suitable coexistence. The proposed antenna is fabricated and the antenna parameters such as reflection coefficient, gain, group delay is effectively measured. The measured proposed antenna parameters are in accordance with the simulated parameters. Equivalent circuit analysis of the proposed antenna is performed and the reflection coefficient obtained through the equivalent circuit analysis is effectively matched with its simulated and measured reflection coefficient. Stable radiation pattern and consistent gain is provided by the proposed UWB monopole notch antenna in the UWB frequency range as well as the in the notch band. The average measured gain of this proposed antenna was found to be 7.1 dBi. The measured group delay is consistent in the UWB frequency domain which is around 0.2 ns. Time domain analysis is performed and the UWB pulse transmission through the proposed UWB notch antenna is thoroughly examined. From the time domain analysis, it is clear that the proposed UWB notch antenna has excellent pulse handling capability in the UWB system. The proposed antenna is highly compact in nature and its characteristics are compared with other similar UWB notch antennas in the literature. From this comparison it is clear that the UWB notch antenna which is proposed performs superiorly with the other contemporary UWB notch antenna and is expected to find future applications in UWB systems for coexistence with the WLAN systems.

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