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Investigations on a low-profile, filter backed, printed monopole antenna for UWB communication

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A compact, printed dual band-notched, filter backed antenna or filtenna, with suppressed radiation characteristics outside the ultra-wide frequency band (UWB) has been scripted in this manuscript. The filtenna has been designed to work in the UWB frequency domain (03.1 - 10.6 GHz), as prescribed by federal communications commission (FCC). Band-notching structures have been incorporated in the radiating element for realization of dual band- notches for WLAN and WiMAX. The novelty lies in the fact that, a microstrip band pass filter has been introduced in the antenna feeding section for improvement of the cut-off frequency and frequency selectivity. An impedance bandwidth ($S_{11} \leq$ -10.0 dB) of 03.1 - 10.6 GHz has been obtained excepting two frequency-notches having centre frequencies of 03.5 GHz and 05.5 GHz, respectively. Promise able simulation results followed by measurement, justify the applicability of the novel filtenna for UWB communications.

Keywords: Filtenna, Band-notch, Band pass filter, UWB communication

1 Introduction

Ever since the approval of UWB communication in the range of 03.1 – 10.6 GHz by federal communications commission[1] in 2002, there has been noticeable research activities related to UWB communication based devices design and development. Later, the need for eliminating the effects from undesired interferences originating from multiple narrow band systems had been realized. UWB antennas with band-notching features have been presented by researchers from all over the world, which are highly effective in blocking the interference effects arising from WLAN/WiMAX frequency bands. Chen *et al*. (2017) have proposed a UWB antenna with balanced band-notching features and a bandwidth of 3.0 GHz to 11.20 GHz consisting of a notched frequency points from 05.10 GHz to 06.10 GHz in literature[2]. A band-notched frequency switchable slot antenna has been proposed by Oraizi and Shahmirzadi (2017) in literature[3]. The antenna possesses a bandwidth of 03.10 GHz to 13.0 GHz and an equivalent fractional bandwidth of 123 %. A frequency-notched differential ultra-wideband antenna along with polarization diversity has been presented by Huang *et al*. 2015 in literature[4]. The antenna bandwidth ranges from 02.75 GHz to 11.0 GHz. A single-layered, band-notched, slotted UWB antenna has been presented by Tu *et al*. 2014 in literature[5]. The antenna has a fractional bandwidth of 126 % (2.78 - 12.3 GHz). A frequency-notched antenna consisting of resonating structures has been proposed by Li *et al*. 2012 in literature[6]. Impedance bandwidth ranging from 03.0 GHz to 13.0 GHz, with frequency notches centered at 05.2 GHz and 05.5 GHz has been obtained. Many other UWB communication systems have been presented in related articles[7-11]. However, in most of these antennas, sufficient attention has not been provided to extract the 03.1 – 10.6 GHz band exactly, as specified by FCC. Since, the radiation outside the FCC specified UWB band has a tendency to interfere with other systems of communication, it is necessary to design an UWB antenna, which would be capable of suppressing the unwanted radiation outside the UWB band. This would be extremely beneficial for elimination of noise and reducing the terminal pressure of the system.

Keeping this motive in mind, we have designed a novel UWB filtenna with suppressed radiation characteristics outside the proposed ultra-wide

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frequency bandwidth. To achieve sharp cut-off frequency without increasing of the antenna size, a microstrip band-pass filter has been integrated in the feeding section. Dual complementary RSRR structures have been employed to implement band-notching features for WLAN and WiMAX. The comparison between proposed and notable frequency-notched ultra-wideband antennas in terms of size and performance has been shown in Table 1.

2 Antenna Design and Simulation

Three antenna structures named as antenna I (Fig. 1), antenna II (Fig. 2) and antenna III (Fig. 3) have been designed with successive variations. Figure 1 shows the complete view of antenna I with dimensions. The antenna consists of an elliptical radiator and a defected ground plane. FR-4, having an electrical permittivity of $\varepsilon_r = 4.4$, has been used as the substrate material. The width of the feed line has been kept equal to 3.0 mm for matching a characteristic impedance of 50 Ω. Figure 4 depicts the frequency response of antenna I. An overall impedance bandwidth of 03.0 – 11.6 GHz has been obtained.

Table 1 – Comparison of notable frequency - notched UWB antennas.

Ref.	Dimension (mm^2)	BW (GHz)	Notch	Radiation outside UWB
[2]	32.8 x 22.8	3.00 – 11.2	Single	Yes
[3]	30.3 x 24.8	3.10 – 13.0	Dual	Yes
[4]	64.0 x 64.0	2.75 – 11.0	Dual	Yes
[5]	30.0 x 28.0	2.78 – 12.3	Single	Yes
[6]	24.0 x 28.0	3.00 – 13.0	Dual	Yes
Prop	22.0 x 28.0	3.10 – 10.6	Dual	No

Our next objective is to introduce band-notches for WiMAX (03.3 - 03.7 GHz) and WLAN (05.15 - 05.85 GHz) microwave frequency arenas. For this purpose complementary RSRR structures have been incorporated in the radiating element. Antenna II, depicted in Fig. 2 is the modified antenna with RSRR structures. Figure 4 shows the frequency response of antenna II with an impedance bandwidth of 3.05 – 11.5 GHz along with two band notches for WLAN and WiMAX.

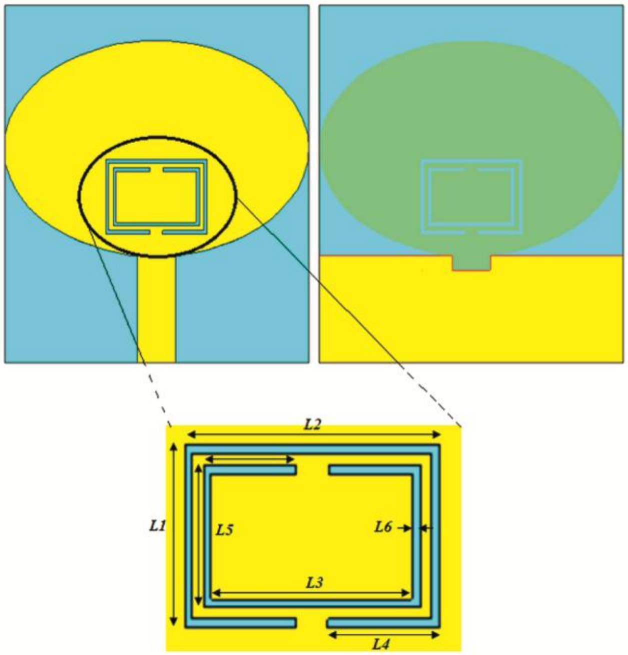

Fig. 2 – Antenna II: (a) foremost view, (b) rearmost view and (c) enlarged view of dual RSRR structure.

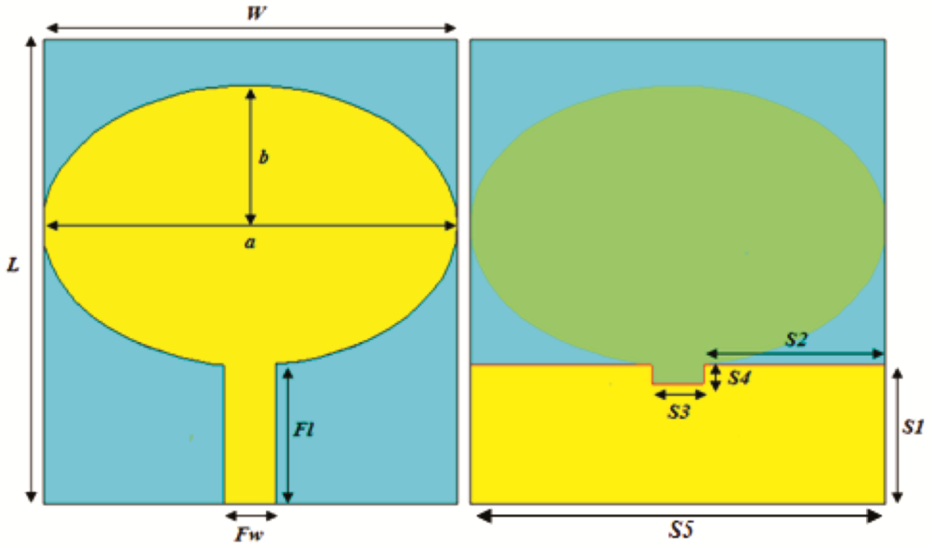

Fig. 1 – Antenna I: (a) foremost view and (b) rearmost view.

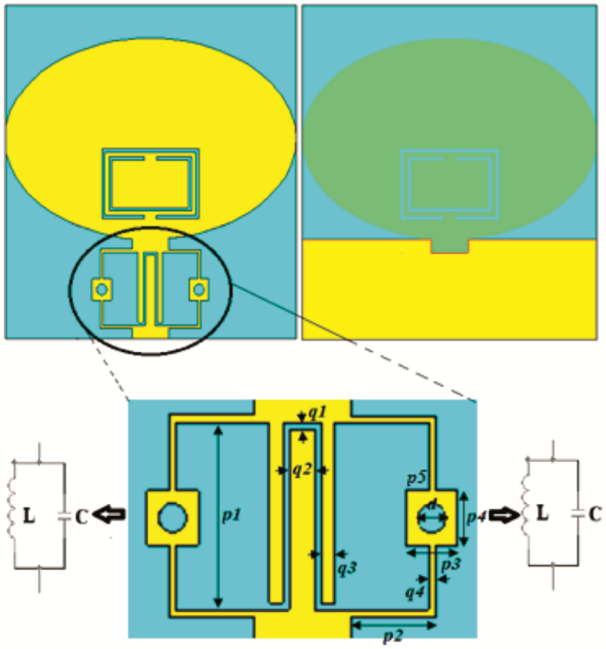

Fig. 3 – Antenna III: (a) foremost view, (b) rearmost view and (c) enlarged view of integrated BPF.

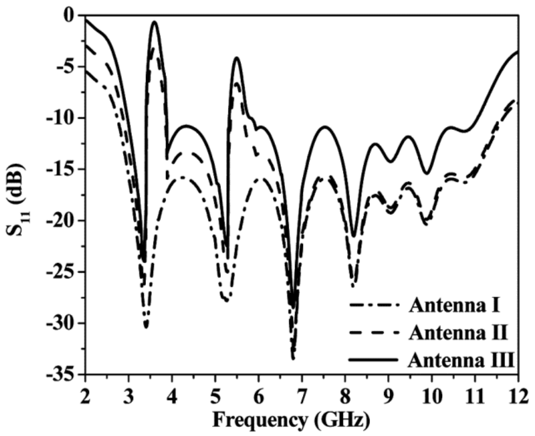

Fig. 4 – Simulated frequency responses of antenna I, antenna II and antenna III.

Now, in order to block the unwanted radiation occurring outside the UWB range, keeping the antenna dimensions fixed, a shorted-stub enabled microstrip band pass filter has been incorporated in the feeding section of antenna II. The new antenna formed namely, antenna III, as displayed in Fig. 3 is our proposed antenna, combined with a band pass filter, also known as a filtenna for convenience. The dimensions of antenna I, antenna II and antenna III are given in Table 2.

In comparison to the BPF proposed in literature[7], instead of four, the number of shorted-stubs (parallel L-C circuits) has been reduced to two, thereby helping in reduction of the circuit complexity.

Table 2 – Various parametric dimension of antenna I, antenna II and antenna III.

Parameter.	Dim. (mm)	Parameter	Dim. (mm)	Parameter	Dim. (mm)
W	22.00	*S3*	02.75	*p1*	09.25
L	28.00	*S4*	00.75	*p2*	02.75
Fl	11.00	*S5*	22.00	*p3*	02.00
Fw	03.00	*L1*	05.50	*p4*	02.25
a	22.00	*L2*	06.50	*p5*	00.75
b	10.00	*L3*	05.25	*q1*	00.25
d	01.00	*L4*	03.75	*q2*	01.00
S1	08.00	*L5*	04.50	*q3*	00.50
S2	10.00	*L6*	00.25	*q4*	00.25

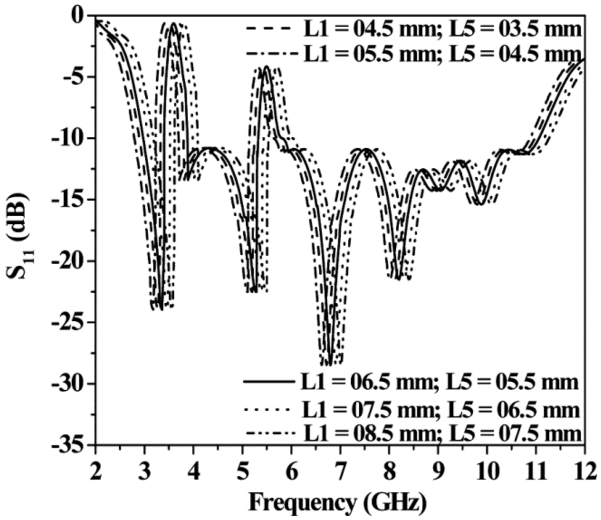

Fig. 5 – Frequency response of antenna III due to parametric variations of *L1* and *L5*.

Figure 4, depicts the return losses, i.e., $|S_{11}|$ for antenna I, antenna II and antenna III. Assuming the '-10.0 dB level' as the label of reference, the achieved impedance bandwidth of proposed UWB antenna with band-pass filter is from 03.10 GHz to 10.60 GHz, i.e., exactly the frequency range proposed by FCC. From the frequency response of antenna III (Fig. 4), we can observe that the radiation characteristics outside the UWB band have been suppressed drastically. As antenna III is a novel combination of UWB antenna along with an integrated band-pass filter (BPF), it has been termed as filtenna for convenience.

2.1 Effect of dual RSRR structure of antenna response

Band-notched characteristics can be introduced in the system by introducing rectangular split ring resonator (RSRR) structures in the elliptic radiating element. The centre-frequency of the notch is changed by means of altering the parametric dimensions. In Fig. 5 the effect of parameters *L1* and *L5* of the dual RSRR structure as shown in Fig. 2(c) on the notched-band centre-frequency has been displayed. The parametric variation effect on the frequency response of antenna III has been detailed in Table 3.

The corresponding parametric dimension for the generated notch-band centre frequency (f_c) can be approximately calculated using Eqs (1 and 2) as:

$$G = \frac{c}{2\, fc\, \sqrt{\varepsilon eff}} \quad \text{... (1)}$$

$$\varepsilon_{eff} = \frac{\varepsilon r + 1}{2} \quad \text{... (2)}$$

Where, ‘c’ represents velocity of light wave in free-space, εeff represents effective electrical-permittivity, and ‘G’, the outer perimeter of each RSRR structure. On analysis of Fig. 5, the centre frequency of the notched-bands have been obtained at 03.5 GHz and 05.5 GHz for *L1* = 06.5 mm and *L5* = 05.5 mm, respectively.

2.2 The BPF effect on antenna response

A band-pass-filter (BPF) has been introduced in the feeding segment for suppressing the radiation outside the UWB range. The BPF configuration mentioned in literature[7] has been given a simplified version. Instead of four, we have used two symmetrical shunted stub elements, thereby reducing the complexity of the circuit. Figure 6 shows the equivalent circuit of the integrated BPF as shown in Fig. 3(c). The shorted-stubs are equivalent to two tank circuits (L-C circuit) connected in parallel along with an inverted admittance connected in series. The frequency responses of antenna II (without BPF) and antenna III (with BPF) have been compared and the result has been reflected in Fig. 7. As observed from the Fig. 7, in comparison with antenna II, antenna III shows an impedance bandwidth of 03.10 – 10.60 GHz with an equivalent fractional bandwidth of 109.48 % and thereby has been successful in eliminating the radiation outside the prescribed UWB bandwidth.

It is possible to understand the cause of generation of band-notches by close observation of the antenna surface current distribution pattern (Figs 8(a), (b) and (c)). Current originating from the BPF integrated feeding section tends to concentrate near the RSRR structures at the corresponding notched-band frequency zones. This uneven distribution of surface current owing to the presence of complementary RSRR structures, as observed from Figs 8 (b) and (c), is mainly responsible for creation of band-notches at 03.5 GHz and 05.5 GHz, respectively.

3 Fabrication, Measurement and Analysis

Prototypes of antenna I, antenna II and antenna III have been fabricated. The simulated and measured

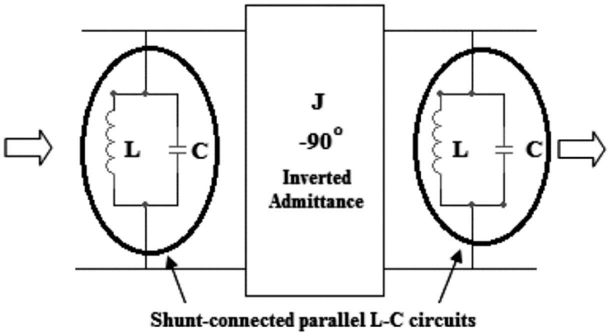

Fig. 6 – Equivalent circuit integrated microstrip BPF-Fig. 3(c).

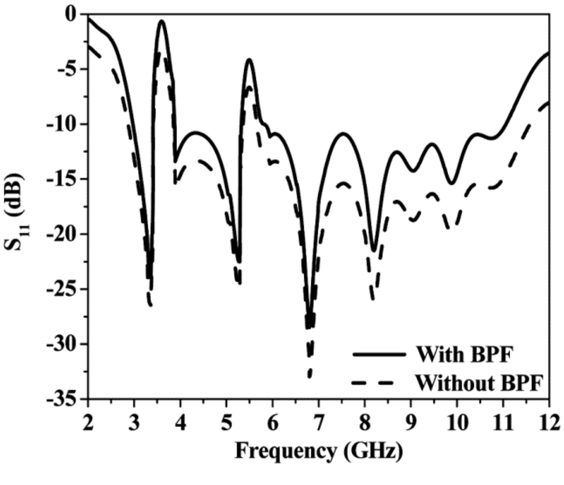

Fig. 7 – Frequency response of antenna with and without BPF.

Table 3 – Effect of parametric variation (*L1* and *L5*) on frequency response of antenna III.

L1 (mm)	*L5* (mm)	Centre freq of notched band(s) (GHz)	Bandwidth (GHz)	Fractional bandwidth
4.5	3.5	3.3/5.2	3.1 – 10.8	110.79 %
5.5	4.5	3.4/5.2	3.2 – 10.7	107.91 %
6.5	5.5	3.5/5.5	3.1 – 10.6	109.48 %
7.5	6.5	3.5/5.6	3.3 – 10.7	105.71 %
8.5	7.5	3.6/5.7	3.4 – 10.9	104.89 %
4.5	3.5	3.3/5.2	3.1 – 10.8	110.79 %

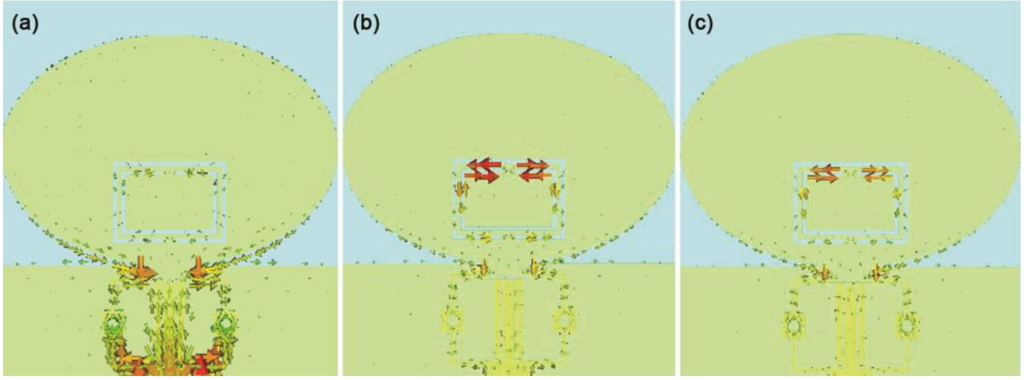

Fig. 8 – (a) Distribution of surface current of antenna III at 03.10 GHz, (b) distribution of surface current of antenna III at 03.50 GHz and (c) distribution of surface current of antenna III at 05.50 GHz.

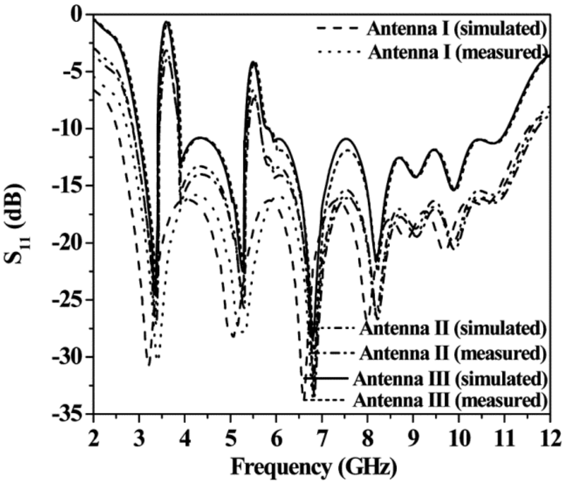

Fig. 9 – Measured/simulated responses of (a) antenna I, (b) antenna II and (c) antenna III.

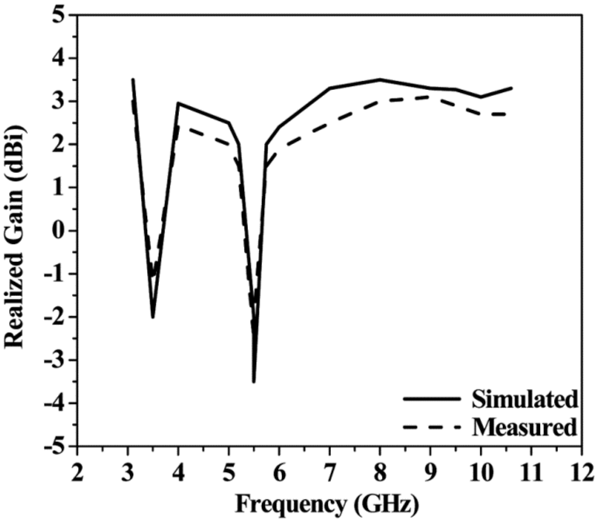

Fig. 10 – Realized gain of antenna III (simulated and measured).

return losses, $|S_{11}|$ have been compared. As observed from Fig. 9, the results obtained from simulation and measurement bear good agreement. Slight deviation may be due to the errors during fabrication and soldering. The radiation pattern, gain and group delay characteristics of antenna III (proposed antenna) have been discussed in the next section.

In the next phase, the antenna gain has been considered for analysis. From Fig. 10 it has been observed that antenna III has a minimum realized gain of ≥ 3.0 dBi throughout the entire impedanceband width except at the frequency-notches, where the realized gain fails to follow the threshold value. Fabricated prototypes have been shown in Fig. 11. In the next phase of analysis the pattern of antenna radiation has been taken into account. The radiation characteristics of antenna III resembles to that exhibited by a typical monopole with almost omni-directional radiating feature. The radiation characteristics of X-Z cross-polarization, co-polarization and Y-Z cross-polarization; co-polarization have been depicted in Fig. 12.

Time domain analysis of proposed antenna III, i.e., the group delay factor is extremely crucial. Signal group delay can expressed as:

$$\delta_g = - \Delta\zeta/\Delta\gamma \qquad \ldots (3)$$

Where, $\Delta\zeta$ and $\Delta\gamma$ are the phase and frequency deviations of the signal, respectively. The rapid fluctuation in group delay is mainly responsible for signal distortion. As observed from Fig. 13, the group delay remains almost constant with some ripples ≤ 0.2 ns. The group delay obeys the acceptable limits throughout the UWB frequency bandwidth excepting the frequency-notches.

Interference of noise generates ripples in the signal response.

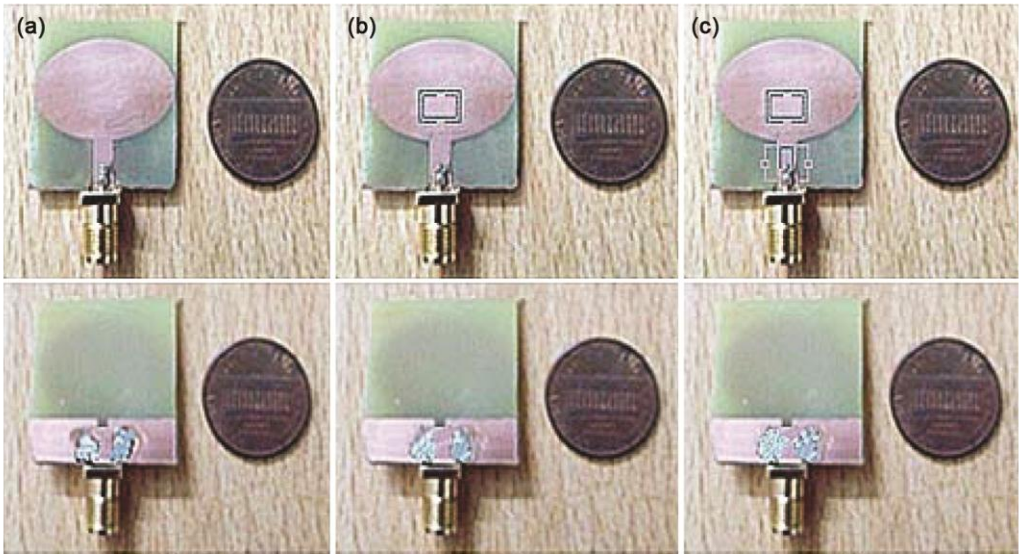

Fig. 11 – Fabricated prototypes of (a) antenna I, (b) antenna II and (c) antenna III.

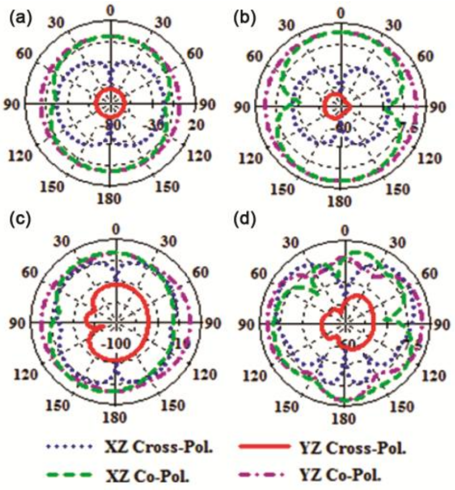

Fig. 12 – Radiation pattern of antenna III at (a) 03.80 GHz, (b) 05.90 GHz, (c) 06.50 GHz and (d) 9.10 GHz.

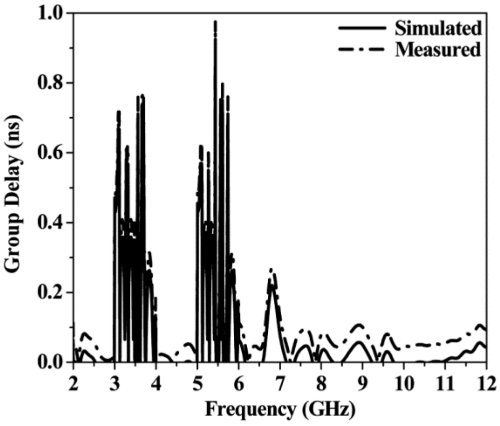

Fig. 13 – Group delay of antenna III (simulated and measured).

4 Conclusions

A compact, printed antenna with suppressed radiation characteristics outside the UWB band has been designed, simulated and experimentally verified. Microstrip band-pass filter has been integrated in the structure to incorporate filtering characteristics and suppress the radiation out of the ultra wide frequency bandwidth of 03.10 –10.60 GHz prescribed by FCC. The novel filter backed antenna or Filtenna has a compact size of 22.0 x 28.0 x 1.0 mm^3. Presence of dual–notched bands is an added advantage, helping in elimination of the unwanted interference from the existing narrow band systems like WLAN (03.3-03.7 GHz) and WiMAX (05.15-05.85 GHz). Good realized gain and radiation characteristics also have been achieved from experimental verifications. Efficient frequency selectivity along with acceptable time domain response justifies the applicability of the proposed filtenna for UWB communications standardized by the FCC.

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