Half Hexagonal Shaped UWB antenna with triple band notch using resonating structures for wireless communication

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Abstract: In this article, an UWB (Ultra-wide Band) compact monopole antenna with triple band-notched characteristics is presented. The antenna structure consists of a half-hexagon monopole with rectangular and square resonant spirals structures for the exclusion of frequency bands for WiMAX (3.25-3.85GHz), WLAN(5.15-5.85GHz), and Fixed/Mobile Satellite Communication (7.55-7.75GHz). The compact antenna of size 28x 29 mm^2 achieves simulated ultra-wide bandwidth of 14.7GHz (2.9GHz-17.6GHz) and measured bandwidth of 14.8GHz (3.21-18.0GHz). The stable gain characteristic is obtained for the passband and gain is reduced to -2.02dBi (3.57GHz), 0.4 dBi (5.3GHz) and-2.75dBi (7.6GHz) at band notch frequencies.

Keywords:

Half Hexagonal Monopole, Resonating Structures, Ultra-wide Band Antenna, Band Notch Characteristics, Defected Ground Structure.

I. INTRODUCTION

The UWB antennas have been attracting many researchers' attention after the declaration of the 3.1-10.6 GHz band for ultra-wideband applications by the FCC [1] for commercial use. Many advantages of the UWB include ultra-wide commercial bandwidth, high data rate, compact size, etc. Though there are many advantages, the UWB system faces many implementation challenges like multipath fading and co-channel interferences due to the coexisting of communication systems i.e., WiMAX band, WLAN bands, and Fixed Satellite/Mobile Communication. By keeping these issues in mind it is desirable to have multi-band-notch characteristics in the antenna which is incorporated in UWB systems.

Various methods have been proposed to achieve band-notch characteristics [2-19]. The most common technique is to cut a slot on the patch or the feed line and the ground plane. In this, the position and size of the slot determine the middle frequency and the bandwidth of the notch. In slot techniques, a quarter-wavelength or half wavelength of different shapes such as U-shaped, L-shaped, split ring resonators are cut in the patch or the ground plane [2-12]. Although the slot methods are efficient in generating band notches, only single or double notches can be produced [3]. Various antenna geometries have been proposed to acquire the single-band and dual-band rejection characteristics obtained using different shapes of slots on the patch [4],[5], parasitic slits [6], inserting CSRR(complementary split-ring resonator) in the microstrip line feed [7], or by using EBG cells [8]. In [9] parasitic coupled loops/resonators are used for achieving multiple band-notches. In [10] semi-circular patch antenna incorporated with a complementary split ring for a dual-band notch is presented. The quasi self-complementary semi octagonal-shaped UWB antenna with a single-band notch (5.15-5.85GHz) with a bandwidth of 2.9-20 GHz is proposed in [11]. In [12] a circular monopole antenna with mushroom-shaped EBG structure is presented for UWB applications with band-notched characteristics. An asymmetric U-shaped monopole antenna with a T-shaped strip of size 20 x 36 mm^2 has been proposed [13]. A novel hp-shaped hexa-band frequency reconfigurable antenna for multi-standard wireless communication has been proposed [14].

The antenna presented and analysed in this article is a simple half-hexagonal with triple-band notch characteristics. The antenna proposed is realized in two stages. In the first stage, a half-hexagon monopole is presented to achieve UWB characteristics. In the second stage, three self-resonating spiral resonators are added; two resonating spirals are coupled with the feed line and one in the ground.

II. ANTENNA STRUCTURE DESIGN AND ANALYSIS

A) Basic UWB monopole design

The proposed structure is designed on the FR-4 substrate with ε_r=4.3, tan δ = 0.025. The antenna has a compact size of 28 × 29×1.59mm^3. The front view and rear view of the designed antenna for triple band-notched characteristics are shown in Fig. 1(a) and Fig. 1(b) respectively. The enlarged view of self-resonating spiral structures is depicted in Fig.1(c). The antenna feed is given by the microstrip line of width W_f=2.74mm. The optimized dimensions are presented in Table 1.

The lower cut-off frequency corresponding to VSWR=2 is calculated by using the following equation [15], with all the dimensions are in cm.

$$f_L = \frac{7.2}{(l+r+g)} \qquad (1)$$

Where *'l'* and 'r' are respectively the length and radius of the corresponding cylindrical monopole antenna. For the hexagon of side length $L_{1=}$1.3cm and ground-patch gap g = 0.15cm, the value of cut-off frequency is 3.0GHz. The *l* and *r* of the cylindrical monopole are related to the hexagonal monopole as follows [15],

$$l = \sqrt{3L_1} \qquad (2)$$

$$r = \frac{3L_1}{4\Pi} \qquad (3)$$

With the above geometrical parameters of an antenna and ground of size L_g=12.5mm the impedance bandwidth obtained (Reflection coefficient (S11) < -10 dB) is 2.8-9.5GHz as it can be depicted in Fig. 2, indicated with the partial ground without slot. The obtained impedance bandwidth does not cover the whole ultra-wideband of 3.1-10.6 GHz; the next step is to increase the higher cut-off frequency of an antenna to cover the full UWB band by introducing a slot in the ground. Thus the partial ground is altered to DGS (Defected Ground Structure) with a rectangular slot on the upper side of the ground as shown in Fig. 1(b). The length and the width of the rectangular slot are L_s=2.5mm and W_s=2mm, which gives a 5mm slot. The length of the ground slot is calculated as [15],

$$L_{gslot} = \frac{\lambda_g}{4} = \frac{\lambda}{4\sqrt{\varepsilon_{reff}}} = \frac{c}{4\,f_{10.6GHz}\sqrt{\varepsilon_{reff}}} \qquad (4)$$

As a consequence of the ground slot, the impedance bandwidth is expanded from 3-9.5GHz to 2.9-13.56GHz and the high cut off frequency is shifted to 13.56GHz from 9.5GHz as shown in Fig. 2(a). After the acquisition of the UWB range, the next step in the design is to introduce band notches to suppress the existing interferences.

B) Basic Design of Resonating Spirals for Band Notch

To achieve band notch characteristics self-resonating spiral structures are introduced. The dimensions of the spiral structures are calculated and optimized according to techniques given in [9]

$$L_{Total} = \frac{4NL_{out} - \left[2N\left(1+N\right)-3\right]\left(S+t_1\right)}{\mathrm{N}} \qquad (5)$$

$$\mathrm{N}_{\mathrm{normalized}} = \text{integer part of } = \frac{\mathrm{L}_{\mathrm{out}} - \left(\mathrm{S}+\mathrm{t}_1\right)}{2\left(\mathrm{S}+\mathrm{t}_1\right)} \qquad (6)$$

In this N is the number of turns, Lout=u_1 is the outer turn side length, S the gap between turns; t_1 is the spiral width and the total effective length of spiral i.e.

$$L_{Total} \approx \mathrm{L}_1 \approx \mathrm{L}_{\mathrm{eff}} \approx \frac{\mathrm{C}}{2\mathrm{f}_{\mathrm{c}\sqrt{\varepsilon_{\mathrm{reff}}}}} \qquad (7)$$

Which is nothing but half of the guided wavelength. Here in this C is the speed of light in free space; ε_{reff} is the effective dielectric constant. To calculate L_{total} for WiMAX (3.25-3.85GHz) the f_c is taken as 3.45GHz and the value of L_{total}=sp_1 (total length of resonating spiral 1) obtained is 24.28mm. Here, sp_1 is the total length of spiral 1. By approximations, the design values of S and t_1 are taken as 1mm. By substituting these values in equations (5) and (6), the optimum value of Lout and N is calculated as 6mm and1.25mm respectively. The length of spiral1 is optimized to 26.5mm. Similarly for the WLAN band notch, for the resonance frequency of 5.4GHz, the calculated L_{total}=sp_2 (the total length of resonating spiral 2) is 20 mm and the optimized values of Lout1 and Lout2 have been obtained as 6 and 4 mm respectively for the t1=t_2=S=1mm. Where $Lout_1$ and $Lout_2$ are the outer turn side length of spiral 1 and spiral 2. The

$Lout_1$ is equal to u_1 and $Lout_2$ is equal to u_2 for spiral and spiral 2 respectively. The third band notch for the Fixed/Mobile Satellite Communication (F/MSC) is achieved by introducing a half-wavelength spiral in the ground plane as shown in Fig. 1. The resonance frequency of the spiral depends on the length (Lout) of the inductive arms and capacitive gap (S) of the spiral, as it is a self-resonating structure. Thus for optimum design and to achieve resonating frequencies the rectangular planner spirals are chosen as shown in Fig. 1(c).

III. RESULTS AND DISCUSSIONS

To overcome the issue of interference in the UWB range, two planar spirals sp1(for WiMAX) and sp2 (for WLAN) are capacitively coupled with the microstrip line for the band notch characteristic, and the third planar spiral is added in the ground plane. The parametric analysis is done for the optimum length of spirals, various positions of the spiral, and the spacing between the feed line and the spiral. The resultant characteristics are shown in Fig.3.Fig.3 (a) and 3(b) show the positions of slot 1 and its S_{11} characteristics for various positions. Thus it can be observed that position 3 is the best among the positions considered. By keeping the slot in this position the effect of the gap between the feed line and spiral structure is observed as shown in Fig.3(c). It can be noted from Fig. 3 (c) that as the gap between the feed line and spiral increases by more than 0.4mm the magnitude of the notch at the 3.5GHz decreases and as the gap decreases by less than 0.4mm the lower cut off frequency gets disturbed.

A similar parametric analysis is done for the WLAN spiral (sp2) and the related results are displayed in Fig. 4. From the obtained results, position1 gives the optimum results. Also, the 0.3mm gap between the feed line and a spiral is optimum for the WLAN characteristic. The third band notch for the F/MSC is achieved by introducing a half wavelength spiral in the ground plane. The optimization of the position and length (g1=gap between the ground and spiral 3 variations) of spiral 3 is shown in Fig. 5. When the spiral resonator 3 is placed in position 3 and position 4, the notch at the desired frequency gets disappeared. From Fig. 5(a) it can be observed that position1 gives the optimum result. When the gap between the ground and spiral 3 is 0.3mm maximum bandwidth is obtained and the sharp band notch is achieved for the F/MSC band as shown in Fig. 5(c).

The optimized dimensional parameters for spiral 1 to acquire band notch for WiMAX u_1 (Lout1) =6mm, S=1=t_1=1mm, and hence the sp1 is 26.5mm. For spiral 2 the optimized dimensional parameters are u_2 (Lout2) =4mm, S=1=t_2=1mm, and hence the sp2 is 20mm which secures the band notch for WLAN. The optimized dimensional parameters for spiral 3 to acquire band notch for F/MSC is u_3 (Lout3) =3.5mm, u_4=3.8mm, S=1=t_1=1mm and hence the L_{total}=sp_3 (Total length of resonating spiral 3) is 14.9mm. The proper position, orientation, and lengths of the spirals decide the characteristics of band notches. The final design consists of a half hexagonal monopole with three resonating spirals to acquire triple-notch characteristics which are shown in Fig. 1.

When all the three self-resonating spirals are added in the design, one in the ground and two coupled with the feed line sharp notches are obtained for WiMAX, WLAN, and F/MSC band. The return loss of less than -10dB is obtained for the range 2.9GHz-17.6GHz excluding the three notches that are 3.4-3.8GHz, 5.0-5.6GHz, and 7.2-7.9 GHz as shown in Fig. 6. The VSWR is also shown in Fig. 6. The obtained gain for the proposed antenna is shown in Fig.7. From the graph, we can depict that a maximum gain of 3.1dBi at12.4GHz is obtained, with a reduced gain of -2.08dBi, 0.40dBiand -2.6dBifor band notch frequencies at 3.56GHz, 5.5GHz, and 7.62GHz respectively.

To validate the antenna design the prototype is fabricated and the measured results are presented. The return loss measurements are carried out by using available VNA (Vector Network Analyzer, Model-MS2028C) and the radiation pattern is measured in the anechoic chamber. Fig. 8 shows the fabricated antenna prototype and the concerning results are presented in Fig.9 and Fig. 10. It can be seen from Fig.8 that the simulated bandwidth ranges from 2.9-17.6GHz and the measured bandwidth is in the range 3.21-18.0GHz. The measured results are slightly different from the simulated one, due to manufacturing tolerance and soldering. The production error (manufacturing) error is the main likely cause of the difference between simulated and measured results. During the fabrication, this error may occur due to incorrect thickness of the substrate layer and dimension inaccuracies. Similarly, the measured and simulated radiation patterns at resonating frequencies are presented in Fig.10. The E-field is unidirectional at 3.1 GHz and 4.3GHz. On the other hand, a bidirectional E- field is obtained at 6.3 GHz. The H-filed radiation pattern is bidirectional at all the resonating frequencies.

The surface current distribution is shown in Fig. 11. The current is mainly concentrated in spiral 1 and edges of the patch at a lower resonating frequency. However, at higher resonating frequency i.e.at 4.3 GHz the current is flowing in spiral 1, spiral 2, and the antenna patch. At 6.2 GHz the current is mainly distributed in spiral 2 and spiral 3. The total efficiency and radiation efficiency of an antenna are presented in Fig. 12. The efficiency s above 60% in the obtained impedance bandwidth and has been reduced below 40% at notch frequencies. The comparison of the proposed work with the reported work is shown in Table 2.

IV. CONCLUSION

The stepwise realization of compact planner UWB antenna with triple notch characteristics is presented. The triple-notch characteristic is validated through simulated results. The impedance bandwidth for VSWR<2 is obtained for the ultra-wide band in the range of 3.2GHz-18.00GHz with triple band-notch for WiMAX, WLAN, and F/MSC band. The simulated gain is stable for passband frequency in the range of 0.9-3.21 dBi and gain is reduced to-2.08 dBi, 0.40dBi, and -2.6dBi at 3.57GHz, 5.3GHz, and 7.6 GHz respectively for notch bands.

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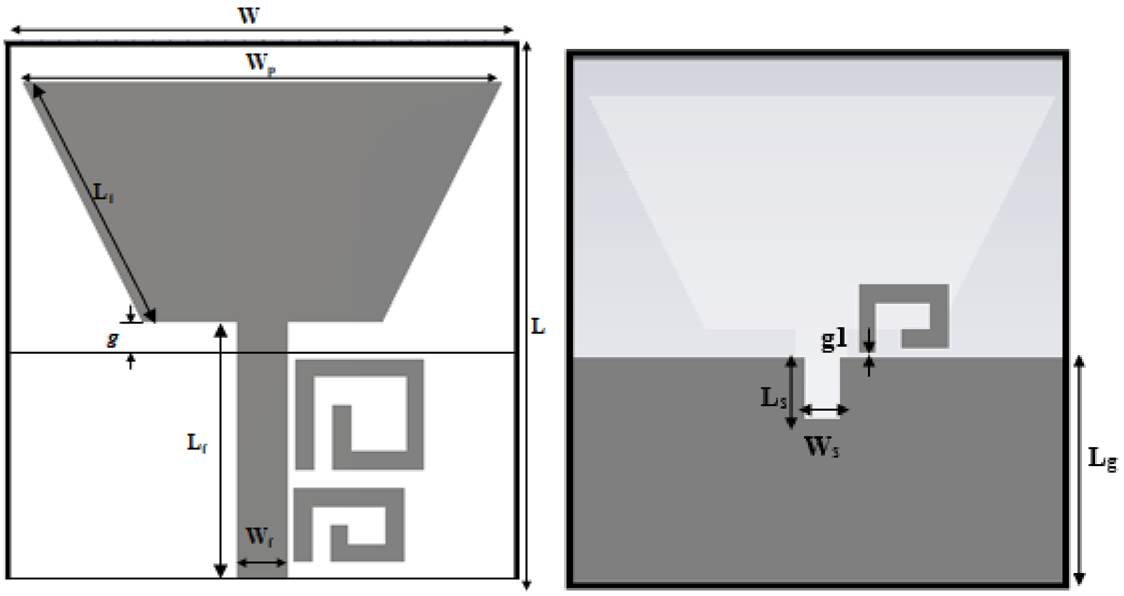
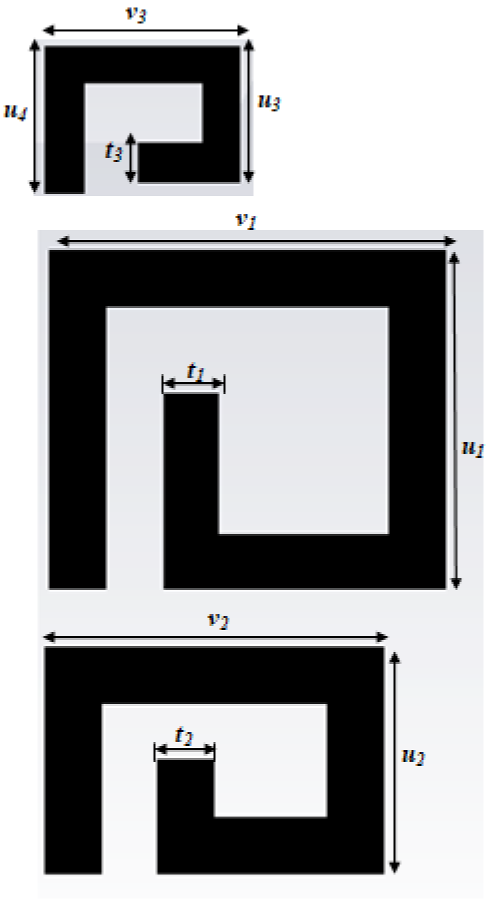


(a) (b)



(c)

Fig.1. Half hexagonal antenna (a) Front view (b) Back view(c) Spiral structures

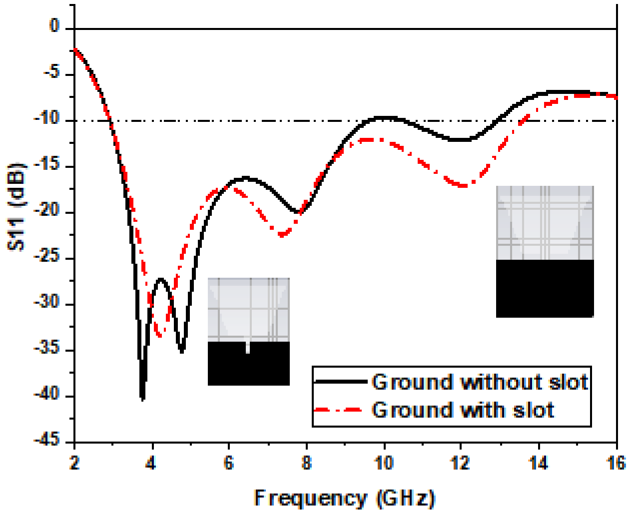
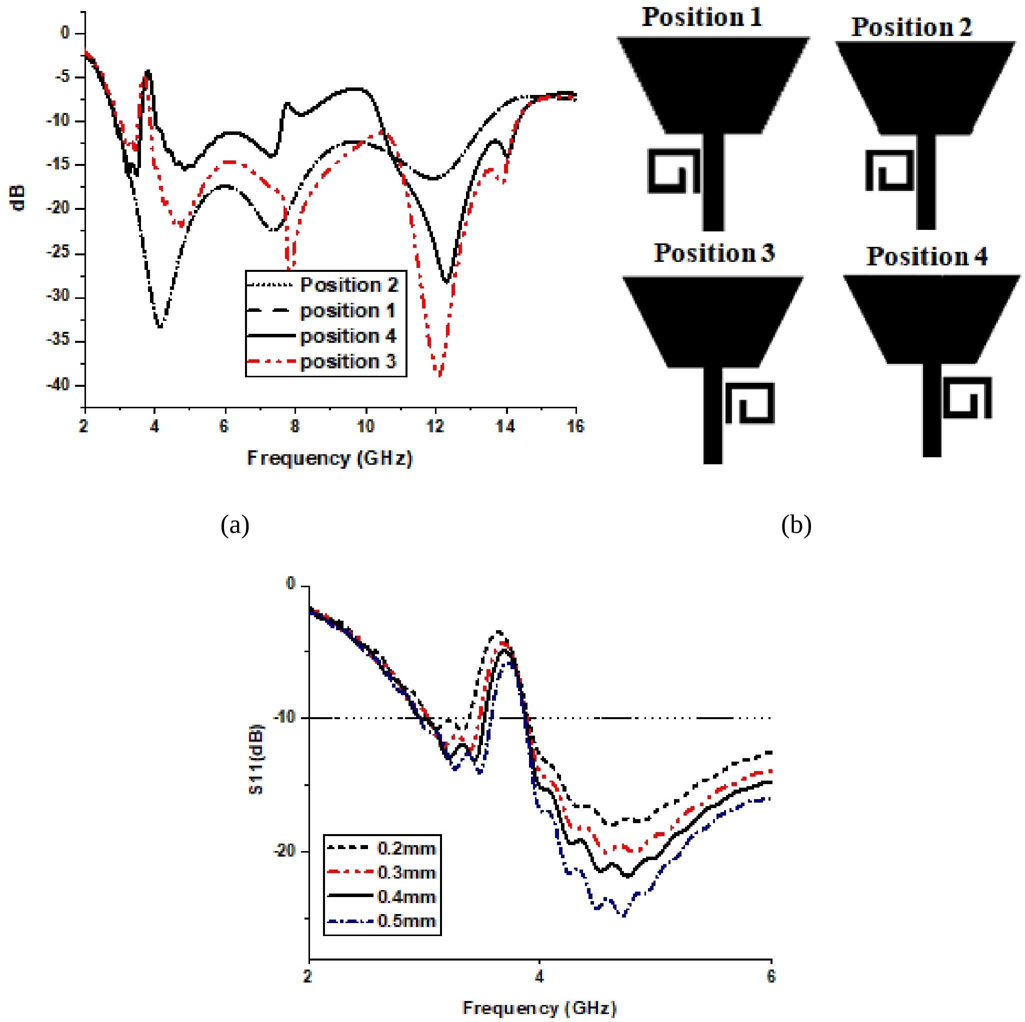


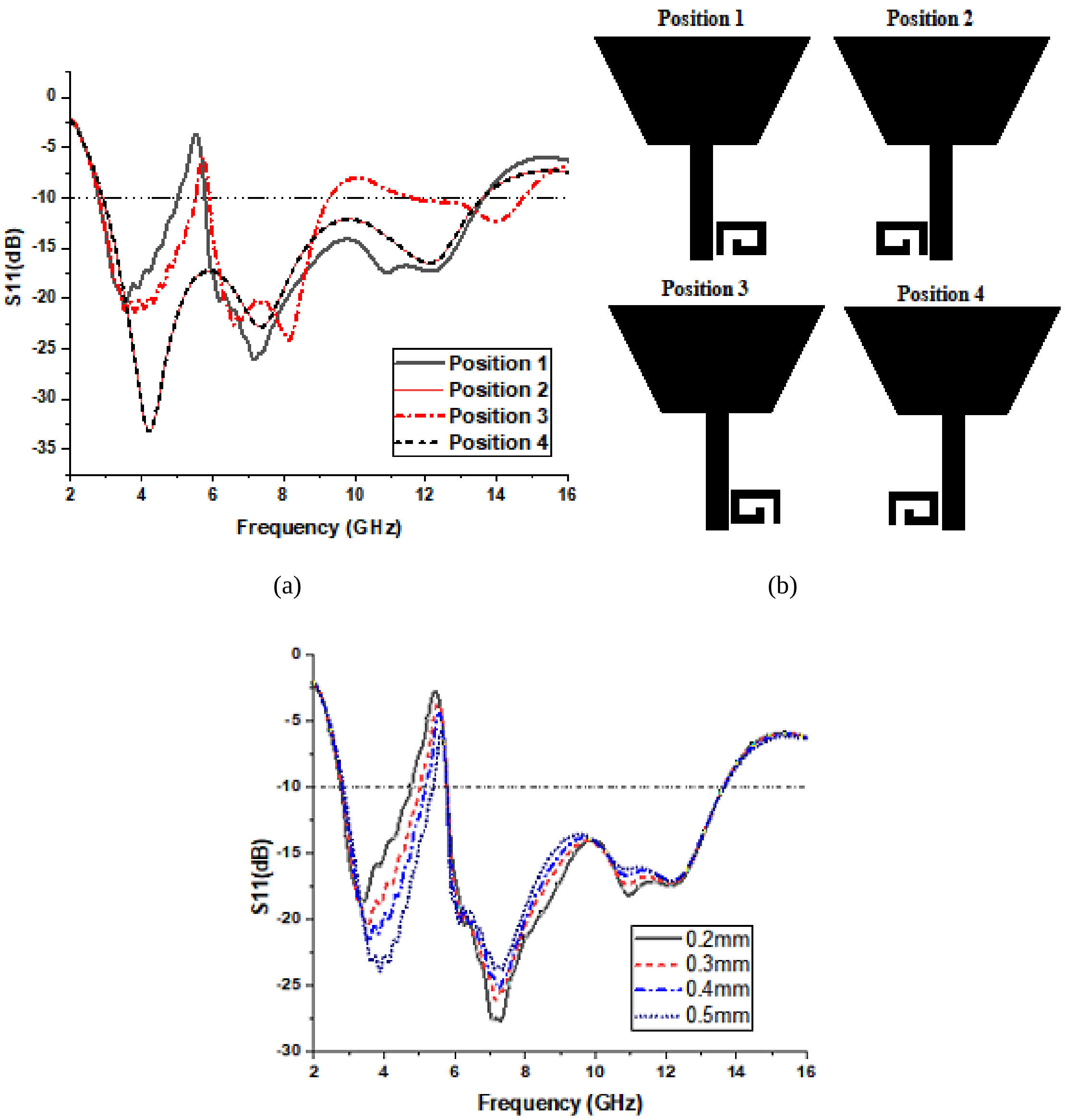
Fig.2. Simulated S_{11} (Return loss) plot for DGS and without DGS



(a) (b)

(c)

Fig.3. Simulated S_{11} for the parametric analysis of spiral 1(a) variation of S_{11} for the position of spiral 1(b) various positions of spiral1(c) variation of gap between feed and spiral 1

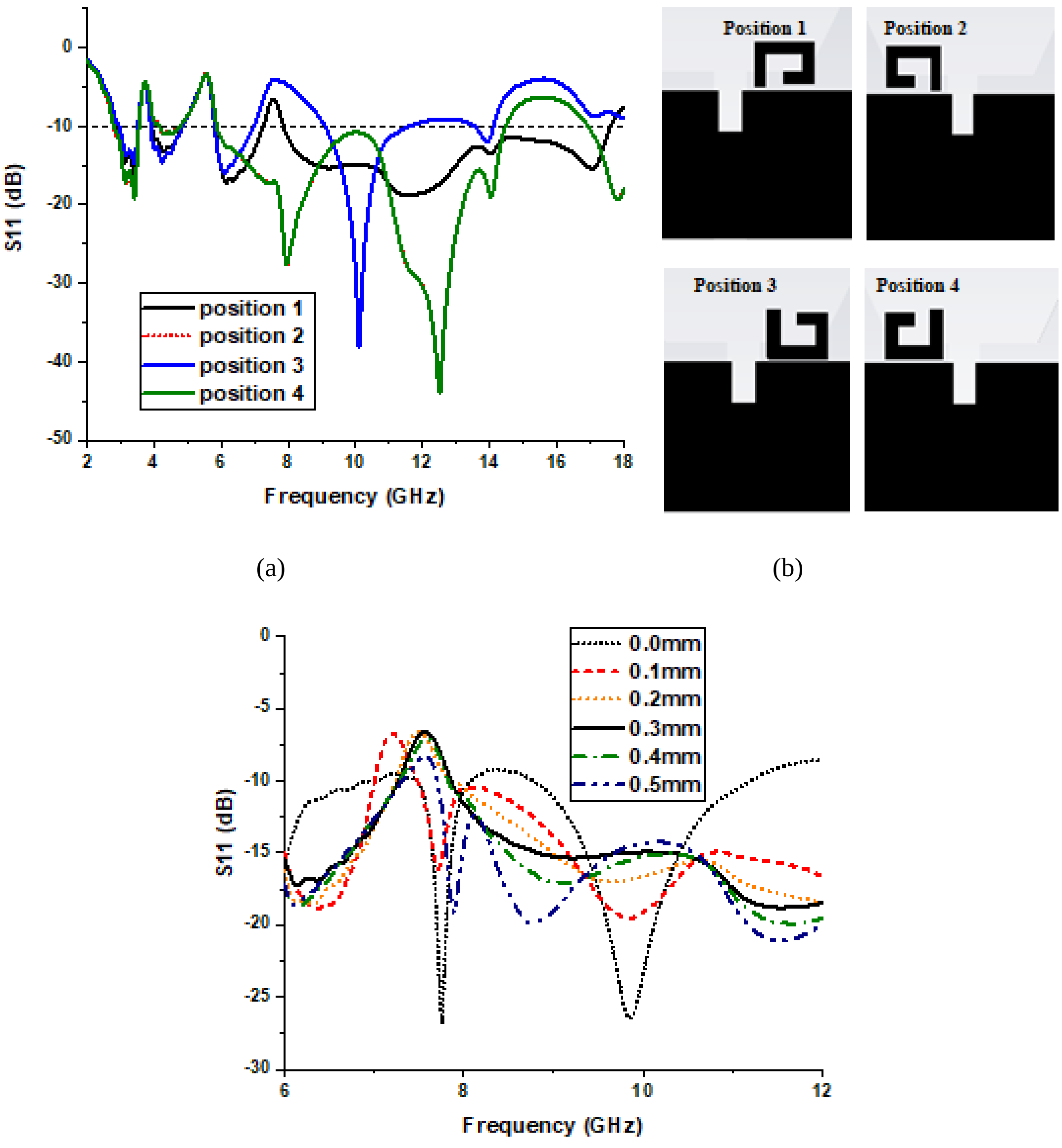


(a)

(b)

(c)

Fig.4. Simulated S11 for the parametric analysis of spiral 2(a) variation of S_{11} for the position of spiral 2(b) various positions of spiral 2(c) variation of gap between feed and spiral 2



(a)

(b)

(c)

Fig.5. Simulated S11 for the parametric analysis of spiral 3(a) variation of S_{11} for the various positions of spiral 3(b) various positions of spiral 3(c) variation of gap between ground and spiral 3

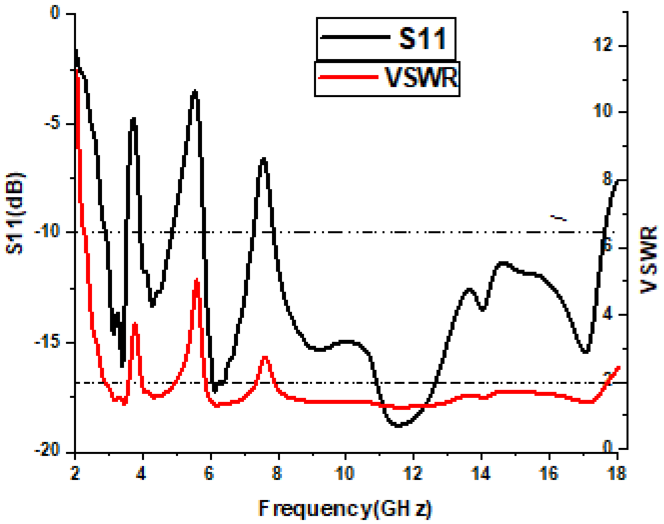


Fig.6. Simulated S11 and VSWR variation with frequency

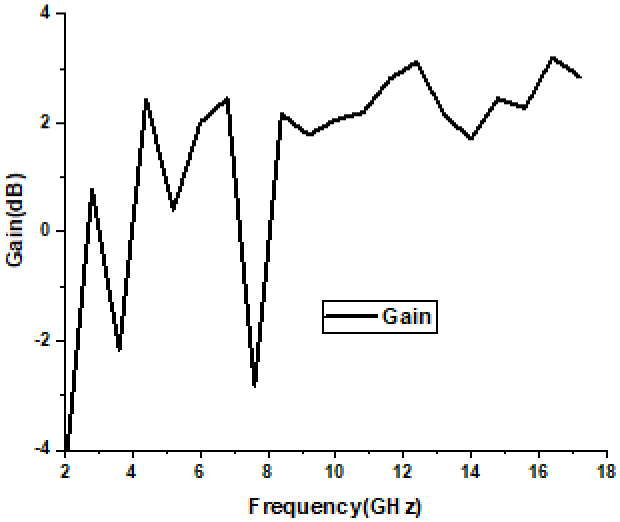


Fig.7. Simulated Gain variations with frequency

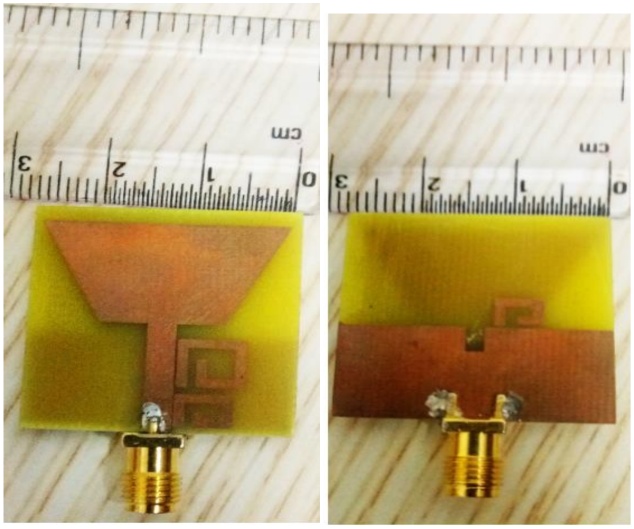


Fig.8. Front view and Back view of fabricated prototype

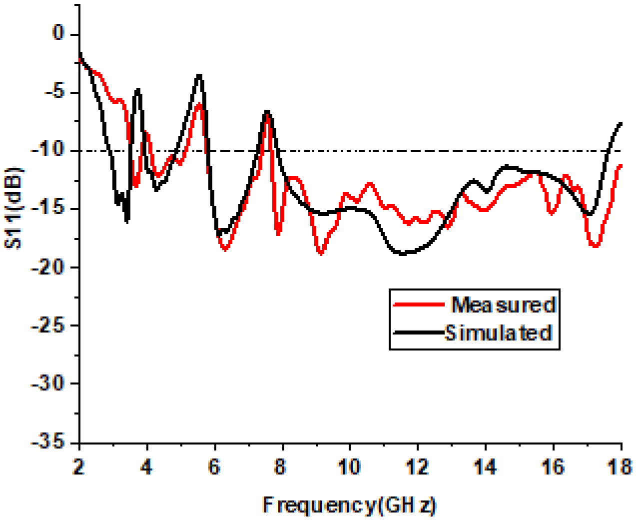
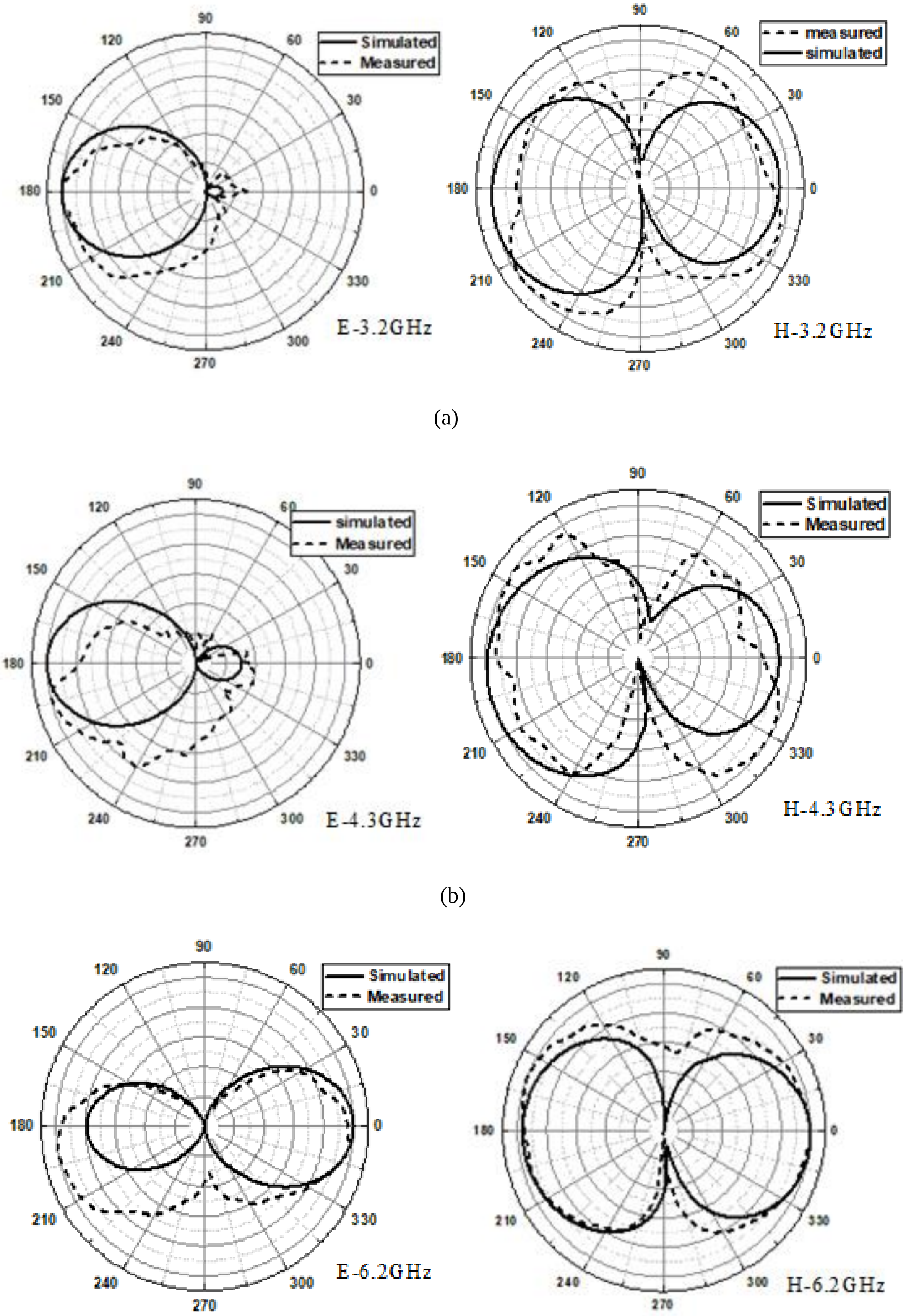


Fig.9. Simulated and measured return loss

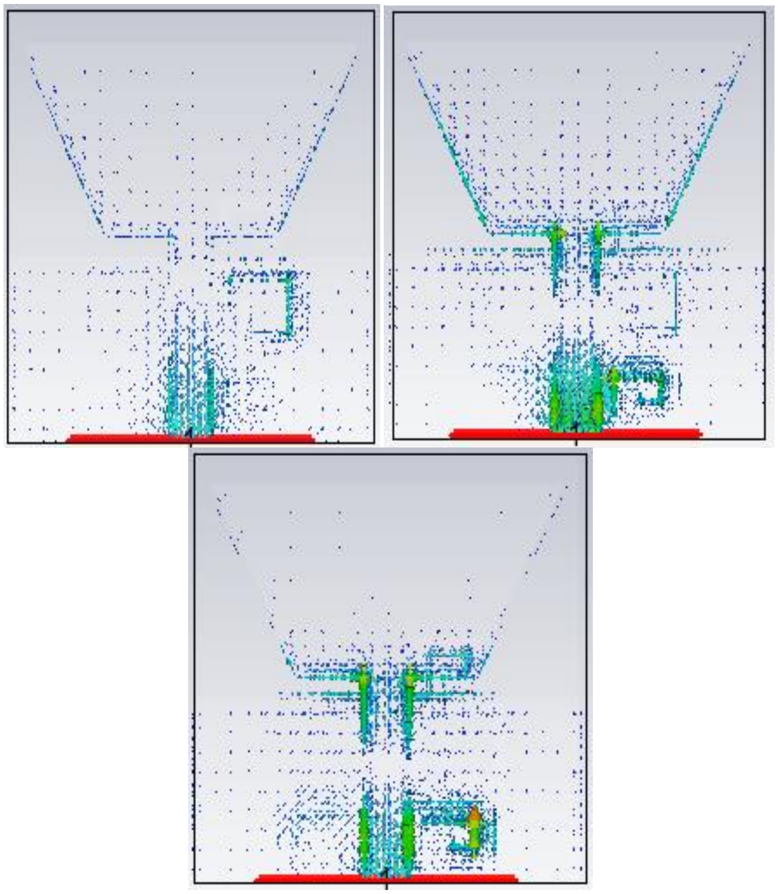


(a)

(b)

(c)

Fig.10. Radiation pattern at resonating frequenceies (a) 3.2GHz (b) 4.3GHz (c) 6.2GHz



(a) (b) (c)

Fig.11. Surface current distributions for resonating frequenceies (a) 3.2GHz (b) 4.3GHz (c) 6.2GHz

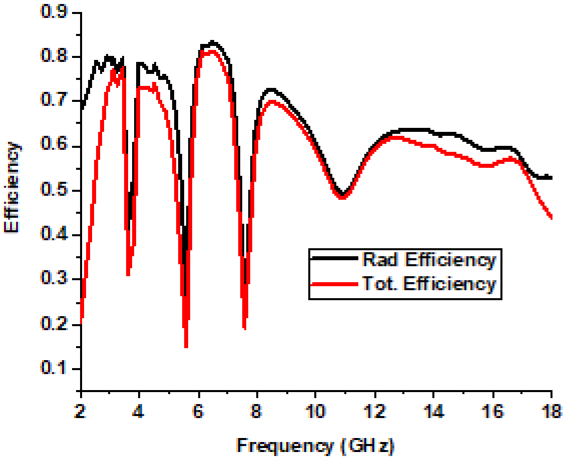


Fig. 12 Variation of total efficiency and Radiation efficiency

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Table 1.Optimised geometrical parameters of an antenna

Antenna parameter	**Values (mm)**	**Antenna parameter**	**Values (mm)**	**Antenna parameter**	**Values (mm)**
L	29	u_2	4	v_1	7
W	28	u_3	3.5	u_1	6
L_g	12.5	u_4	3.8	g_1	0.3
L_f	14	L_1	13	v_2	6
W_f	2.8	L_s	2.5	v_3	5
$t_1=t_2=t_3$	1	Ws	2	g	1.5
$Lout_1$(outer turn side length of spiral 1)	6	$Lout_2$ (outer turn side length of spiral 2)	4	$Lout_3$ (outer turn side length of spiral 3)	3.5
Sp_1(total length of resonating spiral 1)	24.28	Sp_2 (total length of resonating spiral 2)	20	Sp_3(total length of resonating spiral 3)	14.9

Table 2.Comparison of reported band notch antennas with proposed work.

Reference	**Size(mm^2)**	**No of notches**	**Substrate used**	**Bandwidth (GHz)**
[2]	18 × 20	5 GHz(WLAN)	FR4	3.12–10.73
[3]	22 × 26	3.8-4.28GHz(Wi MAX) 5.76-6.16(WLAN)	RT 5880	2.9-12
[4]	10 × 13	5 GHz(WLAN)	FR4	4.36-13.35
[5]	28 × 52	5.15 -6.17 (WLAN)	FR4	3.11 - 13.15
[6]	22 × 24	3.35–3.8GHz 5.12–5.84 GHz	FR4	3.2 - 10.9
[7]	38.5 × 46.4	5.0–5.5 GHz 7.2–7.6 GHz	Metamaterial based	2–12.5
[8]	39 × 35	5.5 GHz	RT/Duroid	3.1-10.6

			4003	
[9]	24 × 17	2.4 GHz Bluetooth 3.3–3.6GHzWiMAX 5.13–5.85GHz WLAN	RT Duroid 5880	
[10]	32 × 30	3.5GHz 5.5 GHz	FR 4	2.8-12GHz
[11]	26 × 36.6	5.15–5.85 GHz	FR 4	2.9-20 GHz
[13]	20 x 36	No notch	FR 4	2.27-7.53 GHz
[16]	32 × 24	5.2 GHz 8.2 GHz	Rogers RO3003	3.1-13
Proposed antenna	**28 x 29**	**3.6GHz** **5.5GHz** **7.54GHz**	**FR 4**	**3.2-18.00GHz**

Bibliographies

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