

# High Performance DGS Integrated Compact Antenna for 2.4/5.2/5.8 GHz WLAN Band

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**Abstract.** *An application specific tri-band hexagonal microstrip antenna with saw tooth shaped defected ground structure (DGS) is proposed. In this paper, a hexagonal microstrip antenna is designed for 5.2 GHz which is basically WLAN band (5.15–5.35 GHz). Now in this structure two defects are suitably incorporated and the positions are so optimized that two additional frequency bands 2.4 GHz, i.e. the Bluetooth band (2.4–2.48 GHz) and 5.8 GHz, i.e. the second WLAN band (5.725–5.825 GHz) are obtained. The fabricated prototype of the proposed antenna occupies an area 35 mm × 27.4 mm. Therefore, the structure has the characteristics of application specific multi band resonance. The variation of different parameters of the microstrip antenna is extensively studied. The proposed multiband microstrip antenna is functional simultaneously at three specific application band frequencies with approximately 84 % surface area reduction for the largest patch dimension corresponding to 2.4 GHz.*

## Keywords

Microstrip antenna, hexagonal patch, defected ground structure, compact antenna, tri band antenna

## 1. Introduction

With the increasing demands of integrating several communication standards in a single compact system the designing of microstrip antenna, one of the vital microwave components, with three or more operating frequencies is becoming very popular. The ISM bands 2.4, 5.2 and 5.8 GHz are widely used not only in the wireless local area networks but also for several wireless devices such as wireless printers, Bluetooth operated gadgets etc. The devices to be operated in these bands require multiband capability to comply with IEEE 802.11, 802.11a, 802.11b, 802.11g standards. Considering such ever increasing demands researchers have made several attempts to design compact microstrip antennas with high percentage of miniaturization for which different tech-

niques, such as cutting regular shaped slits, slots, defected ground structure etc, are used to achieve the desired compactness [1–4]. A perturbation effect in the microstrip antenna is observed due to these techniques for which the antenna can be operated at a lower application frequency band. Efforts are also made to design multiband microstrip antennas which are resonant at more than one application frequency bands simultaneously [5–10]. For example, L-shaped slot, rectangular slot and defected ground plane coupled patch antennas were proposed to achieve multiband characteristics [5]. Design for dual-frequency antennas was proposed [8], consisting of two radiating elements arranged in a stacked structure. A small and low-profile microstrip-fed monopole antenna for triple-frequency operation is proposed where the radiating element was modified by loading it with protrudent strips and feeding it with a cross-shaped stripline [9]. Although the above antennas have many advantages, there are still some performances to be improved. These antenna designs may increase cost or complexity for practical design implementation in [6] and [11], or the overall dimensions of antenna are large as in [2] and [11], [12] thus limiting their integration with the future wireless communication systems.

In the proposed paper, a compact tri-band hexagonal microstrip antenna is designed which is initially resonating at 5.2 GHz i.e. WLAN band. Then by the introduction of two saw tooth shaped defected ground structures, the hexagonal microstrip antenna is made to resonate simultaneously at 2.4 GHz i.e. the Bluetooth band and 5.8 GHz i.e. the second WLAN band, along with 5.2 GHz i.e. the first WLAN band. Thus, a compact hexagonal microstrip antenna with tri-band characteristics is achieved.

## 2. Design Principles

The dimension of the proposed microstrip hexagonal antenna is shown in Fig. 1. The antenna is printed on FR4 substrate of area 35 mm × 27.4 mm, thickness 0.8 mm with dielectric constant ( $\epsilon_r$ ) 4.4 and dielectric

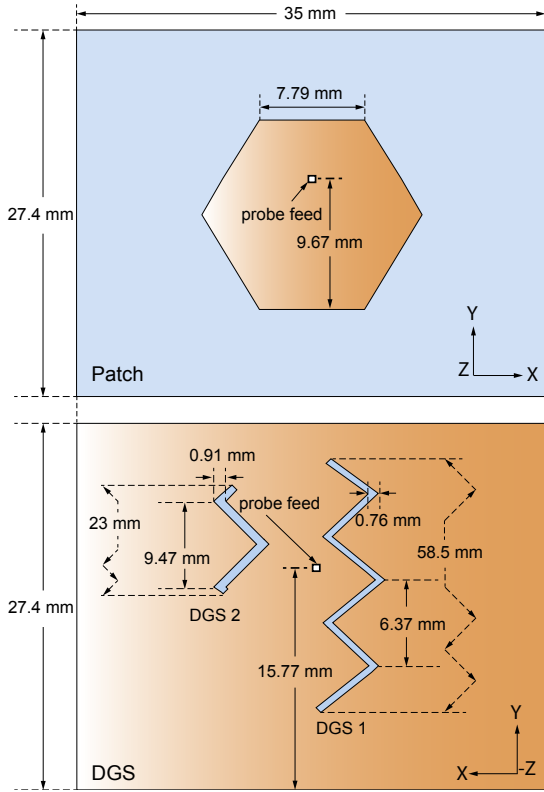


Fig. 1. Antenna layout with dimensions.

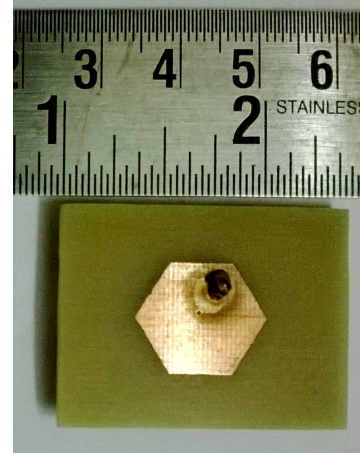
loss tangent ( $\tan \delta$ ) 0.002. Zeland IE3D software tool is used to simulate the proposed tri-band microstrip antenna.

Originally, the hexagonal microstrip antenna was designed to resonate at the WLAN band i.e. at 5.2 GHz (5.15 to 5.35 GHz). The resonance frequency formula of the hexagonal microstrip antenna was derived from the resonance frequency formula of the circular microstrip patch antenna by equating the respective areas [11]. The resonance frequency of the hexagonal microstrip antenna is given by

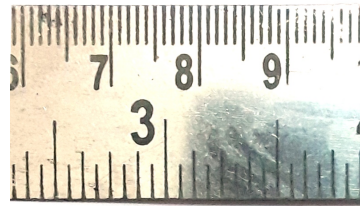
$$f_r = \frac{\chi_{mn}c}{5.7138s\sqrt{\epsilon_{r\text{eff}}}} \quad (1)$$

where  $\chi_{mn} = \chi_{11}$  (for  $TM_{11}$  mode) = 1.84118 and  $\epsilon_{r\text{eff}}$  is the effective dielectric constant of the substrate material.

The antenna is fed by a coaxial probe and the optimum position of the feed is determined using [13]. Then two saw tooth shaped defects are incorporated into the ground plane of the proposed microstrip antenna. The length of the defected ground structures (DGS) is taken to be  $\lambda_0/2$ , where  $\lambda_0$  is the free space wavelength at 2.4 and 5.8 GHz, respectively. The DGS are so positioned that the mutual coupling between the two defects is minimum. Saw tooth shaped DGS structures are used for achieving greater degree of miniaturization in the radiating patch surface area compared to straight slot lines in the same antenna configuration.



(a) Patch Plane.



(b) Ground Plane with DGS.

Fig. 2. Snapshots of the fabricated antenna.

It can be observed that with the integration of the DGS structures the hexagonal microstrip antenna is resonant at 2.4 GHz i.e. the Bluetooth band (2.4–2.48 GHz) and 5.8 GHz i.e. the second WLAN band (5.725–5.825 GHz), along with 5.2 GHz i.e. the first WLAN band (5.15 to 5.35 GHz). Thus, addition of DGS structures leads to antenna miniaturization and multiple resonances.

The final dimensions of the proposed antenna are shown in Fig. 1. The snapshots of the fabricated antenna are shown in Figures 2(a) and 2(b).

### 3. Results and Discussion

Figure 3 demonstrates both the simulated (with and without DGS) and measured  $S_{11}$  versus frequency plots of the proposed hexagonal microstrip antenna. It can be observed that the hexagonal microstrip antenna is found to be resonant simultaneously at 2.4 GHz (i.e. Bluetooth band) and 5.8 GHz (i.e. second WLAN band), along with 5.2 GHz (i.e. first WLAN band). The Bluetooth application band i.e. 2.4 GHz and the second WLAN Band i.e. 5.8 GHz are

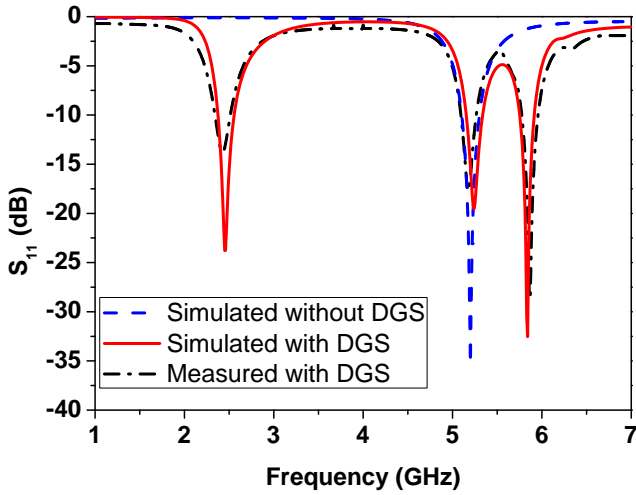
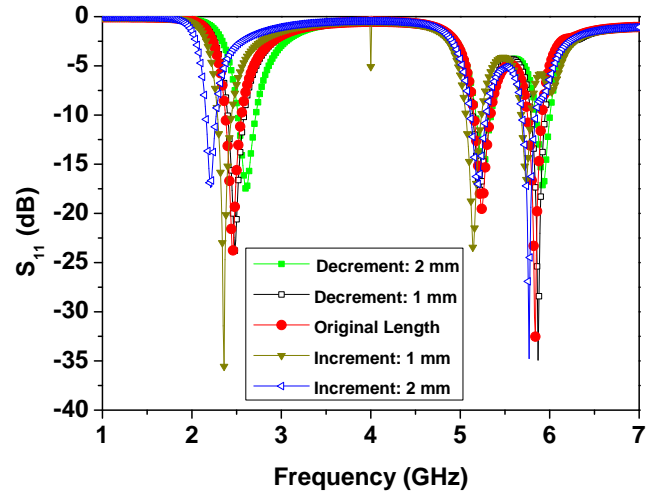
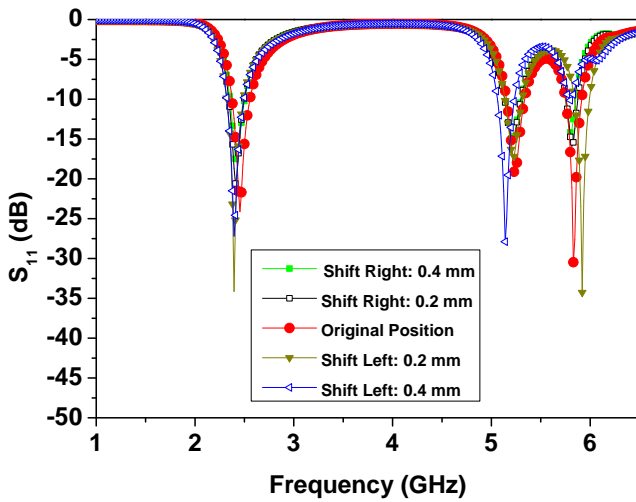


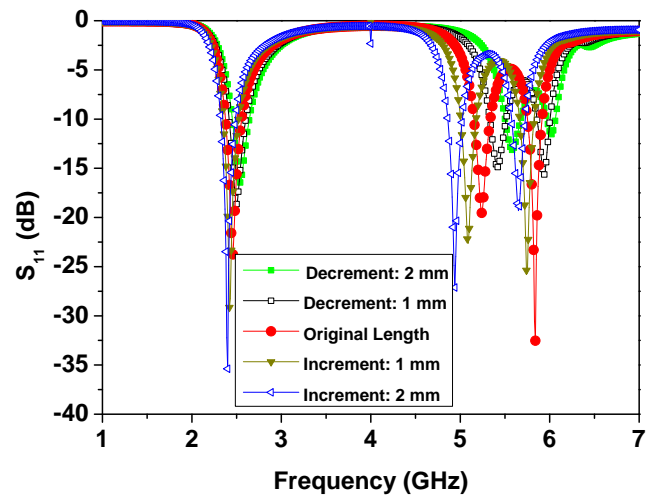
Fig. 3.  $S_{11}$  vs. frequency plot.



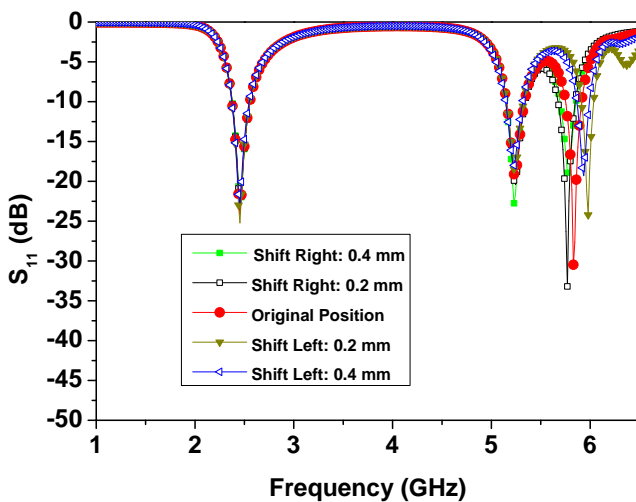
(a)



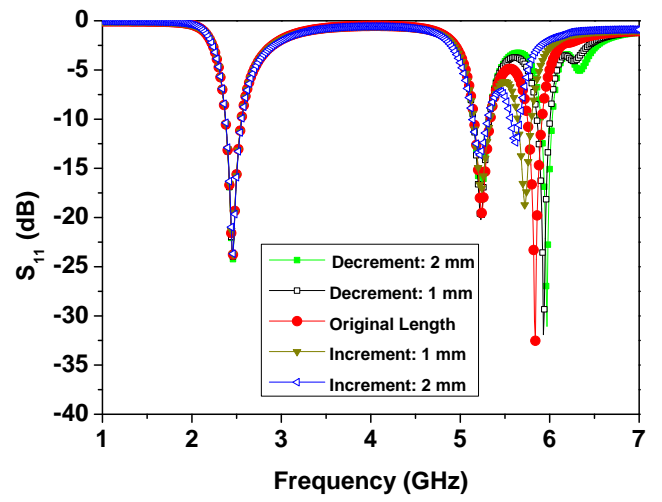
(a)



(b)



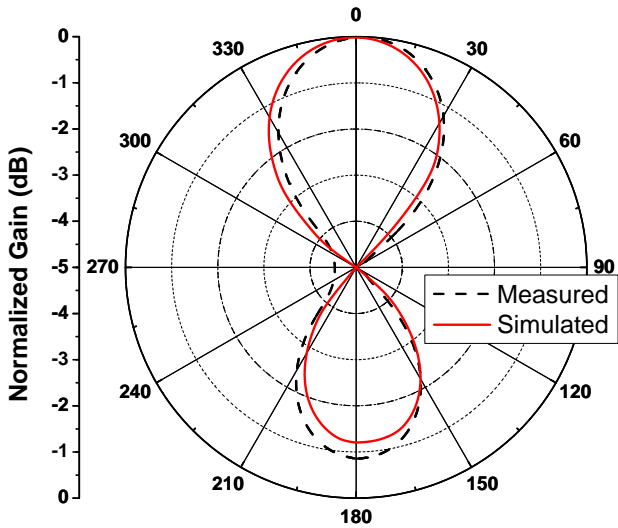
(b)



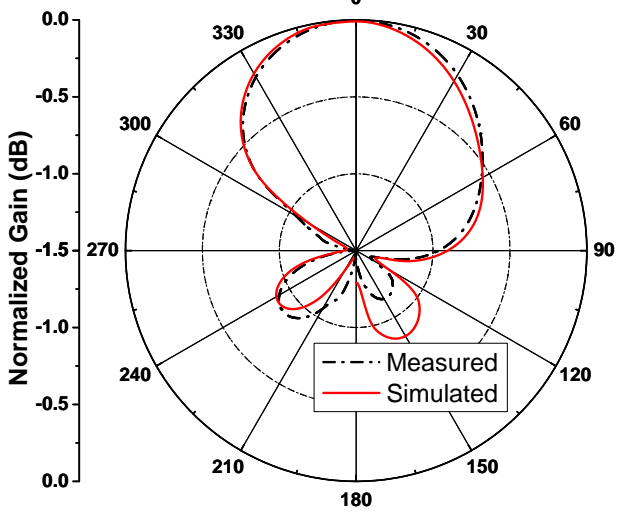
(c)

Fig. 4. Parametric variation of position of (a) DGS1 for 2.4 GHz, (b) DGS2 for 5.8 GHz.

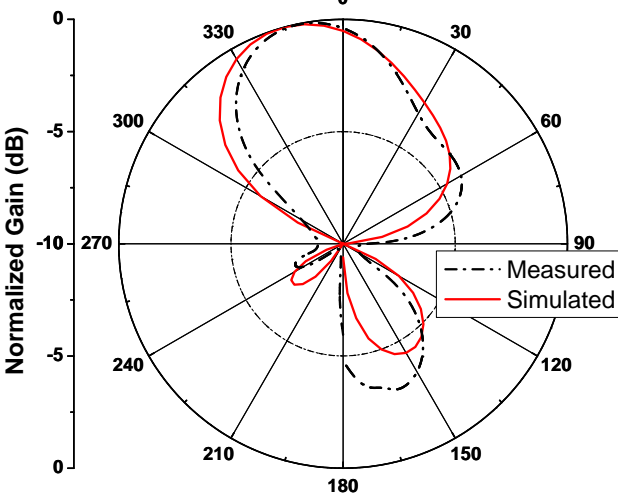
Fig. 5. Parametric variation of (a) length of DGS 1 for 2.4 GHz, (b) length of the hexagonal patch for 5.2 GHz, (c) length of DGS 2 for 5.8 GHz.



(a)

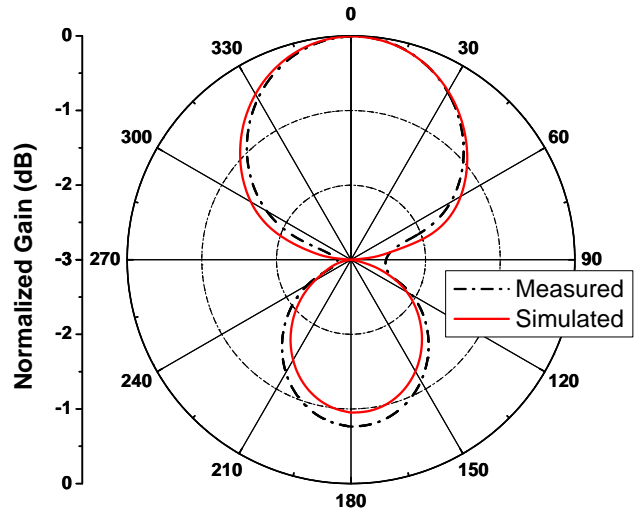


(b)

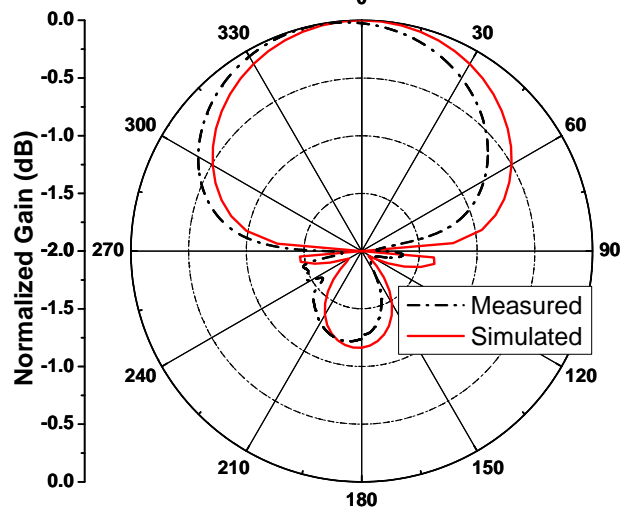


(c)

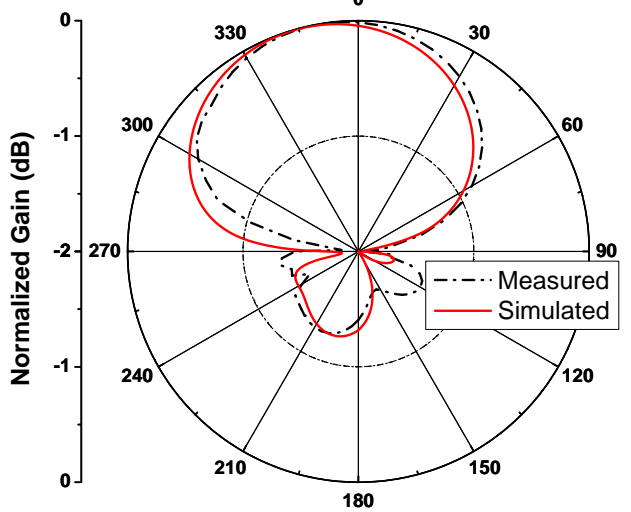
Fig. 6. Normalized E-plane radiation patterns for (a) 2.4 GHz, (b) 5.2 GHz, (c) 5.8 GHz.



(a)



(b)

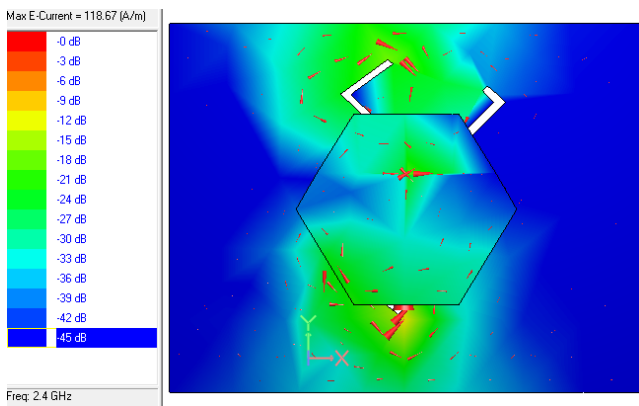


(c)

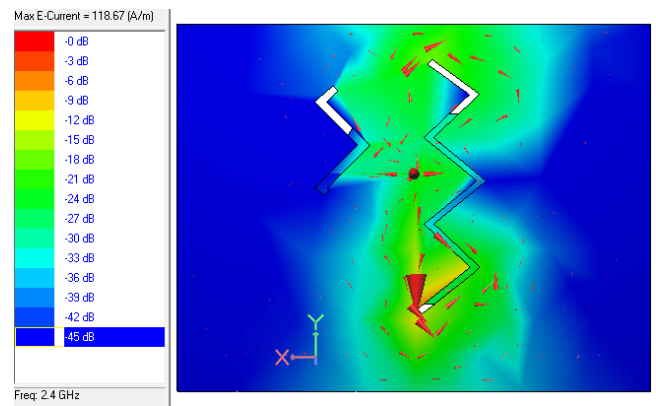
Fig. 7. Normalized H-plane radiation patterns for (a) 2.4 GHz, (b) 5.2 GHz, (c) 5.8 GHz.

Compared Antenna Structures	Frequency (GHz)	Antenna Size (mm <sup>2</sup> )	% Miniaturization	Gain (dBi)
[2]	0.93, 1.8, 2.45, 5.2	38 × 43	80	4.5–7.5
[6]	2.5, 3.5, 5.2, 5.8	25 × 38	Not Mentioned	2.36–3.62
[11]	1.575, 3.71, 5.9	75 × 75	75	5.5, 8 and 9
[12]	2.45, 3.5, 5.28	28 × 40	Not Mentioned	4.72, 6.2 and 3.8
Proposed Antenna	2.4, 5.2, 5.8	27.4 × 35	84	2.02, 5.9 and 4.14

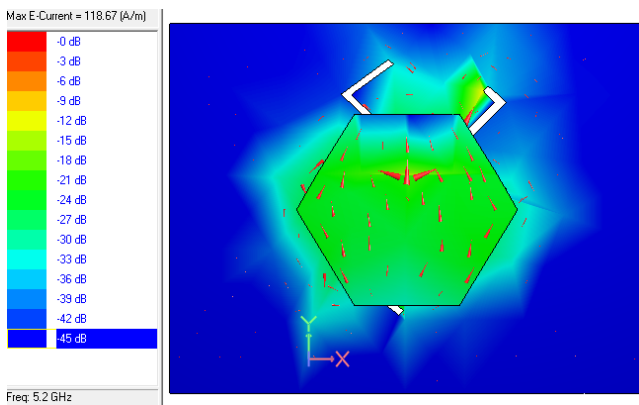
Tab. 1. Comparison of performance of the proposed antenna with some existing compact multiband antenna designs.



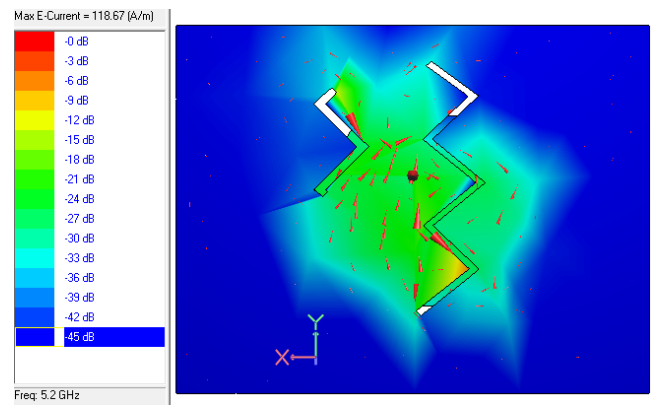
(a)



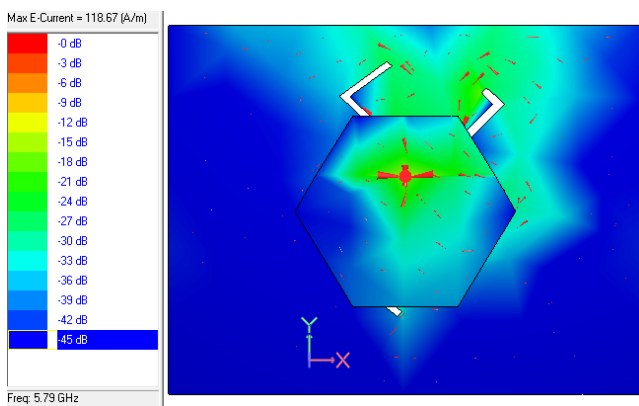
(a)



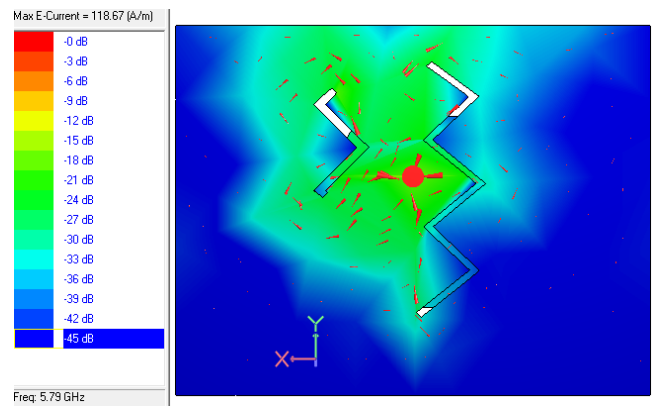
(b)



(b)



(c)



(c)

Fig. 8. Surface current distribution on the patch (a) 2.4 GHz, (b) 5.2 GHz, (c) 5.8 GHz.

Fig. 9. Surface current distribution on the ground plane (a) 2.4 GHz, (b) 5.2 GHz, (c) 5.8 GHz.

achieved by fine tuning the length of the DGS 1 and DGS 2 respectively, as shown in Fig. 1. It is seen that DGS1 and DGS2 behave as half-wavelength resonators at 2.4 GHz and 5.8 GHz, respectively.

The parametric variations for each of the bands (2.4 GHz band due to the length and position of DGS 1, 5.2 GHz band due to length of the hexagonal patch and 5.8 GHz band due to the length and position of DGS 2) are shown in Figures 4(a)–4(b) and Figures 5(a)–5(c). The parametric variations for each of the frequency bands due to the position of the DGS structures on either side of the coaxial feed are illustrated in Figures 4(a)–4(b). It is observed that on varying the position of DGS 1 leftwards the resonant frequency band 2.4 GHz shifts towards the lower frequency range. Likewise, changing the position of DGS 1 rightwards, the resonant frequency band 2.4 GHz drifts towards the higher frequency range. In both the cases, the first WLAN band 5.2 GHz and the second WLAN band 5.8 GHz remains unchanged with the shift in position of DGS 1. On varying the position of DGS 2 leftwards it is observed that the resonant frequency band 5.8 GHz drifts towards the higher frequency range. Similarly, on varying the position of DGS 2 rightwards, the resonant frequency of 5.8 GHz exhibits a tendency to drift towards the lower frequency range. In both the cases, the Bluetooth band of 2.4 GHz and first WLAN band of 5.2 GHz remains unaffected with the shift in position of DGS 2.

From the parametric study illustrated in Figures 5(a) and 5(c), it is observed that as the length of DGS 1 and DGS 2 is increased, the resonant frequency shifts towards the lower frequency range and as the length of DGS 1 and DGS 2 is decreased, it shifts towards the higher frequency range. Thus, greater degree of antenna miniaturization can be achieved by increasing the length of the DGS structures keeping all other antenna parameters constant. Also, using saw tooth shaped DGS structures the overall radiating surface area of the patch is reduced by 84% compared to that of a hexagonal patch antenna resonating at 2.4 GHz designed on the same substrate but without any DGS incorporated into its ground plane.

The parametric variation for the frequency band 5.2 GHz with length of the hexagonal patch is displayed in Fig. 5(b). It can be observed that the variations in the length of the hexagonal radiator has significant effect on the middle resonant frequency band at 5.2 GHz, minor effect on the higher resonant frequency band at 5.8 GHz and negligible effect on the lower resonant frequency band at 2.4 GHz. As the length of the hexagonal radiator is increased the resonant frequency shifts towards the lower frequency range.

It is also found from Figures 4(a)–4(b) and Figures 5(a)–5(c) that each parametric variation is having contribution in one of the resonating frequency bands without any significant variation in the other frequency bands. Addition of the two saw tooth shaped DGS structures has negligible effect on the resonant frequency band 5.2 GHz of the original

hexagonal patch antenna. Variations in the length and position of DGS structures results in significant variations in the two additional frequency bands 2.4 GHz and 5.8 GHz for DGS 1 and DGS 2, respectively.

From the theory of microstrip antenna it is known that the radiation pattern is normal to the surface of the patch. Thus, the normalized radiation patterns for  $\phi = 0^\circ$  and  $\phi = 90^\circ$  are as shown in Figures 6(a)–6(c) and Figures 7(a)–7(c), respectively. It is observed that the proposed antenna shows nearly bidirectional patterns both in the E-plane and the H-plane at three desired operating frequencies. The gain values are about 2.02 dBi at 2.4 GHz, 5.9 dBi at 5.2 GHz and 4.14 dBi at 5.8 GHz.

The comparative study of the performance characteristics of the proposed antenna with different existing compact multiband antenna designs [2], [6], [11], [12] is summarized in Tab. 1. It is observed that the proposed antenna achieves greater miniaturization compared to other existing structures with considerably small overall antenna size and acceptable gain.

## 4. Observation of Current Distribution

The operation mechanism of the proposed multiband can be explained with the help of simulated current distribution as shown in Fig. 8 and Fig. 9. Figures 8(a) and 9(a) together show that for the lowest frequency band (2.4 GHz) the current vectors are essentially concentrated along DGS 1 and the patch. Again it can be observed from Fig. 8(b) and Fig. 9(b) that for the middle frequency band (5.2 GHz) a large number of current vectors is concentrated on the radiator. Figures 8(c) and 9(c). 8(c) portray that for the highest frequency band (5.8 GHz) the current vectors are essentially concentrated along DGS 2 and the patch.

## 5. Conclusion

In this paper, a tri-band antenna has been proposed, prototyped and analyzed. The multiband operation of the proposed antenna is achieved using two saw tooth shaped defects in the ground plane of the hexagonal patch antenna. The primary reason for making the DGS slots saw tooth shaped is to accommodate the resonator length of 58.5 mm for 2.4 GHz within the ground plane area of 35 mm  $\times$  27.4 mm. The antenna shows satisfactory radiation performance with acceptable gain over each of the desired frequency bands and appreciable antenna surface area miniaturization of 84% for the largest resonating length corresponding to the lowest resonating frequency 2.4 GHz. Therefore, it is a good candidate for the proposed multiband application.

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