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Frequency reconfigurable monopole antenna with DGS for ISM band applications

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In this article a compact frequency reconfigurable antenna is presented for wireless communication applications of industrial, scientific and medical band (ISM). The proposed antenna model is designed with the dimensions of 58 mm × 48 mm on FR4 epoxy of dielectric constant 4.4 with the thickness of 0.8 mm. The proposed antenna consists of defected T-shape ground plane, which acts as a reflector. In the design of frequency reconfigurable antenna, BAR 64-02V PIN diodes are used as switching elements and antenna is fed by microstrip transmission line. The proposed antenna can switch at different frequencies (2.5 GHz, 2.3 GHz and 2.2 GHz) depending on the biasing voltage applied to the PIN diodes. The current antenna showing VSWR < 2 in the operating band and providing peak realized gain of 3.2 dBi. A good matching obtained between expected and the measured results.

Keywords: defected ground structure(DGS), frequency reconfigurability, ISM band, PIN diode

1 Introduction

Wireless communication is a way to exchange of data from one place to another place through air medium. Antennas play an exceeding appearance in wireless communications. Various types of antennas and various approaches are used in wireless communications for proficient and protected communications. By the rapid variations of wireless communications, there has been a strong significance in reconfigurable antennas due their effectiveness of various functionalities [1]. Reconfigurable antennas are capable to adopt peculiar frequency and radiation description in a controlled process. The reconfiguration in antennas are inclined to enlarge the antenna performance in various states of events or to satisfy dynamical and efficient requirements. Basically, the reconfigurable antennas can change their fundamental resonating frequencies through electrical, mechanical and by other means. Reconfigurable antennas are divided as frequency, pattern, polarization and bandwidth based on their functions. Reconfigurable antennas have been considered since last few years for various applications like a reconfigurable antenna was designed for wireless and space applications [2]. To produce the reconfigurability, planar inverted-F resonator UWB antenna is suggested in [3].

Earlier frequency reconfigurable antenna designs have been proposed to obtain large tuning ranges by using various antenna topologies and tuning elements. In [4], an electrically small PIFA-based design using switches was proposed to obtain continuous large tuning ranges. A different PIFA-based and slot antenna topologies have been used to obtain continuous wide tuning ranges [5, 6]. From last five years, the special target of the frequency reconfigurable antennas (FRAs) has been on narrow band frequency tuning [7]. Many peculiar methods and architectures has been applied to build frequency reconfigurable antennas. Extensive efforts are presently advancing to develop multi radio mobile platforms like mobile internet devices, laptops and smart phones, to locate various wireless services diffused over a wide frequency range.

One way to achieve the reconfigurable features is to vary the surface current distribution with altering the comparable regional structure. By varying the efficient radiated electrical length, feeding position electrically researchers switching the radiating factors [8]. Another approach to achieve reconfigurability is to make use of phased array structure antenna [9]. Array antennas are possessed with many metallic patches, interconnected with MEMs actuators were suggested in [10]. Varactor diodes limiting the frequency switching range so, PIN diodes are preferred by many researchers because these diodes have the acceptable performance at low cost, simple and ease of fabrication. L-shaped slots of frequency reconfigurable antennas using PIN diodes was proposed in [11]. To achieve frequency reconfigurability a triple H-shaped multiple band patch antenna was presented in [12]. Recently the approach of DGS has been developed to upgrade the features of many microwave devices. DGS is implemented in microstrip antennas to attain benefits like mutual coupling reduction and antenna size reduction *etc* [13]. A coplanar waveguide fed, frequency reconfigurable DGS antenna has been developed in [14]. By using switchable slotted ground structure, a frequency reconfigurable monopole antenna has been presented in [15].

Table 1 shows the comparative analysis of the proposed antenna with the literature. As per the dimension is concerned, the designed antenna occupying compact

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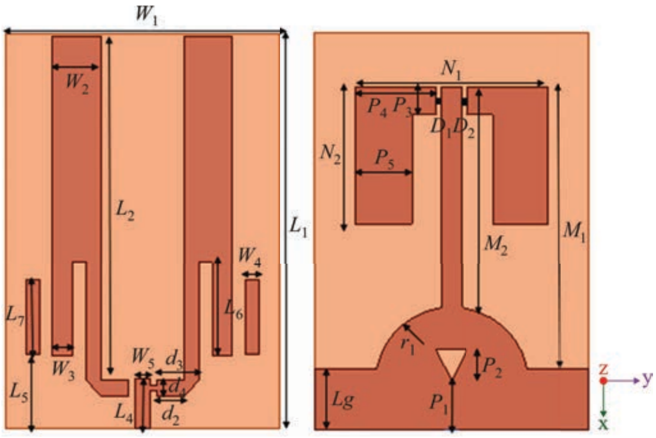

Fig. 1. (a) – front view of antenna, (b) – back view of the antenna

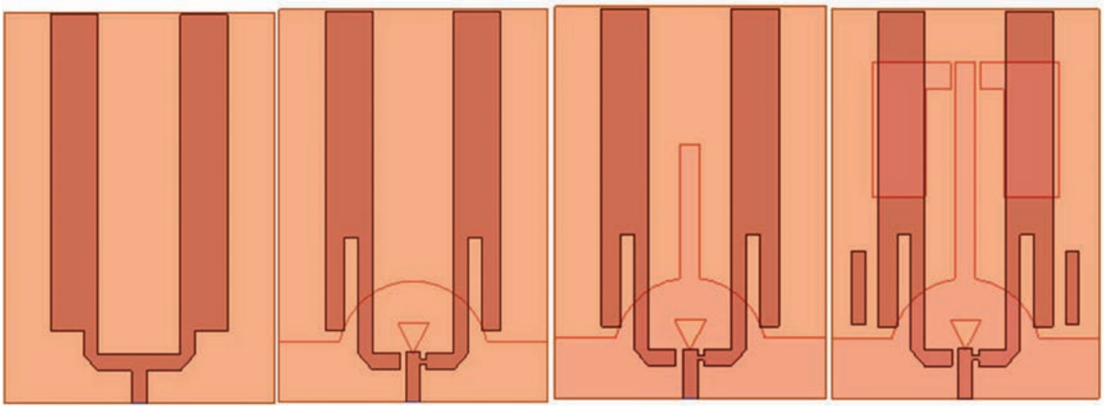

Fig. 2. Iterations of the proposed antenna: (a) – iteration 1, (b) – iteration 2, (c) – iteration 3, (d) – proposed antenna

Table 1. Reference antennas comparison with proposed antenna

Reference	Shape of the antenna	Size (mm)	Frequency range (GHz)	Applications
[7]	Bent half wave dipole	120×65	1.5, 1.44	wide tunable range
[9]	Antenna array	95×60	2.05–2.18	Mobile terminals
[11]	Inverted L-shape microstrip	50×46	2.2–4.75	WiMAX and base station
[12]	H-shapes patch antenna	43×50	0.5–2.5	ISM, GSM
Proposed	U-shaped patch with T-shaped ground plane	58×40	2.2, 2.3 & 2.5	Bluetooth, WLAN, ISM

size and suitable for applications like Bluetooth, WLAN lower band and ISM band.

In this paper, a novel frequency reconfigurable antenna with DGS is presented. The DGS increases the bandwidth of the antenna and it introduces slow wave effect. DGS will increase the electrical length of the antenna and which helps to reduce the resonant frequency and therefore antenna miniaturization is possible. The designed antenna is efficient of switching at multiple frequency bands around 2.5 GHz, which can be used in the systems of industrial, scientific and medical applications, and Bluetooth.

A brief report of design and analysis of proposed reconfigurable antenna is followed by simulation and measured results of proposed antenna parameters return loss, gain, radiation patterns, electric field distributions and surface current distribution.

2 Antenna design

Generally, antenna should be compact in nature for present wireless communication systems, to reduce the weight of the devices. The proposed frequency reconfigurable antenna shown in Fig. 1 consisting of dimensions length (L_1) and width (W_1) are 58 mm × 48 mm. The antenna is fabricated on FR4 epoxy substrate with dielectric constant 4.4 and loss tangent 0.02. The pro-

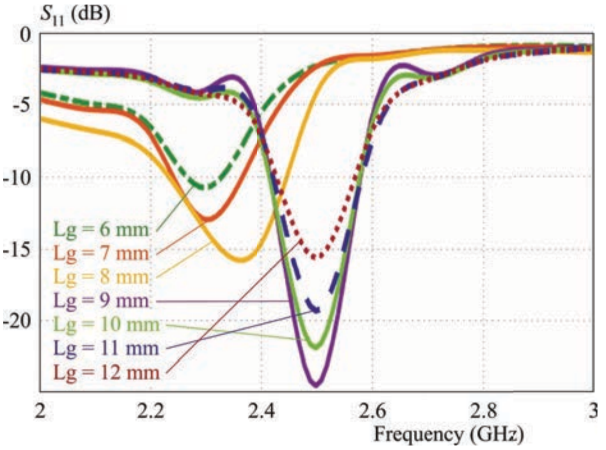

Fig. 3. Simulated parametric analysis by changing the ground length L_g

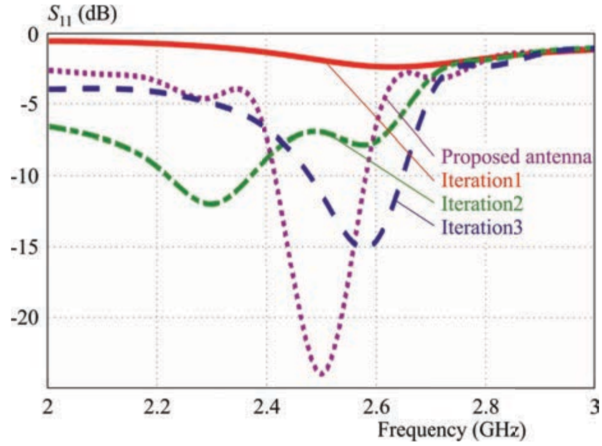

Fig. 4. Simulated return loss of iteration1 to proposed antenna

Table 2. Dimensions of the proposed antenna

Parameter	Size (mm)	Parameter	Size (mm)
L_1	58	d_2	4.1
L_2	50.5	d_3	5
L_g	9	d_4	2.5
L_4	7.3	M_1	41
L_5	11	r_1	5
L_6	13.7	P_3	4
L_7	11	N_1	28
W_2	7	N_2	20
W_3	2.9	P_5	8
W_4	2	P_1	7.2
W_5	2.2	P_2	4.5
P_4	11.8	W_1	48
M_2	32.2	h	0.8

posed frequency reconfigurable antenna has one microstrip transmission line, two parallelly loaded symmetrical radiators, one T-shaped ground plane and two rectangle parasitic elements on either side of the radiating patch. These two parasitic radiators relate to the two diodes D1 and D2 and this connection of the diodes can be observed from Fig. 1. The diode switching will make the connection between these two strips to the radiating patch.

Figure 2 presents the iterations of the antenna and Fig. 2(a) shows the radiating patch element with length ($L_2 = 50.5$ mm) and the width ($W_2 = 7$ mm). The proposed antenna can switch with reconfigurable frequency bands, by controlling the states at different switching conditions at the ground plane. The microwave transmission line is preferable to reduce the distortion in signal routing and high cross talk in high speed digital PCB designs. To improve impedance matching, rectangular stubs are used. In Fig. 2(b), represents the DGS of the proposed antenna. DGS has been used to improve attributes of several microwave devices. And, to increase the bandwidth of the signal. The size of the proposed antenna and mutual coupling is reduced by using DGS. On back view of the proposed antenna there is a semi circle structure, which acts as an impedance transformer between 'M2' and 'Lg' as shown in Fig. 2(b). The T-shape defected ground plane is used, and triangular slot is made on the ground structure. The dimensions of the antenna are presented in Table 2. In the iteration 3 of the antenna, a rectangular stub is added in the ground plane and attached to semi-circular ground. In the proposed antenna parasitic elements are added on either side of the rectangular stub in the ground plane. The parasitic elements are non-radiating and are connected through pin diodes and by making the pin diodes in ON/OFF conditions, the parasitic elements are connected and disconnected based on the conditions, this resulting the shift in the frequency.

The length of the patch antenna is calculated by using the formula [16]

$$L_2 = \frac{1}{2f_r\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{1}$$

where $f_{\rm r}$ is the resonant frequency, $\varepsilon_{\rm r}$ is the dielectric constant of the material, ε_0 is the permittivity of free space and μ_0 is the permeability of the free space.

$$\Delta L = 0.412\frac{\big(\varepsilon_{\rm ref}+0.3\big)\big(\frac{w_1}{h}+0.264\big)}{\big(\varepsilon_{\rm ref}-0.258\big)\big(\frac{w_1}{h}+0.8\big)} \tag{2}$$

where

$$\varepsilon_{\rm ref} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\Big(1+12\frac{h}{w_1}\Big) \tag{3}$$

and h is the height of the substrate.

Figure 3 shows the parametric analysis of the antenna with change in ground length Lg . To understand some of the critical parameters that influence the return loss curves, the parametric analysis is done. The ground plane length is varied from 9 mm to 12 mm. By varying the length of the ground plane, the optimized parameter of 9 mm is finalized for prototyping.

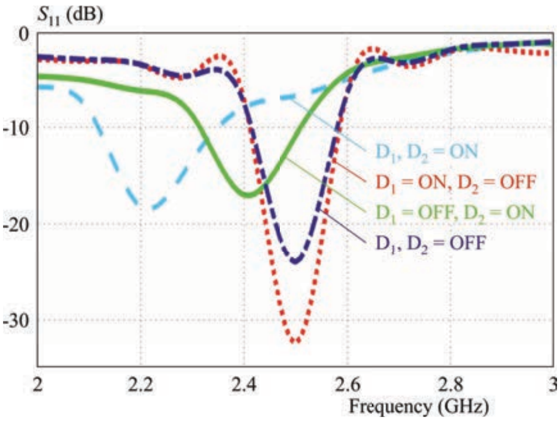

Fig. 5. Simulated reconfigurable condition of the proposed antenna

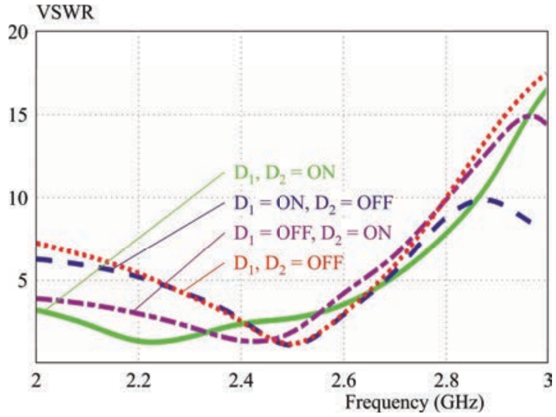

Fig. 6. Simulated VSWR of the antenna at different switching condition

Table 3. Resonant frequencies f_R, frequency range Δf (in GHz) and gain (in dB) for four cases

Case	D1	D2	f_R	Δf	gain
1	0	0	2.5	2.4-2.58	3.2
2	0	1	2.3	2.30-2.5	3
3	1	0	2.5	2.4-2.58	2.9
4	1	1	2.2	2.11-2.35	3.1

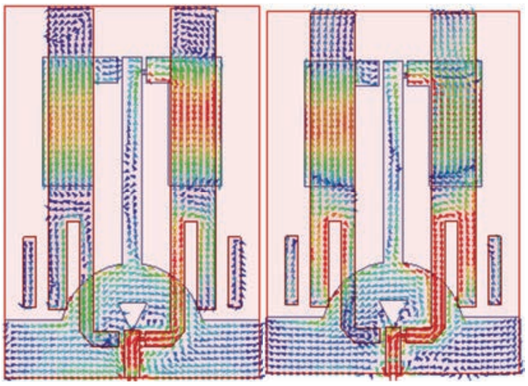

Fig. 7. Simulated surface current distribution of the proposed antenna: (a) – 2.5 GHz (D1 & D2 OFF), (b) – 2.3 GHz (D1 OFF & D2 ON), (c) – 2.2 GHz (D1 & D2 ON)

3 Results and discussion

The resolution of designed frequency reconfigurable antenna with DGS in terms of return loss, radiation pattern, input impedance, surface current distribution, and gain is presented by using electromagnetic simulation software HFSS. The four iterations reflection coefficient results of the antenna are presented in Fig. 4. In the first iteration antenna does not show any resonant frequency. In the second iteration the antenna resonates at the single band and operates at the 2.3 GHz and shows the return loss of −11.8 dB. In this case the antenna is modified by semicircular ground with triangular slot. Further in the next iteration it is modified by placing the stub on the ground structure and for this case the antenna resonating at the 2.5 GHz. At this point antenna showing the minimum return loss of −14.2 dB and this antenna is further modified with the stubs to form inverted T-shaped ground. The antenna resonates at 2.5 GHz and shows the minimum return loss of −24.2 dB with band covering for 2.42–2.58 GHz.

To achieve the reconfigurability, two BAR 64-02V PIN diodes are placed in the ground structure. By placing the diodes on either side of the ground structure, four switching conditions are studied as shown in the Fig. 5. When the both diodes D1 and D2 are in OFF condition, the antenna resonates at 2.5 GHz. when the diode D1 is OFF and diode D2 is ON, the antenna resonates at 2.3 GHz. When both the diodes D1 and D2 are in ON condition, the antenna resonates at 2.2 GHz, which is presented in Table 3. Figure 6 shows the VSWR of the antenna, which is less than 2 at resonating frequencies based on different switching conditions.

The surface current distribution of the proposed antenna with diodes switching conditions are presented in Fig. 7. The distribution of the radiating elements with respect to the diodes ON and OFF conditions are analyzed from Fig. 7(a) which represents the current distribution of the proposed antenna at 2.5 GHz when the all diodes are in OFF condition and observed that the maximum current is distributed along the feed line. Fig. 7(b) shows current distribution of the antenna when the diodes D1 in OFF and D2 in ON condition and the distribution is maximum along the right-side radiating element. Figure 7(c) shows the surface current distribution of the proposed antenna when the diode D1 & D2 in ON condition at 2.2 GHz and the maximum intensity is observed at the radiating patch elements middle portion.

The antenna efficiency depends on the parameter gain. The gain of the proposed antenna with diodes switching conditions are presented in Fig 8. In Fig. 8(a) shows that the gain of the proposed antenna when all diodes are in OFF condition. The gain of the proposed antenna is 3.2 dBi at resonant frequency 2.5 GHz. Figure 8(b) shows the gain of the proposed antenna when the diodes D1 in

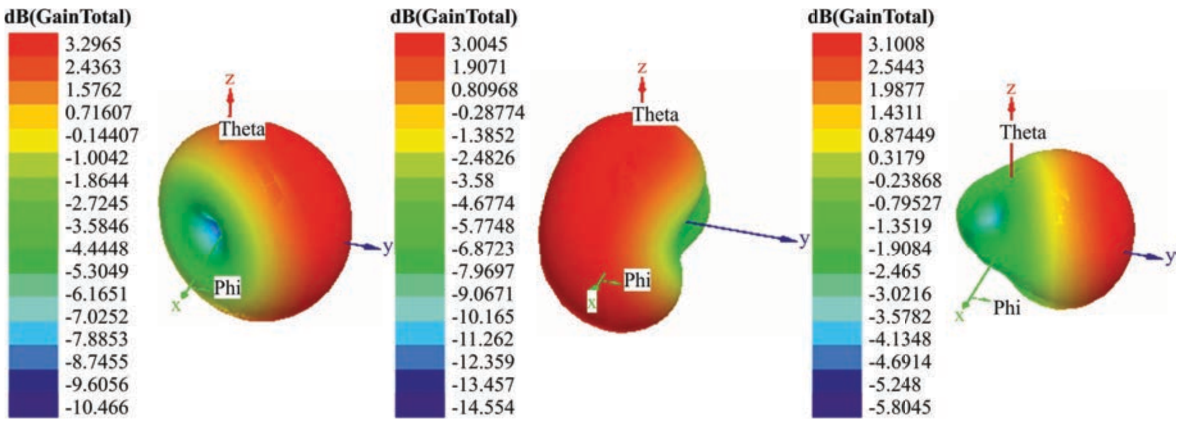

Fig. 8. Simulated 3D-gain of the proposed antenna: (a) – 2.5 GHz (D1 & D2 OFF), (b) – 2.3 GHz (D1 OFF & D2 ON), (c) – 2.2 GHz (D1 & D2 ON)

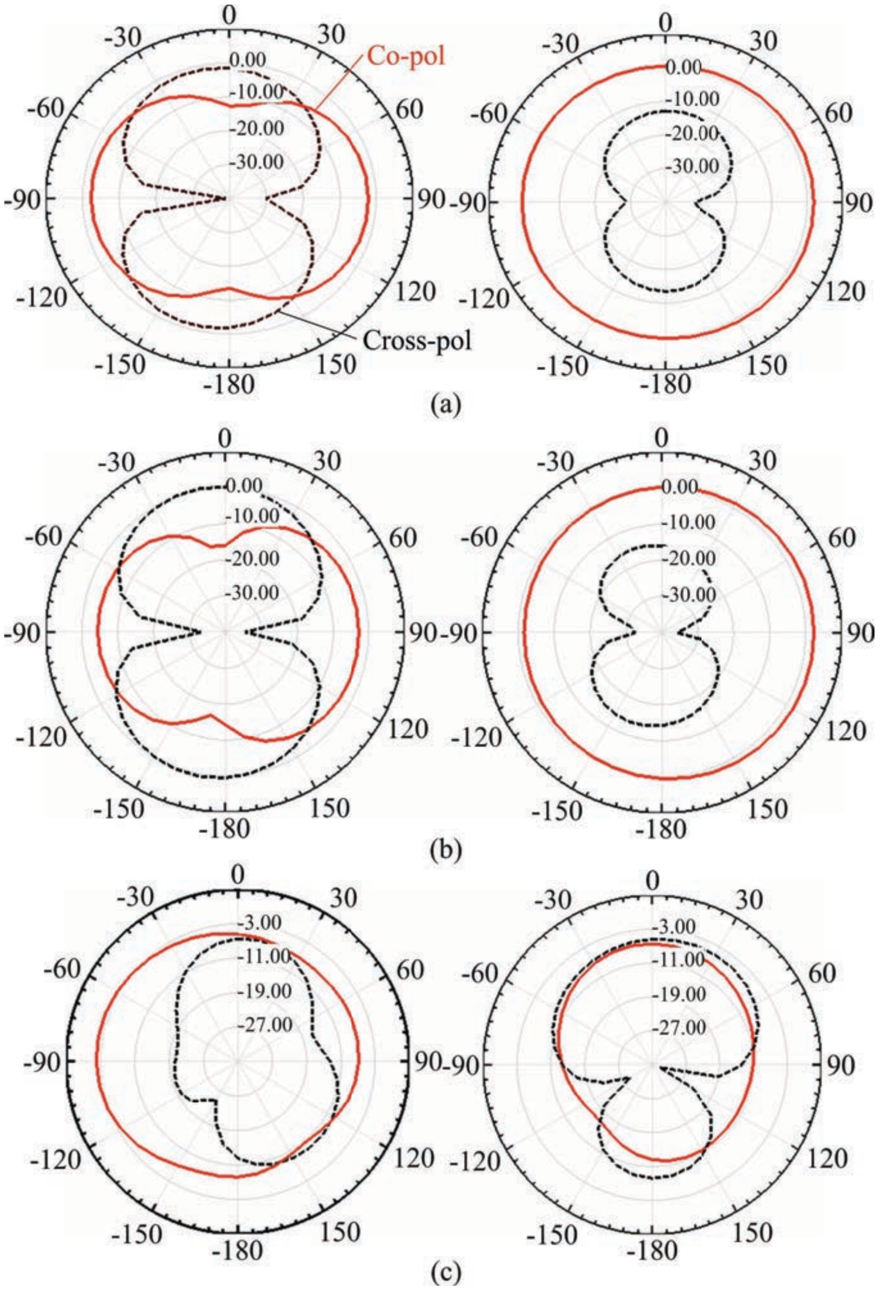

Fig. 9. Simulated radiation pattern of the proposed antenna in E and H-planes: (a) – 2.5 GHz, (b) – 2.3 GH, (c) – 2.2 GHz

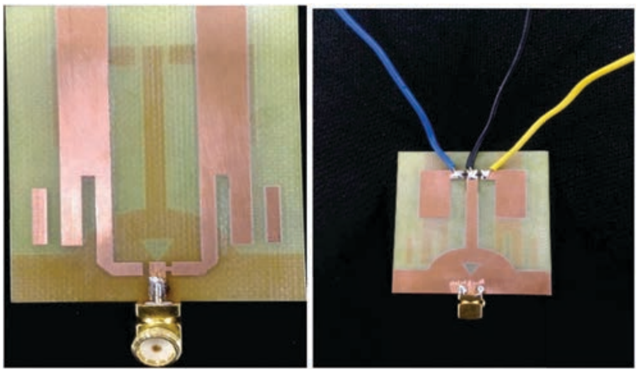

Fig. 10. Prototyped antenna: (a) – front view, (b) – back view with diodes and biasing connection

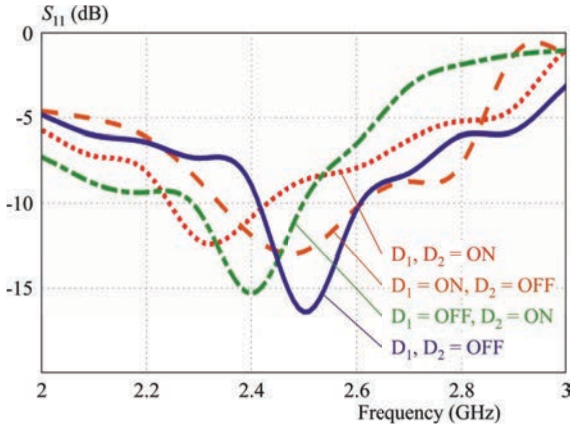

Fig. 11. Measured S_11 with diodes switching

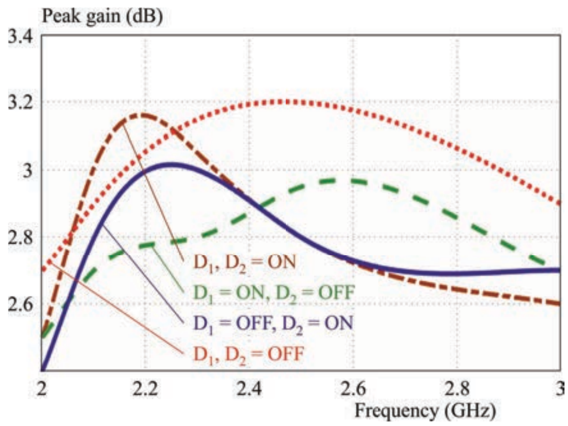

Fig. 12. Measured gain of the antenna with diodes switching

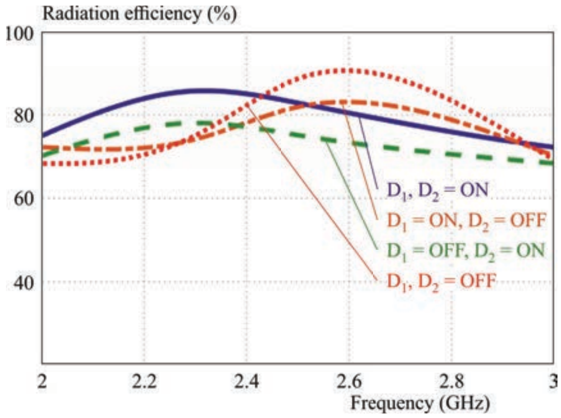

Fig. 13. Radiation efficiency *vs* frequency of antenna at diode conditions

OFF and D2 is in ON condition. The gain of the antenna is 3.0 dBi at resonant frequency 2.3 GHz. Figure 8(c) represents the gain of the proposed antenna when the diodes D1 and D2 are in ON condition. The gain of the antenna is 3.1 dBi at resonant frequency 2.2 GHz.

The radiation patterns of the antenna at the resonating frequencies are given in the Fig. 9. The designed antenna radiation characteristics in both E-plane and H-plane are plotted. The E-plane ($\Phi = 0°$) co and cross polarization (y–z) plane and H-field ($\Phi = 90°$) co and cross polarization (x–z) plane at all switches ON and all switches OFF condition are shown in Fig. 9. H-plane has obtained quasi omni-directional radiation pattern with moderate low cross polarization. The inner circles indicate the cross-polarization levels and outer indicates the co-polarization levels.

The proposed antenna is prototyped on FR4 substrate and presented in Fig. 10. Diodes are placed on the ground plane and biasing is provided with connection to power supply. The measured results with VNA shows the applicability of the antenna in real time environment. The measured results of the reflection coefficient with respect to the change in switching is presented in Fig. 11.

Figure 12 represents the measured gain of the antenna based on diodes switching. It can be observed that the measured peak realized gain values are in close agreement with the simulated gain values from Fig. 8.

The efficiency *vs* frequency is plotted in Fig. 13. Based on the different switching conditions the efficiency of the antenna is varied between 60 to 89 %. When the both switches are in ON condition the maximum efficiency of 89 % is achieved.

4 Conclusion

A novel reconfigurable patch antenna with DGS is presented in this article for wireless communication application of ISM band. The designed antenna has compact size of 58 mm × 40 mm and easy to integrate with implementation. The reconfigurable slot antenna loaded with asymmetric radiators and parasitic elements to attain the require band operation at ISM band, with center frequency 2.4 GHz and 2.5 GHz. By placing two diodes with switching between them made frequency shifting and the proposed antenna shows good return loss ($S_{11} < -10$ dB) at operating bands. A good agreement is obtained between simulated and measured results with respect to frequency reconfigurability.

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References

[1] Shu-Lin Chen, Pei-Yuan Qin, Can Ding and Y. Jay Guo "Cavity-Backed Proximity-Coupled Reconfigurable Microstrip Antenna with Agile Polarizations and Steerable Beams", *IEEE Transactions on Antennas and Propagation* vol.65 , no. 10, 2017, pp. 5553–5558.

[2] C. G. Christodoulou, "Reconfigurable Antennas for Wireless and Space Applications", *Proceedings of the IEEE* vol. 100, no. 7, 2012, pp. 2250–2261.

[3] E. Elham, J. R. Kelly and P. S. Hall, "Integrated Wide-Narrowband Antenna for Multi-Standard Radio", *IEEE Transactions on Antennas and Propagation* vol. 59, no. 7, 2011, pp. 2628–2635.

[4] L. M. Feldner *et al*, "Electrically Small Frequency-Agile PIFA-as-a-Package for Portable Wireless Devices", *IEEE Transactions on Antennas and Propagation* vol. 55, no. 11, 2007, pp. 3310–3319.

[5] Nguyen Viet-Anh, Rashid-Ahmad Bhatti and Seong-Ook Park, "A Simple PIFA-based Tunable Internal Antenna for Personal Communication Handsets", *IEEE Antennas and Wireless Propagation Letters*, vol. 7, 2008, pp. 130–133.

[6] P. Bhartia and I. Bahl, "A Frequency Agile Microstrip Antenna", *Antennas and Propagation Society International Symposium*, IEEE.Vol.20, 1982.

[7] Behdad Nader and Kamal Sarabandi, "Dual-Band Reconfigurable Antenna with a Very Wide Tunability Range", *IEEE Transactions on Antennas and Propagation* vol. 54, no. 2, 2006, pp. 409–416.

[8] Yu Yufeng *et al* "An Electrically Small Frequency Reconfigurable Antenna with a Wide Tuning Range", *IEEE Antennas and Wireless Propagation Letters* vol. 10, 2011, pp. 103–106.

[9] Manteghi Majid, "A Tunable Planar Inverted-f Antenna for Digital Video Broadcast-HandHeld Applications", *Microwave and Optical Technology Letters* vol. 4, no. 11, 2012, pp. 2635–2638.

[10] Konca Mustafa and P. A. Warr, "A Frequency-Reconfigurable Antenna Architecture using Dielectric Fluids", *IEEE Transactions on Antennas and Propagation* vol. 63, no. 12, 2015, pp. 5280-5286.

[11] P. Dimitrios, K. Sarabandi and L. P. B. Katehi, "Design of Reconfigurable Slot Antennas", *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 2, pp. 645–654.

[12] Cai Yaxing, and Zhengwei Du, "A Novel Pattern Reconfigurable Antenna Array for Diversity Systems", *IEEE Antennas and Wireless Propagation Letters* vol. 8, 2009, pp. 1227–1230,.

[13] M. A. Huda, "A Compact Frequency-Reconfigurable Narrowband Microstrip Slot Antenna", *IEEE Antennas and Wireless Propagation Letters* vol. 11, 2012, pp. 616-619.

[14] Mustafa Faisal, "Triple H-Shaped Multiple Band Frequency Reconfigurable Patch Antenna", *Innovative Computing Technology (INTECH)*, Sixth International Conference on. IEEE, 2016.

[15] Heba B. El-Shaarawy, "Novel Reconfigurable Defected Ground Structure Resonator on Coplanar Waveguide", *IEEE Transactions on Antennas and Propagation* vol. 58, no. 11, 2010, pp. 3622–3628.

[16] C. A. Balanis, *Antenna theory: Analysis and design*, Wiley Publication, 3rd Edition, 2005.

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