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Design of a Frequency Reconfigurable Fractal Antenna for Internet of Things (IoT) in Vehicular Communication

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Abstract*: *In this paper, a reconfigurable antenna based on fractal elements is presented. A circular ring- shaped radiating patch is used in this design and a pair of connected circles are used as the fractal elements. The antenna is designed and fabricated on FR4 substrate with dimensions 40x30x1.6mm^3. The switchable functionality of the proposed antenna is investigated by placing two PIN diodes as switching elements which joins circular ring and the fractal elements. The proposed antenna shows the reconfigurable functionality in S-band (2-4 GHz) and C-band (4-8 GHz) when operated at different bias conditions. The simulated model is showing a peak gain of more than 1.3 dB in S-band and more than 3.5 dB in C-band with good radiation efficiency with good radiation characteristics. The proposed design is suitable for vehicular communication applications in an Internet of Things (Vehicles) environment.

Index Terms*: *Fractal antenna, vehicular communication, reconfigurable antenna.

I. INTRODUCTION

Vehicular communications are now growing as an emerging field in which the major research is going on to develop sophisticated vehicular systems for effective communication between driver, vehicle and also vehicle to vehicle. This provides the journey in a safe manner by the providing indication alarms and prediction of possibility of collisions etc. The Internet of Things is another emerging technology which provides the interconnection among various electronic and communication modules/devices. It is not only useful to provide an interconnect solution among various modules in vehicle but also helpful in establishing the realization of connected vehicles. Antennas play a major role in this scenario, to establish good transceiver capabilities with good bandwidth and radiation performance. Several antenna designs were proposed in past years and available in literature. Few of the proposed designs are presented here for dual and wideband-operations, and some reconfigurable structures are discussed. An antenna with square and circular ring slots is etched in the radiating element is proposed in [1], which operates at 2.4/5 GHz frequencies for WLAN applications with a compact antenna size. Another dual-frequency patch antenna with circular slot is demonstrated in [2], which is fed by offset microstrip feed and the dual-frequency of operation at UHF and microwave band is obtained by altering of current distributions which is due to attaching a strip to the radiating edges. In [3], modified monopole UWB antenna is designed, which operates in WiMAX (3.3–3.7 GHz) and HiperLAN2 (5.4–5.7 GHz) frequencies and this is achieved by placing triangular blocks on either sides of circular patch and also by embedding double split ring resonators on ground plane. A frequency reconfigurable antenna with 50mm x 45mm is proposed in [4], with a bow-tie shaped element and it operates in switchable mode among Bluetooth, WiMAX, WLAN by incorporating PIN diodes over the arms of the bow-tie element. A rectangular and U-shaped microstrip patch antenna is proposed with size of 86.3mm x 50mm x 1.585mm which will perform its duty in four bands 1.87 GHz, 3.55 GHz, 3.67 GHz and 5.6 GHz of frequencies attains switching nature placing PIN diodes on different positions [5]. A circular ring-shaped antenna with PIN diodes as switching elements which operates in 2-3 GHz used in wireless communications [6] and it operates in three switching states in polarization. A bidirectional slot antenna in [7] is discussed which switches between both pattern and frequency with the help of slits and PIN diodes for making the antenna to operate in 1.98-2.10 GHz bands. In [8], a compact reconfigurable antenna is proposed which has capability by providing different switching states for three narrow band and a dual-band of operation along with UWB spectrum. A pattern switchable antenna which works at 2.4GHz provides both directional and omnidirectional pattern which is more useful for IoT network system in order to increase communication range is proposed in [9]. To obtain the multi band reconfigurable performance, an antenna of size 40 mm X 12mm X 4mm presented in [10], is embedded with two strips and two RF switching elements which operates in LTE 700,

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GSM 900/1800, and LTE 2300/2500 bands. An inverted T-shaped DGS added with stubs are used to obtain reconfigurable characteristics in a U-shaped patch antenna to operate in ISM band applications [11]. Few antenna designs are presented to obtain multiband [12-15] which employs the fractal geometry and got multiband characteristics based on metamaterial structures [12] and fractal slot structures [13-15] to operate under Vehicular communication applications.

In this work, a compact circular ring structure is chosen as radiating element and incorporated the fractal elements in the antenna geometry to achieve dual band of operation and studied the antenna performance. The design related elements are discussed in Section-2 and Section-3 gives the clear insight of simulation results and its characteristics with reconfigurable functionality of the proposed antenna with all supportive parameters like radiation characteristics, peak gain, efficiency etc and conclusions are presented in Section-4.

II. Antenna Geometry

The geometry of antenna is presented in Fig. 1. The antenna design consists of a circular ring structure of outer radius of 'R_1' and thickness 't'. Two fractal elements are embedded in the region within the circular ring in horizontal direction. These fractal elements are formed by connecting the three circular elements with different radii and whose radius is a fraction of the larger circular element with radius 'a_1'. The scaling factor '$s_f = 0.52$' is used to determine the radius of the next circular element in that connected circular fractal pattern. The antenna is fed with coplanar waveguide feeding with a feedline with of 'W_f' and gap between the feed and ground plane being 'g' as shown in Fig. 1. The geometrical evolution of the antenna is shown with three stages of adding fractal elements to the circular ring which can be understand from Fig. 1. The length 'l_1' is the distance of first circular element from the inner edge of the circular ring, whereas the parameters 'l_2' and 'l_3' represent the inter element distance between the remaining two circular elements in the connected circle fractal structure. The antenna structure is designed on FR4 substrate material with relative permittivity of 4.4 and with loss tangent of tanδ of 0.02 with total substrate dimensions of L_s x W_s x h. The dimensions of the model are presented in Table 1. Fig. 1 illustrates the evolution of the design shown in Fig. 1 with starting phase of circular ring design as shown in Fig. 1(a). The designs with first, second and third iterative circular connected elements are shown in Fig. 1(b-c) respectively.

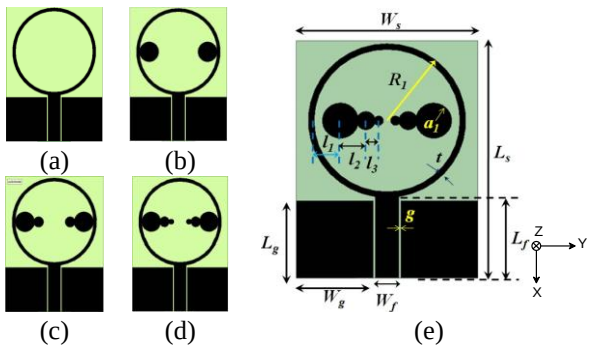


Fig. 1. Iterations of proposed antenna (a) Iteration-1: with circular ring patch (b) Iteration-2: ring connected with first iteration of circles (c) Iteration-3: ring connected with two circular elements (d) Iteration-4: ring connected with three of circular (e) Circular ring monopole antenna with parasitic connected fractal circular elements

The geometry of antenna shown in Fig. 1(e), contains the connected fractal circular elements which are separated by the gap of 1.35mm for inserting the PIN diodes D_1 and D_2 as switching elements respectively placed as shown in Fig. 2. The possible cases of biasing leads to the frequency reconfigurability.

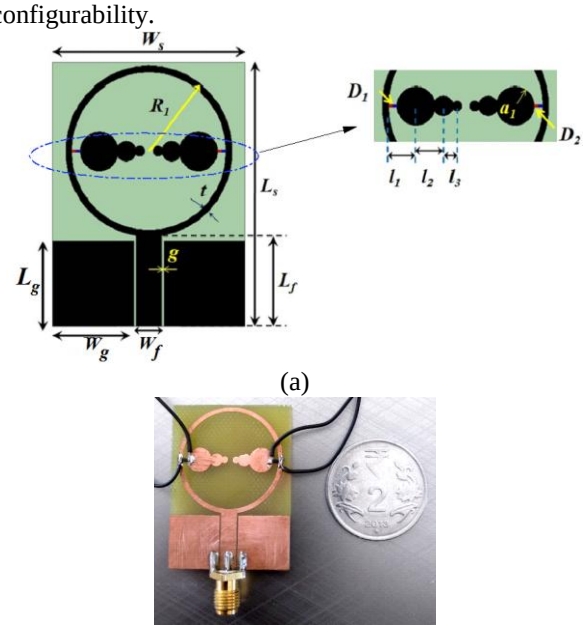


Fig. 2 Proposed reconfigurable antenna (a) simulation model (b) fabricated antenna

Table 1. Dimensions of the proposed antenna geometry

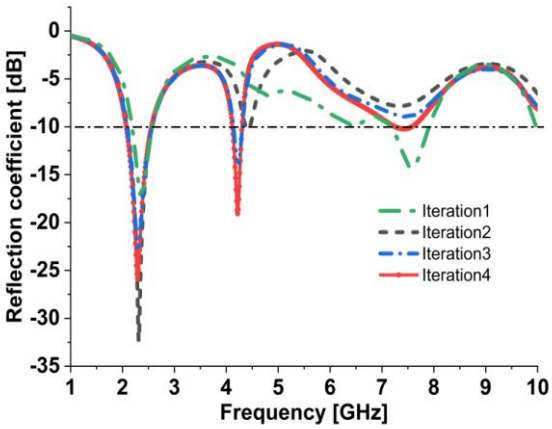
Parameter	L_f	W_f	W_g	L_g	L_s
Value in mm	13.7	3.84	12.73	13	40
Parameter	W_s	g	R_1	R_2	h
Value in mm	30	0.35	13	12	1.6

III. Results and Discussion

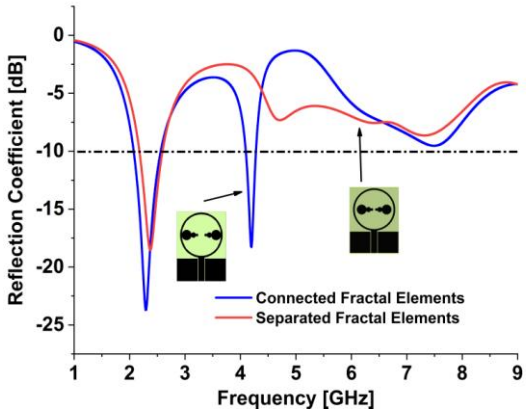
A. Reflection coefficient Vs Frequency Characteristics

The proposed antenna with iterative designs is modelled and simulated in ANSYS HFSS and the simulation results are presented in Fig. 4(a). The variations in the reflection coefficient are plotted in Fig. 4(a) depicts, the variations in the dual band nature of the antenna when the fractal elements connected to the circular ring structure. The antenna with circular ring radiating element shown in Fig. 1(a), is operating in two bands, 2.18-2.58 GHz and 7.18-7.91 GHz, with resonant frequencies at 2.38 GHz and 7.60 GHz in the corresponding bands respectively. When a circular element is connected to the inner edge of the ring in a horizontal manner as shown in Fig. 1(b) the operating bands are 2.1-2.58 GHz

and 4.38-4.45 GHz with minimum reflections at 2.32 GHz and 4.44 GHz respectively. The antenna iteration-3 shows the dual band from 2.08-2.57 GHz and 4.14-4.31 GHz with resonances at 2.31 GHz and 4.22 GHz which is occurred due to adding second level circular elements to the Iteration-2. In the Iteration-4 of the proposed antenna, the operating bands yields as 2.07-2.56 GHz and 4.12-4.28 GHz with resonances noticed at 2.29 GHz, 4.23 GHz respectively. In all of the above iterations, it is observed that, the first band in the region of 2-3 GHz is maintained consistently with small deviations in their lower and upper cut-off frequencies and the resonant frequencies in this band are slightly lowered towards left. The second band initially appeared at 7-8 GHz region is shifted to 4-5 GHz region because of adding fractal elements to the circular ring structure. The levels of reflection coefficients for both resonant frequencies in the operating bands are nearer as the number of fractal elements increased.



(a)



(b)

Fig. 4 Simulated Reflection coefficient vs frequency characteristics (a) for the iterations of the proposed antenna (b) Fractal Structure with connected and parasitic mode.

The simulated reflection coefficient vs frequency performance shown in Fig. 4(b) represents, the case study of antenna with fractal elements in joined mode and gap/separated mode respectively. The gap is created in order to place PIN diodes as switching elements. The dual band (2.07-2.56 GHz and 4.10-4.28 GHz) nature found in Iteration-4 is obtained due to the direct connection of fractal elements. When the gap between the fractal elements and the circular ring exists the single band nature of the antenna is observed at 2.18-2.59 GHz. This case of single and dual band operation for gap and connected modes respectively can be switchable by placing a PIN diode switch. Later, two PIN diodes (BAR64-02V) D_1 and D_2 are placed in those gaps between the circular ring and symmetrical fractal elements and the possible four switching cases are studied and presented in Fig. 5 showing the various plots of reflection coefficient over the frequency response. The observations are tabulated in Table 2. For all switching cases, the operating band in the region of 2-3 GHz is stable and when either of the diodes are forward biased the antenna operates in two bands in the region of 2-3 GHz and 4-8 GHz respectively. During the diodes in OFF state, only single band occurs in the 2-3 GHz region. When both the diodes are in ON condition the operating band occurs in the region of 2-3 GHz with a small additional band of 7-8 GHz.

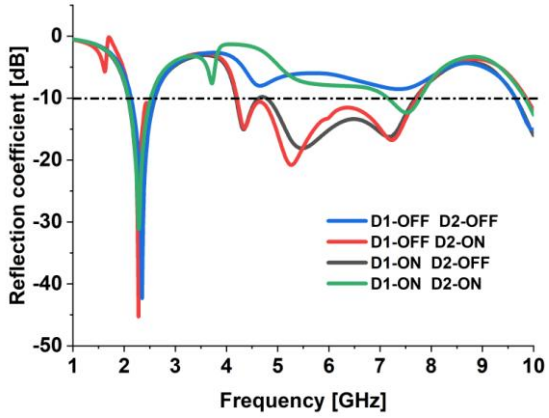
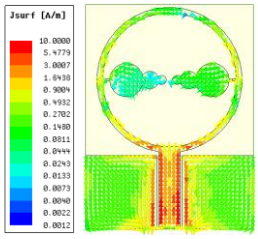


Fig. 5 Simulated Reflection coefficient versus frequency plot for switching cases of diodes D_1 and D_2

B. Surface current distributions of the proposed reconfigurable antenna

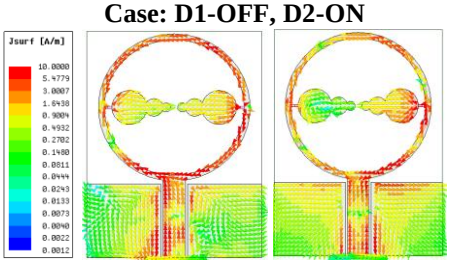
The surface current distributions are plotted in Fig. 6 for various switching cases at their resonant frequencies. The currents are more concentrated at resonant frequencies and the effective electrical length that possess more concentrated regions will help to radiated at that particular resonant frequencies. The denser regions can be observed when the corresponding PIN diodes are forward biased.

Case: D1-OFF, D2-OFF



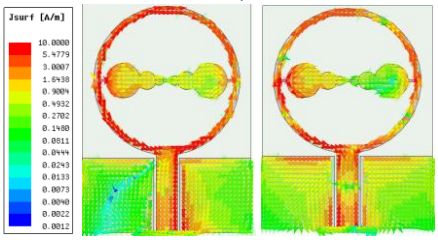
At 2.4 GHz

Case: D1-OFF, D2-ON



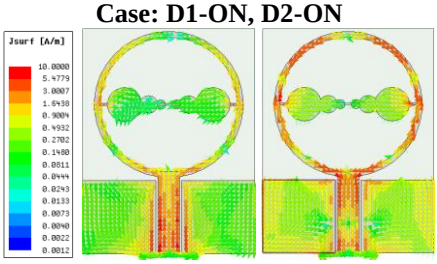
At 2.4 GHz and 5.5 GHz

Case: D1-ON, D2-OFF



At 2.4 GHz and 5.5 GHz

Case: D1-ON, D2-ON

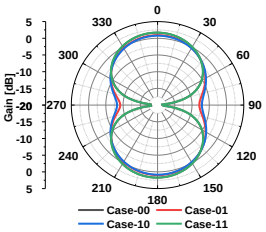


At 2.4 GHz and 7.3 GHz

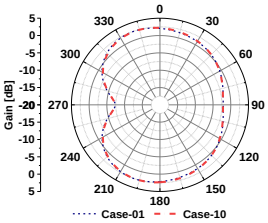
Fig. 6 Surface current distributions of proposed reconfigurable antenna

C. Radiation Performance of the proposed antenna

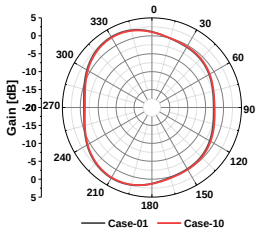
The two-dimensional radiation patterns are presented in E-plane and H-plane respectively in Fig. 7 and Fig. 8. At 2.4 GHz, the antenna has dipole kind of radiation in both E & H-planes. The cardioid shaped and nearly omni directional patterns are observed in the E-plane of the antenna at 4.4 GHz, 5.3 GHz and 5.5 GHz frequencies. A bidirectional pattern is obtained at 7.3 GHz.



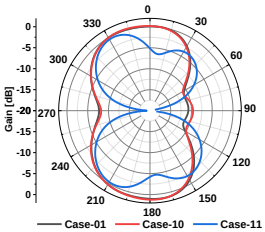
(a) at 2.4 GHz



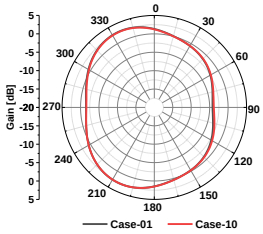
(b) 4.4 GHz



(c) 5.3 GHz



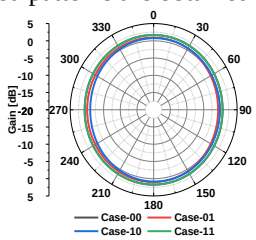
(d) at 5.5 GHz



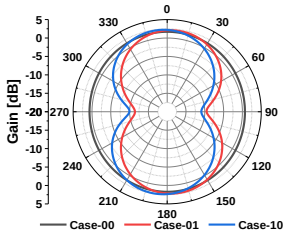
(e) 7.3 GHz

Fig. 7 E-plane Radiation patterns of the proposed antenna at resonant frequencies

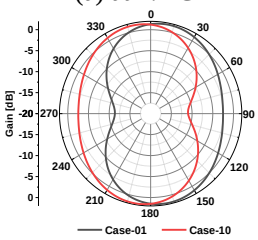
At 2.4 GHz, the antenna radiates omnidirectional in H-plane. The antenna at 4.4 GHz in H-plane radiates omnidirectionally in Case-00 mode, and when either of the diode is turned on, the bidirectional patterns are obtained. The cardioid shaped patterns can be seen at 5.3 GHz and 5.5 GHz on the H-plane of the antenna. The quasi omni directional patterns and flower shaped patterns are obtained at 7.3 GHz.



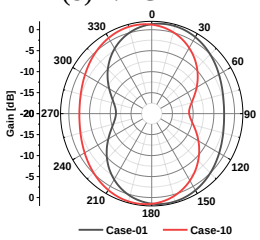
(a) at 2.4 GHz



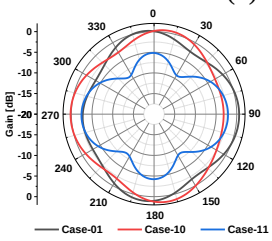
(b) 4.4 GHz



(c) 5.3 GHz



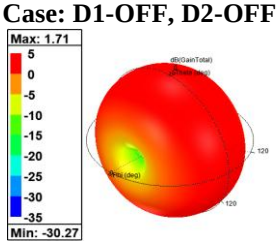
(d) at 5.5 GHz



(e) 7.3 GHz

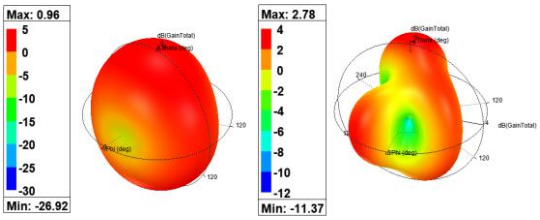
Fig. 8 H-plane Radiation patterns of the proposed antenna at resonant frequencies

Case: D1-OFF, D2-OFF



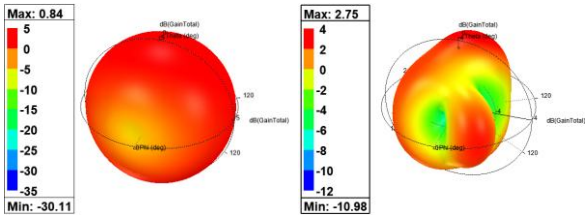
At 2.4 GHz

Case: D1-OFF, D2-ON



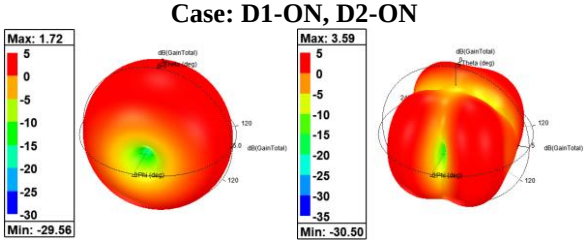
At 2.4 GHz and 5.5 GHz

Case: D1-ON, D2-OFF



At 2.4 GHz and 5.5 GHz

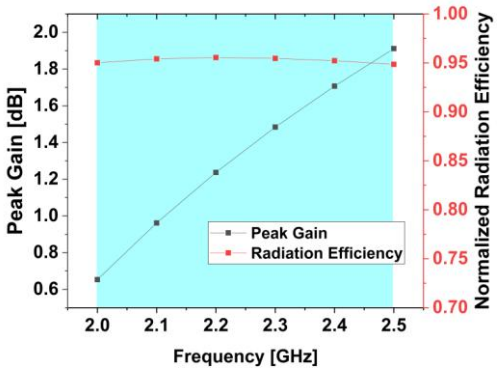
Case: D1-ON, D2-ON



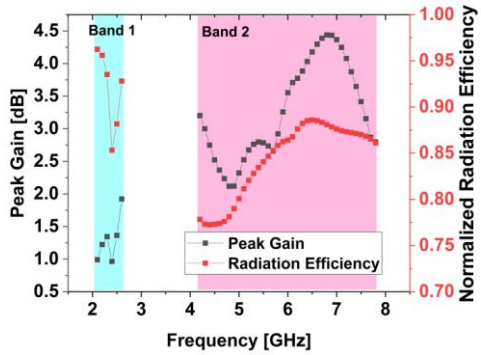
At 2.4 GHz and 7.3 GHz

Fig. 9 Three-dimensional Far-field characteristics of proposed antenna

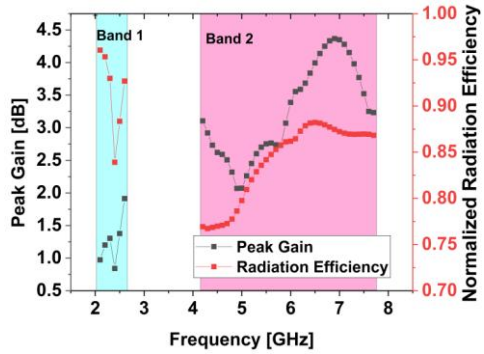
The simulated three-dimensional far-field radiation plots are presented in Fig. 9 for various switching conditions of the reconfigurable antenna. Few resonant frequencies are considered to study the far-field antenna performance. The omni directional properties are observed at 2.4 GHz band in all switching cases of the reconfigurable antenna and at other frequencies like 5.5 GHz, 7.3 GHz the omnidirectional pattern is getting deformed due to the formation of nulls.



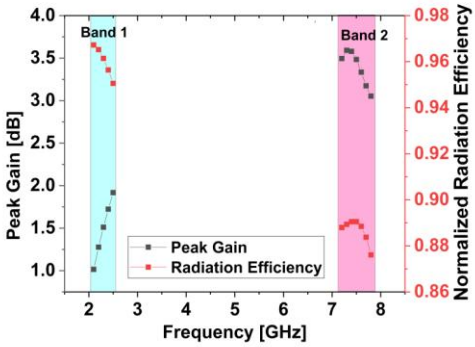
(a) Case: D_1-OFF, D_2-OFF



(b) Case: D_1-OFF, D_2-ON



(c) Case: D_1-ON, D_2-OFF



(d) Case: D_1-ON, D_2-ON

Fig. 10 Peak Gain and Radiation efficiency versus Frequency plots for proposed reconfigurable antenna

Table 2: Antenna characteristics for various switching conditions

Switching Cases for D_1 and D_2	Operating Bands [GHz]	Resonant frequencies [GHz]
00	2.14-2.60	2.35
01	2.12-2.57	2.28
	4.20-7.72	4.36/5.28/7.27
10	2.08-2.60	2.27
	4.19-7.69	4.34/5.52/7.21
11	2.08-2.52	2.29
	7.15-7.78	7.55

Switching Cases for D_1 and D_2	Peak gain [dB] (within operating band)		Radiation efficiency [%] (within operating band)	
	Max	Average	Max	Average
00	2.09	1.6926	95.5	95.1
01	1.3640	1.2009	95.6	90.25
	4.438	3.2870	88.59	84.32
10	1.9128	1.2331	96.04	90.99
	4.4668	3.2433	88.22	84
11	1.9176	1.494	96.72	96.05
	3.5913	3.4646	89.05	88.89

The peak gain vs frequency characteristics of the proposed reconfigurable antenna at four switching cases is also studied and plotted in Fig. 10 and tabulated in Table 2. Among all of the cases, the maximum peak gain is found to be 4.438 dB obtained in the case of D_1-OFF, D_2-ON in the S-band C-band region whereas in S-band 1.9176 dB of gain is observed in the case both diodes are forward biased. The antenna is found to be efficient in all of its switching cases showing more than 85% of radiation efficiency.

IV. CONCLUSION

This paper describes, a design and study of reconfigurable antenna with a fractal concept. The switching cases are evaluated in simulation for various biasing conditions and analyzed the performance of the antenna in terms of its reflection coefficient, radiation patterns, surface current distributions. The proposed antenna consistently operates in 2-2.6 GHz band which has applications in WLAN 802.11b (Wireless Local Area Network 2.4-2.48 GHz), ISM (Industrial Scientific and Medical), Bluetooth, GLONASS, GALILEO like navigation systems, LTE 2300 (Long Term Evolution) band. The other band from 4.2-7.75 GHz region is switchable and it is useful for the applications WLAN 802.11a/n, DSRC (Dedicated Short- range Communication), V2V and V2I applications on vehicular environment and Internet of Vehicles.

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REFERENCES

1. W. Ren. (2008). Compact Dual-Band Slot Antenna for 2.4/5ghz WLAN Applications, *Prog In Electromag Res B*, 8, pp.319-327.
2. Tiang J J, Islam M. T., Misran N, and Singh M. (2011). Circular Microstrip Slot Antenna for Dual-Frequency RFID Application, *Prog In Electromag Res*, 120, pp.499-512.
3. Alhegazi. A, Zakaria. Z, Shairi N. A, Ibrahim I. M, and Ahmed S. (2017). A Novel Reconfigurable UWB Filtering-Antenna with Dual Sharp Band Notches Using Double Split Ring Resonators, *Prog In Electromag Res C*, 79, pp.185-198.
4. Li T, Zhai H, Wang X, Li L, and Liang C. (2015). Frequency-Reconfigurable Bow-Tie Antenna for Bluetooth, WiMAX, and WLAN Applications, *IEEE Antennas Wirel. Propag. Lett.*, 14, pp.171-174.
5. Nazir, Rana I. E., Mir N. U. A., and Afreen K. (2016). Design and Analysis of a Frequency Reconfigurable Microstrip Patch Antenna Switching Between Four Frequency Bands, *Prog In Electromag Res C*, 68, pp.179-191.
6. Saravanan M and Rangachar M. J. S. (2018). Circular Ring Shaped Polarization Reconfigurable Antenna for Wireless Communications, *Prog In Electromag Res M*, 74, 105-113.
7. Majid H A, Rahim M. K. A., Hamid M. R., and Ismail M. F. (2014) "Frequency and Pattern Reconfigurable Slot Antenna," *IEEE Trans. Antennas Propag.*, 62, No. 10, pp.5339-5343.
8. Boudaghi H, Azarmanesh M and Mehranpour M. (2012). A Frequency-Reconfigurable Monopole Antenna Using Switchable Slotted Ground Structure, *IEEE Antennas Wirel. Propag. Lett.*, 11, pp.655-658.
9. Le Huy Trinh, Trong Nhan Le, Robert Staraj, Fabien Ferrero and Leonardo Lizzi. (2017). A Pattern-Reconfigurable Slot Antenna for IoT Network Concentrators," *Electronics*, 6(4), 105.
10. Ban Y, Sun S, Li P, Li J. L., and Kang K. (2014). Compact Eight-Band Frequency Reconfigurable Antenna for LTE/WWAN Tablet Computer Applications, *IEEE Trans. Antennas Propag.*, 62, No. 1, pp.471-475.
11. Shaik Rajiya, Badugu P. Nadh, Munuswami S. Kumar. (2018). Frequency reconfigurable monopole antenna with DGS for ISM band applications, *Journal of Electrical Engg*, 69, No. 4, pp.293–299.
12. Pardhasaradi P., Kesava Sai G, Venkateswararao M, Ganesh B, Tarakaram N, Pavana Teja D. (2019) Metamaterial Inspired Reconfigurable Fractal Monopole Antenna for Multiband Applications, *International Journal of Intelligent Engineering and Systems*, 12, No.2, pp.53- 61.
13. Deepak B S, Madhav B T P, Prabhakar V S V, Lakshman P, Anilkumar T, Venkateswararao M. (2018). Design and Analysis of Hetero Triangle Linked Hybrid Web Fractal Antenna for Wide Band Applications, *Prog In Electromag Res C*, 83, pp.147-159.
14. Madhav B T P, Anil Kumar T. (2018). Design and study of multiband planar wheel-like fractal antenna for vehicular communication applications, *Microw. and Optical Technol. Lett.*, 60, pp.1985-1993.
15. Madhav B T P, Anilkumar T, Kotamraju S K. (2018). Transparent and conformal wheel-shaped fractal antenna for vehicular communication applications, *AEU-International Journal of Electronics and Comm.*, 91, pp.1-10.

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