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Defected Ground Structure based Reconfigurable UWB Antenna for IoT applications

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Abstract*: A defected ground structure reconfigurable UWB antenna is developed and presented in this paper. The proposed antenna switches between a narrow band and ultra-wideband. The proposed antenna occupies the compact dimension 37.5x35x1.6mm^3. In this design, a pair of ohm shaped slots coupled together by a horizontal slot is considered as defected ground structure. The proposed antenna has the capability of sensing the entire UWB range from 3.1GHz to 10.6GHz and extends up to 15 GHz. Later, a study is performed to understand the switching behavior of the antenna when the switching elements are incorporated in the defected ground structure elements of the proposed antenna and compared with ideal switching case, PIN diode switches. The switching conditions of the proposed antenna yields the frequency reconfigurable nature among the spectrum that covers S-band, C-band and UWB with maximum gain of 2.83dB, 5.12dB and 5.2dB respectively which shows the compatible use in IoT devices.

Index Terms*: Defected ground structure, UWB, Internet of Things, Switchable.

I. INTRODUCTION

With rapid development of wireless communication networks based on internet of things, systems with low cost, light weight, less manufacturing cost, high data rate and low power are in demand. A UWB antenna is very efficient as it serves these purposes.

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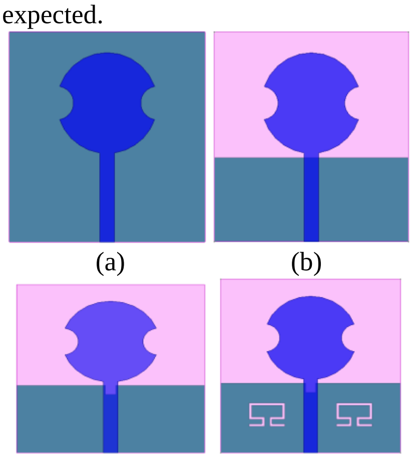
IoT devices are used in various industrial and commercial applications. We require multiple antennas one for each band or a wideband antenna for wireless connectivity of IoT devices. Satellite communications, radars are some of the other applications where UWB antennas are used.

If the antenna parameters such as radiation pattern, frequency bands can be controlled in reversible manner then we call the antenna as reconfigurable. A single reconfigurable antenna can be utilized for various applications as the antenna can be switched in different bands. Reconfigurable antennas are very much suitable for Internet of things modules and some exiting works available in the literature are presented here. A compact size UWB antenna in [1] uses multiple PIN diodes in the slotted ground plane of dimensions 24.5x20mm2. It is developed to attain frequency reconfigurability. A wider bandwidth is attained by using fractal geometry. In [2-8], the defected ground structure-based antennas are discussed for different wireless and IoT applications. A shovel shaped defected ground structure is incorporated on the UWB printed monopole antenna of dimensions 15x18mm2 for obtaining filtering characteristics [9]. A cognitive radio applications-based antenna which is switchable between UWB and narrow band is proposed in [10] with four horizontal slots and integrated switches. Reconfigurable transceiver consists of reconfigurable antenna that is useful for spectrum sensing in 2.4-9 GHz region for cognitive radio applications is discussed in [11]. A defected ground structured antenna with reconfigurable nature is proposed in [9] for ISM band applications. Few antennas are proposed in for applying the switch ability among the notch bands of the antenna with monopole slot structure [12], trapezoidal configuration [13], also presented in [14-22]. A microstrip patch antenna is loaded with defected ground structures to achieve wide -10 dB impedance bandwidth under the X, Ku and K bands technologies is presented in [23]. Reconfigurable antennas to work in S-band, Ku-band with monopole antenna structures are proposed in [24-26]. The antenna demonstrated in [27-28] switches its states and operates in UWB/ Bi-bands and three narrow bands in [28]. In this paper a reconfigurable ultra-wideband antenna is developed which can be used in various IoT applications.

A planar UWB antenna with reconfigurable functionality has been discussed with the study of employing a defected ground structure. The antenna design process is discussed in Section-II with the study of the effects of parametric variations in the antenna geometry and its effects discussed in Section-III. The supportive results and discussions in terms of the antenna parameters are presented in Section-IV and the concluded in Section-V.

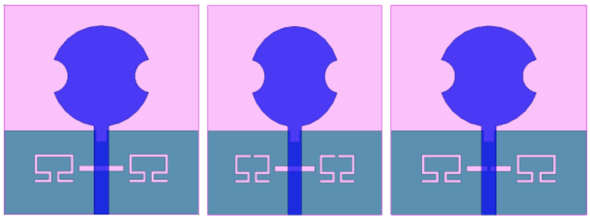
II. ANTENNA DESIGN

A simple UWB antenna is designed on a total area of 37.5x35 mm^2 of substrate before designing a reconfigurable UWB antenna as shown in Fig. 1. The FR4 substrate with relative permittivity of 4.4, and material thickness '*h*' of 1.6mm and loss tangent of 0.02 is used in the design. The top of the substrate is coated with a circular patch of radius '*R*' which is fed by a microstrip feed line of length 'L_f' and width 'W_f'. A circular radiating patch is modified to a shape that is made by cutting the circular patch with two circles of radius 'R_1' on either side of the patch. Initially in the design, the full ground is incorporated on the bottom side of substrate. In the second iteration a partial ground is used by reducing the length of the ground to 'L_g' and coated on the bottom side of the substrate. A small rectangular notch is created with dimensions '*L*' x '*W*' on the top edge of ground plane just below the feedline to achieve better impedance matching in the ultra-wideband range. Later, a pair of identical Ohm shaped slots of thickness 0.5mm are etched in that partial ground plane and the resultant structure is considered as a defected ground structure (DGS). DGS are placed at 8mm from the virtual axis that passes through the feed line. To achieve the narrow band frequency response, a horizontal slot of length 'L_h' and width 'W_h' is etched in between the Ohm shaped DGS pair. These iterative designs are modelled and simulated in ANSYS Electronics Desktop (HFSS) simulation tool. Further, the reconfigurable antenna design is done by incorporating PIN diode as switching elements. Initially ideal switches are used for switching which are later replaced by practical switches. Of all the practical switches, PIN diodes are considered due to their fast switching capability. Three switching elements are used out of which two are incorporated in the pair Ohm shaped defected ground structures and one in horizontal slot. By switching these elements on and off, the UWB range and a narrow band of operation is expected.



(a) (b)

(c) (d)



(e) (f) (g)

Fig. 1 Geometrical Iterations of the proposed UWB antenna with the variations in the ground plane (a) Antenna with Full Ground (b) Antenna with Partial Ground (c) Antenna with Rectangular Notch (d) Antenna with DGS (e) Antenna with Horizontal Slot (f) Case: D_1-1, D_2-0, D_3-1 with ideal switches (g) Case: D_1-0, D_2-1, D_3-0 with ideal switches

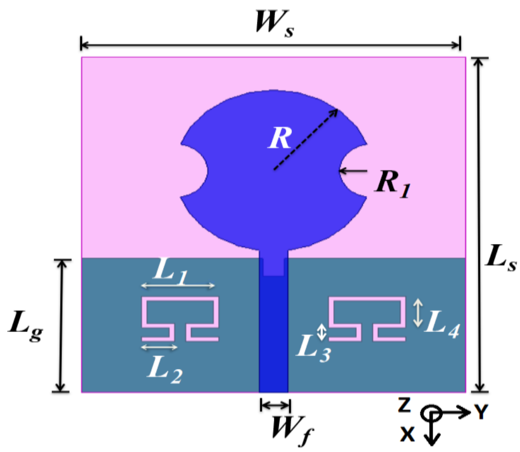
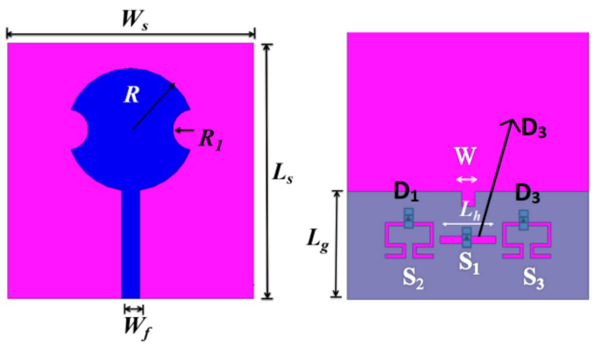


Fig. 2 Geometry of proposed DGS antenna

Table 1 Antenna Parameters

Parameter	Value(mm)	Parameter	Value(mm)
L_s	37.5	W	2
W_s	35	L_1	7
R	9	L_2	3
$R1$	3	L_3	1
W_f	2.6	L_4	3
L_g	15	L_h	8
L	2	W_h	1



(a) (b)

Fig. 3 Geometry of proposed Reconfigurable DGS antenna

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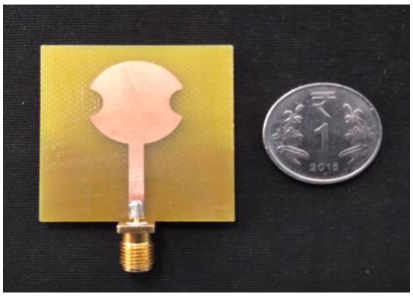
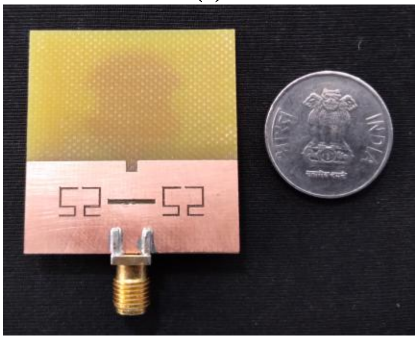
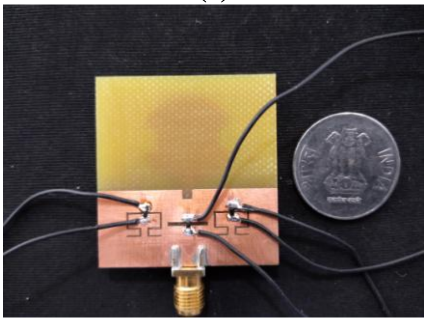


(a)



(b)



(c)

Fig. 4 Fabricated images of the proposed switchable UWB antenna with Defected Ground Structures (a) Top view of the antenna with a circular patch (b) bottom view of the antenna with the ground plane incorporated with DGS (c) Ground plane incorporated with PIN diodes.

III. PARAMETRIC ANALYSIS

The proposed antenna is based on the defected ground structure and hence the parameters that effect the operating band characteristics of the antenna such as the position of DGS slots and horizontal slot are parametrically analyzed. The working of the antenna is also studied by varying the radius of the circular cut.

A. Effect of varying the radius 'R_1' of circular cut

The parameter 'R_1' defines the radius of the circular cut which was made on the either side of the circular patch. This parameter is varied from 2mm to 5mm with step increments of 1mm. When radius R_1 is low, the antenna covers the entire UWB which extends up to 13.2 GHz and as the radius increases the higher cut off frequency reduces.

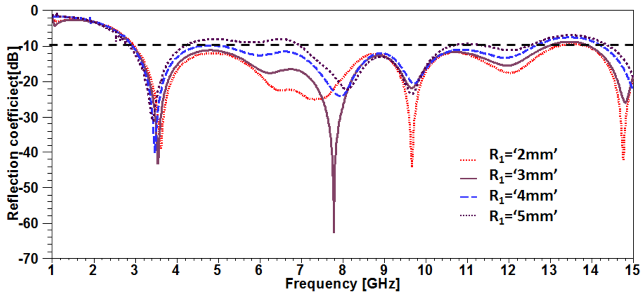


Fig. 5 Effect of varying the radius (R_1) of cut circle

The Reflection losses are found to be increased and even crosses above the -10dB threshold in 4.5 to 7 GHz region and 10 to 15 GHz region as radius is increased. So, an optimal radius of 3mm is considered as two resonant peaks are obtained and the reflection losses are minimum.

B. Effect of varying distance between the defected ground structures 'd_1'

The parameter d1 defines the distance of defected ground structure from the virtual axis through the feedline. As the distance increases the resonance shifts from 3.5 to 4.1 GHz. The defected ground structures have been finally placed at 4.5mm from the center of the virtual axis. The antenna operates over entire UWB range and extends up to 15 GHz.

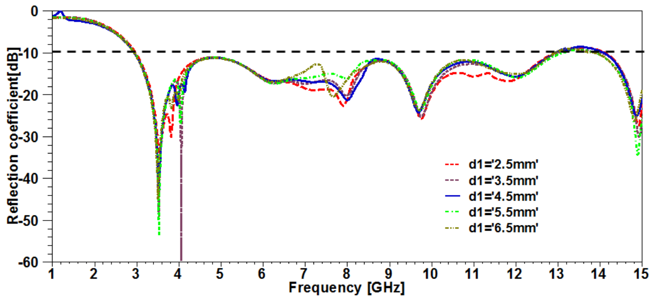


Fig. 6 Effect of varying distance between the defected ground structures 'd_1'

C. Effect of varying the position of horizontal slot '*d*'

The parameter d defines the position of horizontal slot from bottom of the ground plane. The horizontal slot is etched in the ground plane. This parameter is varied from 6mm to 10mm with step increment of 1.375mm. As d increases the reflection loss at resonance frequency decreases under 3 - 4.5 GHz. Reflection losses in the region 6 to 8 GHz increases as d is increased. Finally, the horizontal slot is placed at distance of 8.75mm from bottom of the ground plane where the antenna covers a narrow band from 3.1 to 5 GHz

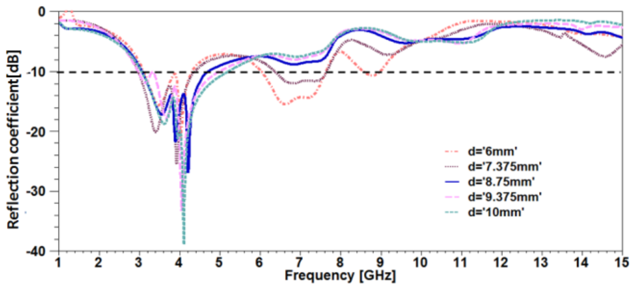


Fig. 7 Effect of varying the position of horizontal slot '*d*'

IV. RESULTS AND DISCUSSION

A. Simulated Frequency response of the antenna

A simple antenna when designed on full ground works only in a narrow band covering a frequency range of 12 GHz to 13 GHz. When partial ground is considered, antenna works for entire UWB range and further extends up to 13 GHz and has a resonant peak at 3.5 GHz. By including rectangular notch in the ground plane, the antenna operates in entire UWB extending and has two resonant peaks at 3.5 GHz and 7.7 GHz. Later defected ground structures are included in ground plane to achieve better impedance matching and for wider coverage of the band extending up to 15 GHz.

Horizontal slot is incorporated between the defected ground structure to achieve reconfigurability with the help of switching elements. Before using PIN diodes, ideal switches are used by shorting them with the ground plane in on case. Three switching elements are used out of which two switches S2, S3 are placed in defected ground structure and S1 in horizontal slot. From all the possible eight cases four have been considered in such a that the operation performed on the switches placed on the defected ground structures is same i.e either both of them are on or both of them are off. When the switch placed in the horizontal slot is on then, entire UWB range is acquired irrespective of the operation performed on the other two switched. When the switch placed in the horizontal slot is off then, antenna works in a narrow band region from 3.1 GHz to 5 GHz irrespective of the operation performed on the other two switches which is used in WiMAX applications. When S2, S3 are OFF and S1 is ON then we get entire UWB range from 3.1 GHz and extending up to 15 GHz. We get the resonant peaks at 3.5 GHz, 3.8 GHz and 7.5 GHz. These ideal switches when replaced with PIN diodes, the reflection losses are slightly higher in the region of 9 GHz to 10 GHz due to insertion losses occurred. In this case we get the resonant peaks at 3.6 GHz, 7.6 GHz and 12.4 GHz. In the other case when S1 is off and S2, S3 are on, the antenna works in a narrow band covering frequency range of 3.1 GHz to 4.1 GHz and the resonant peak is acquired at 3.6 GHz. When the ideal switches are replaced by the PIN diodes, antenna works as dual band antenna. In the first band it works in 3.1GHz to 4.1GHz region. In the second band antenna works in 7.1GHz to 15GHz region. Resonant peaks are acquired at 3.5GHz, 8.1GHz and 12.5GHz.

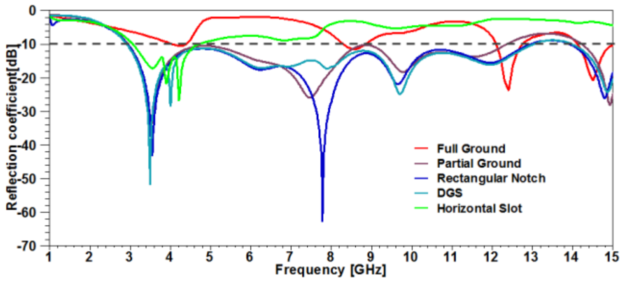


Fig. 8 Reflection coefficient S_{11} Vs Frequency characteristics of proposed antenna iterations

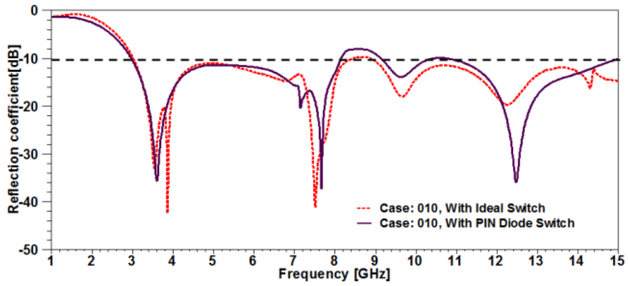


Fig. 9 Reflection coefficient S_{11} Vs Frequency characteristics of the proposed reconfigurable antenna for D_1-OFF, D_2-ON, D_3-OFF case with ideal and PIN diode switches.

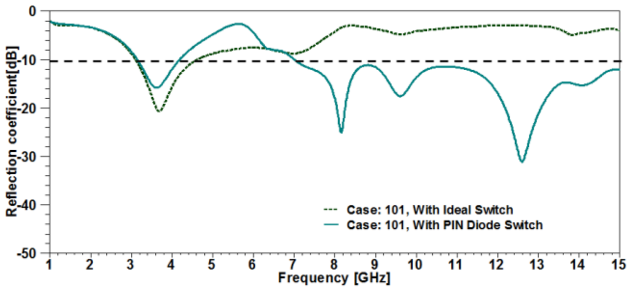


Fig. 10 Reflection coefficient S_{11} Vs Frequency characteristics of the proposed reconfigurable antenna for D_1-ON, D_2-OFF, D_3-ON case with ideal and PIN diode switches.

B. Radiation & surface current performance of designed antenna

The radiation pattern is similar for the first resonant frequency 3.5 GHz in 101 case and 3.6 GHz in 010 case though the operations performed on diodes are altered as shown in Fig. 11 and Fig. 12. E plane radiation pattern of the designed antenna is in dumbbell shape whereas H plane is omnidirectional in both the cases. For second resonant frequency 8.1 GHz in 101 case and 7.6 GHz in 010 case, the E plane radiation pattern develops two minor lobes in 0 to 180^o and H plane is nearly omnidirectional. E plane radiation pattern in 101 case has flat response in -120^o to -180^o whereas 010 case has round response for second resonant frequency. For third resonant frequency 12.5 GHz in 101 case and 12.4 GHz in 010 case, E plane almost regains its dumbbell shape and H plane is omnidirectional with two minor lobes. These radiation patterns can be clearly observed in 3D polar far field reports as shown in Fig. 13 and Fig. 14 for 101 and 010 cases respectively at their resonant frequencies. The surface current distributions of the patch and ground plane are shown in Fig. 15, Fig. 16 and Fig. 17. The peak gain and radiation efficiency of the UWB antenna with defected ground structure for both the cases 101 and 010 are shown in Fig. 18. In 101 case peak gain is achieved in operating band of 7.03-15 GHz as 5.1213dB and radiation efficiency as 93.44% in the operating band 3.15-4.17 GHz. In 010 case peak gain is achieved in operating band 9.13-15 GHz as 5.2038dB and radiation efficiency as 93.75% in the operating band 2.95-8.17 GHz.

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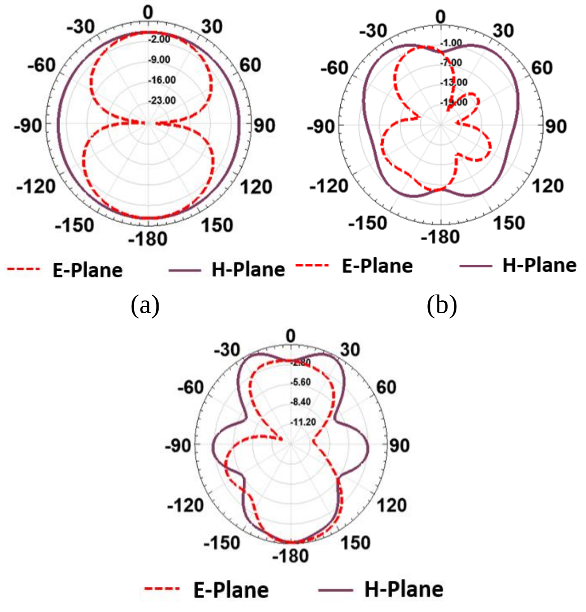
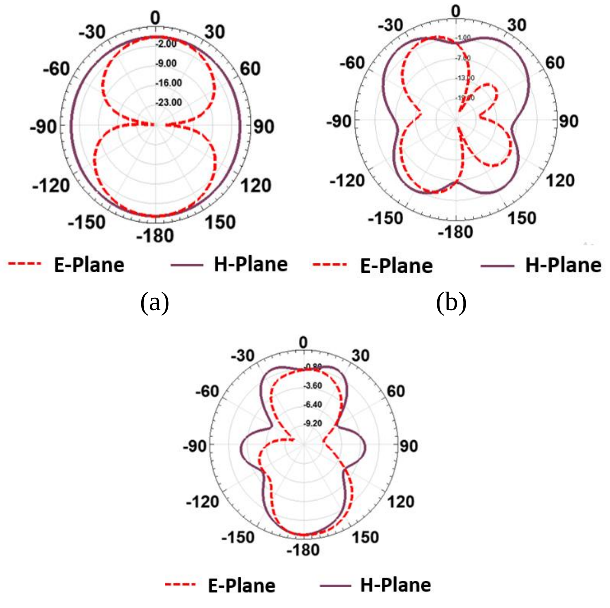


(a) (b)

(c)

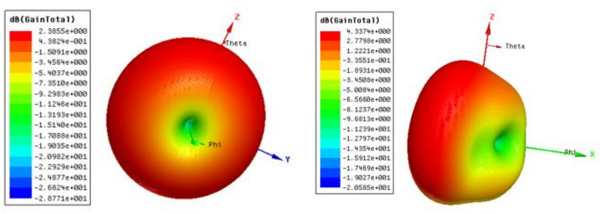
Fig. 11 Radiation pattern of the designed antenna for D_1-ON, D_2-OFF, D_3-ON case (a) 3.5GHz Frequency (b) 8.1GHz Frequency (c) 12.5GHz Frequency



(a) (b)

(c)

Fig. 12 Radiation pattern of the designed antenna for D_1-OFF, D_2-ON, D_3-OFF case (a) 3.6GHz Frequency (b) 7.6GHz Frequency (c) 12.4GHz Frequency



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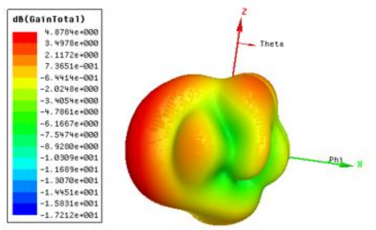
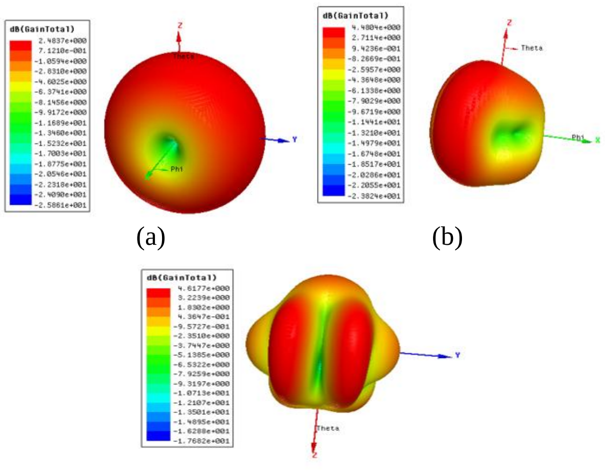


(c)

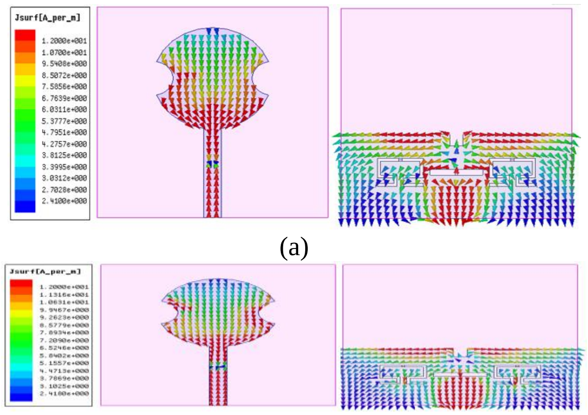
Fig. 13 3D Far field radiation of the proposed antenna for D_1-ON, D_2-OFF, D_3-ON case (a) 3.5GHz Frequency (b) 8.1GHz Frequency (c) 12.5GHz Frequency



(a) (b)

(c)

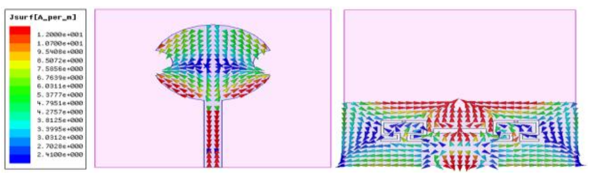
Fig. 14 3D Far field radiation of the designed antenna for D_1-OFF, D_2-ON, D_3-OFF case (a) 3.6GHz Frequency (b) 7.6GHz Frequency (c) 12.4GHz Frequency



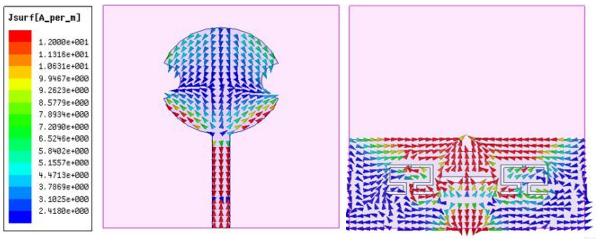
(a)

(b)

Fig. 15 Distribution of surface currents on patch and ground of the antenna (a) For 101 case at 3.5 GHz (b) For 010 case at 3.6 GHz.

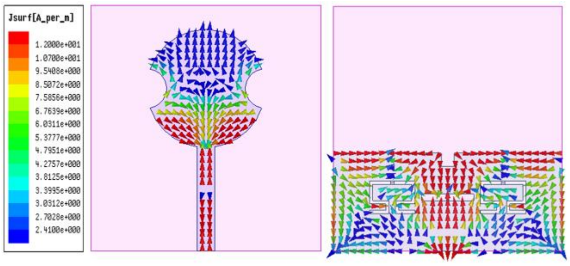


(a)

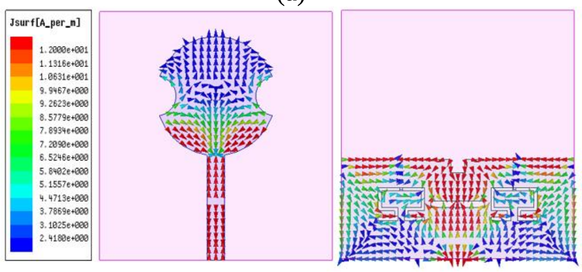


(b)

Fig. 16 Distribution of surface currents on patch and ground of the antenna (a) For 101 case at 8.1 GHz (b) For 010 case at 7.6 GHz.



(a)



(b)

Fig. 17 Distribution of surface currents on patch and ground of the antenna (a) For 101 case at 12.5 GHz (b) For 010 case at 12.4 GHz.

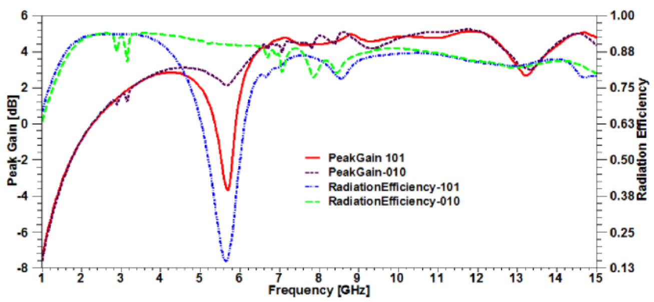


Fig. 18 Peak gain and radiation efficiency of antenna in both the cases 101 and 010

Table 2 Consolidated antenna performance for the switching cases of the proposed design

Switching Cases	Operating bands [GHz]	Resonant frequencies [GHz]	Peak Gain [in dB]	Radiation Efficiency %
101	3.15-4.17	3.5	2.8331	93.44
	7.03-15	8.1, 12.5	5.1213	86.85
010	2.95-8.17	3.6, 7.6	4.8740	93.75
	9.13-15	12.6	5.2038	88.52

V. CONCLUSION

A simple reconfigurable UWB antenna is designed using ideal and practical switching elements. Defected ground structures are employed in the partial ground plane for better impedance matching and a horizontal slot is incorporated to achieve frequency reconfigurability along with three switching elements. The ideal switches are used to obtain entire UWB range from 3.1-10.6GHz extending up to 15GHz and a narrow band in 3.1-5 GHz for WLAN applications. Later these ideal switches are replaced by PIN diodes. By using them we obtain ultra-wideband from 2.95-10.6 GHz extending up to 15GHz and a dual band in the regions 3.15-4.17 GHz and 7.03-15 GHz for 010 and 101 cases of diode biasing respectively. Also proposed UWB antenna having a wider bandwidth can be efficiently used in IoT applications.

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