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Design and Study of a CPW Fed Truncated Circular Patch Switchable Band-Notched UWB Antenna

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Abstract*: A reconfigurable Ultra Wideband antenna is developed and presented in this paper. The proposed antenna has the dimension of 32x36x1.6mm^{3}and shows its compactness. In this design, a pair of J-shaped slots combined together in the radiator of the antenna. The proposed antenna has the UWB range from 3.1-10.6GHz and extends up to 13GHz. Later, a study is conducted to apprehend the switching behavior of the antenna when the switching elements are incorporated in the combined J-shaped slot in parallel mode. The switching elements we used in this paper are PIN diodes (BAR64-02V). The switching conditions of the proposed antenna yields the frequency reconfigurable for notch band nature among the spectrum that covers WLAN and UWB which shows the compatible use in IoT devices.

***Index Terms*: Notched band, Reconfigurable, Ultra-Wideband antenna, WLAN.**

I. INTRODUCTION

The most important part of any communication system is antenna. An aptly designed antenna will improve data rates, increase range, security and improve the user experience. However, these basic antennas impose restrictions on the performance of overall system that arises due to fixed antenna characteristics. To eliminate or overcome such restrictions, antennas are made reconfigurable so that their behavior can adjust the inconsistent environmental conditions and system requirements. One of the biggest challenges in modern communication devices is to provide a single antenna for different applications. Existing antenna systems are limited to some applications. So, it is important to design a single reconfigurable antenna for multiple applications. It can be controlled to modify the frequency properties in a reversible manner which are suited for any particular application.

Ultra-wideband (UWB) systems continued to point up the attention because of their promising advantages of low-power consumption, low cost, and high data rates. UWB modules is employed in Wireless Personal Area Networks (WPAN), PC peripherals, mobile computers, imaging devices and several other applications. UWB antennas with band-notch characteristics can facilitate to reduce the in-band interferences within their bandwidth ranging from 3.1-10.6 GHz. Currently, several methods are available on the UWB antenna design and obtained notch band for rejecting some frequency bands to meet our desired requirements. To avoid the electromagnetic interference between the UWB system and the wireless system, notch band functionality is necessary. Several antenna styles regarding reconfigurable UWB applications are reported within the literature. In this a UWB antenna operates within the band of 3–10 GHz region has been planned and a notch band is achieved to serve different applications.

In [1], a rectangular slot antenna is proposed which consists of a inset-coupled M-shaped radiating stub, to obtain the wideband and reconfigurable filtering characteristics through incorporating the PIN diodes in an open/short-ended interdigital E-shaped resonator structure. A square-ring resonator with CPW feed is proposed in [2] which is further attached with a bandpass filter with short-circuit lines and incorporated with varactor diodes to provide the reconfigurability for a wideband and a continuous narrow band mode. One compact reconfigurable antenna in [3], with five switchable states is presented for switching among the UWB state, three narrowband states and a dual-band through the implementation of switchable slotted design in the ground plane of the antenna. A planar antenna with log-periodic dipole antenna configuration shown in [4], is integrated with notch filter to reject the 2.1-2.6 GHz band from a complete operating range of 1-6 GHz impedance bandwidth according to -10dB of S_{11} of the antenna with the U-shaped slot in the transmission line. In [5], the rounded corners geometry is used and enhanced the -10dB bandwidth and antenna's gain and achieved the dual-band performance with CPW fed rectangular shape blocks.

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A compact CPW fed monopole antenna having amoeba shape is shown in [6], which is asymmetric along its axis and provide notch band characteristics with the fractal aperture design.

In [7], an antenna is designed with the concept of rotated circular patch design yields high gain in the S-band and radiates with circular polarization through the given feeding method. The notch band characteristics are attained in the designed antenna presented in [8], which is composed of a trapezoidal monopole with DGS and it also radiates with circular polarization characteristics. Semicircle monopole antenna is implemented with MIMO technique is discussed in [9] to mitigate polarization diversity across UWB range including the two rejected bands from 2-5 GHz and 7-11 GHz. An antenna with MIMO structure is proposed in [10], achieves the WIMAX notch characteristics, for which the shorting stubs are placed on the reverse side of the antenna. Etching the U-shaped slot in the antenna's trapezoidal radiating element yielded the S-band WiMAX notch characteristics in [12]. A curved monopole antenna with wideband characteristics and a monopole with notch characteristics are presented in [13] shows the impedance bandwidth if 16 GHz and a split ring resonator based circular monopole antenna design discussed in [14] yields the dual notch characteristics with the SRR and CSRR structures deployed in the design. In [15] the notch band and its tunability is realized by the pi-shaped slot loaded with lumped varactor. An antenna in [16] with CPW feed uses the T-shaped stub, a pair of inverted S-shaped slots results the dual notch bands and its complementary operating bands of the antenna and the band-stop and bandpass response in [27] is tuned by varactor tuning of S-SRRs. In [17-19] switching elements are embedded in the antenna's ground plane and made the antenna switchable for the notch bands and other notch band reconfigurability techniques in the monopole antennas are discussed in [20-22], a polarization reconfigurable antenna with controlling pin diodes at S-band is discussed in [23]. Differently oriented parasitic strips are forming S-shaped radiator and the switching elements incorporated shifts the antennas operating frequency according to bias conditions which is discussed in [24]. The RF path selection within 3-port antenna structure presented in [25], is altered by PIN diode DC bias control and achieved reconfigurable filtering. An antenna comprising of circle-like slot with a trident-feed structure is turned as the antenna with notch band by incorporating the pair of nested C-type stubs on the back plane of substrate and these are connected through via as mentioned in [26]. The antenna's effective electrical length is altered to tune the single-fed slot loaded antenna in the range of 540-890 MHz region through the PIN diode and solid-state switches by controlling bias voltages is presented in [28]. In [29] an antenna with bow-tie configuration is proposed for obtaining pattern reconfiguration by employing the CPW-to-slot-line transitions, Vivaldi tapered slot pair with four PIN diode switching elements and provides the omnidirectional, end-fire pattern switching. An antenna with circular radiating element having three matching stubs is proposed in [30] to provide switching between 4 states namely low and high frequencies and LHCP, RHCP states through the bias control of PIN diodes.

Inspiring from the above-mentioned methods of enhancing the antenna's impedance bandwidth, incorporating notch bands and providing reconfigurability, in this paper, an antenna design is presented by modifying a circular radiator with a pair of connected J-shaped (inverting mode) is proposed and its reconfigurable notch band characteristics are discussed. The design parameters are given and discussed in Section-II with subsequent discussion of simulation results in Section-III along with reconfigurability and concluded in Section-IV.

II. DESIGN METHODOLOGY OF ANTENNA

The antenna design proposed, is built of four successive iterations and the first iteration is designed with a rectangular radiator over a ground plane which is rectangular in shape with specified dimensions as given and with a FR4 epoxy dielectric substrate. The rectangular partial ground is used and the CPW feed. The radiating patch and the rectangular ground are separated with a gap of '*Sp*' as shown in Fig 1(a). In the second iteration, the rectangular patch is modified by chamfering its top corners with a side length of 'a' as shown in Fig. 1(b), this is done to expect the improvement in antenna's impedance bandwidth. In the third design of the proposed design, the bottom corners of the truncated rectangular patch are rounded as presented in Fig 1(c). Finally, in fourth iteration, rectangular patch at partial ground is changed to semi-elliptical shape to have a better performance of antenna as specified in Fig 1(d).

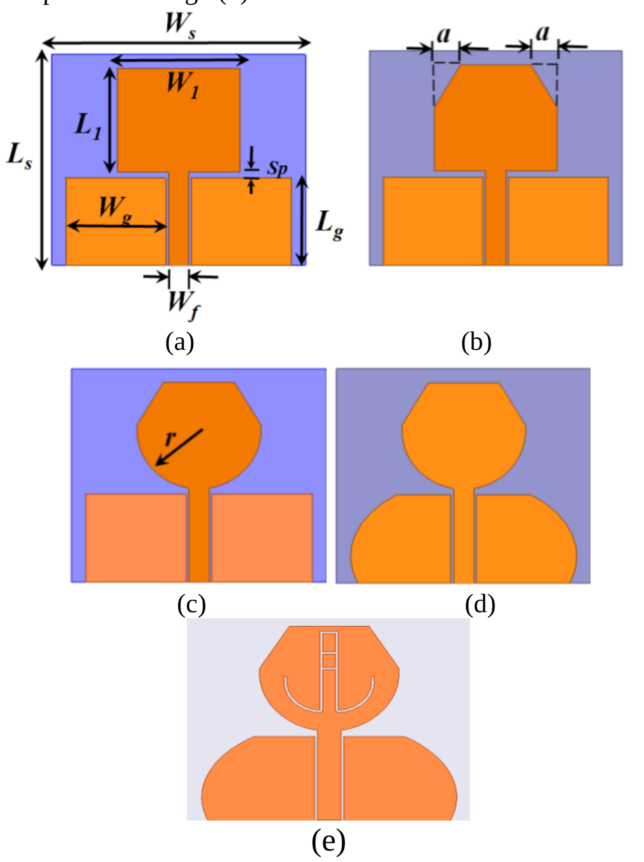
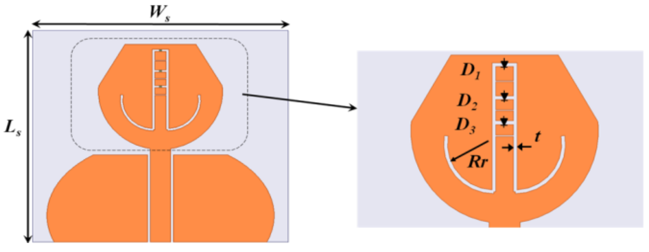
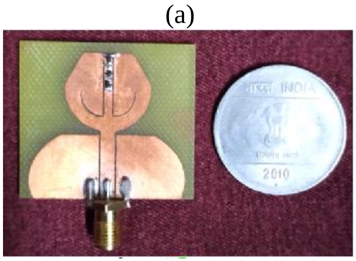


Fig. 1 Successive geometrical alterations towards UWB antenna – (a) Iteration-1: Rectangular patch with CPW feed (b) Iteration-2: Truncating top radiating patch (c) Iteration-3:

Antenna with semi-elliptical shape at bottom of the radiating patch (d) Iteration4: Semi elliptical ground e) Iteration-5: Two J-shaped slots combined together. Later on, the band rejection at desired frequencies is realized by incorporating two connected J-shaped slots which are composed in the circular patch of design iteration-4 as shown in Fig. 1(e). These J-shaped slots are made by joining one end of arc shaped slots which are extended by the narrow rectangular slots. This pair of J-shaped slots are connected together at their upper edges and successively joined at another two locations in the middle also. The successive merging of slots will help to create notch performance in the 3-4 GHz bands. To achieve DC biasing three slots are etched in the patch and the diodes are placed in these slots parallel to each other such as D1, D2 and D3. The anode terminal of the diode is placed towards the top of the patch as shown in Fig. 2(a). Now these three diodes will be having eight cases like off-off-off, off-off-on, off-on-off, off-on-on, on-off-off, on-off-on, on-on-off and on-on-on. According to these cases we can switch the antenna performance respective to our desires and can make antenna work at different bands which suites our band notch applications.



(a)



(b)

Fig. 2 (a) Geometry of proposed notch band reconfigurable antenna (simulation model) (b) fabricated design

Table 1: Antenna design parameters

Parameter	L_s	W_s	r	R_r	L_1	W_1
Value (in mm)	32	36	8	3	15	17
Parameter	L_g	S_p	W_f	a	W_g	h
Value (in mm)	13	1.8	3	3.5	14	1.6

III. RESULTS AND DISCSSIONS

A. Operating band characteristics of proposed reconfigurable antenna

The geometrical modifications and the reconfigurable version of the proposed antenna are modelled and simulated in ANSYS HFSS simulation tool and the frequency response for various geometrical alterations are observed and presented in Fig 3. It can be identified that the operating modes for different frequencies for different antennas are varying. The proposed antenna has good impedance matching from 3GHz to 12GHz. In the first iteration, the antenna is working at a band from 2.61 to 5.7 GHz and the resonant frequency is 3.8447. For the second iteration the working band lies between 2.94 to 5.58 GHz and resonant frequency is 3.8894 GHz. In continuation with this, the antenna works at a band from 2.65 to 12.92 GHz and resonant frequency is 3.5468 GHz as well as 10.0553 GHz in the third iteration. For the fourth iteration the operating band is between 2.62 to 13.49 GHz and resonant frequencies are 3.5021GHz, 7.4191 GHz, 10.9787 GHz respectively. The results obtained for the four iterations are shown in Fig. 3.

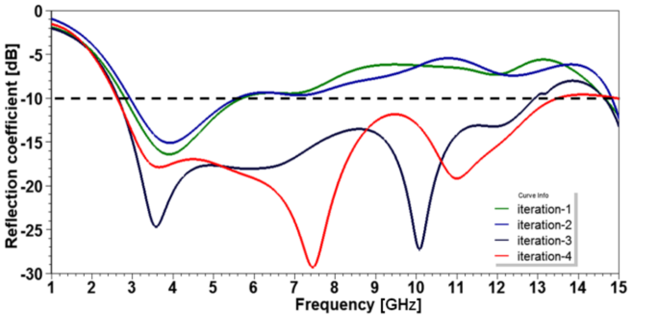


Fig. 3 Reflection Coefficient Vs Frequency characteristics of Antenna Iterations

For iteration-5, the antenna works from 2.80 to 13.62 GHz and the resonant frequencies are 3.1563,4.0756,7.6609 respectively as indicated in Fig. 4. The working band and resonant frequencies are computed through the reflection coefficient vs frequency curves presented in Fig. 3, Fig. 4 according to -10 dB impedance bandwidth criteria.

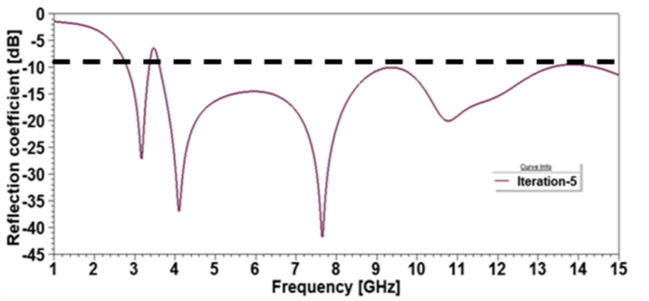


Fig. 4 Simulated S_{11} Vs Frequency characteristics of Antenna Iteration-5 (with connected J-shaped slots)

The antenna characteristics are observed at different switching cases are simulated and presented for various bias conditions of the PIN diodes D1, D2, D3. The plots are presented in Fig. 5, Fig. 6 shows the shift in the notch band occurred in the 3-3.5 GHz and 3.5-4 GHz region. The small notch is noticed in the region of 9-10 GHz band. The consolidated operating band characteristics are statistically presented in Table 2.

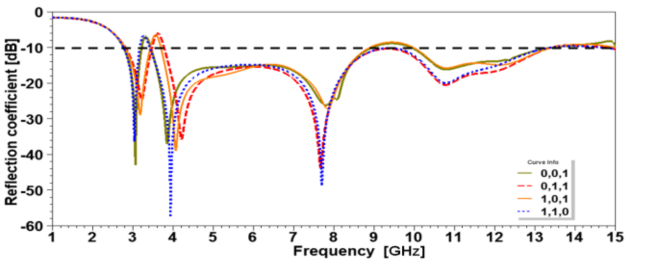


Fig. 5 Simulated performance of S-parameters for the biasing conditions of diodes D1-D3 (001, 011, 101, 110) where 1-ON, 0-OFF

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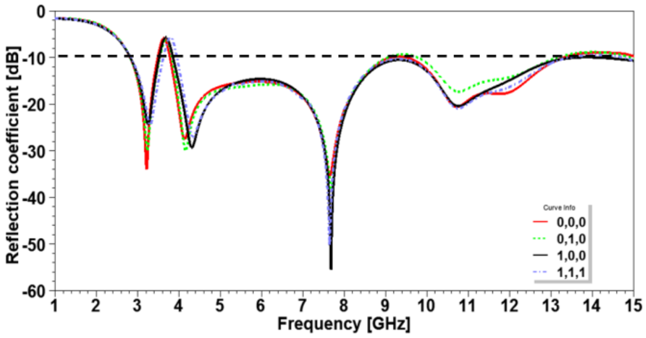


Fig. 6 Simulated performance of S-parameters for the biasing conditions of diodes D1-D3 (000, 010, 100, 111) where 1-ON, 0-OFF

A tuneable kind shift in the notch centre frequency of antenna is observed in the Fig. 4 for cases 000, 010, 100, 111.

B. Far-field characteristics of the reconfigurable states for the antenna proposed

Far-field pattern for the realized antenna could be better understood by studying 2D principle plane patterns and 3D polar plots

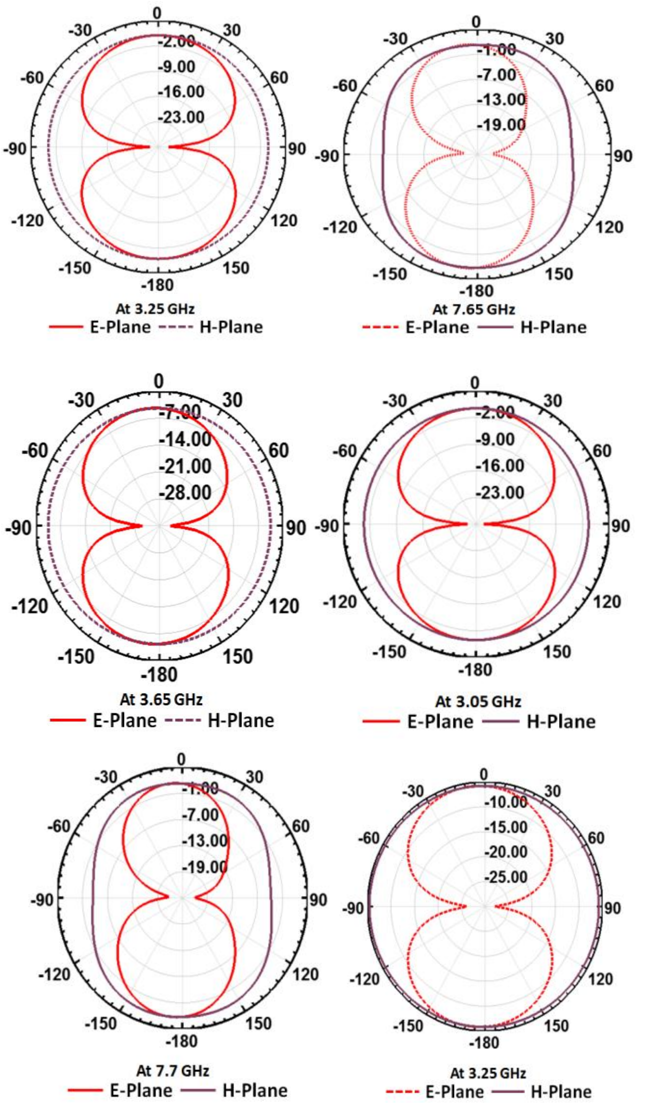


Fig. 7 Radiation patterns of the proposed antenna at resonance and notch frequency

Radiation pattern is similar for the first resonant frequency 3.25 GHz in 011 case and 3.05 GHz in 110 case though the operations performed on diodes are altered. E-plane radiation pattern of designed antenna is of dumbbell shape whereas H-plane is Omni directional in both the cases. For second resonant frequency 7.65 GHz in 011 case and 7.7 GHz in 110 case, the E-plane radiation pattern develops nearly dumble in 0 to 180^{o} and H-plane is nearly Omni directional. For third resonant frequency 3.65 GHz in 011 case and 3.25 GHz in 110 case, E-plane almost regains its dumble shape and H plane is Omni directional. These radiation patterns can be clearly observed in 3D far field reports as shown in Fig. 8 and Fig. 9 for 011 and 110 cases respectively at their resonant frequencies. It shows that the results are almost omni directional and at notch bands, gain is lowered.

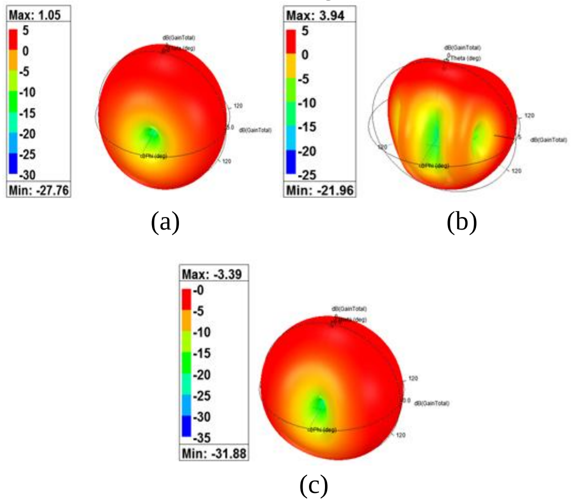


Fig. 8 3D far field report of antenna for biasing case-011 case a) 3.25 GHz frequency b) 7.65 GHz frequency c) 3.65 GHz frequency

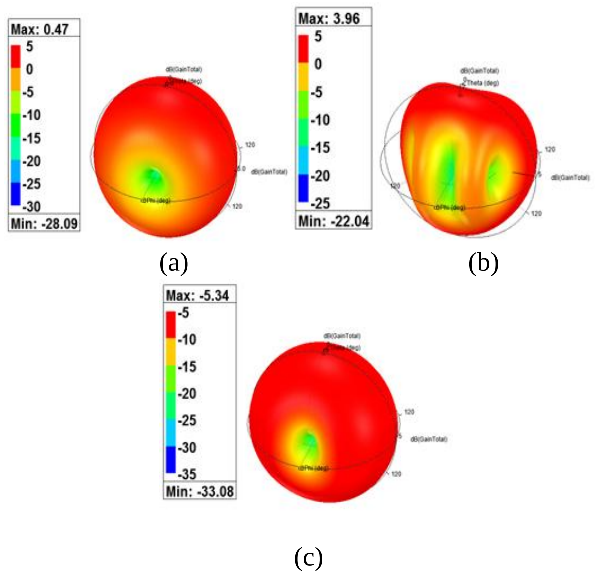
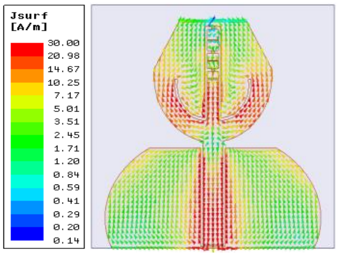
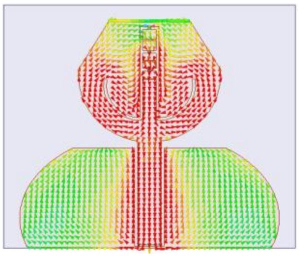


Fig. 9 3D far field result of antenna for 110 case (a) 3.05GHz frequency (b) 7.7GHz frequency (c) 3.25GHz frequency

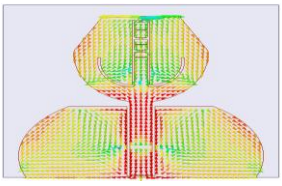
Surface current elements of the radiator and (partially etched) ground plane are shown in Fig. 10 and Fig. 11.



(a)

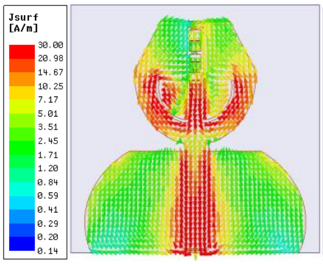


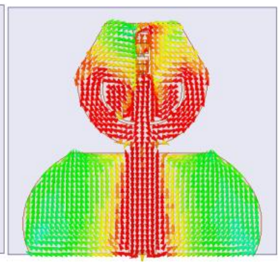
(b)



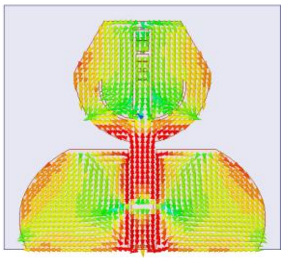
(c)

Fig. 10 Surface current distribution for biasing case-011 case at (a) 3.25GHz (b) 3.62GHz (c) 7.67GHz





(a) (b)



(c)

Fig. 11 Surface current flow for biasing case-110 at (a) 3.05GHz (b) 3.27GHz (c) 7.7GHz

Surface currents in Fig. 10, Fig. 11 shows that at different switching cases, at the notch band, the antenna possesses currents blockage near slots structures also the density is more at the diode region when it is turned to forward bias condition.

Table 2 Consolidated antenna parameters when different switching conditions are applied to the proposed reconfigurable antenna

Switching Cases	Operating bands / Resonant Frequencies [GHz]	Notch bands / Notch Center Freq [GHz]	Peak Gain [in dB] (Operating band)	Radiation Efficiency (Operating band)	Peak Gain [in dB] (Notch band)	Radiation Efficiency (Notch band)
000	2.82-13.30	3.49-3.79	4.8214	0.9534	-5.5569	0.2451
	3.22/4.15/7.65	3.64				
001	2.772-13.43	3.22-3.45	4.8801	0.9494	-5.7347	0.2291
	3.07/3.85	3.32				
010	2.82-13.16	3.54-3.83	4.7124	0.9551	-5.2050	0.2330
	3.25/4.15/7.69	3.69				
011	2.82-13.42	3.48-3.78	4.9716	0.9527	-5.3388	0.1905
	3.23/4.22/7.67	3.62				
100	2.83-14.08	3.53-3.86	4.8500	0.9539	-4.8533	0.2207
	3.26/4.31/7.67	3.69				
101	2.80-13.44	3.40-3.70	4.8990	0.9519	-4.6789	0.2149
	3.18/4.08/7.87	3.57				
110	2.77-13.39	3.12-3.42	4.9630	0.9514	-5.3415	0.2614
	3.05/3.94/7.70	3.27				
111	2.84-13.41	3.63-3.95	4.8970	0.9558	-4.7088	0.2424
	3.31/4.35/7.64	3.80				

IV. CONCLUSION

In this study, the simulation and fabrication of CPW Fed truncated circular patch antenna with band notched performance is discussed. As per the discussion and analysis above it is evident that the antenna is able to produce a tunable kind of notch band radiation characteristics within the UWB spectrum. The major switching in the notch band is clearly observed within the 110 and 011 cases of diode biasing conditions and the obtained switching notch bands are 3.12-3.42 GHz and 3.48-3.78 GHz respectively with sharper notch center. The substrate size of antenna is finalized to be 32 mm × 36 mm x 1.6 mm with a CPW fed modified circular patch shape and the very low radiation efficiency is found at notch bands which are nearer to 20%. The peak gain of the antenna for operating band of antenna is noticed more than 4.5 dB and the negative gain is seen in the notch band which shows a better rejection capability of antenna.

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