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MULTI-FREQUENCY RECONFIGURABLE ANTENNA WITH BAND NOTCH CHARACTERISTICS FOR WIRELESS APPLICATION

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Abstract:

In the past few years, Ultra-wide band technology has become a major area of study due to its merits such as low-power requirement, large channel capacity thus high data-rate, less sensitivity to the multipath effect and jamming resistance. As a result of these merits, they are being used in applications like short-range indoor communications, cognitive radio, sensing and imaging systems, radar, target localisation and characterisation, automotive applications etc. Another major emerging field of interest is the reconfigurable antennas because of their low cost and low profile characteristics. A major problem faced by Ultra-wide band technology is the overlapping of the narrow and wideband signals when a number of devices are connected simultaneously leading to interference problems. This issue of electromagnetic interference can be addressed by merging the Ultra-wideband technology with the concept band-rejection, which can be implemented with reconfigurable antennas. This new technology can be applied for WiMax and Wi-fi applications. The concept of band-rejection is made possible by using switching elements like PIN diodes, varactor diodes, radiofrequency (RF) micro electro mechanical system (MEMS), GaAs-field– effect transistors and optically controlled switches. Most of the already existing antennas are either capable of rejecting or tuning single band only (Wimax or WLAN separately) or they do not support full Ultra-wide band technology (no rejection) mode. In order to overcome these disadvantages, a simple, planar and easy to control Ultra-wideband antenna with on-demand rejection capability is proposed. In our proposed system compact design and analysis of reconfigurable notch band antenna using DGS for UWB (3.1-10.6 GHz) applications is proposed. The basic design has main feature to reduce interference from narrow band frequencies and the design has ability to recall notch bands according to different states of switches placed on defected ground plane.

Index Terms – reconfigurability, ultra-wideband, band-notch, DGS, band-rejection, pin-diodes, microstrip.

1. INTRODUCTION

In any wireless communication system, when a radio frequency (RF) signal is produced in a transmitter, some device must be used to spread out this signal through space to a receiver. This function is performed by antenna. Microstrip antenna contains a radiating patch on one surface of a dielectric substrate and a ground plane on other surface. The patch conductor is made of copper. Relative permittivity of the substrate must be low to increase the fringe fields which are responsible for radiation. They have several applications over the band of frequency range starting from 100 MHz to 50 GHz. The main disadvantage is the narrow bandwidth.

1.1. UWB Standards

In 2002, FCC has stated the band of frequency starting from 3.1 GHz to 10.6 GHz for ultrawide band (UWB).The main advantage of UWB antenna is that they are capable to utilize the complete ultrawide band spectrum and when an interfering signal shows up, the antenna can alter its arrangement in order to produce a notch band which removes the interference from the coexisting system. Main problem with the ultrawide band antenna is interference from various applications with narrow band. There are several narrow band standards that coexist within the UWB, of which the commonly used bands are IEEE 802.16 WiMax(3.3–3.6 GHz; 5.25–5.825 GHz), IEEE 802.11a wide local area network (WLAN) (5.15–5.35 GHz; 5.725–5.825 GHz), HiperLAN/2 (5.15–5.35 GHz, 5.47–5.725 GHz). This overlap of bands causes electromagnetic interference when a number of devices run simultaneously at these bands. In such a case, narrow band communication devices with strong signal transmission cause in-band interferences with nearby UWB systems, while the UWB systems may also interfere with those narrow band devices that have a weak signal reception. Thus, most important aim of antenna design is to define an ultrawide band antenna which covers about the complete ultrawide band with smallest interference from presented narrow band applications. For reducing EMI, frequency bands of offered applications should be detached from ultrawide band. Reconfigurable notch bands in UWB antennas are dynamic research plot. The advantage of the antenna with reconfigurable notch band is to make maximum utilization of the frequency spectrum resources and work collectively well with the presented narrowband wireless services. In this regard, many UWB antennas with intrinsic band-rejection properties have been studied using different techniques. However, band-rejection is not constantly required; rather on-demand band-rejection is more desirable.

1.2. Reconfigurability

Reconfiguring property of antenna is classified into four fundamental types: frequency reconfigurable, polarization reconfigurable, pattern reconfigurable and hybrid reconfigurable (the combination of any of the above three). Frequency reconfigurable antennas are capable of changing their resonant frequency for various operating bands. Conventional antennas and microstrip antennas are pivotal to applications in modern communication and navigation systems. Unlike conventional microwave antennas, microstrip antennas can conform to both planar and non-planar surfaces. Military or civilian applications such as space and weight restricted aerospace vehicle structure microstrip antennas are better suited in comparison to conventional antennas. In this proposed model, reconfigurability can be achieved in the antenna by using Pin diodes.

This paper mainly helps to analyse the architecture for wireless applications of DGS-based multi-frequency antenna. This Multi-frequency operation is achieved with open-end U shape slot in the ground plane. The proposed antenna design, layout and ideas are represented in Section 2. Section 3 depicts the conceptual antenna architecture, configuration and values of the various parameters for designing antenna. Section 4 portrays the performance of the proposed design. Section 5 summarises the overall system analysis.

2. ANTENNA CONFIGURATION

The literature survey was done based the concept of antennas that operate in Ultrawide band range with varied structure and the optimal structure for an antenna to work under UWB range along with the concepts of frequency notching and reconfigurability was selected .

2.1. Proposed antenna structure

The geometry of the designed multi-frequency reconfigurable antenna for wireless applications is shown. The rectangular shape patch element is placed on an FR4 substrate with a height of 1.6 mm and relative permittivity (εr) of 4.4 and a tangent loss of 0.002. The metallic ground plane is present on the other side of the patch. The optimized dimension of radiating patch is15 × 12 mm^2 and the ground plane is 32.5 × 27.5 mm^2.The FR4 substrate is used due to its properties like feasibility and affordability. The proposed antenna is excited by 50Ω micro strip feedline to attain better impedance matching. The designed antenna is based on the concept of defected ground structure (DGS), which is implemented to improve the performance and to obtain a wide frequency spectrum.

The U shaped slot is engraved in the ground plane to improve the bandwidth and to obtain multiband capability of the designed antenna. The dimension of slot determines the frequencies to be notched and the width of slot decides the bandwidth of frequencies to be notched. By inserting two PIN diodes in the slot, the designed antenna can operate in different frequency band. Several switching techniques are used to obtain any operating condition of reconfigurable antenna. A patch antenna uses PIN diode for several modes of switching to control the surface current.

2.2. Proposed Antenna geometry

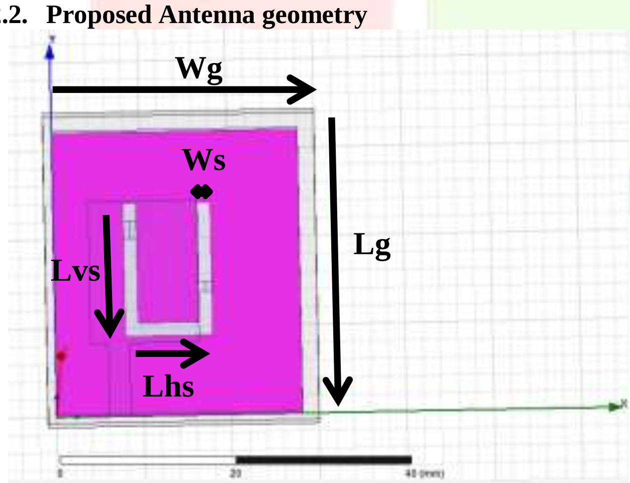

Fig 1: Ground plane with slot

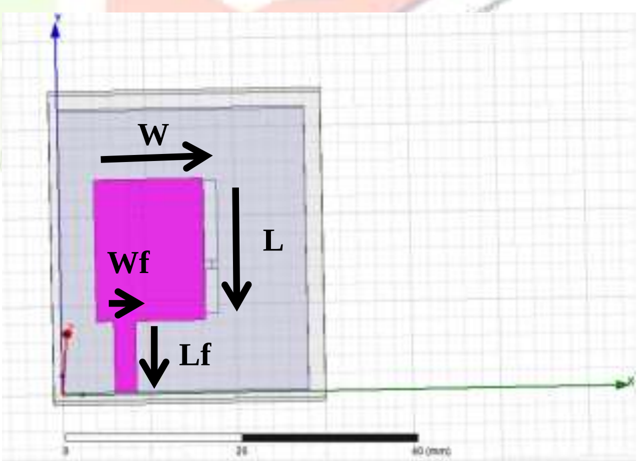

Fig 2: Patch

The following figures (1) & (2) represent the dimensions of the ground plane and the patch with which the antenna has been designed for UWB application. The values for each dimension have been specified in the table presented below. The rectangular structure has been selected not only because of its wide operating frequency in the UWB range but also because of its efficient notching capability in the required frequency band. In addition to this, PIN diodes are introduced in the slot for achieving reconfigurability.

Table 1: Dimensions of the Reconfigurable Antenna with DGS

Parameters	Dimensions
Wg	27.5 mm
Lg	32.5 mm
W	12 mm
L	15 mm
Wf	2 mm
Lf	8 mm
Lvs	12 mm
Lhs	9 mm
Ws	1.2 mm

2.3. Patch and feeding technique

The patch for microstrip antenna is varied based on the type of application. Microstrip patch antennas can be classified based on their physical range. Different types of patches have different purposes. There are diverse Defected Ground Structure configurations like square, rectangular, circular, dipole, printed and elliptical. There are different slots in patch antenna configuration such as A slot, H slot, E slot, U slot patch antennas. They are used for different bands of frequency.

Microstrip line feeding method is used here. It is very simple to design and fabricate. But this technique suffers from some limitations like, if the substrate thickness is increased in the design then the surface current and the spurious radiation also increases. Because of that the cross polarization radiation arises which are undesirable. Microstrip line feed can be used in the conditions where performance of the antenna is not a considered largely.

3. DESIGN PROCEDURE FOR UWB RECONFIGURABLE ANTENNA

Generally, a radiating patch over a defected ground plane is a suitable combination for achieving nearly 50 Ω impedance matching across a wide frequency range. Simultaneously, such a structure enables designing low cost, planar wide bandwidth antennas with enhanced radiating properties. Thus, the proposed design starts with a rectangular radiator over a rectangular defected ground plane that helps in band rejection in the UWB range and then gradually evolves to a reconfigurable antenna after the introduction of PIN diodes that act as switching elements.

3.1. Introduction of slots

After designing a well matched UWB antenna, band rejection is achieved by etching a U shaped slot on the ground plane which is called the Defected Ground Structure. DGS is an emerging technique for improving the various properties of microwave circuits, like the narrow bandwidth, cross-polarization, low gain, and so on.

The frequencies to be rejected are controlled by adjusting the length of slot (Lslot) and the width of the U shaped slot (Wslot).The length of the slot is calculated by using the formula,

$$Lslot = c/4fl \sqrt{\varepsilon eff} \quad , \text{c is the speed of light}$$

3.2. Introduction of PIN diodes

In this antenna design, the concept of reconfigurability is achieved by using PIN Diodes in the slots that are etched on the ground plane. PIN diodes are used for the reason that, they perform high speed switching and are of compact size. Pin diodes are used for switching. A patch antenna uses PIN diode for several modes of switching to control the surface current path length. The slot length is changed according to the different operating states of the diode and this helps in rejecting various frequency bands. Length of the slot is changed due to the ON state of diodes.

During ON state, the diode behaves like a short circuited path and there is a flow of current, due to this effective length of the slot is decreased. During the ON state of diodes, antenna resonates at higher frequencies. During OFF state, length of the slot is increased so that the antenna resonates at lower frequencies. The antenna covers high operating frequency bands when all the switches are in ON state.

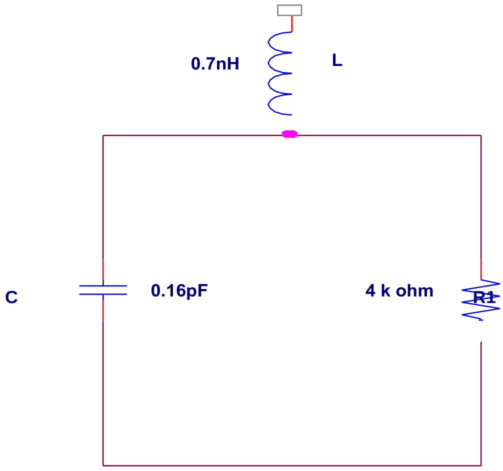

Fig 3: Equivalent Circuit of Pin diode in Reverse biased Condition

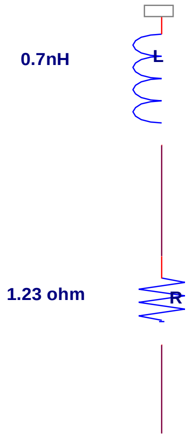

Fig 4: Equivalent Circuit of Pin diode in Forward biased Condition

The equivalent circuit of Pin diode contains an inductance L of value 0.7 nH in series with resistance R of value 1.23 ohm and in reverse biased condition it consists of Capacitance C of value 0.16 pf in parallel with resistance R of value 4 kohm with inductance L of value 0.7 nH in series with parallel combination of capacitance and resistance.

4. SIMULATED RESULTS AND DISCUSSION

The proposed antenna structure is designed and simulated by using Ansys HFSS 13.0 software. The various parameters such as return loss (S_{11}), VSWR, radiation pattern and gain are observed for various conditions of diode D1 and D2. The concept of reconfigurability is explained by the switching of diodes D1 & D2 and it makes the antenna to radiate and notch different frequency bands for different conditions.

Consider state 1, when both the diodes D1 & D2 are in OFF state (both are reverse biased) and the antenna has two different resonant frequencies f1= 4.1 GHz with S_{11}= -26.29 dB and f2= 9.2 GHz with S_{11}= -34.82dB. This state of the diodes notch the frequency range 3.1 GHz – 3.6 GHz; 4.7 GHz – 5.2 GHz; 6.4 GHz – 7.0 GHz and the rest is passed.

In state 2, when the diode D1 is in OFF condition (reverse biased) and D2 is in ON condition (forward biased), the observed return loss states that the antenna resonates in multiband frequencies f1= 3.8 GHz with S_{11}= -15.79 dB, f2= 5.8 GHz with S_{11}= -16.39 dB and f3= 9.2 GHz with S_{11}= -29.75 dB. This state of the diodes notches the frequency range 3.1 GHz – 3.6 GHz; 6.5 GHz – 7.0 GHz and it passes the rest.

In state 3, when the diode D1 is in ON condition (forward biased) and D2 is in OFF condition (reverse biased) and the observed return loss states that the antenna resonates in multiband frequencies f1=4.1 GHz with S_{11}= -23.49 dB, f2= 9.1 GHz with S_{11}= -29.66 dB. This state of the diodes notches the frequency range 3.1 GHz – 3.6 GHz; 4.5 GHz – 5.4 GHz and it passes the rest.

Now consider state 4, when both the diodes D1 & D2 are in ON state (forward biased) and the antenna has two different resonant frequencies f1= 6.1 GHz with S_{11}= -15.92 dB and f2= 9.1 GHz with S_{11}= -29.05dB. This state of the diodes notches the frequency range 3.1 GHz – 3.6 GHz; 4.4 GHz – 5.45 GHz and it passes the rest.

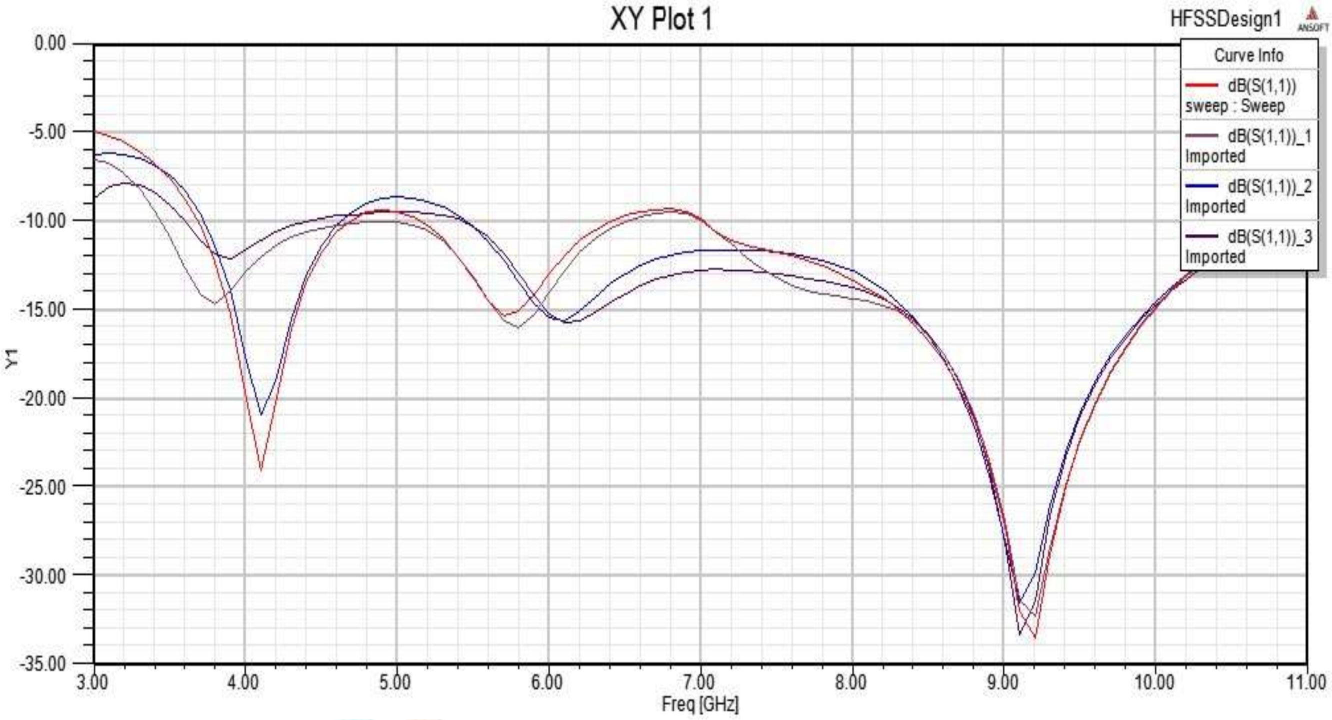

Fig 5: S_{11} Comparison chart for the various modes of operation of PIN Diode

- OFF OFF
- OFF ON
- ON OFF
- ON ON

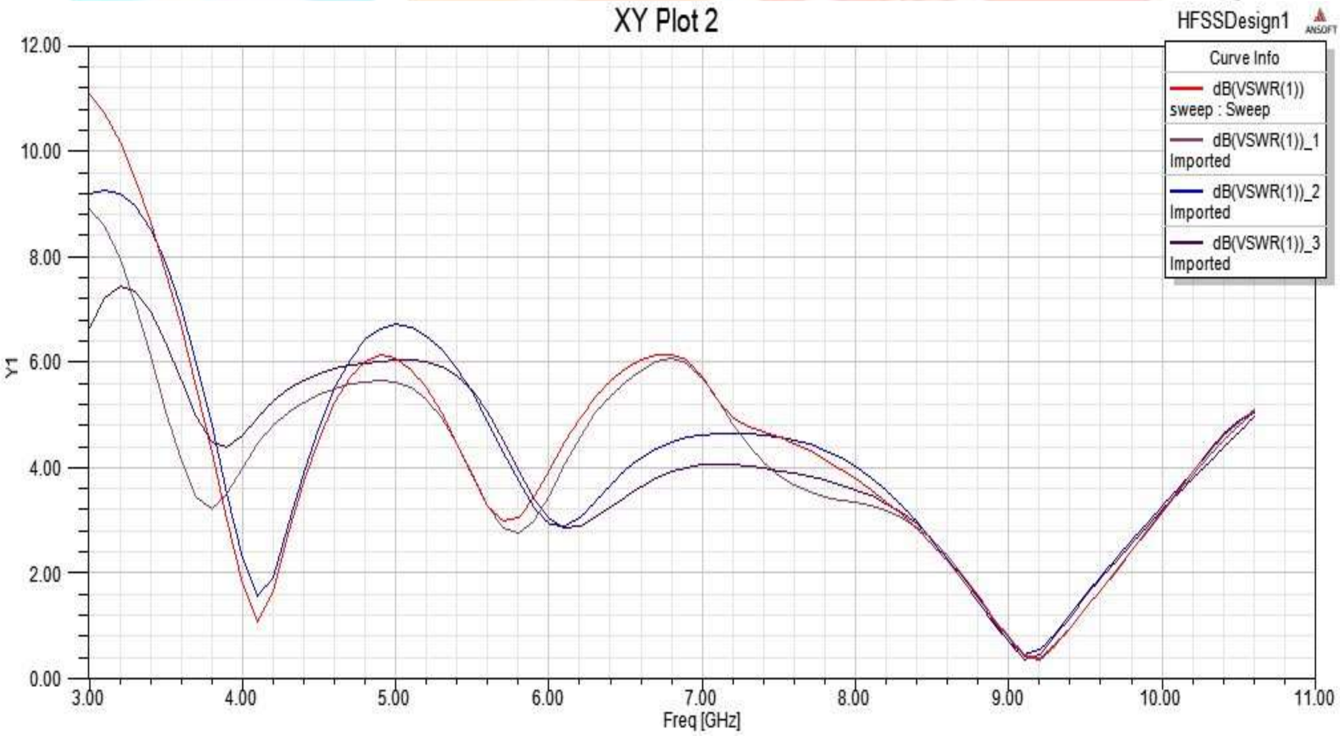

Fig 6: VSWR Comparison chart for the various modes of operation of PIN Diode

Table 2: Different configurations and operations based on the status of the two PIN Diodes

S.NO	DIODE 1	DIODE 2	PASSED FREQUENCY (GHz)	NOTCHED FREQUENCY (GHz)	GAIN (dB)
01.	OFF	OFF	3.6 GHz – 4.7 GHz 5.2 GHz – 6.4 GHz 7.0 GHz – 10.6 GHz	3.1 GHz – 3.6 GHz 4.7 GHz – 5.2 GHz 6.4 GHz – 7.0 GHz	7.48 dB
02.	ON	OFF	3.6 GHz – 4.5 GHz 5.45 GHz – 10.6 GHz	3.1 GHz – 3.6 GHz 4.5 GHz – 5.4 GHz	6.92 dB
03.	OFF	ON	3.6 GHz – 6.5 GHz 7.0 GHz – 10.6 GHz	3.1 GHz – 3.6 GHz 6.5 GHz – 7.0 GHz	7.42 dB
04.	ON	ON	3.6 GHz – 4.4 GHz 5.45 GHz – 10.6 GHz	3.1 GHz – 3.6 GHz 4.4 GHz – 5.45 GHz	7 dB

5. GAIN ANALYSIS OF PROPOSED STRUCTURE

Radiation pattern is another important property of an antenna which is used for measuring the maximum amount of energy radiated in a direction which is also termed as directivity. It is the amount of energy focussed in a specific direction. Radiating property of antenna is used to measure the transmission/receiving property of an antenna. The E-plane represents the electric field in the direction of maximum radiation while the H-plane represents the magnetic field in the direction of maximum radiation. Spherical coordinate system is used for plotting the graph both θ and φ is used.

The simulated results of radiation pattern are given in Figs. 7, 8, 9 & 10.

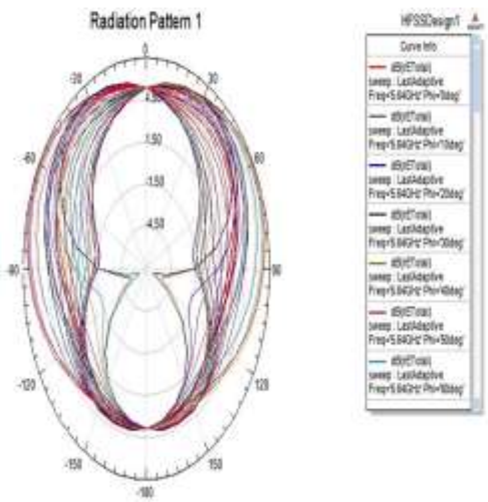

Fig 7: Diode D1 – OFF ; Diode D2 - OFF

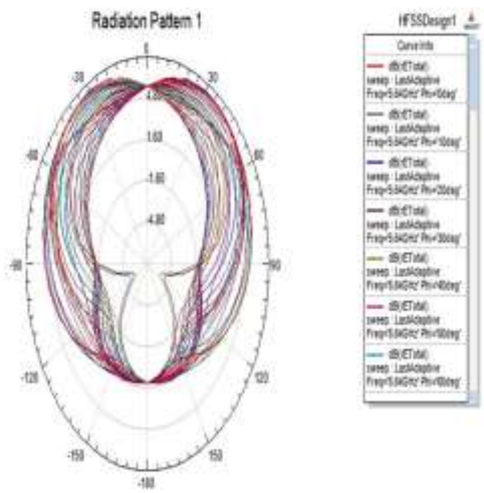

Fig 8: Diode D1 – OFF ; Diode D2 - ON

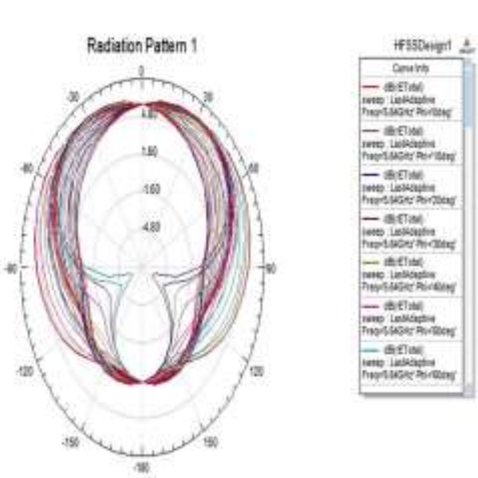

Fig 9: Diode D1 – ON ; Diode D2 - OFF

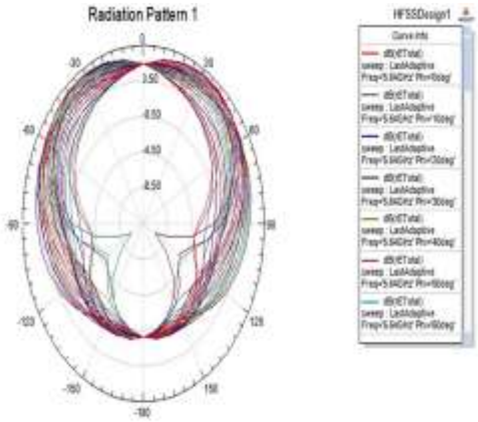

Fig 10: Diode D1 – ON ; Diode D2 - ON

From the polar plot graph of the radiation pattern, it can be observed that radiation pattern obtained is Omni-directional at the resonant frequencies.

6. CONCLUSION

A UWB antenna with On-demand band rejection & reconfigurability is proposed. The antenna can work in four modes based on the states of the diodes. A U-shaped open-ended slot is used to achieve frequency notching and controlled reconfigurability is achieved with the help a low power control arrangement that consists of two PIN diodes. For better understanding, the design process and detailed analysis on the reconfiguration mechanism are presented. The antenna is built on a low-cost FR4 substrate and is tested to validate the performances. Stable radiation pattern is obtained with a significant improvement in gain across the band. With the added flexible rejection capability of the antenna, it aids in avoiding mutual interference between UWB and the other narrow-band receivers. The proposed antenna can improve signal quality, system capacity and efficiency in the communication link.

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