Metamaterial inspired ultra wide band notched reconfigurable MIMO antenna for cognitive radio platform and wireless applications

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Cognitive Radio (CR) platform represents a technology resolution to increasing spectrum capacity and utilization. The conventional microstrip antennas lag in low gain and narrow bandwidth and it is the one of the major limitations .The most recent design for practical CR platform and wireless application is reduction in size with improvement in gain, bandwidth and multiple frequency operation. The challenging part was to develop metamaterial primarily based signature structures and techniques that overcomes the limitation of the conventional antenna by increasing the gain, bandwidth and applicable for multiple frequency operation. This paper proposes a Metamaterial inspired ultra wide band notched reconfigurable MIMO antenna for cognitive radio platform and Wireless applications. The projected antenna consists of two split ring resonators metamaterial antenna with reconfigurability. The split ring resonator used in this structure increase the wide band characteristics. By introducing a single switch at each gap of metamaterial structure, their impact can be activated and deactivated which ends in reconfigurable antenna. The projected antenna has better results of S-Parameters for ultra wide band (UWB), band notched operation, frequency reconfigurability and simulated using High Frequency Structure Simulator machine software package.

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Keywords: Ultrawideband (UWB), Split ring resonator, T-shaped ground plane, reconfigurable, Multiple input multiple output (MIMO)

1. Introduction

In the recent years electromagnetic metamaterials (MTMs) are widely used for antenna applications. These specifically designed composite structures have some special properties that cannot be found in natural materials. Metamaterials are also called Double negative (DNG) materials, Left handed materials (LHM) etc. The employment of metamaterials could enhance the radiated power of an antenna. Negative permittivity and permeability of these engineered structures can be utilized for creating electrically small antenna, extremely directive, and reconfigurable antennas. These, metamaterial based primarily antennas have also demonstrated the improved efficiency & bandwidth performance. The simplest scenario is the case where a transceiver transmits signals in one frequency and receives at another frequency. In this case, instead of using a separate antenna for each band, a frequency-reconfigurable antenna is used. The reconfigurable antenna becomes compact and reduces the system cost and also the implementation becomes easier. The most important objective in the design of these antennas is to keep the desired radiation-pattern and polarization characteristics all over the operational frequency bands. This is a challenging task because normally the physical size of the antenna cannot be easily modified during the operation. After all it’s perpetually attainable to use mechanical switches to modify the antenna’s physical characteristics. An important technical breakthrough towards achieving high channel capacity in multipath environments is MIMO systems. Multiple antenna system at both transmitter and receiver ends is to enhance the efficiency of the communication system.

2. Literature review

The need of the hour is to optimize antenna parameters like gain and bandwidth. The desirability to have a compact antenna configuration further deteriorates these two parameters as gain and bandwidth both are directly related to the size of the antenna. In order to increase the gain, techniques such as loading of high permittivity dielectric substrate [1], inclusion of an amplifier type active circuitry [2] and stacked configuration [3] are used. Bandwidth improves if the substrate thickness is increased, or the dielectric constant is reduced. Use of thick substrates with the help of air or foam along with impedance matching technique [4], suspended microstrip antenna with a dielectric resonator [5], truncating and slotting the patch in C shape, U shape, E shape [6], etc. have raised the bandwidth up to 30%. Use of metamaterials (MM) for further improving the performance of microstrip antennas (MSA) has been the recent trend in this field. This paper ends in the contribution of SRR metamaterial structure rather than patch antenna that has distinct characteristics of bandwidth enhancement.

Multiple-input-multiple-output technology, with the potential of skyrocketing high data rate while not requiring additional frequency spectrum or power, has been drawing abundant attention [7]. Multiple antennas installed in the transmitter and/or receiver in MIMO communication systems with low coupling between them is shown in the Fig. 1.

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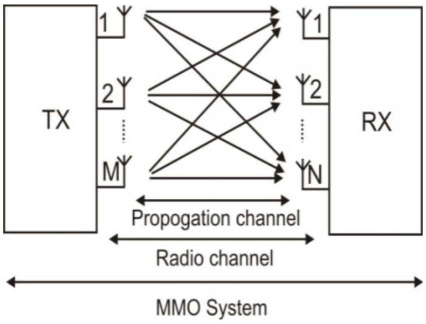

Fig. 1. MIMO antenna

However, for portable devices where the space is extremely limited, installing MIMO antennas with low coupling is always a great challenge for antenna designers. The UWB from 3.1 to 10.6 GHz, assigned by the FCC for unlicensed use, overlaps with the WLAN frequency band and hence the UWB system and WLAN systems may interfere with each other. One of the possible solutions to this problem is to design the UWB antenna with band notched characteristic [8]–[10],[17]. In [11]–[14],[18] MIMO antennas with notched characteristics were studied to suppress interference from the WLAN systems. This paper ends in UWB MIMO band notched reconfigurable antenna. The design feature is that split ring resonator is designed instead of the patch and switches can be provided at the slots. The vertical strip at the edge of ground plane provides band notched characteristics. Activating the switches activates SRR and band notch disappears. The projected antenna system can be used for CR platforms and MIMO applications. Results show that the antenna will operate from 3.1 GHz to more than 15 GHz with wide band characteristics. Mutual coupling between the ports is greater than -15dB.The switching characteristics were studied for on and off states and band notch shows no interference with WLAN systems.

3. Antenna design

3.1. Split ring resonator

Split ring resonator is a typical metamaterial structure. Meta material is a combination of "meta" and "material" Meta is Greek word which suggests altered or changed [11]. Those electromagnetic properties are altered. They are typically man made material. The metamaterial is outlined as "a material that gains its properties from its structure rather than directly from its composition". The conductor width, gap openings and the length are the parameters which are optimized so as to realize proper resonant frequency.

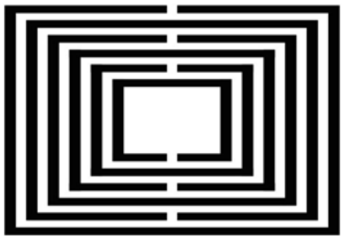

Fig. 2. Structure of split ring resonator

It consists of square shaped rings with gaps in between them on the opposite side of both the rings. This structure is printed on a substrate as shown in Fig. 2.

3.2. Split ring resonator analysis

The Split ring resonator analysis is employed to obtain the resonant frequencies as prescribed in [15]-[16]. The resonant frequencies of split ring occur at half wavelength comparable to each loop length. When two resonators with two different frequencies are coupled the frequency shift depends upon the coupling between the two rings. Electromagnetic fields penetrate through the rings and current is induced. Gaps represented by S prevent current flowing around the ring which considerably increases the resonance frequency of the structure. This is the slot where switches are inserted. Here l_1 and l_2 are the length of the rings and W is the width of each ring as shown in Fig. 3.

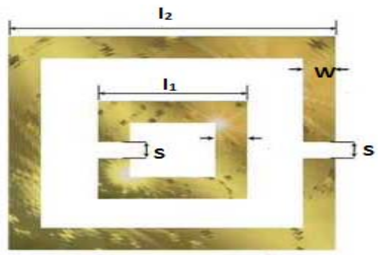

Fig. 3. Microstrip structure of split ring resonator

With the help of the below equations, a theoretical study was done on the identification of the length of the ringAverage loop lengths

$$L_1 = 4 \times l_1 - S - 4 \times W \quad (1)$$

$$L_2 = 4 \times l_2 - S - 4 \times W \quad (2)$$

Resonant frequency of each loop occurs at half wavelength.

$$f_1 = \frac{c}{2L_1\sqrt{\varepsilon_{eff}}} \quad (3)$$

$$f_2 = \frac{c}{2L_2\sqrt{\varepsilon_{eff}}} \quad (4)$$

After numerical calculations for f_l= 3GHz L_l=33.3mm where c is the velocity of light.. Substituting the value of L_l in equation (1), the length of the ring l_l=3.2 mm ≈ 3 mm and subsequently l_2= 9mm. Hence the geometry of split ring resonator as shown in Fig. 4.

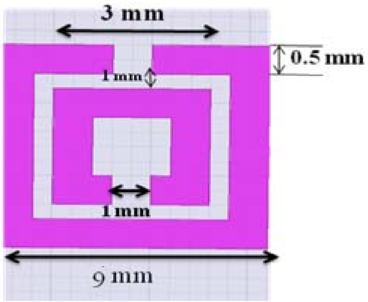

Fig. 4. Geometry of split ring resonator

4. UWB reconfigurable antenna

Split ring resonator was introduced as slots in the, ground plane or as conducting strips near to feed line. Resonator implemented in ground plane provided good matching characteristics but was used for dual band operation [19]-[20]. Resonator implemented as slot in patch works in UWB band from 4GHz to 10GHz. One of the switching characteristics results in non-notched UWB response. Resonator was implemented as conducting strips near to ground plane as shown in Fig. 5. Simulation on the S parameters of the UWB reconfigurable metamaterial has been carried out and results are shown in Fig. 6 and Fig .7. It can be shown the antenna has a low cutoff frequency (for S11 < −10 dB) of about 4 GHz (which is higher than 3.1 GHz required for the UWB). Reconfigurablity is not obtained for multiband operation.

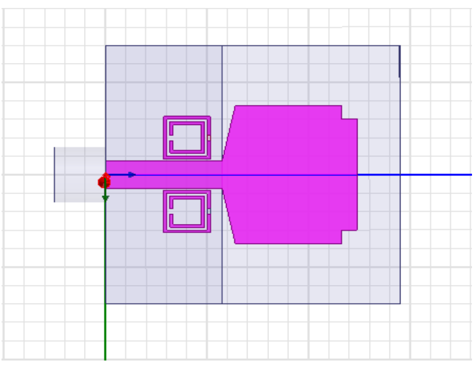

Fig. 5. Existing UWB reconfigurable antenna

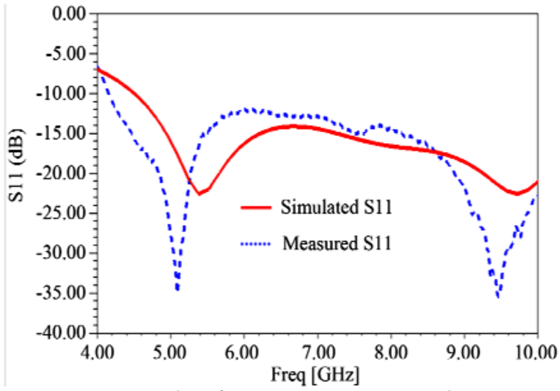

Fig. 6. Results of UWB response-return loss Vs frequency

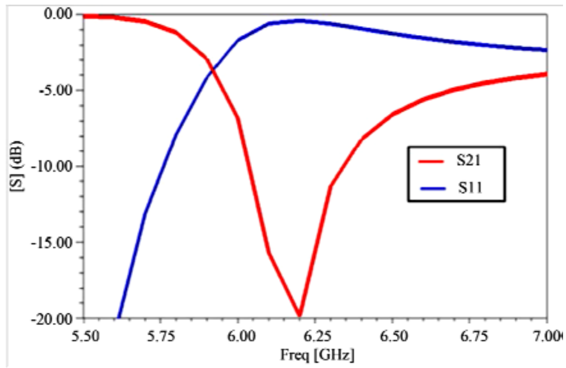

Fig. 7. Existing switching conditions

5. Applications of metamaterial UWB band notched reconfigurable antenna in CR platform

The proposed antenna improves the isolation between the elements and satisfies UWB characteristics and also band notch reconfigurability. The metamaterial split ring resonator is meant rather than patch on the substrate that improves the bandwidth. It is a well-known proven fact that if the thickness of the substrate of the patch antenna is increased, its bandwidth also improves. But the major disadvantage of increasing thickness reduces efficiency. This drawback has been overcome by split ring resonator structure. By introducing the switches within the gap of metamaterial structure reconfigurability can be obtained. The switches work in parallel configurations. When they are in ON state they perform switching characteristics. Switching them OFF will bring back UWB response. This antenna performs UWB (3.1–10.6 GHz) transmission. The tunability of the antenna at notch frequencies by integrating switches is required to minimize the interference between the primary and the secondary user. One important point is that for both MIMO scenarios, the impact of isolation and mutual coupling needs to be studied. The T-shaped ground stub in the proposed UWB band notched reconfigurable antenna for MIMO has two main functions: providing better matching for the antenna and enhancing isolation between the radiating elements. Earlier Y-shaped stub was stub was used. It occupies more space. A T-shaped is used because the size of the antenna can remain compact. The vertical strips are used to provide good impedance matching characteristics.Patch antenna is replaced by split ring resonator. Fig. 8 shows Metamaterial UWB reconfigurable antenna for MIMO applications and CR platform

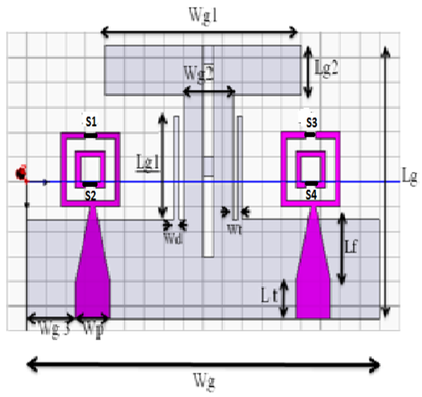

Fig. 8. Proposed Metamaterial UWB band notched reconfigurable antenna

The dimensions of the proposed antenna are given in Table 1. The antenna is fabricated on a 1.6 mm thick (i.e.) h =1.6 mm Taconic RF-35 substrate. The essential parameters for the design ε_r= 3.5, h=1.6 mm, tan δ = 0.002.

Table. 1. Design parameters of Metamaterial UWB band notched Reconfigurable antenna

Wg	Wg1	Wg2	Wg3	Wd	Wt
36	20	5	5	0.5	0.5
Wp	Lg	Lg1	Lg2	Lf	Lt
3.5	22	8.3	4	6	3
S1	S2	S3	S4		
1	1	1	1		

6. Results and discussion

6.1. Return loss

The designed antenna is simulated by using HFSS 13 simulator (High Frequency Structure Simulator).

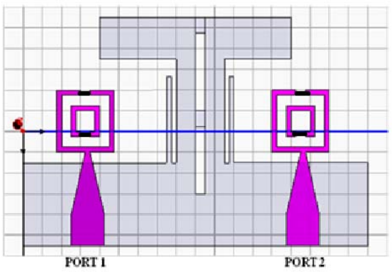

Fig. 9. View of proposed antenna

Fig. 9. shows the proposed antenna. The antenna has simulated impedance bandwidth S_{11}< -10dB from 3.1 to 15 GHz. The reconfigurable antenna works as follows. When the switches are deactivated it shows UWB response as shown in Fig. 10. For switches 1&2 in the ON state the reflection coefficient is below -25 dB and the resonant frequency is 5.6GHz as shown in Fig. 11. For switches 1&2 in the OFF state the reflection coefficient is below -25 dB and the resonant frequency is 6.25GHz as shown in Fig.11. For switches 3&4 in the ON state the reflection coefficient is below -10dB and the resonant frequency is 9GHz. For switches 3&4 in the OFF state the reflection coefficient is below -10dB and the resonant frequency is 12.4GHz as shown in Fig.12.The T shaped stub in the ground plane provides isolation with mutual coupling -15dB from 3.1 to 15 GHz as shown in Fig. 14.This shows that this antenna is suited for MIMO operation in FCC UWB band. The vertical strips provide band notch characteristics to suppress interference from WLAN band [21].

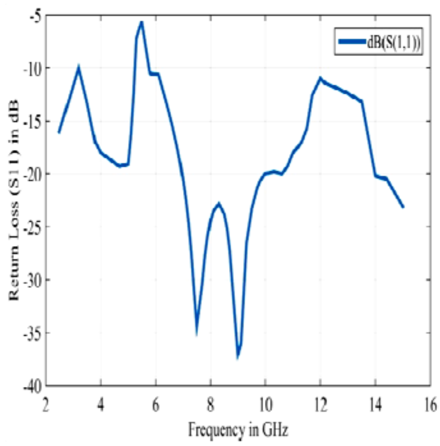

Fig. 10. Return loss of proposed UWB band notched antenna (All Switch "OFF" condition)

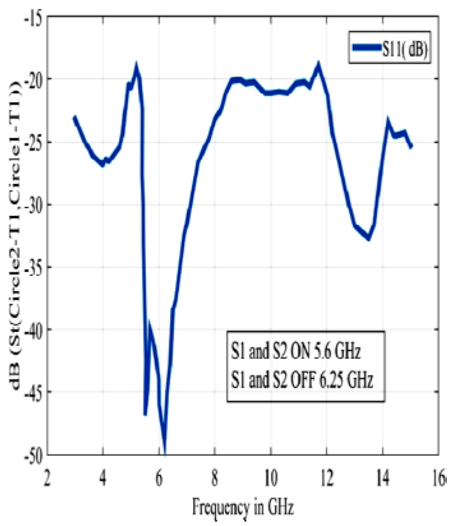

Fig . 11. Switching conditions for various condition of switches S1 and S2 ON/OFF

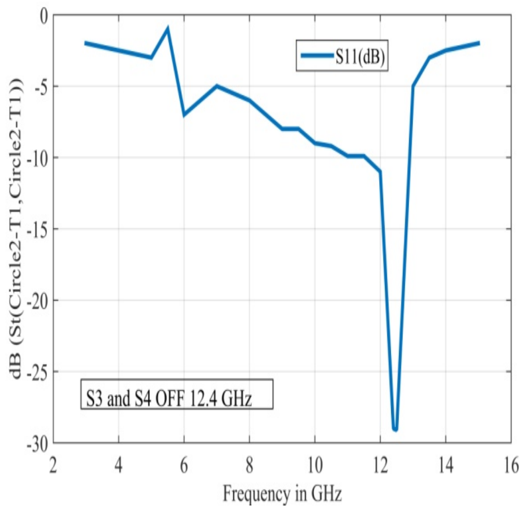

Fig . 12. Simulated output of switches when S3 and S4 are OFF

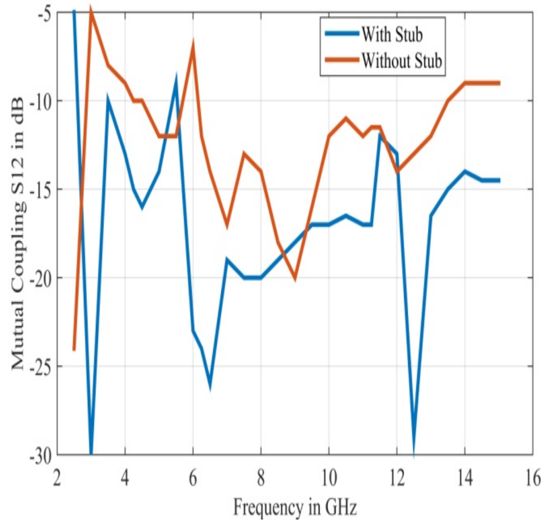

Fig. 14. Simulated mutual coupling of proposed MIMO antenna

6.2. Effects of T shaped ground

The design was initially analyzed without any decoupling structure with a partial isolated ground planes on the back of antennas, the results were then compared with the proposed novel modified T shaped stub. The layout of the ground structures used for comparison is illustrated in Fig. 13.The mutual coupling of the modified stub shows significant improvement when compared to stubless design As observable from Fig. 14, the isolation between the two radiating elements shows significant improvement with the introduction of modified T stub, especially in the frequency band from 5 to 6.5 GHz making this structure useful for ISM band at 5.8 GHz. The isolation between the antenna elements is better than 15 dB in the complete UWB frequency range.

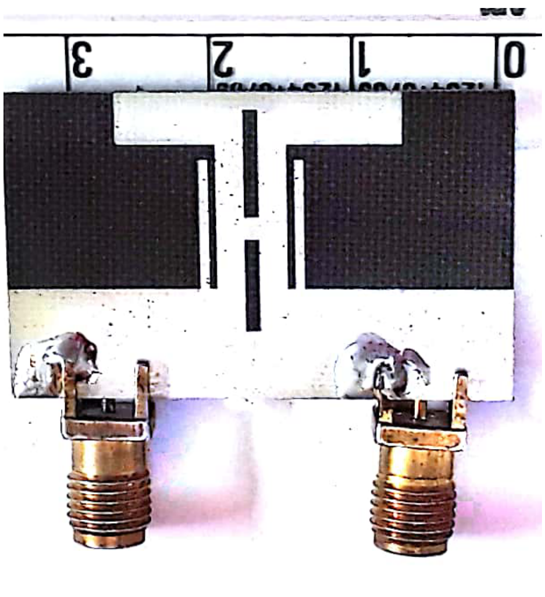

Fig . 13. Layout of T shaped stub

6.3 Results validation

The prototype of the proposed antenna is shown in Fig. 15. The antenna is fabricated on a 1.6 mm thick (i.e.) h =1.6 mm Taconic RF-35 substrate. The essential parameters for the design ε_r= 3.5, h=1.6 mm, tan δ = 0.002.

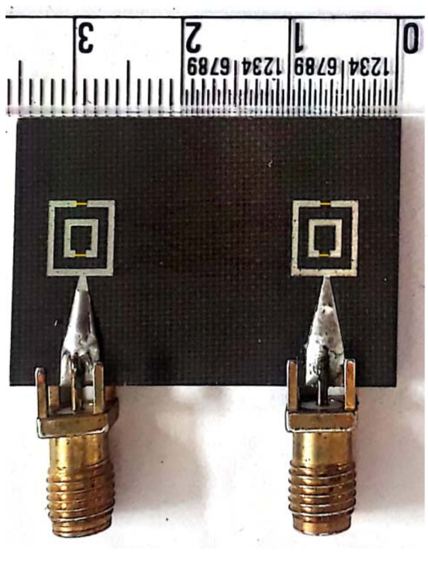

Fig. 15 Prototype of proposed metamaterial UWB band notched MIMO reconfigurable antenna

The measurements were taken on Agilent network analyzer. A comparison of the simulated and measured return losses is shown in Fig. 16. The measured results show an increased radiating bandwidth from 3.3 to 15 GHz. It is evident that measured results exhibit a very good agreement with the simulations. The simulated and measured mutual coupling results in Fig. 17 shows good agreement. The simulated and measured results of switches in Fig. 18 shows that the proposed radiating structure has good switching capability to be used in CR platform. The results of radiation pattern in Fig. 19 show that the antenna is stable over entire UWB frequencies.

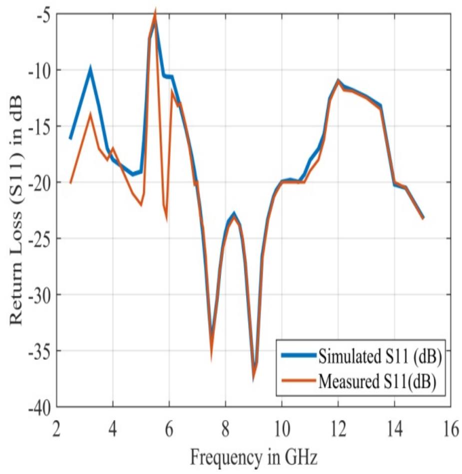

Fig. 16 Simulated and Meaasured return loss

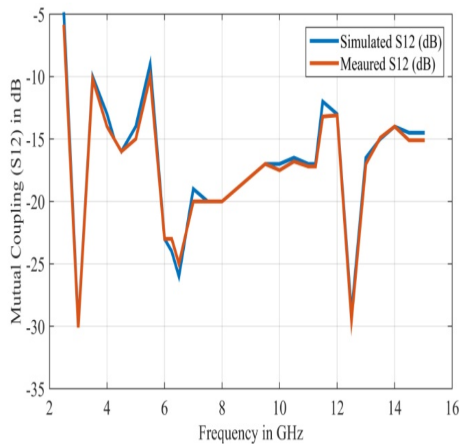

Fig. 17 Simulated and measured results of mutual coupling

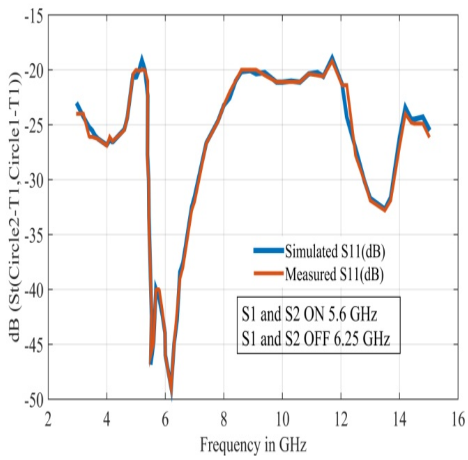

Fig . 18. Simulated and measured output of switches when S1 and S2 are ON and OFF

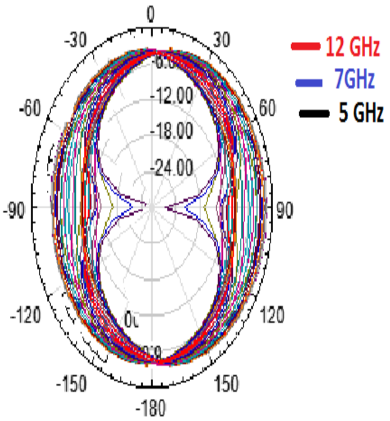

Fig. 19 Radiation pattern at 5,7 and 12GHz

6.4. Comparison with other UWB MIMO antennas

It is observed from Table 2 that the proposed antenna shows relatively better performance than other UMAs. The proposed UWB bandnotched reconfigurable antenna structure provides a significant improvement in performance, in terms of various parameters such as bandwidth, isolation, radiation pattern and reconfigurability compared to the other antennas in the literature.

Table. 2. Comparison of existing and proposed UWB MIMO reconfigurable antenna

Antenna	This work	18	19	20	21
Size(mm$^{2)}$	21X35	23X39.8	25X27	22X24.3	39.8X50
Bandwidth (GHz)	**3-15**	3-12	3-11	3-10.6	2.7-12
S_{12}(dB)	>20	>20	>15	>15	>17
WLAN Bandnotch	Yes	Yes	No	No	Yes
Reconfigurable	**Yes**	No	No	No	No

7. Conclusion

This paper presents the simulated results of a future signature Metamaterial reconfigurable band notched antenna for MIMO applications and cognitive radio platform. It has been shown that the proposed structure exhibits wideband characteristics from 3.1 to 15 GHz, good switching capability with the assistance of switches integrated in the slots of metamaterial structure and no interference with WLAN band with the vertical strips near to ground plane. The T shaped ground stub shows good isolation between the two antennas. While not the utilization of ground stub the mutual coupling is greater than-20dB in UWB band which is enough for good performance. With the utilization of ground slot there is lowering of mutual coupling over the entire UWB band.

When our planned signature reconfigurable metamaterial antenna is utilized in design instead of microstrip patch antenna, multiband operation was observed with an improvement of bandwidth with switching capability, compared to the conventional patch antenna for CR applications. Summing up, the simulated and measured results give a clear scenario of proposed antenna. Thus, metamaterial inspired novel strategy can be utilized to realize radiating antennas for CR platforms.

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