Frequency Reconfigurable Microstrip Circular Patch Antenna for Wireless Devices

Ghanshyam Singh, Mithilesh Kumar

Abstract— In this paper, a frequency reconfigurable circular antenna design and development is proposed for wireless devices. In the proposed design, a circular patch antenna with circular slot using two PIN diodes at the centre frequency 10 GHz was designed and simulated frequency reconfiguration is achieved in the frequency range of 9.69-10.2 GHz and the measured results shows the same effect in the frequency range of 10.33-11.01 GHz. The frequency reconfiguration is carried out by switching the diodes on/off states. In the fabricated structure of proposed geometry the diodes are replaced by microstrip line for on-state as an ideal case. The antenna is designed on FR4 substrate (εr= 4.54) of thickness (H) 1.6 mm. The proposed structure was simulated by using the electromagnetic (EM) simulation software. The optimized structure was fabricated using microwave integrated circuit (MIC) techniques on same substrate. The return loss was measured using the Vector Network Analyzer. The simulated and measured return loss shows the close agreement.

Index Terms— Microstrip Line, Patch Antenna, resonance Frequency,Return Loss, Insertion Loss, Reconfigurable and Slot.

1 Introduction

WITH the rapid development of wireless communication devices and systems, the reconfigurable antennas are gaining great attention. Different characteristics (such as resonant frequency, radiation patterns, polarization, etc) of these novel antennas can be reconfigurable through the change of the structures. The concept of reconfigurable antenna firstly appeared in D.Schaubert's patent "Frequency-agile, polarization diverse microstrip antenna and frequency scanned arrays" in 1983 [1]. To obtain the switchable ability of the antenna, the concept of a reconfigurable antenna was proposed a few years ago [4-7]. The reconfigurable characteristics of antennas are very valuable for many modern wireless communication and radar system applications, such as object detection, secure communications, multi-frequency communications, and vehicle speed tests and so on.

Microstrip antennas provide very lucrative features such as small size, lightweight, low cost, conformability to planar and non-planar surfaces, rigid, and easy installation. They have a wide range of application in wireless communication especially in mobile communication devices and are becoming more general due to low cost and versatile designs.

The patch antenna can reconfigure by cutting rectangular or half-circular or circular slots. The slot in the patch changes the electrical dimensions of the patch element and hence gives a variation in the resonant frequency and phase of reflection from an individual patch element. Different types of slots in the patch element are used and their dimensions have been varied in order to observe the relationship between maximum attainable linear phase range and the loss performance [9]. However, the limitation of this method is that we have to design different antenna structures for different slot configurations.

A frequency reconfiguration design technique is proposed by using slot configuration in the microstrip rectangular patch antenna with two diodes connected inside the slot with on and off state working strategy. The frequency reconfiguration scheme was simulated by switching between the diodes for on/off-state and for the fabricated structure switching was shown as an ideal diode that is replaced by microstrip line for on-state and open circuit for off-state. In this scheme, the frequency reconfiguration was achieved for three different resonant frequencies [13-14].

Now in this paper, a new technique is proposed for the frequency reconfiguration of circular microstrip patch antenna using circular slot. Inside the circular slot two diodes connected with on and off state working strategy. In fabrication process diodes are replaced by microstrip lines for on and off state working.

The organization of this paper is as follows. In Section 2, antenna design and optimization topologies are explained. In Section 3, frequency reconfiguration procedure is described. In Section 4, the simulation structures and results are described. In Section 5 fabricated structures and results are explained and measured results are compared with simulated results. In Section 6 simulated and measured return losses are compared for three different configurations. Finally, the paper is concluded in Section 7.

2 Antenna Design And Optimization

The proposed circular patch element is designed using the substrate FR4 (εr=4.54) while the height of the substrate is 1.60 mm. The dimensions of the microstrip circular patch element was calculated at the centre frequency of 10 GHz by conventional design procedure of circular patch is given in [10]. The PIN diodes located at specific positions are used to create short circuits across the slot. By carefully controlling these diodes, the induced current distribution around the slot can be changed, resulting in different antenna radiation patterns. Thus, a pattern reconfigurable antenna can be

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achieved [11]. Slots and switches are used in order to obtain both frequency and polarization reconfigurability. Speciacally, three different polarization states have been obtained: a Right-Hand Circular Polarization, a Left-Hand Circular Polarization and a Linear Polarization [12].

The proposed design of frequency reconfigurable circular patch antenna is simulated on EM simulation software. The optimized diameter of circular patch is d= 6.1 mm. The port excitation is kept at a distance of 8.9 mm from the patch element. The width of microstrip feed line is W = 3 mm and length is L= 5.9 mm. The length of Quarter line transformer is t= 3 mm and width is 0.5 mm.

The conventional circular patch structure was modified by introducing a circular slot that is shown in the Fig. 1. The inner diameter and outer diameter of circular slot are 2 mm and 4 mm respectively is inserted in the circular patch structure. The two diodes D1 and D2 are placed between the inner and outer circles in the circular slot configuration.

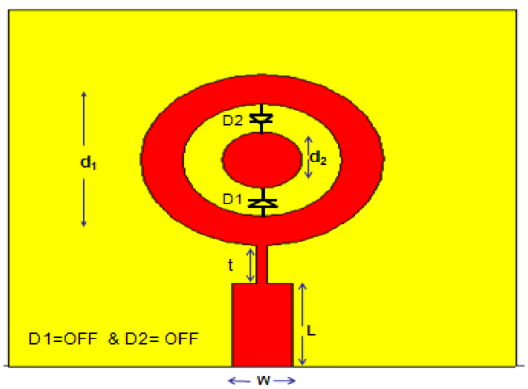

Fig.1. Reconfigurable design of circular patch antenna

3 Reconfiguration Procedure

The circular patch antenna used in design is very easy to reconfigure by connecting diodes between inner and outer circular slots. There are three different configurations of the two connecting diodes (D1 & D2). In the first case, both two diodes (D1 and D2) are in off-state. Therefore, the inner slot is work as a single cavity resonator. In the second case, one diode (D1) is in on-state and it performs as a closed switch and another diode (D2) in off-state and it act as open switch. In third case, both diodes (D1 & D2) are in on-state and operate as the closed switches. Hence, the same structure can be reconfiguring for different cavities and it resonates on three different frequencies.

In the fabricated structure the diodes are replaced by using simply microstrip lines, because we know that in ideal case the diode works as an open switch for the off-state and works as a closed switch in on-state. Accordingly, in fabricated structures for the on-state of diodes are replaced by microstrip lines between connectors and for off-state none any microstrip line is connected.

4 Simulated Structures And Results

The electromagnetic (EM) simulation software is used to simulate the proposed structure of frequency reconfigurable microstrip patch antenna. The structure of antenna is designed on substrate FR-4 with dielectric constant 4.54 and thickness is 1.6 mm. The frequency reconfigurations were achieved for three different cases as follows; Case-I: when both diodes are in off-state, Case-II: when one diode is in on-state and other diode in off-state, and Case-III: when both diodes are in on-state.

4.1 Case-I when both diodes (D1and D2) are in off-state

When both two diodes (D1 and D2) are in off-state then the two contacts is acting as open switch, so the result depends only on the circular configuration, the simulated return loss is at the frequency 9.69 GHz. The simulated design for case-I is shown in fig. 1. Diode D1 & D2 both are in off-state so the both diodes are works as open circuits. The simulated return loss for this structure is shown in fig. 2; the loss is -14.84 dB at the resonance frequency 9.69 GHz. The insertion loss of structure is shown in fig. 3. Comparison of reurn and insertion loss is shown in fig. 4.

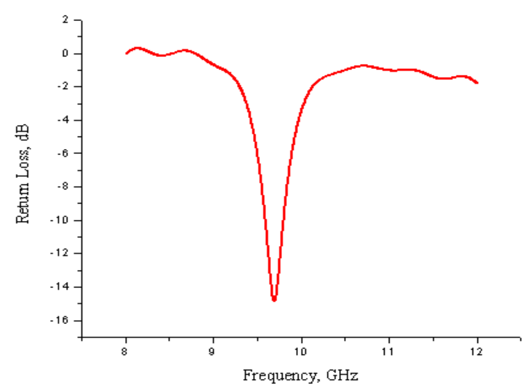

Fig.2. Simulated return loss for case-I

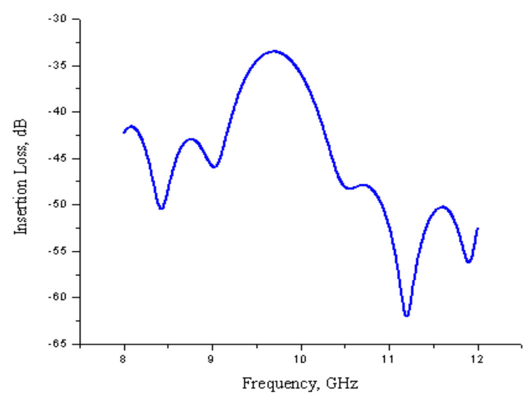

Fig.3. Simulated insertion loss for case-I

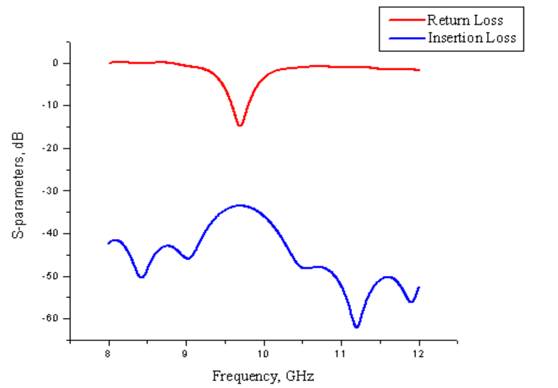

Fig.4. Comparison of return and insertion loss for case-I

4.2 Case-II when one diode (D1) is in on-state

When diode (D1) is in on-state then one contact is act as closed switch and another diode (D2) in off-state and it act as open switch, so result depends on the circular slot configuration and switchable configuration of diode D1. The simulated design for case-II is shown in fig. 5. Diode D1 is in on-state and diode D2 is in off-state so one switch is works as closed switch and second works as open switch. As shown in fig. 6, the simulated return loss is -11.87 dB at the resonance frequency 9.83 GHz, so now we can say that when diode D1 is on the resonance frequency is shifted. The simulated insertion loss is shown in fig. 7. Comparison of reurn and insertion loss is shown in fig. 8.

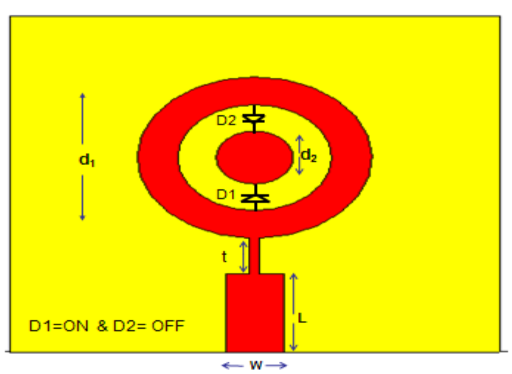

Fig.5. Simulated structure when diode (D1) is in on-state

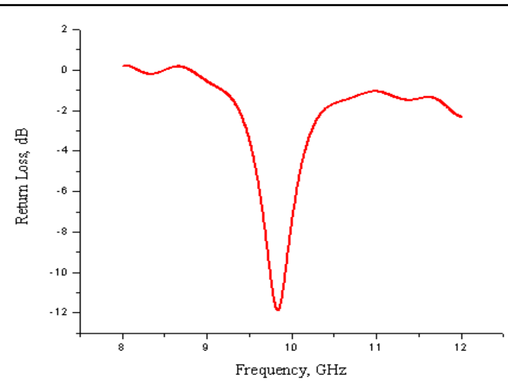

Fig.6. Simulated return loss for case-II

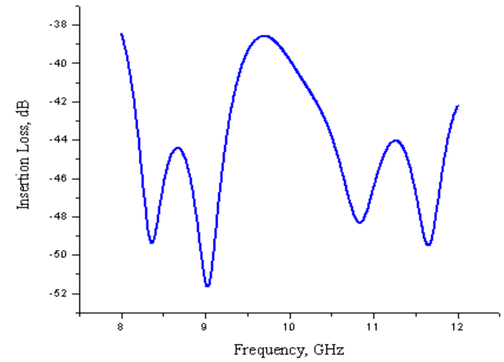

Fig.7. Simulated insertion loss for case-II

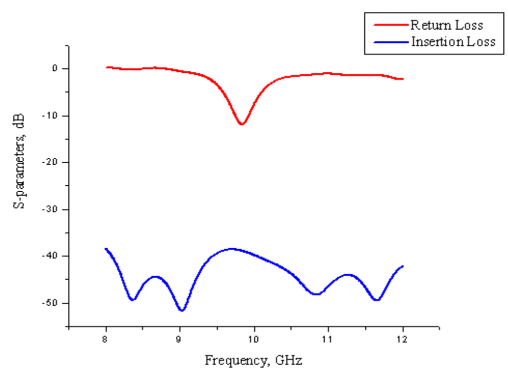

Fig.8. Comparison of return and insertion loss for case-II

4.3 Case-III when both diodes (D1 & D2) are in on- state

When both diodes are in on-state then both contects are act as closed switch, result depends on the circular slot configuration and switchable configuration of diodes D1 & D2. The simulated design for case-III is shown in fig. 9. Diode D1 and diode D2 both are in on-state so both switches are work as closed switch. As shown in fig. 10, the simulated return loss is -13.43 dB at the resonance frequency 10.18 GHz, so when both diode are in on-state again the resonance frequency is shifted, so this frequency shifting shown the frequency reconfiguration. The simulated insertion loss is shown in fig. 11. Comparison of reurn and insertion loss is shown in fig. 12.

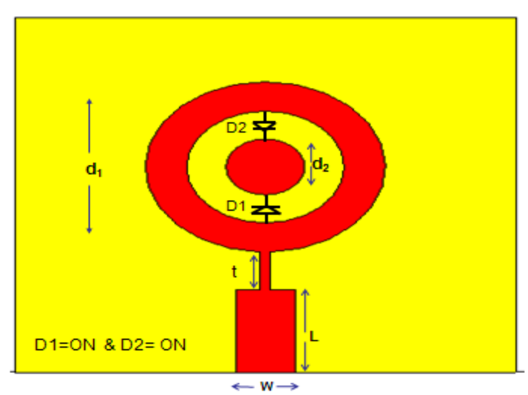

Fig.9. Simulated structure when diodes (D1 & D2) are in on-state

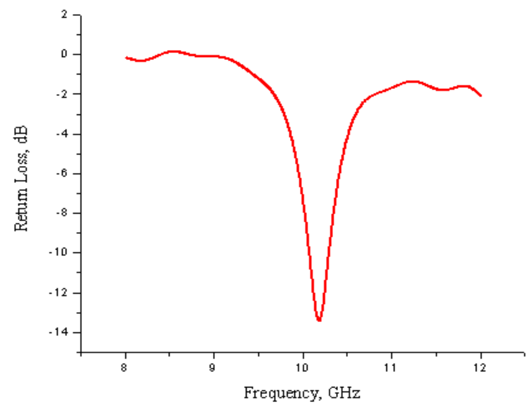

Fig.10. Simulated return loss for case-III

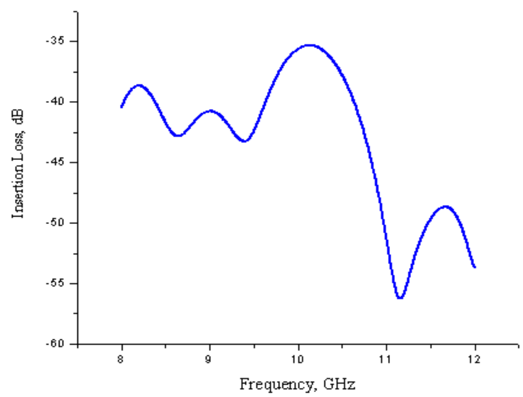

Fig.11. Simulated insertion losses for case-III

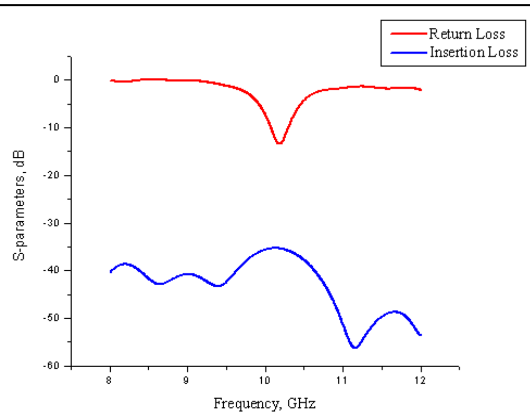

Fig.12. Comparison of return and insertion losses for case-III

5 Fabricated Structures And Results

In the fabricated structure the diodes are replaced by using simply microstrip lines, because we know that in ideal case the diode works as an open switch for the off-state and works as a closed switch in on-state. Accordingly, in fabricated structures for the on-state of diodes are replaced by microstrip lines between connectors and for off-state none any microstrip line is connected.

The designed proposed structures were fabricated using the microwave integrated fabrication (MIC) technique (as mentioned in section 4.4.1) on the same substrate FR-4. The substrate has dimension 25.4 × 25.4 mm², dielectric constant 4.54, and thickness 1.6 mm. The printed antennas were tested using vector network analyzer (VNA). The measured results are compared with simulated results for same three cases.

5.1 Case-I when both diodes (D1and D2) are in off-state

In fabricated structure for this case no any strip line in connected between the connectors as shown in fig. 13 and resonance frequency 10.33 GHz was measured for return loss below -10dB as shown in fig. 14. The comparison of measured and simulated return loss for case-I is shown in fig. 15.

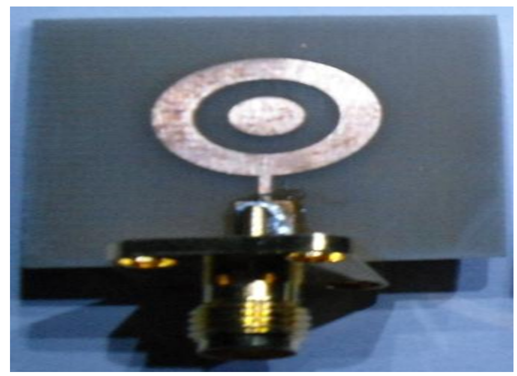

Fig.13. Fabricated structure when diodes (D1 & D2) are in off-state

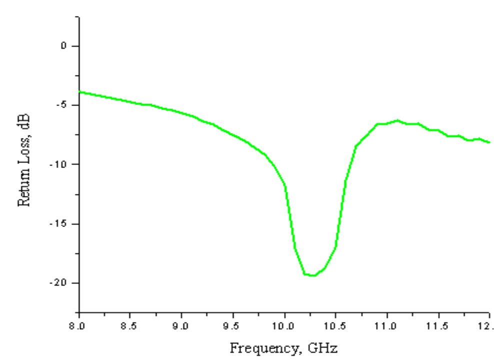

Fig.14. Measured return loss for case-I

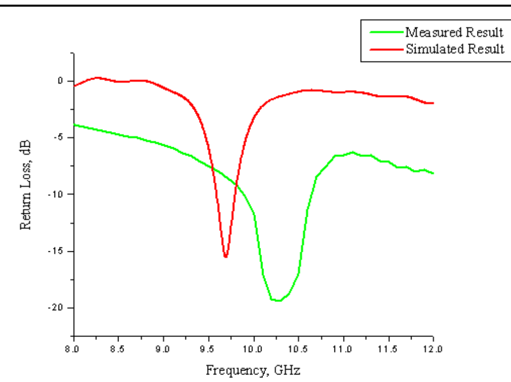

Fig.15. Comparison of measured and simulated return loss for case-I

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5.2 Case-II when one diode (D1) is in on-state

In fabricated structure for this case diode D1 is replaced by connecting strip line between the connectors of diode D1 as shown in fig. 16 and return loss below -10dB on the resonance frequency 10.59 GHz as shown in fig. 17. The comparison of measured and simulated return loss for case-II is shown in fig. 18.

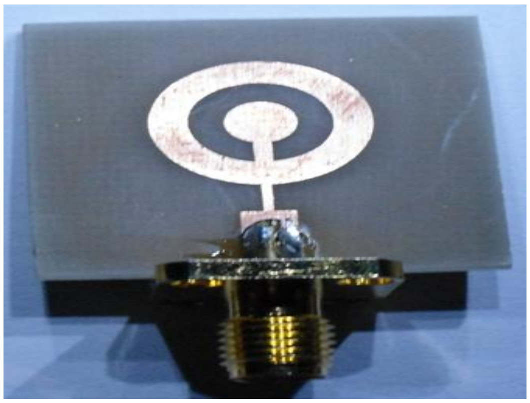

Fig.16. Fabricated structure when one diode (D1) is in on-state

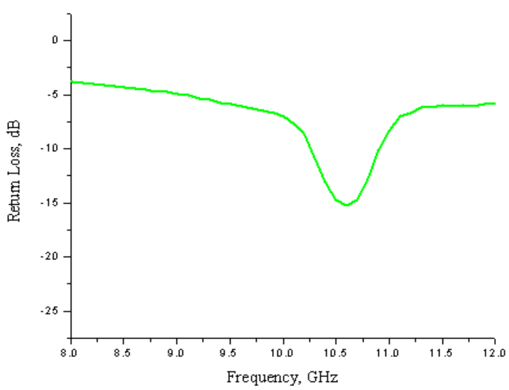

Fig.17. Measured return loss for case-II

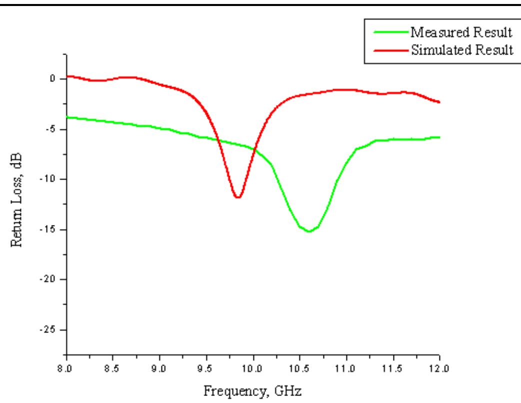

Fig.18. Comparison of measured and simulated return loss for case-II

5.3 Case-III when both diodes (D1 & D2) are in on- state

In fabricated structure for this case diode D1 and Diode D2 are replaced by connecting strip lines between the connectors of diode D1 and diode D2 as shown in fig. 19 and the resonance frequency 11.01 GHz at the return loss below -10 dB as shown in fig. 20. The comparison of measured and simulated return loss for case-III is shown in fig. 21.

Fig.19. Fabricated structure when diodes (D1 & D2) are in on-state

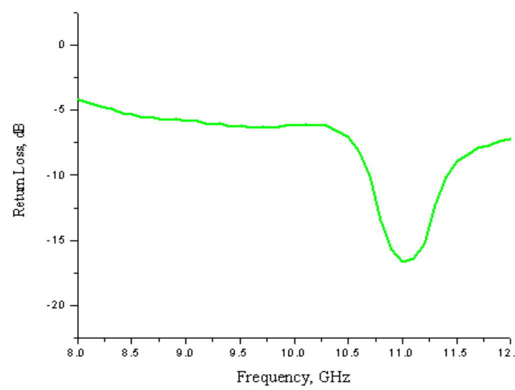

Fig.20. Measured return loss for case-III

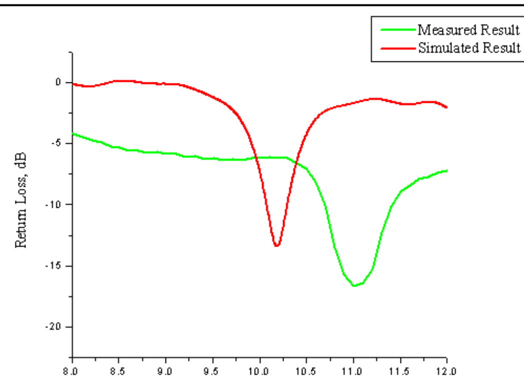

Fig.21. Comparison of measured and simulated return loss for case-III

6 Comparison Of Results

By comparing the return loss; S_{11} parameters for these three cases we can easily judge the effect of different diode connection configurations and also the change in bandwidth and resonance frequency as shown in fig. 22. The number of tuning frequencies is shifted as the numbers of ON-state diodes are increased in the structure.

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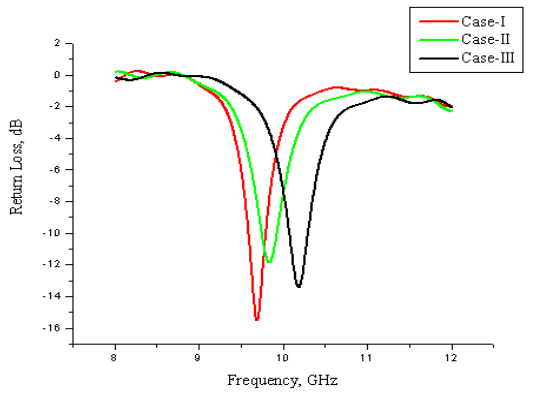

Fig.22. Comparison of simulated return losses

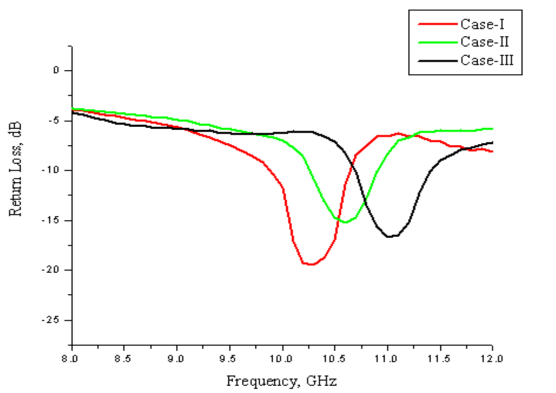

Fig.23. Comparison of measured return losses

The measured results for frequency reconfigurable antenna are shown in the fig. 23. The measured results are showing the close agreement with the simulated results. The proposed antenna can be used in the wireless communication

7 Conclusion

In this paper, the design of a reconfigurable circular microstrip patch antenna has been described and their simulated results are compared with measured results. This reconfigurable patch antenna can be used for different resonance frequencies. By analyzing simulated and measured results, it showed that by using circular slot and diode switching the return loss shifts and hence the resonance frequency is also changed. This reconfigurable antenna can further be modified by using RF-MEMS switches for fast switching purposes.

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