A Slotted Fork Shaped Patch Antenna with Improved Bandwidth and Isolation for MIMO Systems

S. Gopi Chand[1], S. UdaySai Kiran[1], T. Naga Pavan[1] and K. Jagadeesh Babu[2]

[1]Students of Dept of ECE, SACET, Chirala, AP, India
[2]Professor & Head of the Dept ECE, SACET, Chirala, AP, India

jagan_ec@yahoo.com

Abstract

A compact slotted Fork shaped patch antenna for multi-band applications with improved bandwidth and isolation characteristics is presented in this paper. The proposed antenna resonates at multiband of 4.2 GHz, 5.96 GHz, 7 GHz, 7.46 GHz, 9.93 GHz and 11.49 GHz frequencies for VSWR ≤ 1.6, with an improved impedance bandwidth of 33.8%. A 2×2MIMO system is developed using the proposed antenna giving an excellent isolation of 38 dB between the two antennas. The developed antenna system can be widely used for the 4G, WLAN and Wi-MAX applications. The proposed antenna is a good choice for MIMO systems operating for several wideband applications.

Keywords: *Slotted Fork shaped patch antenna, multi-band, Impedance bandwidth, Mutual coupling, VSWR*

1. Introduction

The microstrip patch antenna is one of the most preferred antennas due to its low cost, light weight, simple implementation process and conformability. The microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. However, the general microstrip antennas suffer from narrow bandwidth, which limits their application in modern communication systems like MIMO systems, *etc*... In recent years the demand for the design of tri-band [1] or multiband antennas is increased, as these antennas can integrate more than one communication standards in a single compact system. In this paper, we propose a novel slotted Fork shaped microstrip patch antenna giving multiband operation with improved bandwidth and reduced mutual coupling with a simpler structure.

The major problem faced by the MIMO system [2] engineers, when working on small Personal Digital Assistants (PDA) is mutual coupling, which mainly arises due to the smaller spacing between the elements. Usually, in multiple input and multiple output systems the basic aim is to minimize the correlation between the multiple signals. The parameter that describes the correlation between the received signals in highly diversified environments is mutual coupling, which deteriorates the performance of the communication system [3].

The mutual coupling depends on the distance between the elements in a MIMO system. If the distance between the antennas is more, the mutual coupling becomes less and vice versa. However, the distance between the antennas cannot be maintained too large as MIMO systems have their major applications in mobile terminals, laptops, and WLAN access point's wireless communication [4], where size of the device can't be maintained too large. The main source of mutual coupling is surface current flowing through the ground surface. To reduce these surface currents flowing on the ground surface, there are several techniques like Electromagnetic band gap structure [5], defected ground structure [6], decoupling techniques, *etc*... However, all these methods make the design of the antenna more complicated.

In the present work, a slotted Fork shaped patch antenna MIMO system is proposed with improved bandwidth and reduced mutual coupling compared to the antenna discussed in [7]. The designed antenna resonates at a multiband of 4.2 GHz, 5.96 GHz, 7 GHz, 7.46 GHz, 9.93 GHz and 11.49 GHz with an improved impedance bandwidth of 33.8% and the obtained mutual coupling between the antenna elements is small and is less than -38dB. In section 2, the proposed antenna geometry is presented and in Section 3 the two element MIMO array system is presented.

2. Antenna Design

As mentioned earlier, the main drawback of patch antenna is narrow bandwidth. Hence, the present work mainly focuses on the improvement of impedance bandwidth. The impedance bandwidth of the patch antennas can be improved by using various techniques like introducing parasitic elements, increasing the thickness of substrate and modifying the shape of the antenna and by introducing slots on the patch. The proposed antenna offers an improved bandwidth of 33.8%, which is better than bandwidth obtained in [8] and [9], and the comparison results of proposed antenna and the antenna proposed in [8] is shown in Figure 7. The patch antennas are fabricated with various shapes and the most widely designed antennas are E shaped patch antenna, H shaped patch antenna [10], U slotted patch antennas [11], *etc*... Among all these antennas, E shaped patch antennas are widely used as they give better performance in terms of both impedance bandwidth and mutual coupling. The antenna proposed in the present work gives better results compared to all the above mentioned antennas in terms of both impedance bandwidth and mutual coupling.

The structure of the proposed antenna is shown in Figure 1. The dimensions of the geometry are given in the Table 1. For better performance, a thick dielectric substrate having a low dielectric constant is desirable as it provides better efficiency, larger bandwidth and better radiation. Here, the substrate selected for the design of the proposed antenna is RT/duroid®5880 of thickness 3.2 mm and with low permittivity (εr=2.2). The dimensions of the substrate are taken as $100 \times 90 \times 3.2$ mm^3.

Table 1. Dimensions of the proposed antenna

Parameter	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Units (mm)	6	3	3	10	8	14	8
Parameter	H_1	H_2	H_3	H_4	H_5	H_6	H_7
Units (mm)	16	12	2	20	3	3.5	1.25

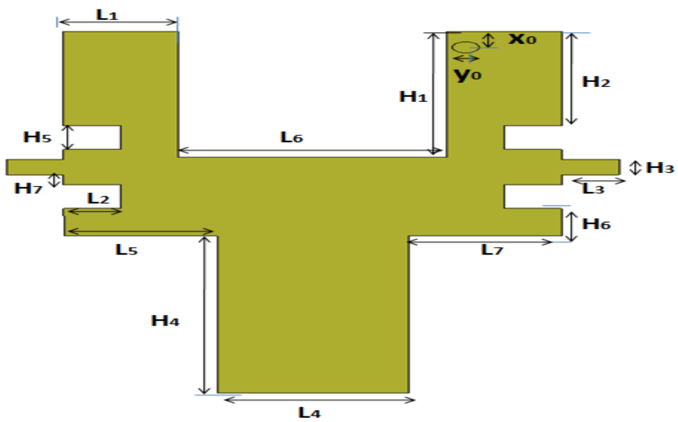


Figure 1. Proposed slotted Fork shaped microstrip patch antenna

Microstrip patch antennas can be fed by a variety of methods. These methods are classified into two categories which are contacting (direct) and non-contacting. The four most popular feeding techniques used are microstrip feed, co-axial probe feed, aperture coupled and proximity coupled feeding. Here the whole system is fed by a co-axial probe at the position (X0, Y0) = (2 mm, 1 mm) as it is simpler to implement.

The area of the proposed antenna is 26 × 46 mm^2. The left and right arms have same dimensions. L_1 is the length of the arm and H_1 is the width of the arm, L_4 and H_4 are the length and width of the center arm respectively. L_6 is the distance between the left and right arms. Four rectangular slits were placed on each side of patch, which are responsible for the improved bandwidth. The length of the slit is L_2 and the width of the slit is H_5. There are two slits added on each side as shown in Figure 1 and the length of the slit is L_3 and the width of the slot is H_3. The return loss of the proposed antenna is shown in Figure 2, giving an impedance bandwidth of 33.8 % between the frequencies 9 GHz to 12.7 GHz, resonating at 4.2 GHz, 5.96 GHz, 7 GHz, 7.46GHz, 9.93 GHz and 11.49 GHz frequencies.

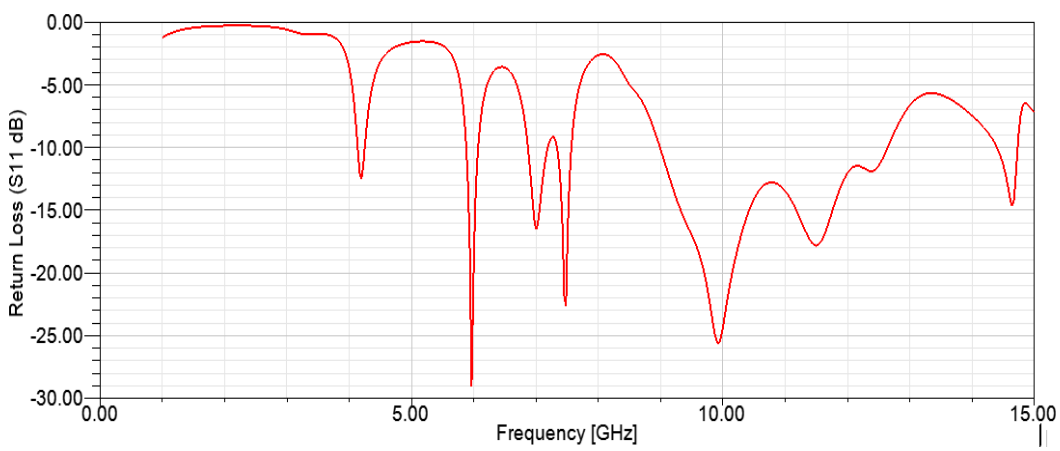
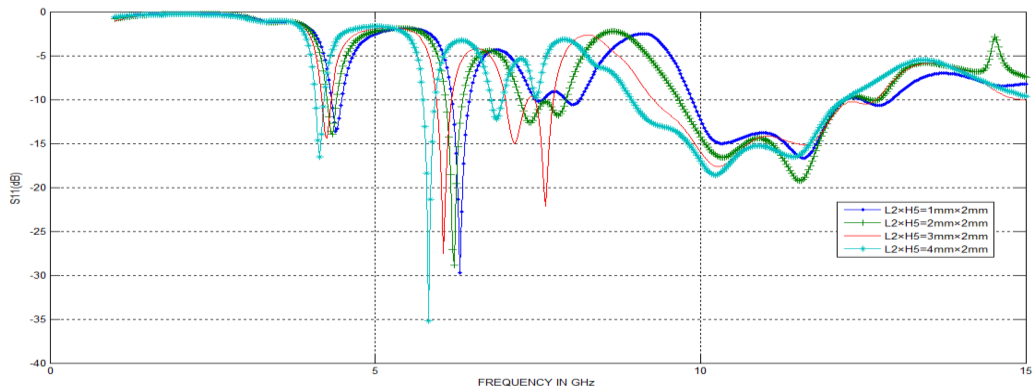


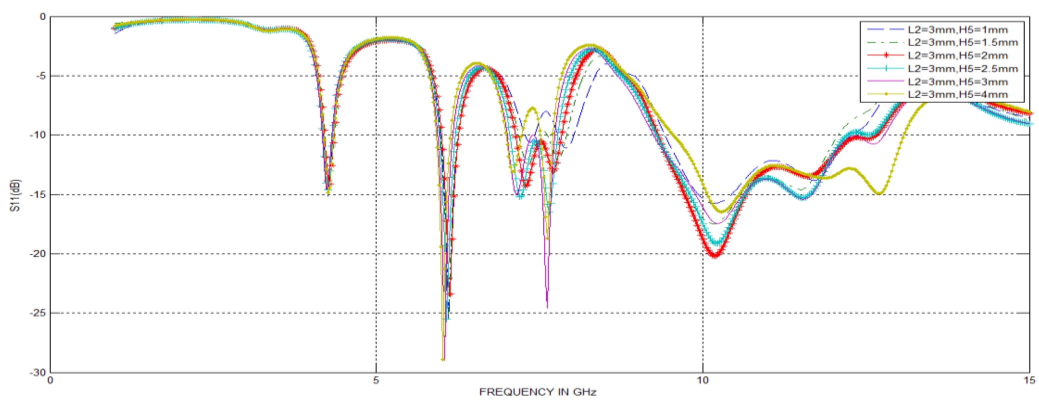
Figure 2. Return loss of the proposed antenna

There are four rectangular slits on each side and another two rectangular slits are added on each side of the patch as shown in Figure 1. The parametric analysis of slit dimensions is given below. The Figure 3(a) presents the simulated results of the proposed antenna with slot lengths L_2= 1, 2, 3 and 4 mm at H_5=2mm. The return loss is observed to be better at L_2=

3mm. Figure 3(b) shows the simulated results of the proposed antenna with slot widths H_5= 1, 1.5, 2, 2.5, 3 and 4 mm at L_2=3mm. At H_5=3 mm, the return loss is found to be better compared to other values. Hence, these particular values of L_2 and H_5 are chosen for the design of the antenna.



(a) Effect of L2 on Return loss at H5=2mm



(b) Effect of H_5 on Return loss at L_2=3mm

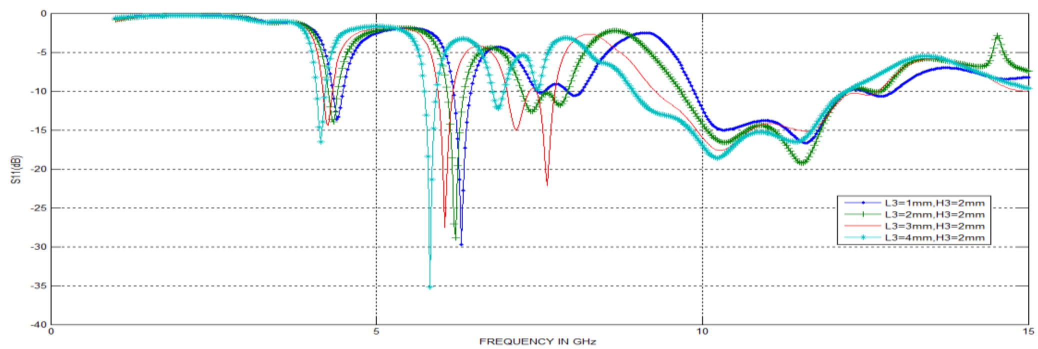
Figure 3. Effect of four rectangular slits on Return loss

In Figure 4(a) the effect of L_3 on return loss is examined with different lengths L_3= 1, 2, 3 and 4 mm at H_3= 2 mm and the results are observed to be better at L_3= 3 mm. Figure 4(b) presents the return loss of the proposed antenna with different values of H_3=1, 2, 3 and 4 mm at L_3=3mm. The response is observed to be better for H_3= 3mm. Hence, these particular values of L_3 and H_3 are chosen for the design of the antenna.

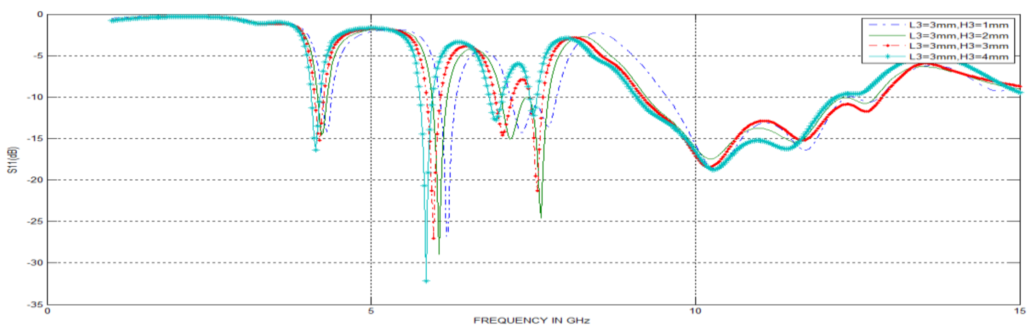
3. Two Element MIMO Array Using the Proposed Antenna

The main parameter that effects the performance of the MIMO system is mutual coupling. The aim of any MIMO system designer is to reduce the mutual coupling between antennas, when they are closely placed. However, when multiple antennas are involved at closer spacing the design issues are more complicated compared to a SISO (Single Input Single Output) system. The reduction in mutual coupling can be achieved by properly choosing the shape of the antenna and without increasing the distance between the elements. The mutual coupling can be minimized by using diversity techniques as explained in [9] and [12].

In the present paper, a 2×2 MIMO system is developed by using the proposed slotted Fork shaped patch antenna as shown in Figure 5. For the proposed MIMO system, the separation between the elements is taken as 10 mm. For the proposed MIMO array, the dimensions are taken same as that of the single slotted Fork shaped antenna shown in Figure 1.



(a) Effect of L_3 on return loss at H_3= 2mm.



b) Effect of H_3 on return loss at L_3=3mm

Figure 4. Effect of two added rectangular slits on Return loss

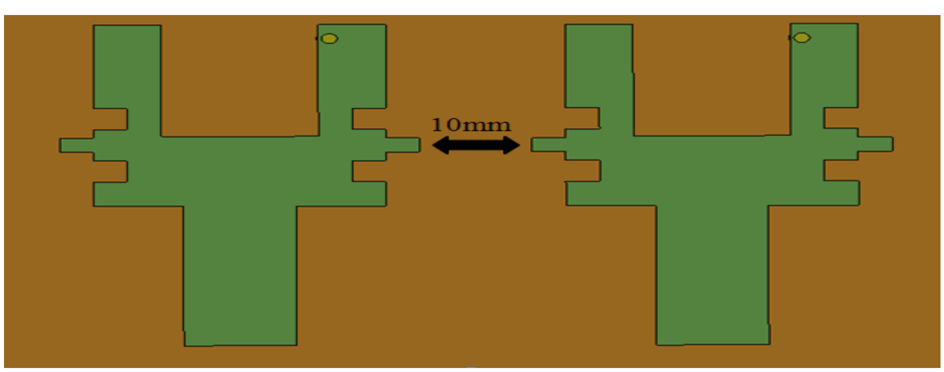


Figure 5. A two element MIMO system using proposed slotted Fork shaped antenna

The Figure 6 shows the simulated results of return loss and the mutual coupling in dB. The system resonates a multiband 4.2 GHz, 5.96 GHz, 7 GHz, 7.46 GHz, 9.93 GHz and 11.49 GHz with an improved impedance bandwidth of 33.8% (9 GHz to 12.7 GHz) and the obtained mutual coupling between the antenna elements is small and is less than -38dB. Also, the obtained bandwidth by using the proposed antenna is very high compared to the normal E-shaped patch antenna [9].The return loss of single antenna and their corresponding resonant frequencies and isolation of 2 ×2 MIMO system are given in Table 2.

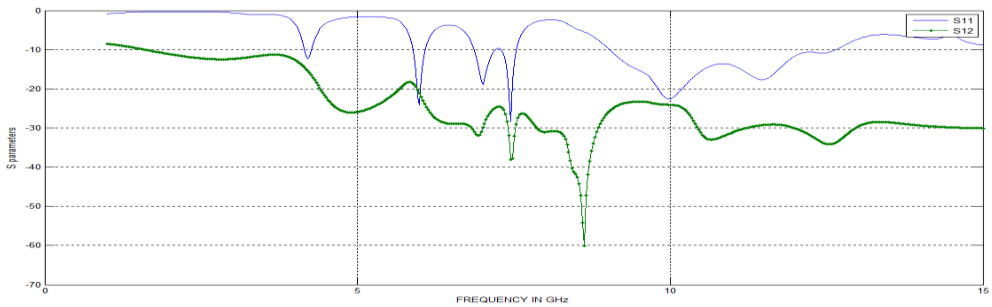


Figure 6. S parameters of proposed slotted Fork shaped microstrip patch antenna

Table 2. Results obtained with the proposed antenna

S.No	Resonant Frequency (GHz)	Return Loss (dB)	Isolation (dB)
1)	4.2	-12.3	-15
2)	5.96	-29	-20
3)	7	-12.3	-15
4)	7.46	-22	-**38**
5)	9.93	-25.5	-24
6)	11.49	-17.6	-30

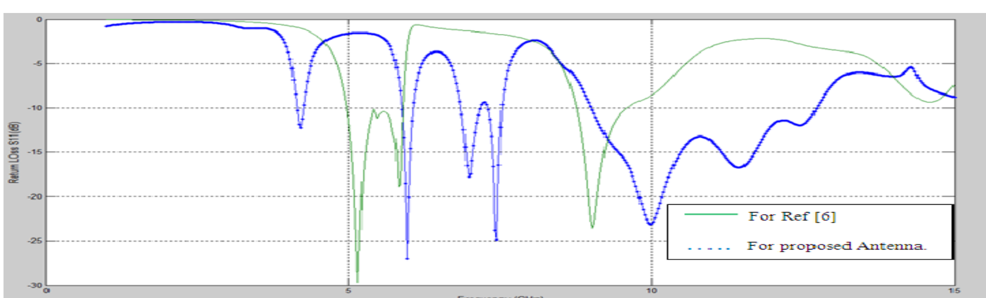


Figure 7. Comparison of proposed antenna and antenna proposed in [8]

The VSWR plot of the proposed MIMO array is presented in the Figure 8. The plot gives the desired values of VSWR at the resonant frequencies, which are less than 1.6. The VSWR value is observed as 1.6, 1.11, 1.21, 1.4, 1.14 and 1.3 at the resonant 4.2GHz, 5.96GHz, 7GHz, 7.46GHz, 9.93GHz and 11.49 GHz respectively, indicating improved matching conditions. The Figure 9 shows the obtained radiation Patterns of the proposed antenna. The Figure 10 shows the gain plot of the proposed antenna.

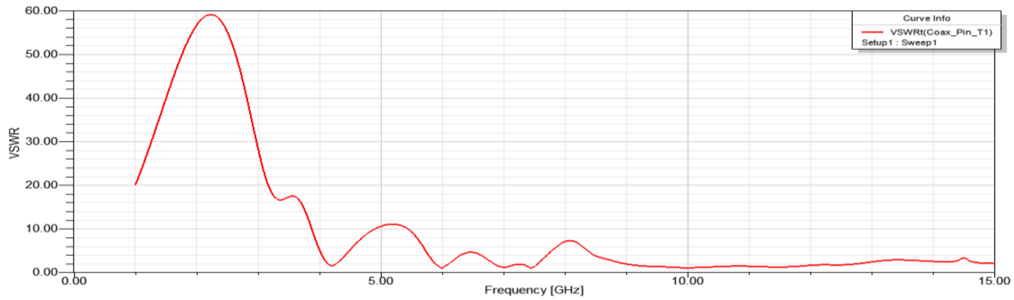
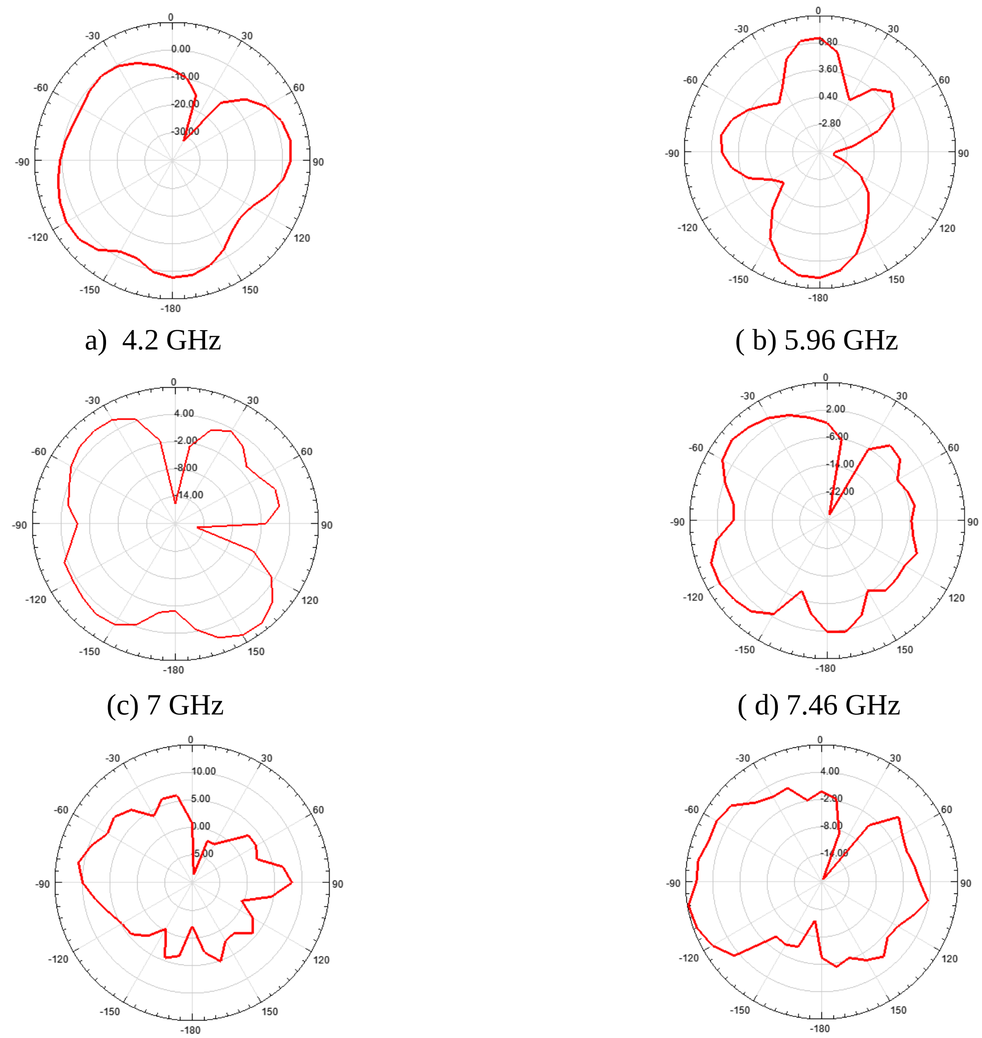


Figure 8. VSWR plot of the proposed Antenna



a) 4.2 GHz

(b) 5.96 GHz

(c) 7 GHz

(d) 7.46 GHz

(e) 9.93 GHz

(f) 11.49 GHz

Figure 9. Radiation patterns of the proposed antenna

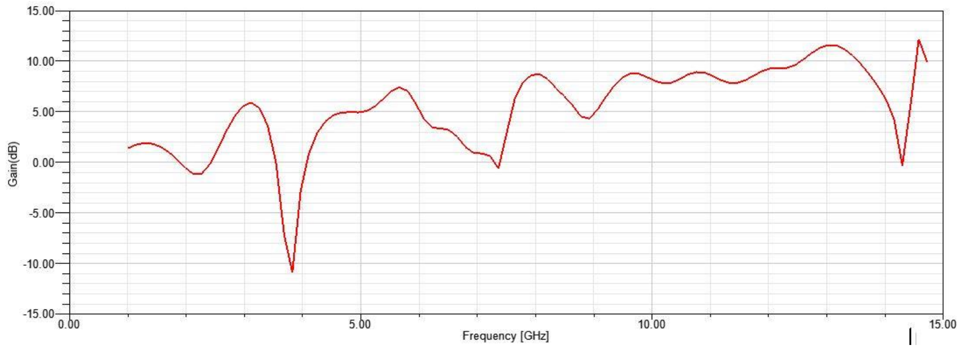


Figure 10. Gain plot of the proposed antenna

4. Conclusion

In this paper, a slotted Fork shaped patch antenna is proposed and a two element MIMO array is developed using the proposed antenna. The proposed antenna resonates at a multiband of frequencies 4.2 GHz, 5.96 GHz, 7 GHz, 7.46 GHz, 9.93 GHz and 11.49 GHz with an improved impedance bandwidth of 33.8% and a reduced mutual coupling of –38 dB. These characteristics are well suited for all 4G MIMO applications. The proposed study can be extended by employing more number of antennas in MIMO system for improving the channel capacity of the MIMO systems.

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Authors

S. Gopichand completed the B.Tech degree in Electronics and Communication Engineering in 2013 from the JNTU University, Kakinada. His areas of interest include Microstrip Antennas, MIMO Antennas, and Wireless communications. He is a member of ISTE.

S. UdaySaiKiran completed the B.Tech degree in Electronics and Communication Engineering in the year 2013 from the JNTU University, Kakinada. His areas of interest include, Wireless communications and MIMO Antennas and Microstrip Antennas. He is a member of ISTE.

T. Nagapavan completed the B.Tech degree in Electronics and Communication Engineering in the year 2013 from the JNTU University, Kakinada. His areas of interest include, Microstrip Antennas. He is a member of ISTE.

K. Jagadeesh Babu is working as Professor & HOD in E.C.E Dept., at St. Ann's College of Engineering & Technology, Chirala, INDIA and he is presently working towards the Ph.D. in E.C.E Dept, JNTU, Hyderabad. His areas of interest include Microwaves, Neural Networks, MIMO Antennas, Wireless communications. He published 20 papers in reputed Journals like WILEY, SPRINGER, ELSEVIER, *etc*… He is a member of ISTE and IAENG.