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Isolation Frequency Switchable MIMO Antenna for PCS, WIMAX and WLAN Application

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Abstract: In this study, a lumped component based frequency reconfigurable multiple-input-multiple-output (MIMO) receiving wire design is presented. The proposed antenna is composed of a planar structure in form of F-shaped together with a slotted and defected ground structure for bandwidth and isolation enhancement. The MIMO antenna operates in six frequencies upon the state of the four lumped element switches. The proposed receiving wire design exhibits a multiband frequency reconfigurable characteristics from 1-7GHz with isolation of more than 14dB for the whole band, with efficiency of about 75%. The MIMO antenna's behavior in terms of ratio of square root of the sum of power reflected wave to the incident wave (TARC), ECC and CCL are all within the acceptable limits. The design is suitable for personal communication system (PCS), WIMAX and WLAN wireless applications.

Keywords: MIMO, Frequency reconfigurable, Lumped elements, Mutual coupling.

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1. INTRODUCTION

The demand for multiple/wideband operating frequencies in wireless communication framework is increasing these days. With these, frequency reconfigurable MIMO antennas have gained a remarkable recognition due to their ability to adjust the operating frequency band based on spectrum availability [1]. Frequency reconfigurable antennas are better choice as they work over small band and reject the clamor from unused ones which upgrades the unwavering quality of the framework. Reconfigurable MIMO antennas proffer's a solution where by it can switch or tune the operating frequency to a desired band by using some techniques. We have several types of reconfigurable antennas such as radiation pattern reconfigurability [2], frequency [3] - [8], polarization [9] and bandwidth [10].

This study only focused on frequency tunable antennas. One of the challenges of the MIMO antenna is the electromagnetic interaction among the array elements termed as mutual coupling [11]. Designing the MIMO antennas requires a lot of consideration for minimizing the mutual coupling effect because, the effect severely degrades how the MIMO antenna performs. Several designs of frequency reconfigurable MIMO antennas have been proposed in [12] - [19] of which most of the designs are reconfigurable antennas. A design of reconfigurable metal edge MIMO handset reception apparatus with circulated bolstering is introduced in [12]. The antenna depends on switches and the antenna cluster idea. Another design of reconfigurable antenna based on reconfigurable microstrip feedline is presented in [13], in which varactor diodes are integrated within the feedline to achieve frequency reconfigurability. A design presented in [14] used RF switch for frequency tuning capability. The RF switch is used in the ground short pin of the dual port antenna for impedance switching. A pin diode is used in [15] to achieve operating band reconfigurability. The antenna framework gives switchable band gap capability for WIMAX (3.2 - 3.8GHz) band. The used of microelectromechanical (MEMS) switch is presented in [16] - [17]. The reception apparatus is proficient in beam steering on the XZ-plane upon MEMS put on the antenna feeding line. A pattern and frequency reconfigurable antenna is presented in [18]. The antenna used a single feed line with the help of diodes. The radiation pattern reconfiguration is achieved by rotating the patch. A lumped element switch is employed in [19] and [20]. The lumped components are utilized in the simulation environment to accomplish tunable capacitance which is responsible for frequency reconfigurability. However, the methodology used in majority of the above mentioned papers have some disadvantages for the fact that they are not easily modeled and are not conveniently integrated within the structure.

In this paper, a 2x2 isolation frequency reconfigurable MIMO antenna is designed on the FR4 substrate with thickness of 1.6mm. The MIMO antenna transmits in six different frequency bands which include personal communication system (PCS), WIMAX and WLAN band. The lumped components are employed as switch within the radiator to accomplish the frequency reconfigurability. The value of the R used which configure the state of the switch is R= 1Ω (switch ON) and R=1kΩ (switch OFF). A space of 1mm is saved for the integration of each switch. The rest of the manuscript is sorted out as follows: section 2 is the antenna geometry and design, while section 3 discussed the simulation results, section 4 presents the MIMO system metrics and section 5 finishes up the study.

2. ANTENNA DESIGN

2.1 Antenna Geometry

The proposed frequency reconfigurable MIMO antenna is derived from two planar rectangular monopole antenna fed by 50Ω microstrip line. The step-by step design procedure is shown in figure 1. The detailed geometry of the top and bottom view are shown in figure 2A and 2B, respectively. The optimum parameters of the proposed antenna are given in table 1. The 2x2 reception apparatus is designed on FR4 substrate with a permittivity of 4.3, tan δ = 0.025, and 1.6mm thick. The electromagnetic design and simulation of this work are performed in the commercial full wave simulator CST 2017 version.

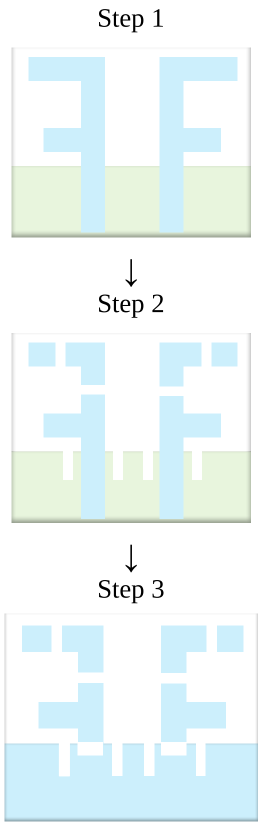


Figure 1. The design evolution of the 2x2 MIMO antenna

2.2 Parametric Analysis of the Design

The design evolution is presented using three different steps as mentioned above. Besides, the reflection coefficient plots for all the intermediate steps involved in design process are provided in figure 3 for identifying the effect or influence of each design step on the impedance bandwidth. The step 1, as shown in figure 1 is a 2x2 monopole with a partial ground plane having a length of G_L=16mm. In the second step, slits are added in the ground plane which, alters the current distributions in the plane. The surface current of defective ground structure in step 2 alter the input impedance of the MIMO antenna and improve the impedance bandwidth. Four different slits are also added on the radiating elements which helps in improving the impedance bandwidth and also serve as a place where our switches can be integrated for reconfigurability. In the final design step, that is, step 3 two notches are employed in the ground plane. The two notches introduced in step 3 alter the surface currents in the ground plane and contributes in impedance matching around -18dB as shown in figure 3.

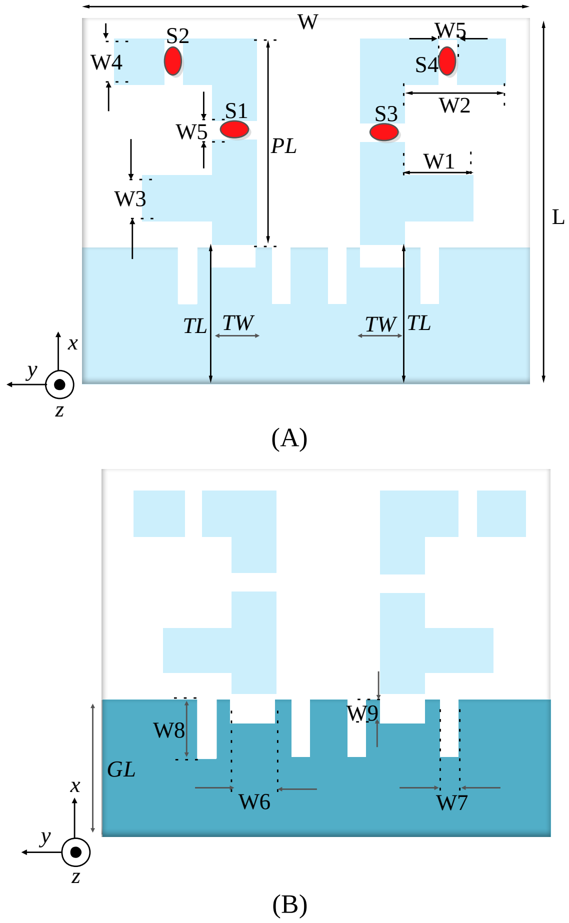


Figure 2. 2x2 MIMO antenna geometry: A, top layer, B, ground plane

Table 1. Optimized antenna parameters

Parameter	Size (mm)	Parameter	Size (mm)
L	40	W_2	9
W	50	W_3	2
G_L	16	W_4	3
P_L	23	W_5	1
T_L	16	W_6	3
T_W	3	W_7	2
H	1.6	W_8	5
W_1	2.81	W_9	0.4

3. RESULTS AND DISCUSSION

3.1. Reflection Coefficient of the MIMO Antenna

Four element switches is used for four possible modes of procedure which is shown in table 2. Lumped element switch is preferred because it is easily configured in CST as a resistor of 1Ω and 1kΩ to control the switch in ON and OFF mode respectively. The MIMO antenna operates in mode 1 when the switch is set in the ON state. In this mode the MIMO antenna gives two frequencies of 1.7GHz and 5.1GHz. The two frequencies are used for PCS and WLAN application. Figure 4 shows the simulated S_{11} for the ON state. Figure 5 remain the isolation coefficient (S_{21}) of the MIMO antenna. Mode 2 is the OFF state that is, when the four switches are off, 3.35GHz was realized as shown in figure 6, while figure 7 is the S_{21} of the MIMO antenna when the switch is off. Mode 3 is when S_1 is ON, S_2 is OFF, S_3 is ON and S_4 is OFF, 5.6GHz is attained as shown in figure 8. The S_{21} of the mode is presented in figure 9. In mode 4 which is the last mode S_1 is OFF, S_2 is ON, S_3 is OFF and S_4 is ON, two dual frequencies are realized at 3.3GHz and 5.28GHz as depicted in figure 10. The S_{21} is shown in figure 11. In all the four modes more than 14dB isolation is attained.

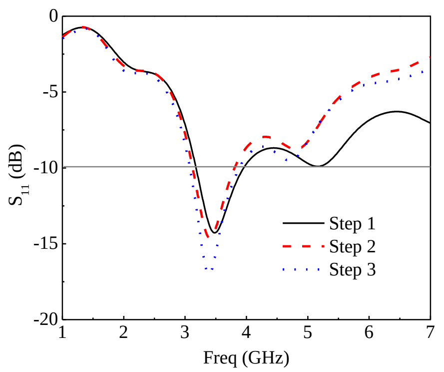


Figure 3. S_{11} plots for each design step

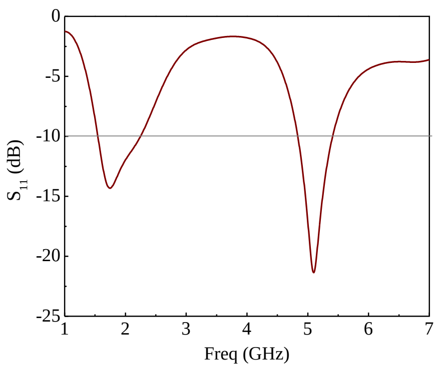


Figure 4. Simulated S_{11} for mode 1

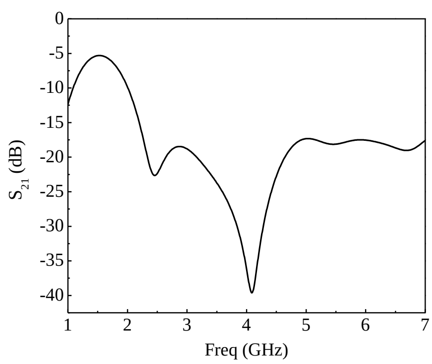


Figure 5. Simulated S_{21} for mode 1

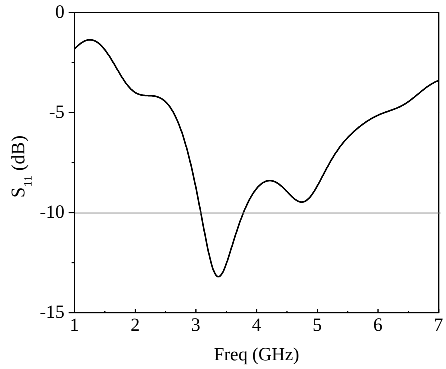


Figure 6. Simulated S_{11} for mode 2

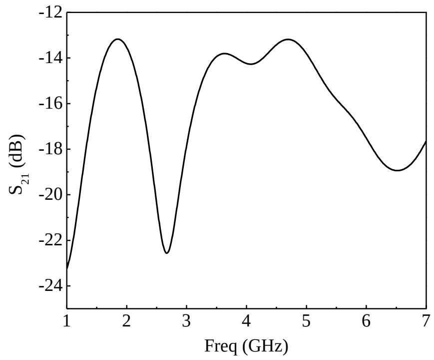


Figure 7. Simulated S_{21} for mode 2

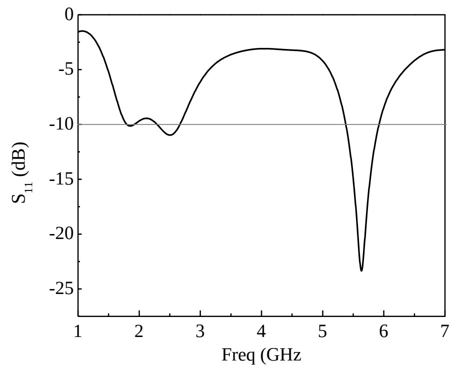


Figure 8. Simulated S_{11} for mode 3

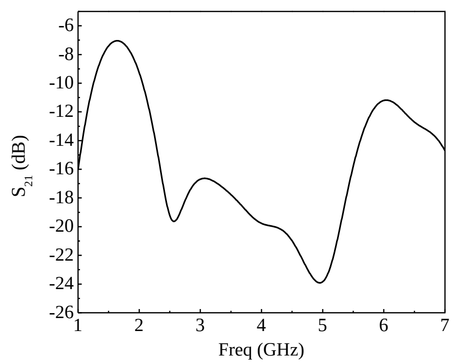


Figure 9. Simulated S_{21} for mode 3

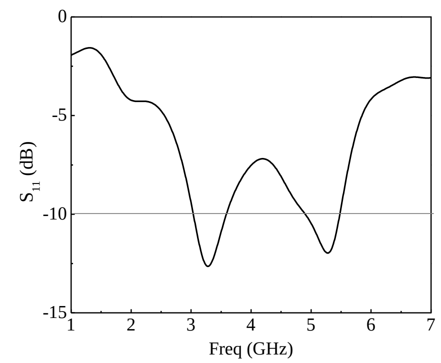


Figure 10. Simulated S_{11} for mode 4

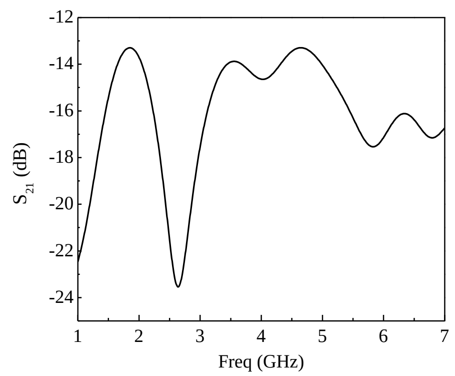


Figure 11. Simulated S_{21} for mode 4

Table 2. Frequency mode of the proposed antenna

Modes	**S_1**	**S_2**	**S_3**	**S_4**	**Frequency**
Mode 1	ON	ON	ON	ON	1.7GHz, 5.1GHz
Mode 2	OFF	OFF	OFF	OFF	3.35GHz
Mode 3	ON	OFF	ON	OFF	5.6GHz
Mode 4	OFF	ON	OFF	ON	3.3GHz, 5.28GHz

3.2 Radiation Pattern of the MIMO antenna

Radiation pattern of the proposed 2x2 MIMO antenna are simulated using CST studio version 2017. The plot at 1.7GHz, 3.3GHz and 3.35GHz is shown in figure 12, while figure 13 is the pattern plot at 5.1GHz, 5.28GHz and 5.6GHz.. As can be seen from all the plots the MIMO antenna has approximately omnidirectional radiation pattern

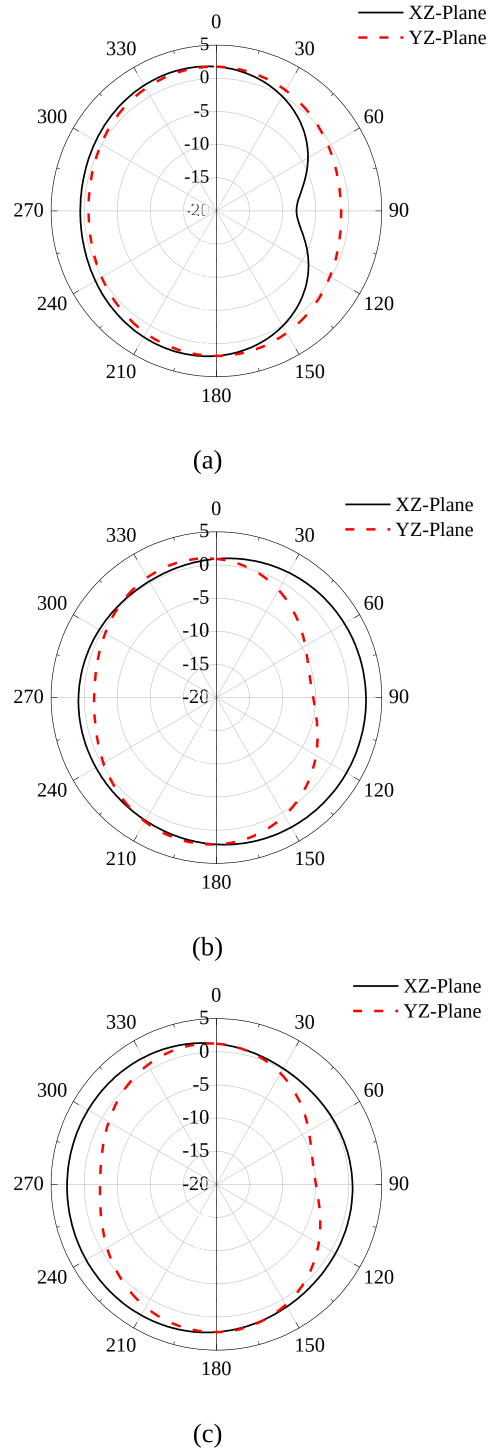
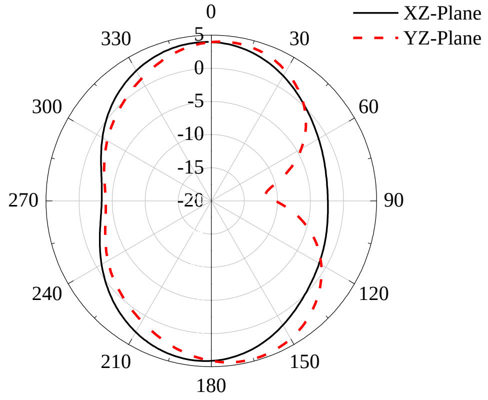
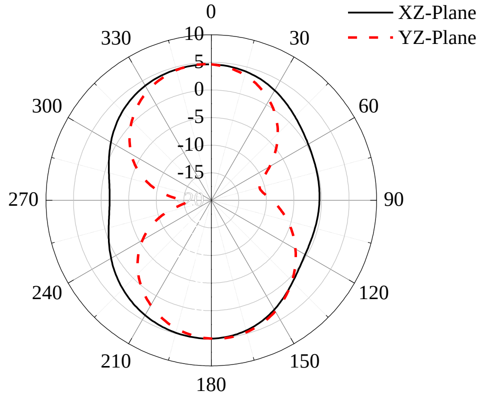


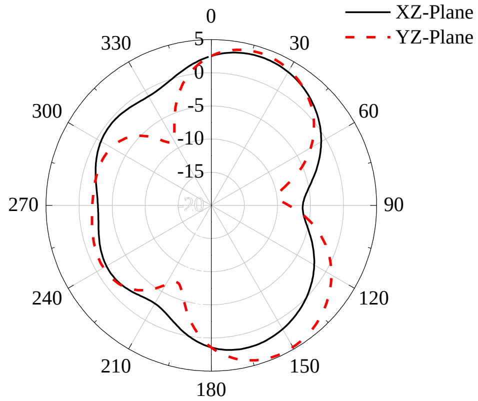
Figure 12. Radiation pattern at (a) 1.7GHz, (b) 3.3GHz, and (c) 3.35GHz



(a)



(b)



(c)

Figure 13. Radiation pattern at (a) 5.1GHz, (b) 5.28GHz and (c) 5.6GHz

4. MIMO SYSTEM METRICS

The important parameters which serves as the determinant factors for the coupling coefficient between the MIMO antenna elements is called the envelope correlation coefficient. Virtually ECC factor must be less than 0.5 and is usually computed using the S-parameter given in equation 1. The ECC plot is pictured in figure 14 which is lower than 0.001 over the frequency of interest. Another important parameter for the implementation of MIMO antenna is diversity gain, it is obtained when two or more antennas are used, which is calculated using equation 2. Diversity gain plot for the proposed MIMO antenna is presented in figure 15. It is clearly seen that the value is almost 10dB. A good diversity gain performance is clearly exhibited by the antenna.

$$ECC = \frac{\left|S_{11}^{\bullet}S_{12} + S_{21}^{\bullet}S_{22}\right|}{\left(1-\left|S_{11}^{2}\right|-\left|S_{21}^{2}\right|\right)\left(1-\left|S_{22}^{2}\right|-\left|S_{12}^{2}\right|\right)} \quad (1)$$

$$DG = 10\sqrt{1-ECC^{2}} \quad (2)$$

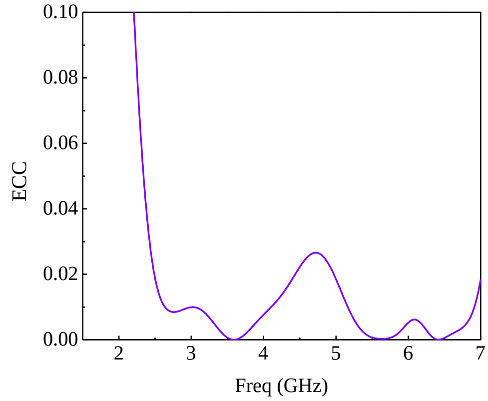


Figure 14. ECC of MIMO antenna system

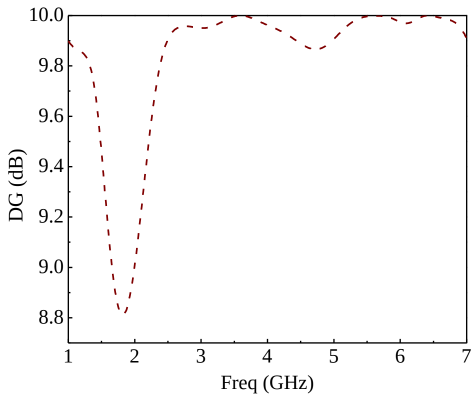


Figure 15. Diversity gain of the MIMO antenna

Total active reflection coefficient (TARC) is one of the coupling coefficient between the MIMO antenna elements for a two-port MIMO antenna. TARC can be computed using equation 3 [21]. The TARC is dependent on scattering parameters from port 1 to port 2 and vice versa. Practically, the value of TARC must be lower than 0dB. Figure 16 is the TARC plot using Matlab 2018 and origin 8 for the plot. θ is considered as variable angle which is related to phase of excitation signal. TARC was considered from 0 degrees to 180 degrees with an interval of 30^{o}. The plot reveals that $0 \le r_{a}^{t} \le 1$.

$$TARC = \frac{\sqrt{\left|S_{11}+S_{12}e^{j\theta}\right|^{2}+\left|S_{22}+S_{21}e^{j\theta}\right|^{2}}}{\sqrt{2}} \quad (3)$$

Increasing the number of antennas will lead to an increase in the channel capacity of the MIMO system, some losses will be included in the channel due to the presence of correlation. Channel capacity loss is one of the important feature that describes data rate that can be supported in a particular channel. CCL can be calculated from simulated S-parameters using the equation 4 below. The CCL is presented in figure 17 in which, the plot shows that the CCL are less than 0.2 over the frequency of interest.

$$CCL = -\log_2 \det\left(\psi^R\right) \quad (4)$$

Figure 18 is the peak gain over the frequency and the efficiency of the MIMO antenna, more than 70% of efficiency is attained by the MIMO antenna.

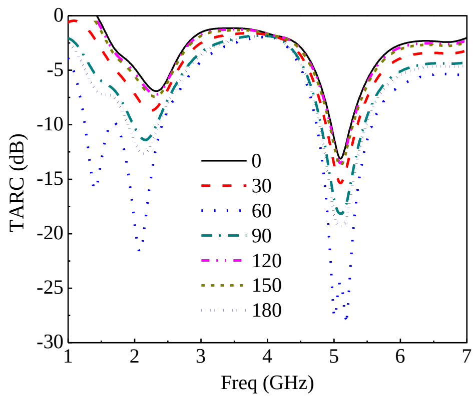


Figure 16. TARC of the 2x2 MIMO antenna system

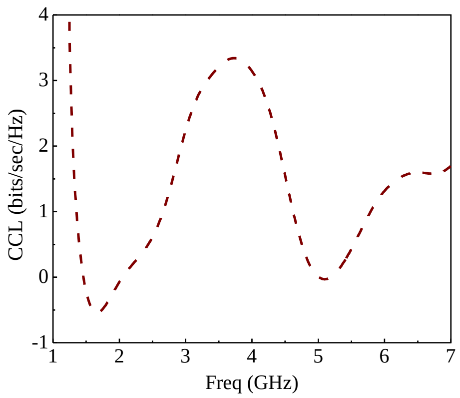


Figure 17. CCL of the 2x2 MIMO antenna system

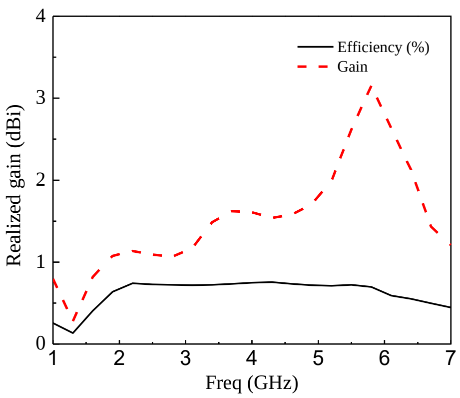


Figure 18. Realized gain and efficiency of the MIMO antenna

5. CONCLUSION

This work presents a frequency reconfigurable MIMO antenna for PCS, WIMAX and WLAN application. Numerical outcomes are given to exhibit the proposed model. With an efficiency of more than 70% the proposed antenna provides low polarization diversity aims at attaining the low mutual coupling which provides low latency, increased user rate, reduce cost and energy and finally increase the capacity in terms of traffic and connections.

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