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L	L_{G1}	L_{G2}	L_P	L_{F1}	L_{F2}	L_{ST}	I_{S1}	I_{S2}	I_{S3}
22	10	3.5	6	3.8	7.2	15.2	2	7	10
W	W_{G1}	W_{G2}	W_{G3}	W_{F1}	W_{F2}	W_{ST}	W_S	I_{S0}	
36	36	1.9	17	2	1	1	0.5	1	

Table: Dimensions Of Proposed Mimo Antenna

The dimensions of the projected MIMO antenna is depicted in Fig. 1. The antenna is realized on a $36 \times 22\text{mm}^2$ FR4 substrate. This substrate is 1.6mm thick has relative dielectric constant of 4.4 and has loss tangent 0.019. The MIMO antenna consists of two identical monopole antenna elements represented as MA_1 and MA_2 . A Flag-shaped stub is placed at the center on the ground. Flag-Shaped stub is hosted on the ground to reduce the mutual coupling between elements and enhance the isolation between ports 1 and 2. The two antenna elements, MA_1 and MA_2 are placed in parallel on side of the substrate with dimensions of $L_p \times L_p$ are fed by micro strip line with dimensions of $W_f \times L_f$ through port 1 and 2. The ground plane placed on back side of the substrate with dimensions $W \times L_{G1}$ and as a rectangular slits with dimensions of $W_{ST} \times L_{ST}$.

III. RESULTS AND ANALYSIS

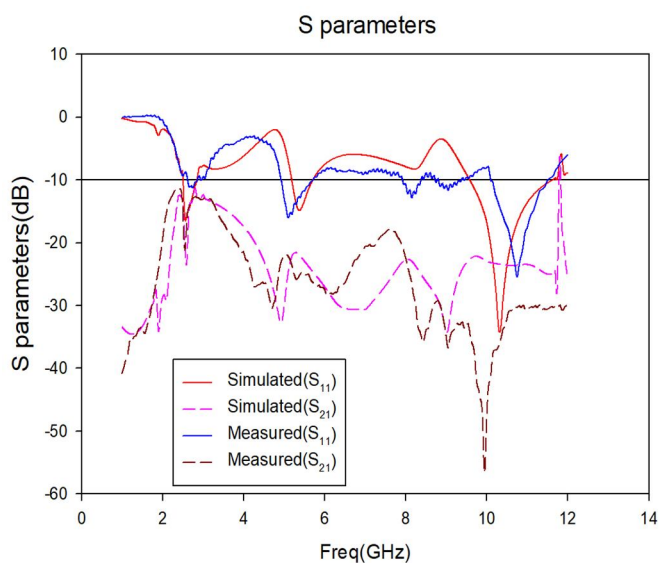


Fig. 2. Simulated and Measured Results S_{11} and S_{21} of MIMO antenna.

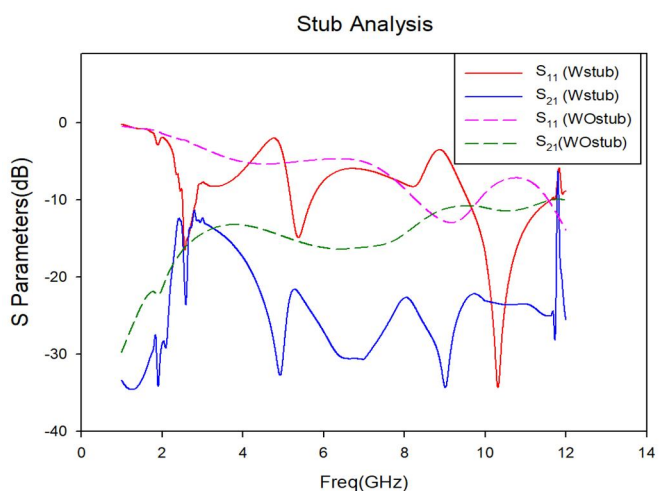


Fig. 3. Comparison between S_{11} and S_{21} with and without T-shaped stub.

When Flag-Shaped Stub is excluded from the designed MIMO antenna the Return loss is -2dB at 2.58GHz, -5dB at 5.2GHz and -8dB at 10.55GHz. Again when Flag-Shaped Stub is introduced better Return loss is obtained at all three frequencies and isolation increases rapidly due to the coupling path introduced by the Flag-Shaped Stub and cancel out the coupling between Monopole antennas.

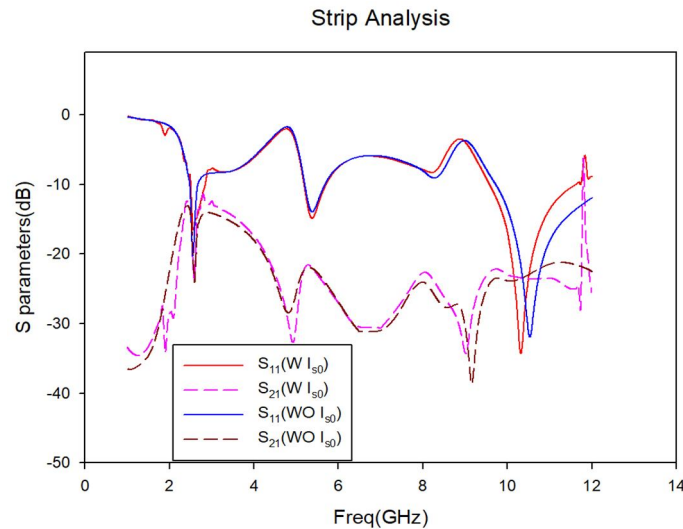


Fig. 4. Simulated Results S_{11} and S_{21} with and without strip I_{s0} .

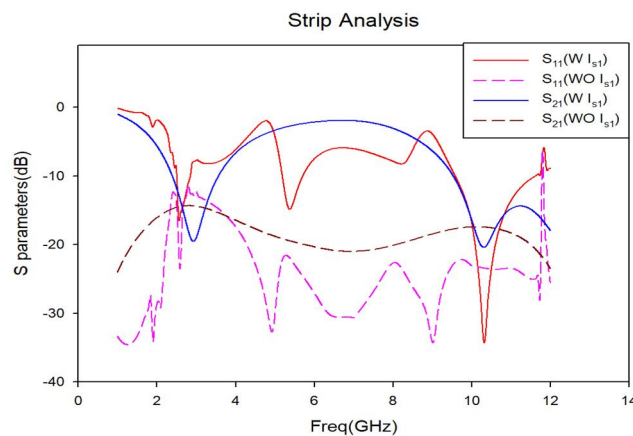


Fig. 5. Simulated Results S_{11} and S_{21} with and without strip I_{s1} .

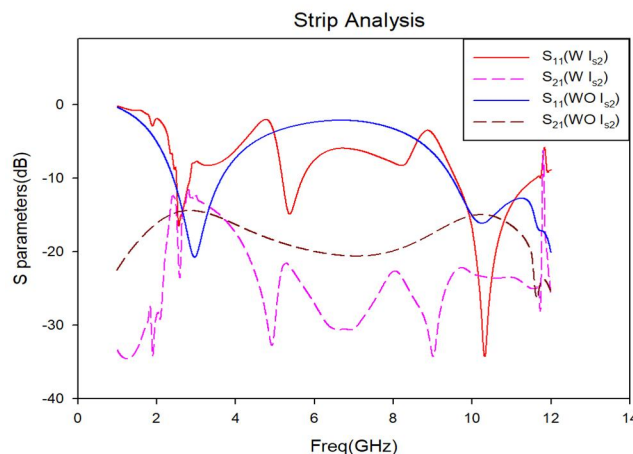


Fig. 6. Simulated Results S_{11} and S_{21} with and without strip I_{s2} .

Above Fig .4, Fig .5 and Fig .6 represent the analysis of S parameters of MIMO antenna with and without strips I_{s0} , I_{s1} and I_{s2} .

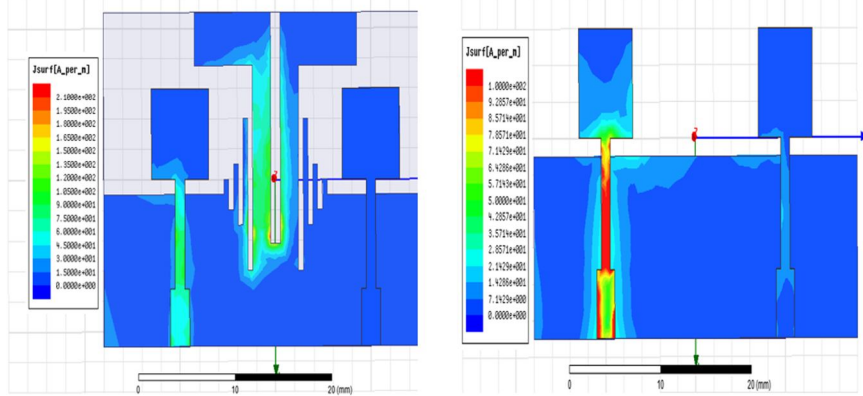


Fig. 7. Simulated Current Distribution Results with and without T shaped Stub at 2.58GHz.

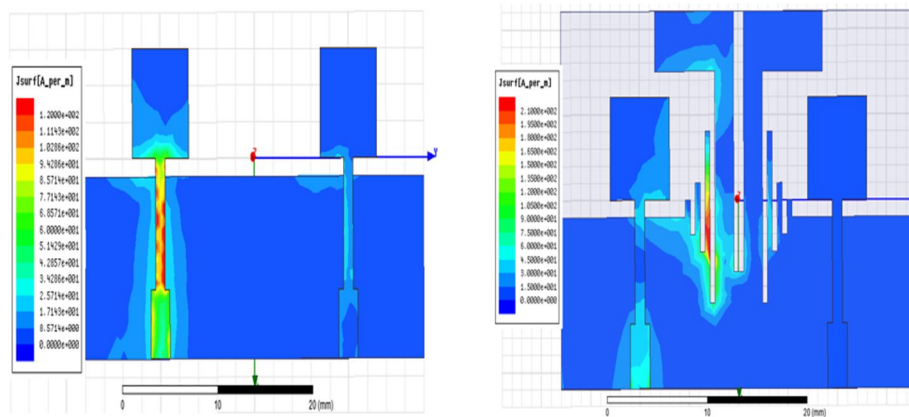


Fig. 8. Simulated Current Distribution Results without and with T shaped Stub at 5.2GHz.

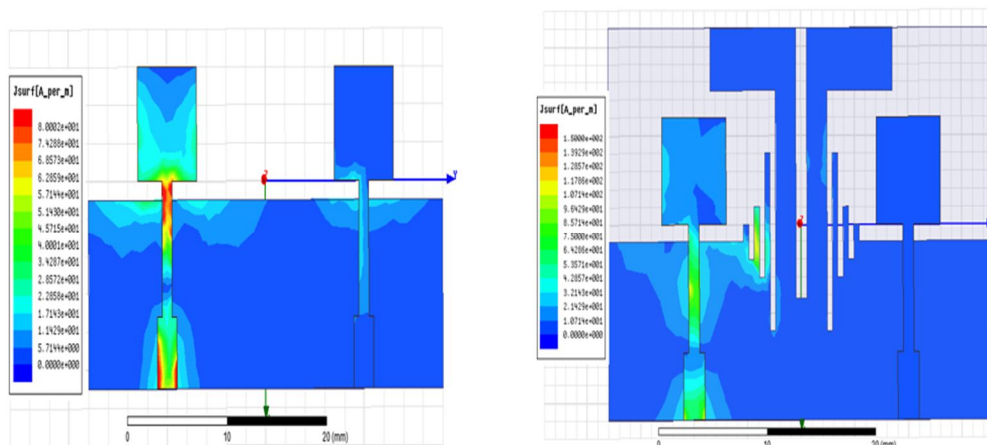


Fig. 9. Simulated Current Distribution Results without and with T shaped Stub at 10.55GHz.

Without T shaped stub in the proposed MIMO antenna there will be a high coupling between two Monopole antennas, this can be observed in Fig .7 for 2.58GHz and similarly for other two other frequencies in Fig .8 and Fig .9. As we have implemented Defective Ground Structure (DGS) technique by introducing T shaped stub and strips produces another coupling path and this creates another coupling current which cancel out the signal between the two Monopole antennas. We can observe that the coupling between two Monopole antennas in Fig .7, Fig .8 and Fig .9 for 2.58GHz, 5.2GHz and 10.55GHz respectively. □

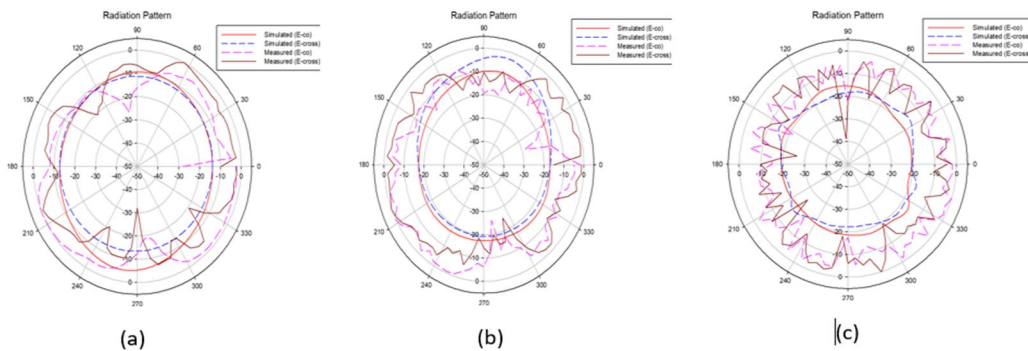


Fig. 10. Radiation Pattern of E-co and E-cross at 2.58GHz, 5.2GHz and 10.55GHz.

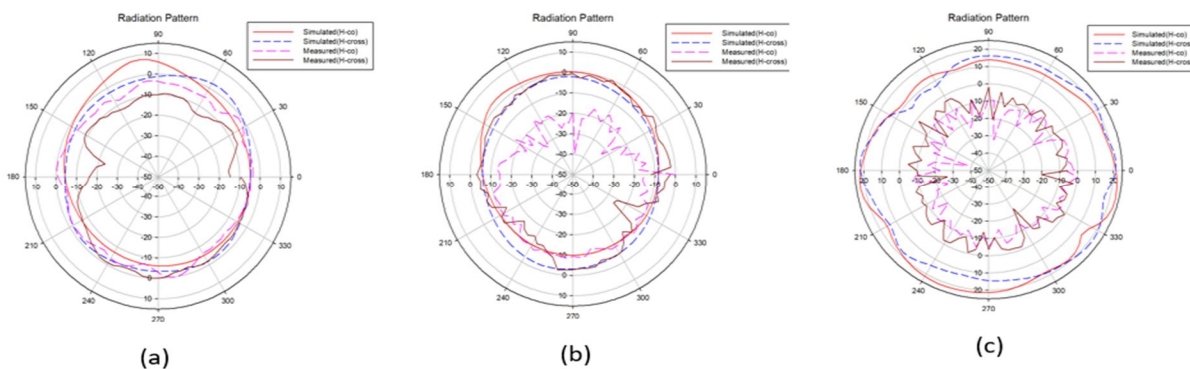


Fig. 11. Radiation Pattern of H-co and H-cross at 2.58GHz, 5.2GHz and 10.55GHz.

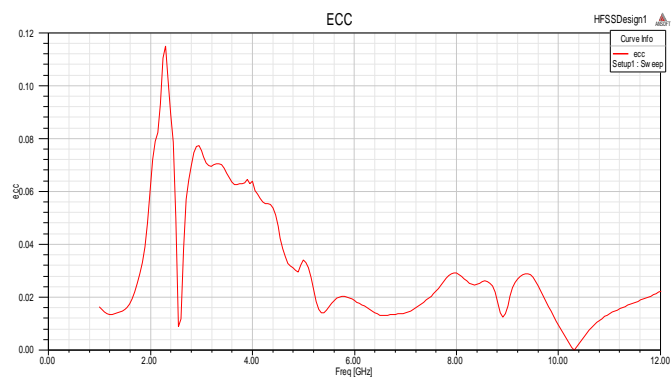


Fig. 12. Envelope correlation coefficient (ECC) of MIMO antenna.

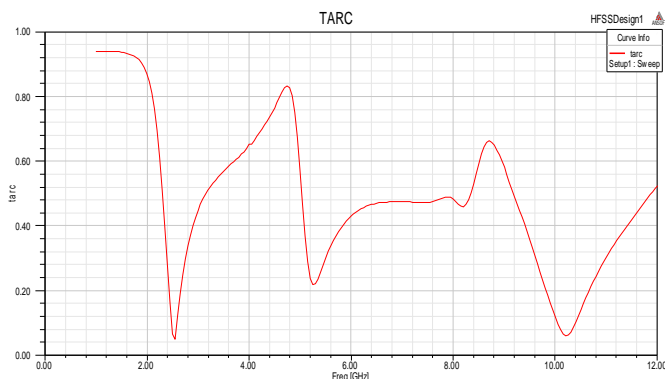


Fig. 13. Total Active Reflection Coefficient (TARC) of MIMO antenna.

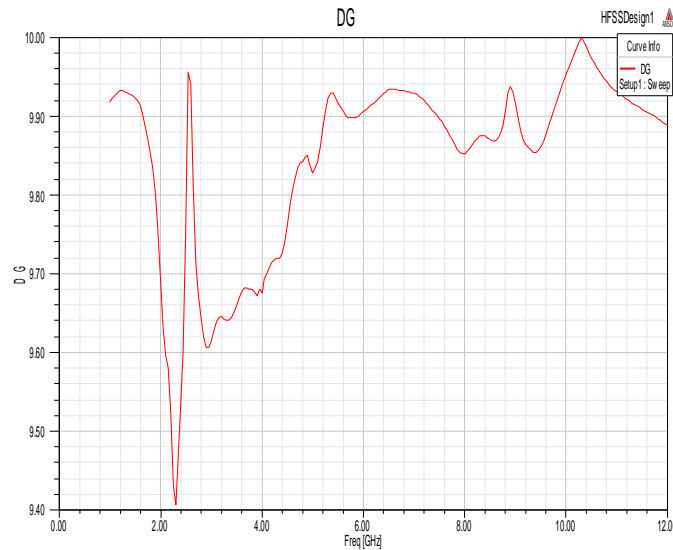


Fig. 14. Diversity gain (DG) of designed MIMO antenna.

The Envelope correlation coefficient (ECC) and Diversity Gain (DG) are two significant parameters to calculate the effectiveness of the MIMO antenna system. ECC concludes how individualistic the two antennas radiation patterns are. On the off chance, that one antenna is very horizontally polarized and the other antenna is very vertically polarized then the correlation between the two antennas would be zero. When ECC=0, it expresses that the antennas are completely decoupled, while ECC=1, it expresses that the antennas are essentially short circuited.

$$|\rho_{e12}|^2 = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{|(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)\eta_{rad1}\eta_{rad2}|^2} \quad (1)$$

Where 1 and 2 refers to the antenna elements 1 and 2 and radiation efficiencies of the antenna elements are η_{rad1}, η_{rad2} . MIMO antenna must satisfy the condition of low correlation [$\rho_{e12} < 0.5$]. In the Fig. 12, we can notice that the simulated result for ECC of the MIMO antenna is less than 0.12.

Diversity gain is characterized as the increase in the Signal to Noise (SNR) due to addition of one or more communication channel, or how much transmission power can be reduced when diversity scheme is introduced, without any loss. Diversity gain (DG) is expressed in terms of decibels (dB). The diversity gain (DG) for the proposed MIMO antenna is obtained using equation (2).

$$DG = 10\sqrt{1 - |\rho_{e12}|^2} \quad (2)$$

TARC is characterized as the proportion of the square root of total reflected power divided by the square root of total incident power, TARC can be expressed as

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

The Total Active Reflection Coefficient (TARC) for the proposed MIMO antenna is simulated using the equation (3).

IV. CONCLUSION

The proposed antenna is of dimension $36 \times 22mm^2$ with two Monopole antennas placed above the surface of the substrate and T-shaped stub and strips are located on other side of the substrate. This stubs and strips introduces an additional coupling path and this path creates a coupling current, reduces the coupling effect between the two identical monopole antennas, and increases the isolation between the antennas. The designed MIMO antenna operates at three band of frequencies 2.4-2.74GHz, 5-5.4GHz and 9-11GHz respectively. The Proposed MIMO antenna is intended for various applications such as LTE2500, WiMAX and WLAN. The Designed antenna of size of $36 \times 22mm^2$ has effectively secured three wideband of 2.4-2.74GHz, 5-5.4GHz and 9-11GHz that has applications in LTE2500 (2.5-2.7GHz), WLAN (5.15-5.35GHz), WiMAX (2.35GHz, 2.5GHz), Radar Detector(10.475-10.585 GHz), aeronautical navigation(9.3-10GHz), aeronautical military system(9.3-10.5GHz).



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