2×2 Compact Multi-Band MIMO Antenna with Bandwidth Enhancement

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Abstract - *A miniaturized 2×2 Multi-band MIMO (Multi-input, Multi-output) patch antenna is introduced in this paper. The antenna, proposed in the paper, covers wide range of electromagnetic spectrum including some parts of C, X, Ku, K and ka bands. The antenna also includes notch bands between different resonant frequencies to avoid interference. The antenna covers 5.5-7.2GHz in C-band, 8.4-9.6GHz in X-band, 13.2-17.3GHz in Ku-band, 21.2-22.7GHz in K-band and 25.6-28.6GHz in Ka-band. The given antenna is constructed using two hexagonal patches fed with microstrip lines and a defected ground surface. The defects in the ground plane help in receiving proper isolation between the ports. The suggested antenna is simulated using hfss software and the results received by simulation are attached in the paper. The effective return loss for all the operating bands is less than -10dB. The coefficient of correlation, termed as ECC for the suggested design is less than 0.05dB. The Mutual Coupling and Isolation both are less than -20dB. The antenna is highly efficient having the radiation efficiency around 81.5%. The designed antenna is compact in size with dimensions of 28mm × 17mm × 1.6mm.*

Key Words: *MIMO (Multi-input Multi-output), ECC (Envelope Correlation Coefficient), Mutual Coupling, Isolation.*

1. INTRODUCTION

The growth of communication systems using wireless services is at its peak. This extreme growth has not only changed the basic requirements of the wireless industries but also increased the expectations of the antennas manufacturers. Now the demand is to have an antenna with wideband operability and compact in terms of occupied area. A wideband antenna finds beneficial when it is needed to cover more than one electromagnetic band in single application. To get access to all major communication applications like Satellite communication, radar communication, WLAN, WiMAX etc. a UWB antenna is designed [1]. A UWB antenna can find its operability in number of frequency ranges usually that covers 3.1GHz to 10.6GHz. There is number of literatures available today, in which wideband monopole antennas are suggested. The primary approach applied by the researcher to receive improvement in terms of effective or fractional BW of the antenna is to introduce slots or defects in the resonating surface or with the bottom plane [2-3]. These slots introduced in the ground plane couples a finite impedance with the patch and subsequently decrease the operating frequency region and with the existing operating band and introduce more operating bands in the antenna characteristics [4-5]. Another approach for getting enhancement in the bandwidth is to use different types of patches having different shapes or asymmetric slots [6-11]. Also, some researchers have used CSRR or EBG structures to get antennas with large bandwidths [12-14].

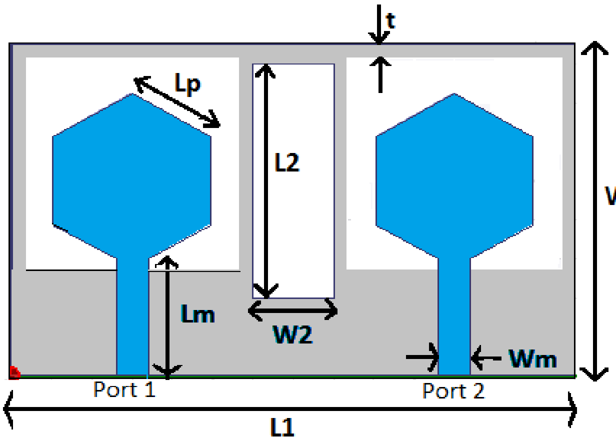
The drawback with all these approaches is that it may results in fading in times of multipath conditions. To deal with this problem antenna arrays are used. Also, a MIMO antenna can also be designed to avoid this problem which may not be a solution of the problem but also result the antenna bandwidth to a large extent. These antennas also have high efficiency and better in terms of directivity.

The work in this paper suggests a MIMO antenna structure that shows multi-band operability and improves the antenna fractional bandwidth. The antenna can operate in number of bands in the electromagnetic spectrum. It covers the number of antenna applications in X, Ku, K and Ka bands. The proposed design is simulated using the hfss v15 software and all the results are calculated and attached with the paper.

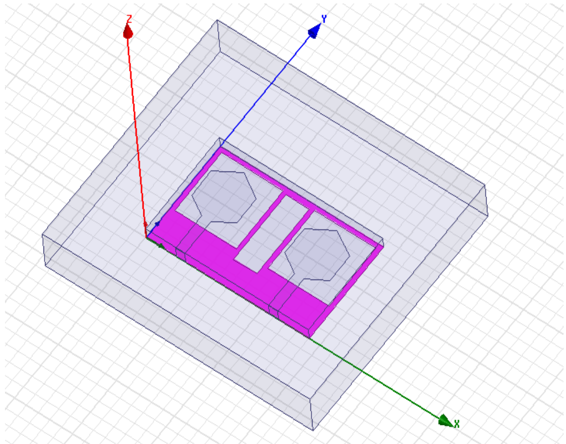
2. PROPOSED GEOMETRY OF MIMO ANTENNA

The suggested 2×2 compact and multi-band MIMO resonator is constructed on an easy available and low-cost FR-4 epoxy glass substrate having relative dielectric const. (ε_r= 4.4), loss-tangent (tanδ=0.02) and the thickness 1.6mm. The structure consists of two hexagonal shaped patches fed using microstrip lines of 50Ω impedance. The patches of the antenna are positioned to match the impedance with the microstrip lines so that the spurious radiation can be reduced to its maximum extent. The ground plane of the antenna is designed to get maximum efficiency and enhanced bandwidth using minimum effective ground area. The overall geometrical aspects of the simulated work are arranged in the table 1 below. Figure 1 below shows the

MIMO structure from top view and hfss design of antenna extracted from the hfss software.



(a)



(b)

Fig.1. Proposed 2×2 MIMO Antenna (a) UPPER SURFACE showing patch with the ground structure, (b) hfss model

TABLE I

2×2 Compact MIMO Antenna: DIMENSIONS

Side	Units (mm)	Side	Units (mm)
L_1	28	L_m	5.9
W_1	17	W_m	1.6
L_2	12	L_p	4.25
W_2	4	t	0.75

In the figure 1(a), blue area denotes the patch whereas grey area denotes the ground structure. The two patches are connected with two lumped ports (port 1 and port 2) through microstrip lines that provide excitation to the antenna.

3. EFFECT OF DEFECTED GROUND PLANE

The structure of bottom surface of any patch antenna is the deciding plane for its impedance and the resulted radiation characteristics [15-17]. Figure 2 below depicts the structure of the ground plane of the designed antenna. The plane is configured to get the best possible radiation characteristics.

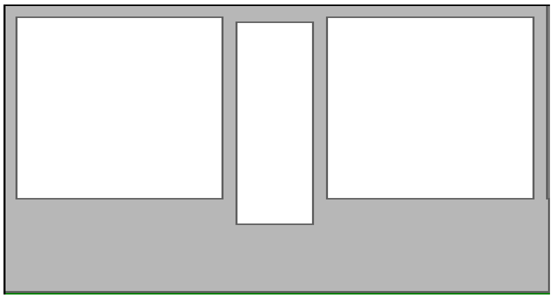


Fig.2. Design of the suggested ground plane

The plane is configured by keeping in mind that it may reduce the mutual coupling between antenna elements. Figure 3 shows the plot of mutual coupling parameter S_{12} with respect to frequency. The plot illustrate that it is below -20dB for all the operating frequency range.

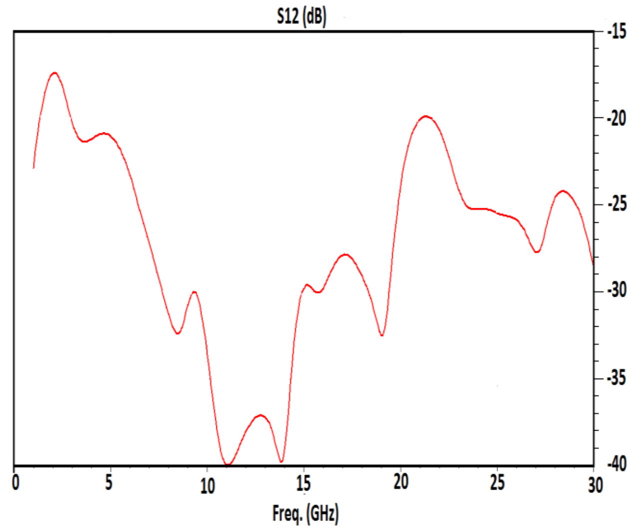


Fig.3. Simulated plot of Mutual Coupling (S_{12} dB)

Figure 4 shows the flow of currents in the resonating patch and the ground when the port 1 is excited. When the excitation is applied to the port 1, the surface current start to flow from the port 1 to 2, as shown in the figure, the isolation resulted is good shown in figure 5.

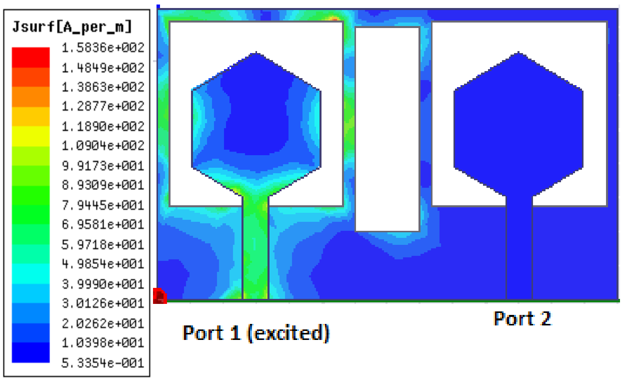


Fig.4. Surface current density distribution in patch and ground plane

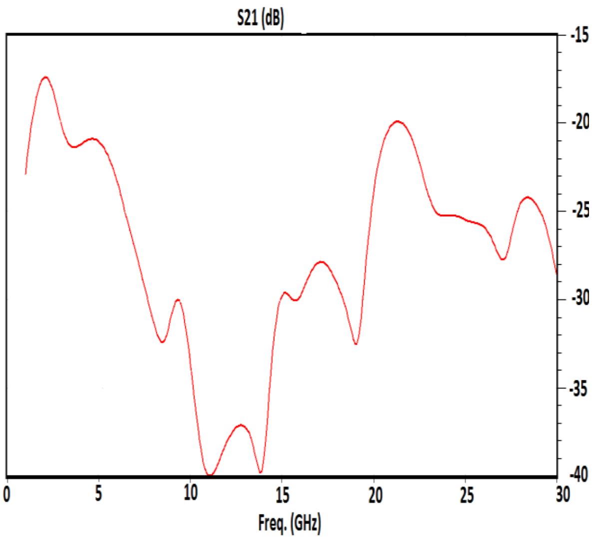


Fig.5. Simulated plot of Isolation (S_{21} dB)

4. RESULTS AND DISCUSSIONS

Designing of a MIMO antenna is entirely different from designing a basic microstrip antenna because in this case, we need to take care about the mutual coupling and isolation of the various antenna elements. If the antenna elements get coupled, they affect the antenna parameters adversely. This is the reason, the isolation among the elements must be high and the correlation factor must be low.

The most important parameters that define the characteristics of a MIMO antenna are discussed below-

4.1 Reflection Coefficient (S_{11}) and Total Active Reflection Coefficient (TARC) – Figure 6 shows a combine plot of return loss and TARC for the proposed antenna. The return loss or the parameter of the reflection for the antenna is measure of the parameter S_{11} whereas TARC is calculated as,

$$\mathrm{TARC} = \sqrt{\frac{(S_{11}+S_{12})^2 + (S_{21}+S_{22})^2}{2}}$$

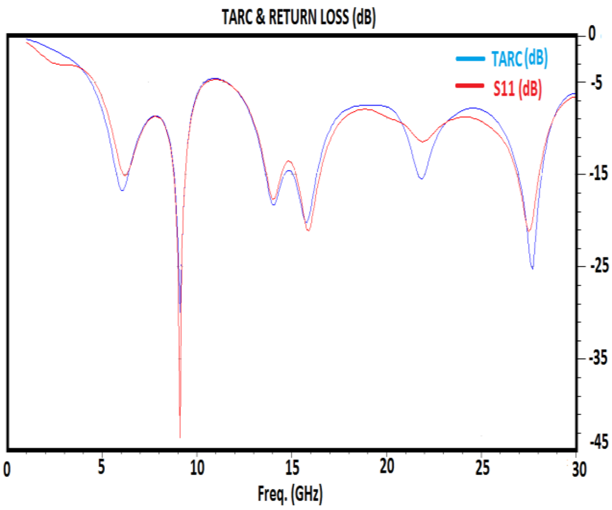


Fig.6. Simulated plot of Return loss and TARC (dB)

The antenna gives multi band response. The pass bands of the antenna includes 5.5-7.2GHz in C-band, 8.4-9.6GHz in X-band, 13.2-17.3GHz in Ku-band, 21.2-22.7GHz in K-band and 25.6-28.6GHz in Ka-band.

4.2 Envelope Correlation Coefficient (ECC) – The Envelope correlation coefficient of the Multi-input, Multi-output antenna can be calculated as,

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

For a MIMO antenna, the accepted threshold for the ECC is 0.5. ECC value less than 0.5 is acceptable for the MIMO antenna. Figure 7 gives the plot of ECC vs frequency for the proposed antenna.

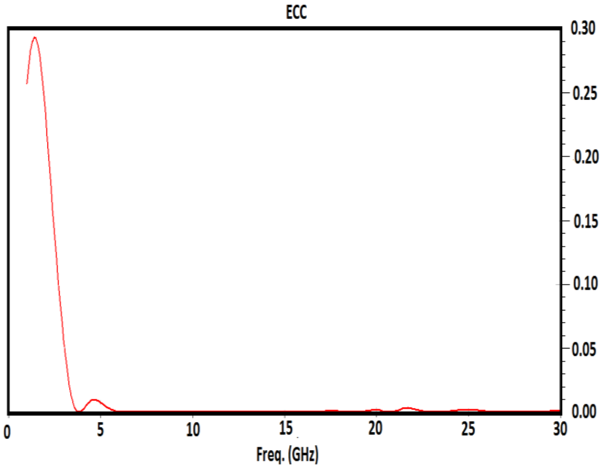


Fig.7. Simulated plot of ECC

4.3 Diversity Gain (DG) – The term denotes the difference between the extents of powers for the entire MIMO system and the extent level of the single diversity channel. Diversity gain can be calculated as,

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

Figure 8 below depicts the graph of Diversity gain (DG) for the given system. The average DG for the simulated antenna is 10dB.

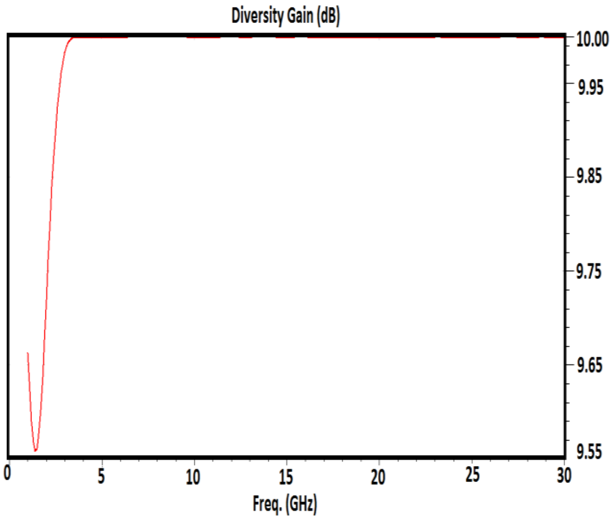


Fig.8. Simulated plot of Diversity gain

4.4 Radiation Pattern – Figure 9 depicts the radiation diagram of the compact MIMO antenna with respect to its total gain value. Figure 10 shows the E-plane's and H-plane's Co & Cross Polarization. The radiation diagrams are drawn at the resonating frequency of 15GHz.

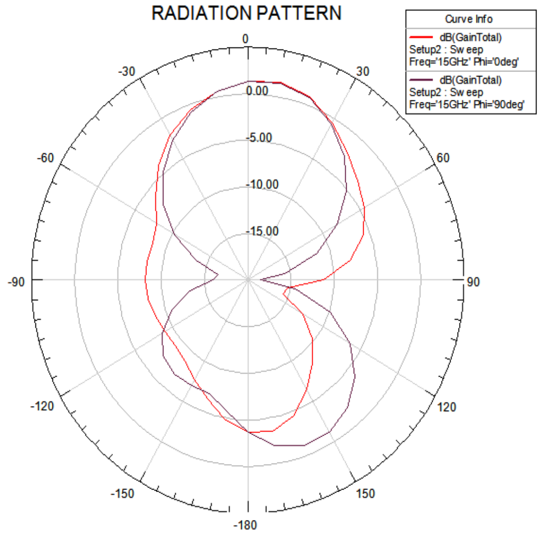
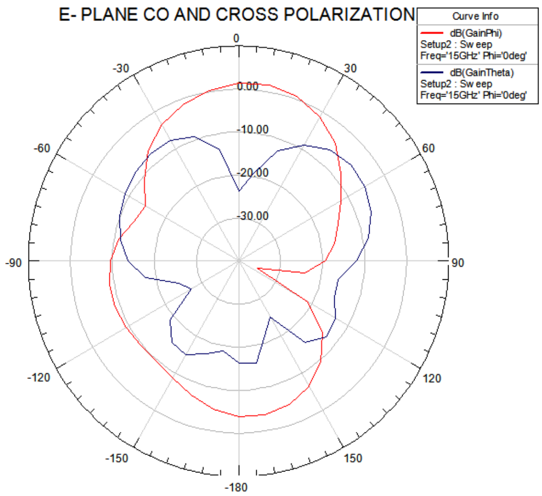
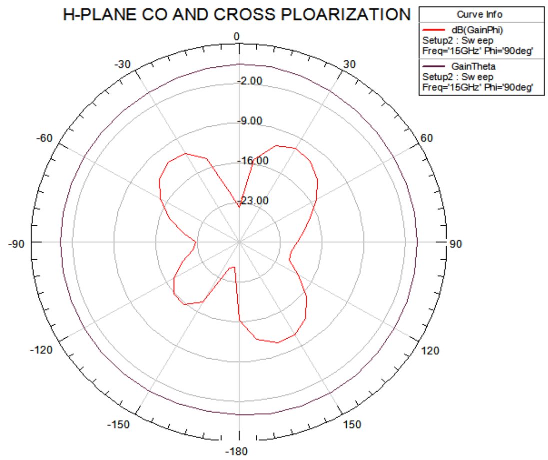


Fig.9. Radiation Pattern at 15GHz



(a)



(b)

Fig.10. (a) E-plane's Co & X-Polarization, (b) H-plane's Co & X- Polarization

TABLE II
E-plane and H-plane & X-Polarization

Reference plane	Co-Polarization (dB)	X-Polarization (dB)
E-plane	1.34	-23.84
H-plane	1.36	-23.84

4.5 Radiation Efficiency – Radiation efficiency of an antenna depends on its power gain and its directivity. As we know that,

$$G_P = \eta . G_D$$

Where Gp denotes the peak value of the antenna power gain and G_D denotes the directive gain or directivity. Figure 11 shows the combined plot of Power Gain (G_P) and Directive Gain (G_D) for the designed antenna.

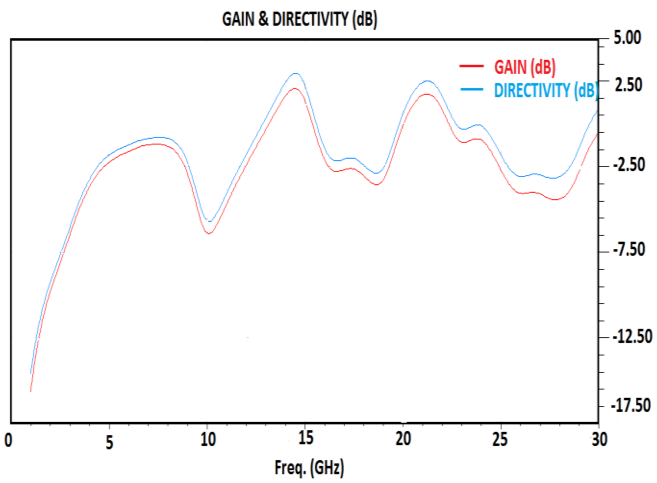


Fig.11. Simulated plot of Gain and Directivity

The peak measure of power gain for the designed antenna is 2.06dB and the peak value of directivity is 2.99dB. The resulted radiation efficiency for the proposed antenna is 81.5%.

4.6 Voltage Standing Wave Ratio (VSWR) - Antenna's impedance matching ability is decided by its VSWR. Figure 12 depicts the graph of the parameter for the designed antenna. The antenna gets good matching conditions for all the operating bands.

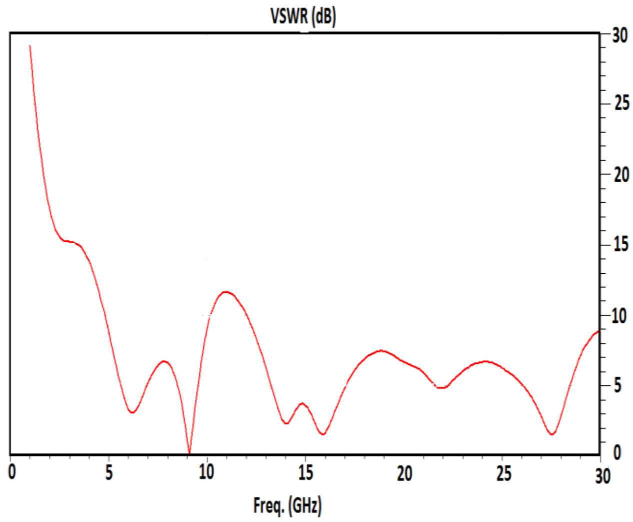


Fig.12. Simulated plot of VSWR

5. CONCLUSION

A multi band 2×2 MIMO antenna is suggested in the paper. The simulation process for the designed antenna is conducted using hfss software to obtain the radiation characteristics. The proposed antenna shows good radiation features in terms of its return loss, ECC, DG, radiation pattern and VSWR. The antenna also results miniaturization in the antenna dimensions. Table 3 shows a comparison of the proposed antenna with the other referenced works.

TABLE III
Comparison of proposed antenna with other references

References	Operating Frequency Bands (GHz)	Antenna Efficiency (%)	Dimensions (mm×mm)
[18]	2-12	-	22×26
[19]	2-12	75	42×24
[20]	2-12	75	23×29
[21]	3-20	75	18×34
[22]	2-12	80	32×32
Proposed Antenna	**5.5-28.6 (with four notch bands)**	**81.5**	**28×17**

Hence, the proposed antenna is miniaturized in size and shows multiband response having four notch bands to avoid interference. The antenna finds its application mainly in satellite and radar communication covering X, Ku, K and Ka bands.

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