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Mutual Coupling Reduction Techniques on a Multiband Compact Planar MIMO Antenna

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***Abstract:** In wireless communication era, reduction of total size of devices is a challenge faced. Miniaturization results in placing the antenna elements closely. This in turn results in mutual coupling between the elements of the antenna due to which it suffers from high signal correlation and low antenna efficiency. This paper manifests a comparative study of numerous mutual coupling reduction techniques developed to improve the performance of MIMO antenna. A multiband compact planar MIMO antenna is designed and Neutralizing Line, Electromagnetic Band Gap, Meander Line and Defected Ground Structure are implemented on the proposed antenna to reduce the mutual coupling and to enhance isolation. The structure consists of two C-shaped monopoles, each operating at 2.4-2.45 GHz and 5.2-5.25 GHz frequency bands. The antenna design is simulated and the performance is measured in terms of S-parameters (return loss i.e. S11 < -10 dB; isolation i.e. S21 < -15 dB) and Voltage Standing Wave Ratio (1 < VSWR < 2) for the propounded mutual coupling reduction technique. MIMO antennas are prevailing in WLAN, Wi-Max, LTE (Long term evolution), and many other RF technologies like portable devices, automotive devices etc. as they are helping in improving the spectral efficiency.*
***Keywords:** Neutralizing Line (NL); Electromagnetic Band Gap (EBG); Meander Line (ML); Defected Ground Structure (DGS); Single Input Single Output (SISO); Single Input Multiple Output (SIMO); Multiple Input Single Output (MISO); Multiple Input Multiple Output (MIMO); Wireless Local Area Network (WLAN); Wi-Max; Long Term Evolution (LTE)*

I. INTRODUCTION

Wired network used cables to connect numerous devices. The connecting cables included fiber optic, optical fiber, twisted pair, coaxial cables etc. Though wired technology helped in establishing connections over various parts of the globe, the mobility, data rate and many other factors were limited. To overcome the limitations of wired network, there was a shift from wired to wireless technology. As transmission and reception of data in wireless communication requires antennas, the importance of antennas increased. In conventional wireless technology, SISO antennas were used for transmission and reception of data. SISO antennas were the simplest antennas to implement but their performance was degraded due to data rate limitation [1]. As SISO antennas lacked diversity, the performance was improved by SIMO and MISO antennas as they improved the transmitter and receiver diversity respectively. MIMO antennas provided robustness by providing multiple path and improving SNR [2].

Today, high channel bandwidth and high rate of transmission of data has become a necessity. MIMO antennas helped in achieving high speed wireless communication, improving channel capacity, through-put and have overcome the multipath effect and fading which existed before [3]. MIMO antennas have the advantage of MISO and SIMO. Depending upon the requirement of different frequency bands, various designs of MIMO antennas are proposed: monopoles, cross-polarized dipoles, Planar Inverted-F Antennas (PIFAs) for WLAN, and planar antennas for Ultra Wide Band (UWB). MIMO antennas have multiple transmitters and receivers and thus suffer from mutual coupling thus increasing the coupling power which can be due to surface currents flowing from one element to another element or due to electromagnetic interaction between the antenna elements [4]. The issue of mutual coupling is a major issue which results in changing the radiation patterns and also degrading the radiation characteristics [5]. It increases as the space between the antennas decreases. Several mutual coupling reduction techniques have been proposed to enhance isolation thus reducing the problem of mutual coupling and improving the overall performance of MIMO antenna.

The performance of the MIMO antennas can be achieved by using different strategies which can be classified as circuit level decoupling and antenna level decoupling. Circuit level decoupling technique can be used when the antenna impedances are known, limiting its usefulness when used with distributed elements. This technique is suitable for LTE but the total efficiency is compromised. DGS, neutralizing line, parasitic scatterers and polarization diversity comes under antenna level decoupling where the antenna structure needs to be modified. Among the various technique mentioned parasitic scatterers are proven to be more efficient (0.5dB efficiency loss for an isolated single monopole) [6]. The isolation problem in a dual band antenna was simplified to a single band problem by using stub resonator technique.

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To enhance the isolation, a metal strip was included between the two structures, each consisting of a T-shaped monopole and a T-shaped stub grounded structure. The isolation achieved for higher and lower frequency bands are less than -26dB and -20dB, respectively [7]. Mutual Coupling was reduced in a compact planar (2x1) MIMO antenna by proposing a parasitic element structure having a rectangular shape with 10 square slots. Due to the insertion of parasitic element between two port waveguide, an isolation of -25dB was obtained [8]. Parasitic elements create an opposition to the coupling field and thus the total coupling is reduced in MIMO antenna. The coupling which occurs between the adjacent antennas can be reduced by providing a negative coupling with the help of a decoupling network. Hybrid couplers are used to enhance isolation in lumped elements. There are two types of meta-material (MTM) based antennas. One is called MTM based antenna which uses ENG (Epsilon Negative), MNG (μ Negative) or DNG (Double Negative) substrate and the other is called MTM-inspired antenna which utilizes MTM unit cell such as the SRR (Split Ring Resonator), CSRR (Complementary Split Ring Resonator). By Using Open Slot Split Ring Resonator (OSSRR) with a two element patch array antenna results in an isolation of -37dB at an operating frequency of 2.4GHz. In electromagnetic environment where the polarization is in the plane of electric field, a single row of Folded Split Ring Resonator (FSRR) can be used to obtain an isolation of -45dB and two row of FSRR can be used to obtain an isolation of -56dB as they produce a current to balance inductive and capacitive effect [9]. The structure of ground plane can be modified to avoid the EM waves to propagate and thus acting as a band stop filter (suppressing harmonics greater than 30dB) by using defected ground structure. The isolation was highly improved from -29dB (using meander line as a mutual coupling reduction technique) to -59dB by using this technique. Electromagnetic Band Gap (EBG) structures help to reduce the mutual coupling (more than 20dB) in MIMO antennas as it reduces the surface wave in E-Plane [10]. According to [11] by using neutralizing line technique for a crescent shape radiator in a MIMO antenna, there is a considerable improvement in the correlation coefficient, capacity loss and Total Active Reflection Coefficient (TARC) when neutralizing line was introduced. Neutralizing line reduced the correlation coefficient and capacity loss from 0.091dB to 0.0017dB and from 0.9089bits/s/Hz to 0.6854bits/s/Hz and the TARC was also decreased from -12.29dB to -17.02dB.

II. ANTENNA DESIGN

The design is a simple C-shaped dual band monopole antenna which is designed to operate at 2.4GHz and 5.2GHz frequency band. Here the substrate used is FR-4 Lossy and occupies 40 x 80 mm^2. The ground plane occupies 40 x 60 mm^2 as shown in [12].

Table 1: Antenna Design Specifications (according to Fig. 2(a))

Parameters	Value (mm)	Parameters	Value (mm)	Parameters	Value (mm)
L1	60	L7	60	W5	5
L2	20	L8	20	W6	3
L3	17	W1	10.5	W7	40
L4	2	W2	3	T	1.6
L5	10	W3	2	H	0.035
L6	80	W4	13	ϵ	4.4

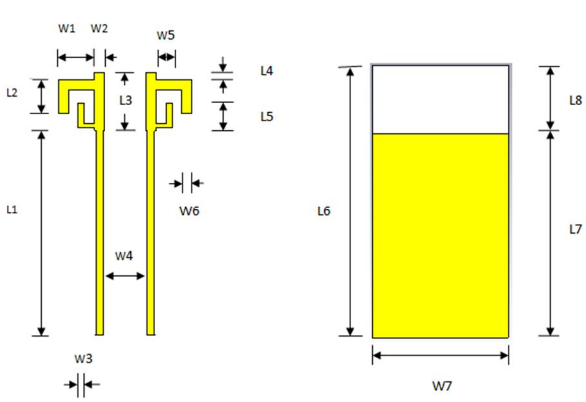

Fig 2(a): Antenna Layout (Front & Back view)

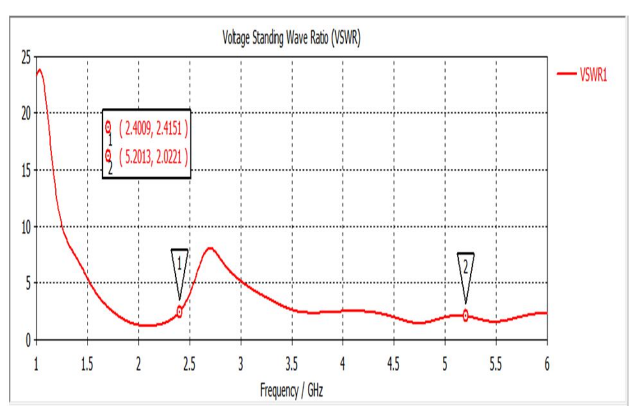

Fig 2(b): VSWR

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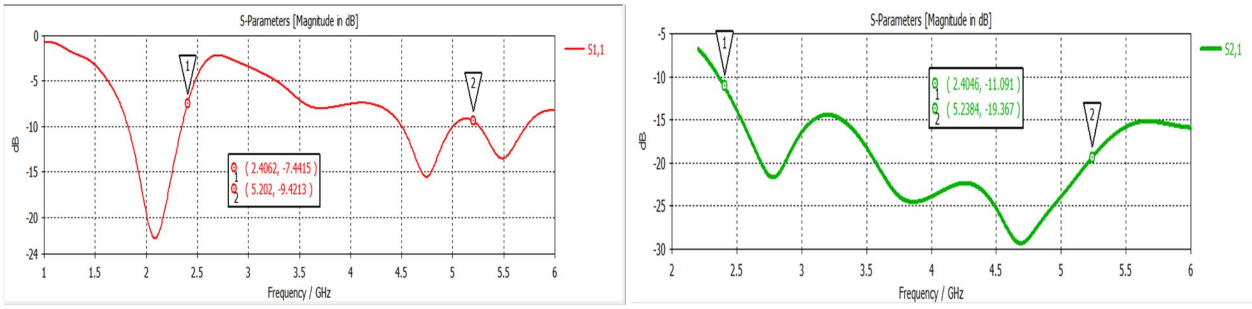

Fig. 2(c): Return Loss & Isolation (S1,1 & S2,1) of the antenna

III. IMPLEMENTATION OF MUTUAL COUPLING REDUCTION TECHNIQUES:

A. Neutralizing Line

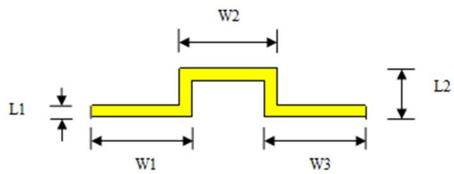

Fig. 3.1(a): Neutralizing Line I

Table 2: Antenna Design Specifications (according to Fig. 3.1(a))

Parameters	Value(mm)	Parameters	Value(mm)	Parameters	Value(mm)
L1	0.5	W1	4.5	W3	4.5
L2	3	W2	4		

A neutralizing line helps in improving isolation as it produces an opposition to the existing coupling. Thus the mutual coupling is reduced at certain frequencies as the existing coupling gets cancelled due to delivery of some current from first antenna to the second antenna [13].

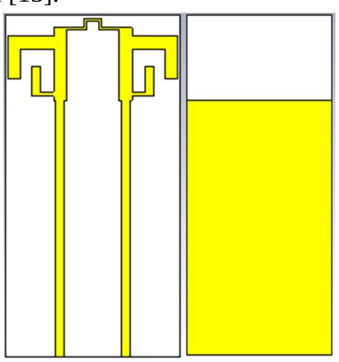

Fig. 3.1(b): Antenna Layout using NL I

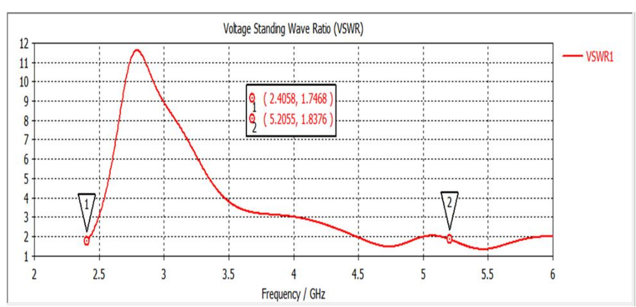

Fig. 3.1(c): VSWR

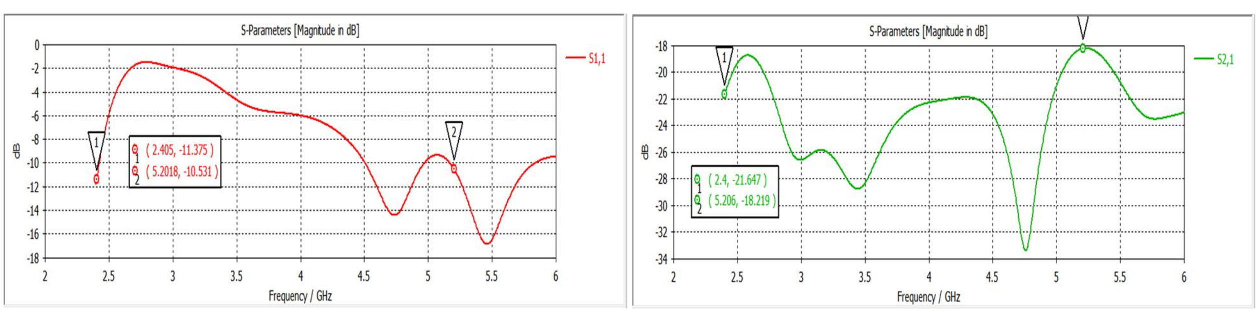

Fig. 3.1(c): Return Loss & Isolation (S1,1 & S2,1) of the antenna using NL I

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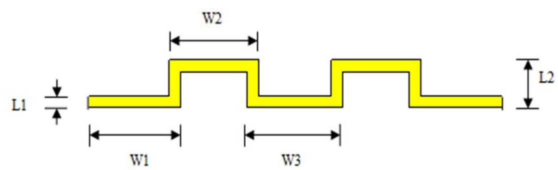
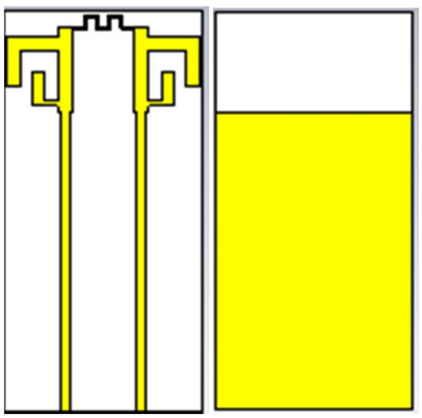


Fig. 3.1(f): Neutralizing Line II

Table 3: Antenna Design Specifications (according to Fig. 3.1(f))

Parameters	Value(mm)	Parameters	Value(mm)	Parameters	Value(mm)
L1	0.5	W1	2.65	W3	2.65
L2	3	W2	2.65		



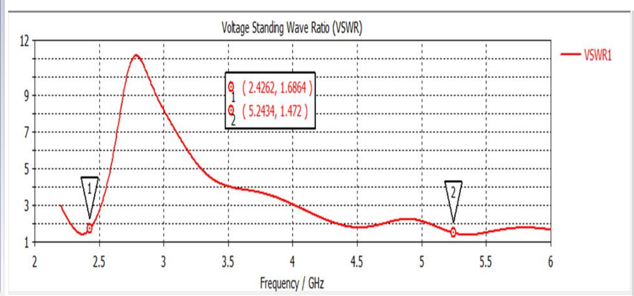
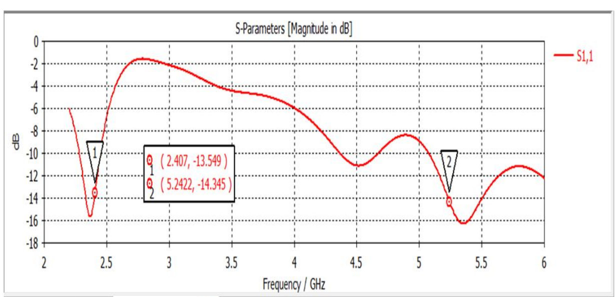


Fig. 3.1(g): Antenna Layout using NL II

Fig. 3.1(h): VSWR



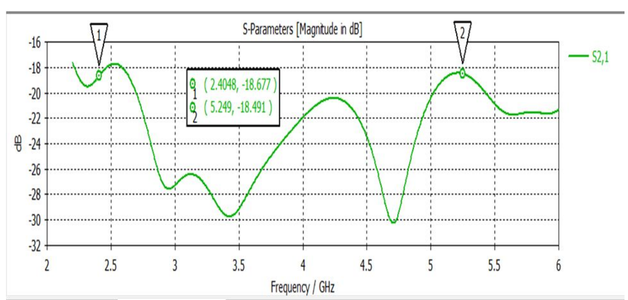


Fig. 3.1(h): Return Loss & Isolation (S1,1 & S2,1) of the antenna using NL II

B. Electromagnetic Band Gap

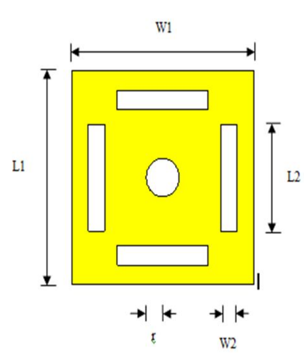


Fig. 3.2(a): Electromagnetic Band Gap

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Table 4: Antenna Design Specifications (according to Fig. 3.2(a))

Parameters	Value(mm)	Parameters	Value(mm)	Parameters	Value(mm)
L1	5.5	W1	5.5	R	0.5
L2	2.5	W2	0.5		

In EBG structure the mutual coupling is reduced by suppressing the surface waves. In [10] an EBG structure is created by cutting slots on a metal sheet and then repeating those structures periodically to create frequency band gaps. According to [14] pass band and stop band characteristics are created due to EBG.

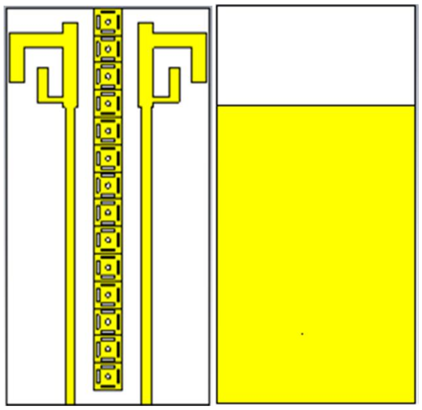

Fig. 3.2(b): Antenna Layout using EBG

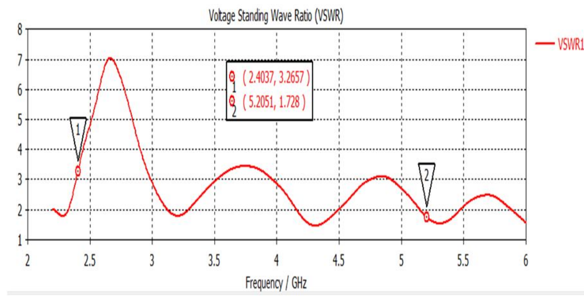

Fig. 3.2(c): VSWR

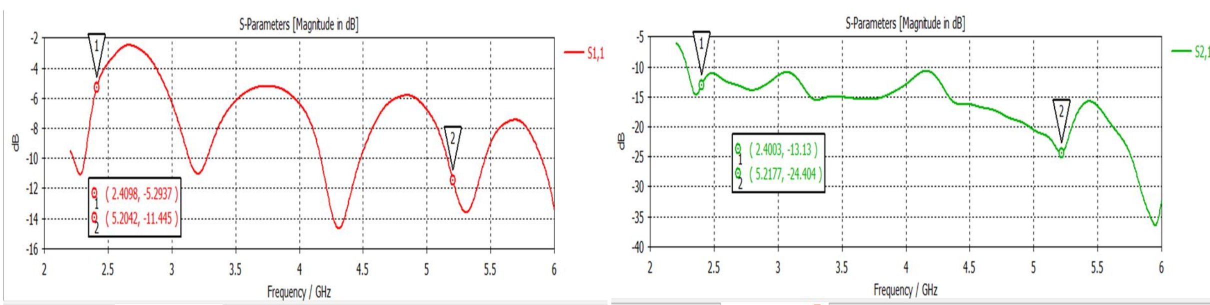

Fig. 3.2(d): Return Loss & Isolation (S1,1 & S2,1) of the antenna using EBG

C. Defected Ground Structure

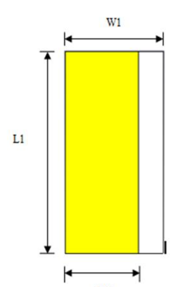

Fig. 3.3(a): Defected Ground Structure

Table 5: Antenna Design Specifications (according to Fig. 3.3(a))

Parameters	Value(mm)	Parameters	Value(mm)	Parameters	Value(mm)
L1	80	W1	40	W2	30

Slots or defects integrated on a single ground plane are referred as DGS, which acting as a band stop filter suppresses higher order harmonics. DGS helps in improving gain, bandwidth and radiation characteristics of MIMO antenna [15].

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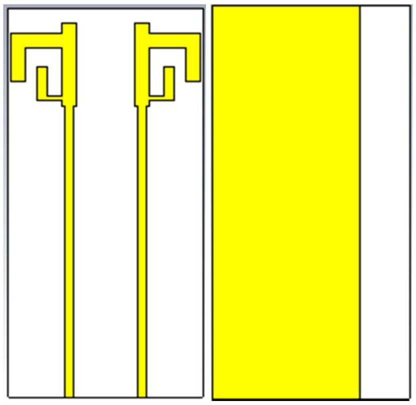

Fig. 3.3(b): Antenna Layout using DGS

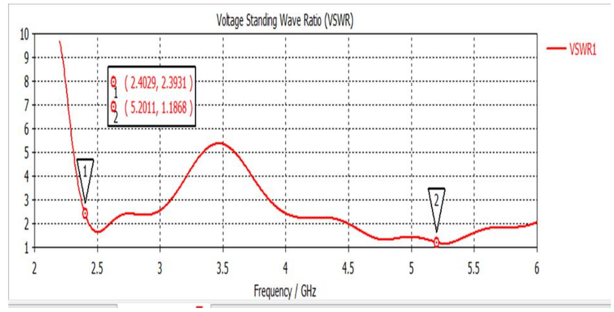

Fig. 3.3(c): VSWR

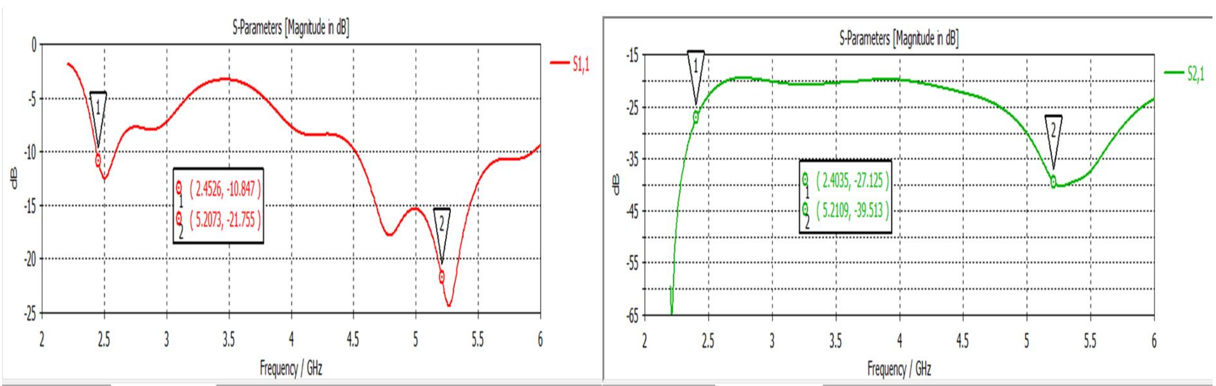

Fig. 3.3(c): Return Loss & Isolation (S1,1 & S2,1) of the antenna using DGS

D. Meander Lines

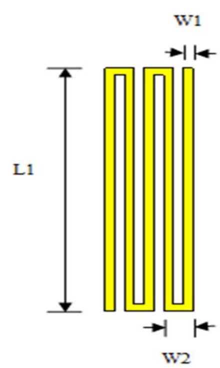

Fig. 3.4(a): Meander Line

Table 6: Antenna design Specifications (according to Fig. 3.4(a))

Parameters	Value(mm)	Parameters	Value(mm)	Parameters	Value(mm)
L1	17	W1	0.5	W2	1.5

A wire like structure is inserted between the two monopoles forming a meander line which contributes in reducing mutual coupling. Signal from one element to another is supressed by forming a coupling path and thus contributing towards reduction of orignal coupling [16].

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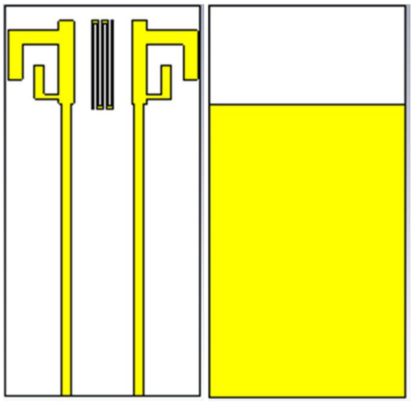

Fig. 3.4(b): Antenna Layout using ML

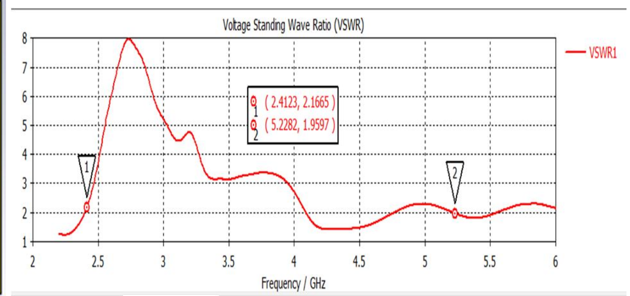

Fig. 3.4(c): VSWR

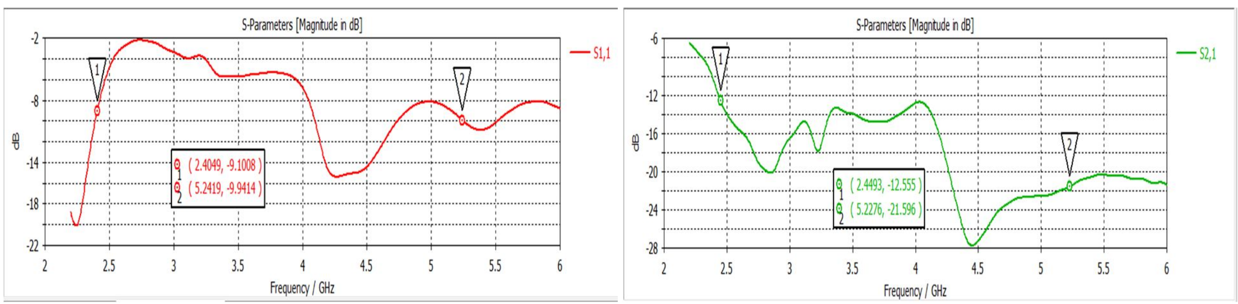

Fig. 3.4(c): Return Loss & Isolation (S1,1 & S2,1) of the antenna using ML

IV. RESULT TABLE

Table 7: Comparison of various techniques

Sr. No.	Techniques	Frequency (GHz)	Return Loss (S1,1) (dB)	Isolation (S2,1) (dB)	VSWR	Gain (dBi)	Directivity (dBi)
1.	Antenna Layout	2.4	-7.4415	-11.091	2.4151	2.826	4.620
		5.2	-9.4213	-19.367	2.8221	2.872	5.185
2.	Neutralizing Line I	2.4	-11.375	-21.647	1.7468	3.138	4.445
		5.2	-10.531	-18.219	1.8376	4.260	6.523
3.	Neutralizing Line II	2.4	-13.549	-18.677	1.6864	3.127	4.445
		5.2	-14.345	-18.491	1.4720	4.331	6.471
4.	Electromagnetic Band Gap	2.4	-5.2937	-13.130	3.2657	0.864	4.922
		5.2	-11.445	-24.404	1.7280	4.705	2.135
5.	Defected Ground Structure	2.4	-10.847	-27.125	2.3931	1.202	3.867
		5.2	-21.755	-39.513	1.1868	3.478	5.498
6.	Meander Line	2.4	-9.1008	-12.555	2.1665	3.069	4.674
		5.2	-9.9414	-21.596	1.9597	2.667	5.114
		5.2	-14.625	-49.083	1.4425	3.559	5.501

V. CONCLUSION

A compact multiband planar (2 X 2) MIMO antenna is presented and imposed with numerous techniques for reducing the mutual coupling. The simulated results are tabulated and examined to find out the best mutual coupling reduction technique. The study manifested that Neutralizing Line II shows optimum results considering S-parameters (S1,1= -13.549dB & -14.345dB at 2.4GHz and 5.2GHz ; S2,1= -18.677dB &-18.491dB at 2.4GHz and 5.2GHz respectively) and VSWR (VSWR= 1.6864 & 1.472 at 2.4GHz and 5.2GHz respectively).

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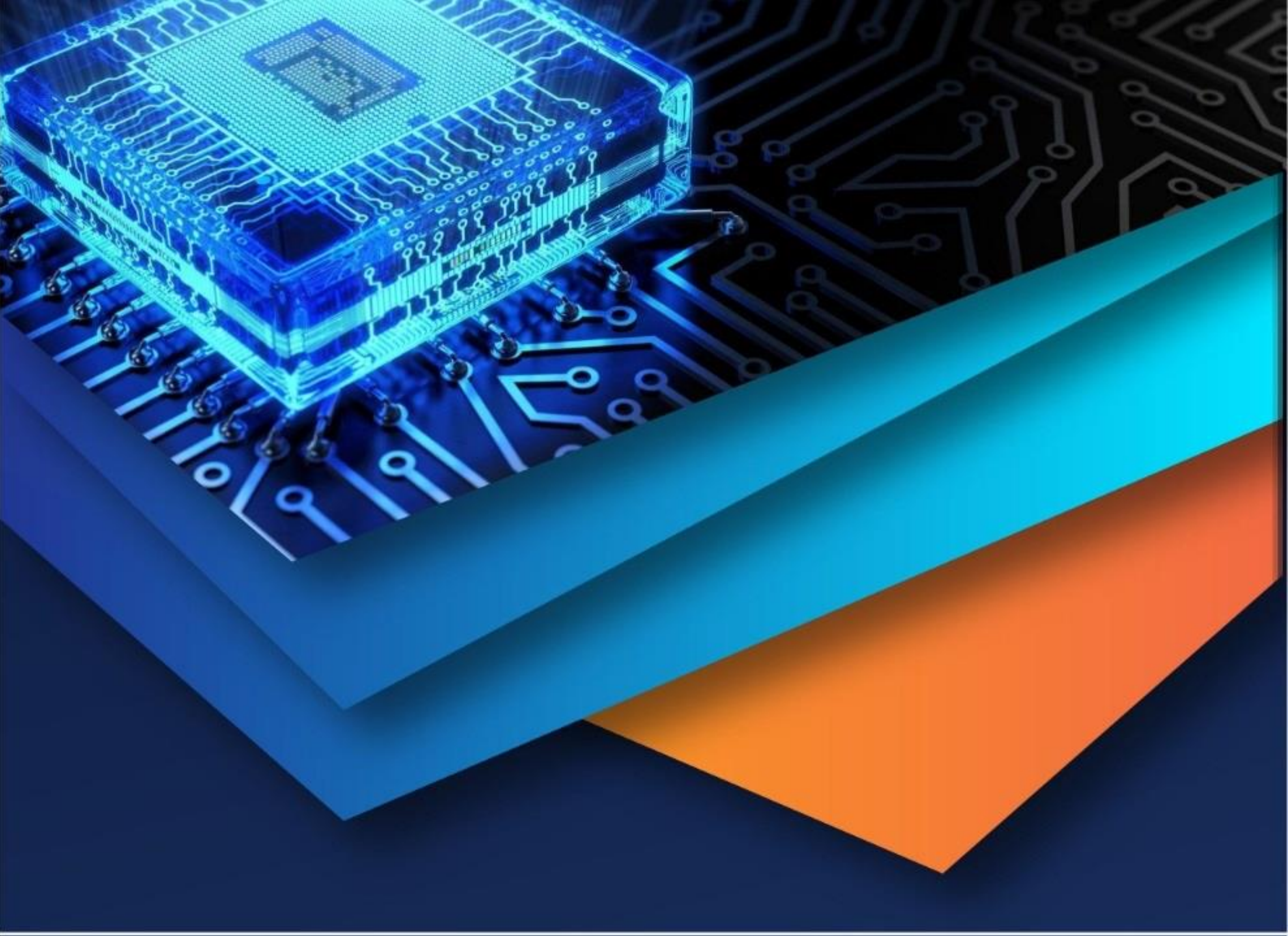

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