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# Isolation Enhancement in Multi-band and Wideband MIMO Antenna Systems: A Review

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***Abstract:*** *Design of multi-band and wideband Multiple-input and multiple-output (MIMO) system has gained the attention of antenna engineers. The modern communication devices are expected to be small in sizes which compel the researchers to design compact antenna system. To design compact MIMO systems, the antenna elements are placed in close proximity that leads to the coupling phenomenon ultimately degrading the antenna performance. Therefore, designing a compact system with low mutual coupling is one of the challenges. This paper reviews isolation techniques in multiband and wideband MIMO antenna systems which have been reported in the literature. Various metrics determining the MIMO suitability of an antenna are also presented.*
***Keywords:*** ***A*** *Review, Isolation, MIMO antenna, Multi-band, Wideband*

## I. Introduction

High data rates and system reliability offered by MIMO antenna system is the reason of these systems being integrated in recent wireless communication standards. In modern devices having multiple applications, multiple antennas may need to be integrated. This may lead to increased size of the antenna system which does not cater to the requirement of compact devices. Hence, the design of Multi-band and wideband MIMO antenna system has become todays need. This system has the capability to be functional at various frequencies at the same time with little multipath fading and high capacity. Small spacing in between the antenna elements results in mutual coupling and destroys the antenna performance. Thus, the design of a compact MIMO system with good amount of isolation between the antenna elements is one of the main challenges.

Mutual coupling is the effect of small distances between the antenna elements and the common ground plane they share. It is known to cause high correlation on the transmitting and receiving sides, affect diversity gain in the case of diversity antennas and the radiation efficiency. Overall, it degrades the performance of a MIMO system. Study of mitigating the problem of mutual coupling phenomenon had started several decades ago and efforts have been devoted to combat mutual coupling between the antenna elements to improve the radiation properties. Moreover, the diversity performance of the antenna is also evaluated through parameters like the Envelope Correlation Coefficient (ECC), diversity gain (DG), Mean Effective Gain (MEG), Total Active reflection Coefficient (TARC).

## II. Isolation Techniques in Multiband and Wideband MIMO antennas

Mutual coupling is usually caused due to the surface wave propagation along the substrates. The alteration in the distribution of the surface currents may lead to the depression of the surface waves which is achieved by using the techniques already reported in the literature. Diversity techniques which include space diversity, polarization diversity and pattern diversity provided in the literature are also the isolation enhancement techniques of their kind. Isolation enhancement methods usually cover single bands. The decoupling network, parasitic element, defected ground structures, use of metamaterials as well as neutralization lines are of this kind. To provide multi-band or wide-band isolation, the basic structures need to be modified to accommodate this. This paper reviews various isolation mechanisms employed to achieve significant isolation in multiband and wideband MIMO antenna systems [1-15]. Antennas incorporating multiple isolation techniques are also reported [16-17]. The parameters determining the MIMO/diversity performance of an antenna are also presented.

### 2.1 USE OF METAMATERIALS

Metamaterial (MTM) inspired electromagnetic band gap structures are periodic arrangement of dielectric materials identified with characteristics such as frequency stopbands, passbands and bandpass. The operating band of frequencies depends on their dimensions. Hence proper design of EBG structures in multi-element antenna system result in significant amount of isolation in between the antenna elements [1-3].

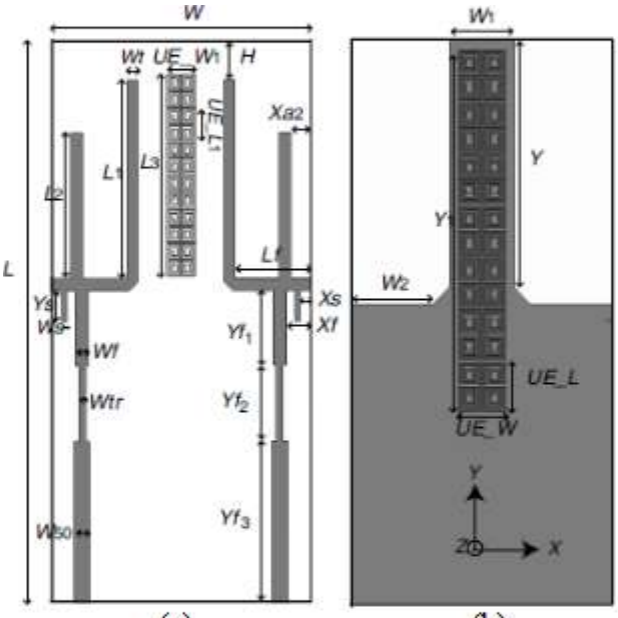


Figure 1. Geometry of 2x1 4-shaped MIMO antenna system deploying CLLs (a) Top layer (b) Bottom layer.

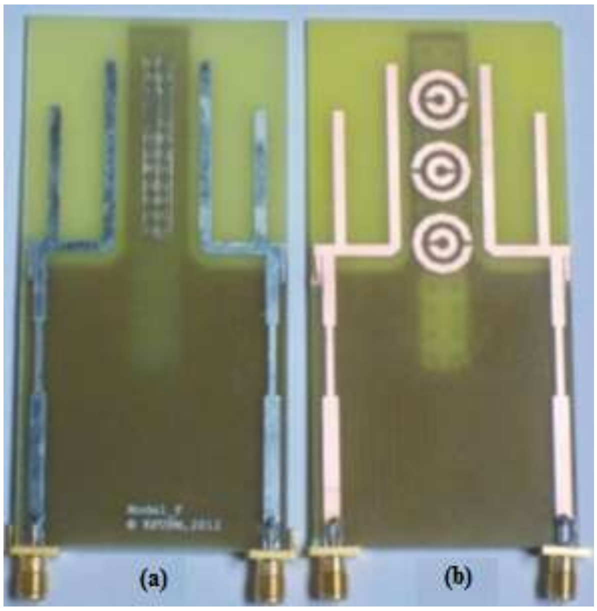


Figure 2. Fabricated dual-band MIMO system with isolation structure (a) only CLL (b) combined CLL and SRR.

A dual-band two 4-shaped element MIMO antenna covering 827-853 MHz and 2.3-2.98 GHz is presented in [1]. After the introduction of array of capacitively loaded loops (CLLs) between the radiators as shown in Fig. 1, isolation of 18.9 dB and 9.8 dB was obtained in the higher and the lower bands respectively. The resonance frequency of each spiral like MTM unit element depends on the inductance and capacitance of the structure. Another MTM based dual band MIMO antenna for WLAN application is presented in [2]. The orthogonal placement of radiators could achieve resonance at 2.4 GHz and 5.25 GHz while a coupling of -25 dB over the operating frequency bands was obtained by the introduction of two split ring resonators (SRRs). In [3], the isolation performance of the proposed structure with the one presented in [1] is compared. The difference in both is the isolation mechanism structure shown in Fig. 2. It consists of combination of CLLs and SRRs. The CLL array etched on the ground plane provides a 3 dB isolation improvement compared to [1] while the SRR is used to provide a band stop filter behaviour in the frequency band centered around 2.7 GHz.

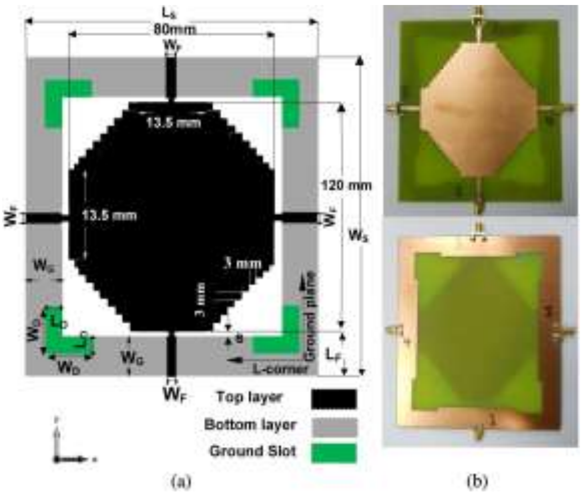


Figure 3. (a) Geometry of the Wideband MIMO antenna (b) Top layer (Radiating element) and bottom layer (Ground plane with DGS) of fabricated prototype

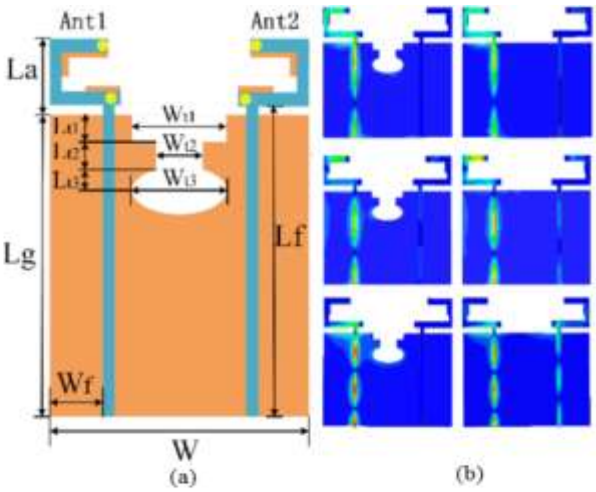


Figure 4. (a) Triband MIMO antenna with ellipse ended stepped slot (b) Current distribution with and without slots.

### 2.2 USE OF DEFECTED GROUND STRUCTURE

Defected Ground Structure (DGS) is the most common and easiest, in terms of fabrication and analysis, of all the isolation techniques reported. Any defect etched in the ground plane changes the effective capacitance and inductance of the structure which disturbs the current distribution [4] in the same. Hence, DGS is effective in reducing the mutual coupling.

In [5], a wideband MIMO antenna operating at the frequency band of 1.8-2.9 GHz is presented. This band serves the application for Wi-Fi and LTE wireless access point (WAP). The radiator is a 4 port element with the shape of a modified rectangle with a four-stepped line at the corners that yields wide bandwidth. Modification in the rectangular ground plane is done by introducing 4 L-shaped slots in each corner. This is shown in Fig. 3. Creating slots in the ground plane reduces the current coupling in between the ports. Thus an isolation greater than 15 dB is obtained over the operating wideband.

A triband MIMO antenna with symmetrically placed folded monopoles for WLAN/WiMAX applications presented in [6] is shown in Fig 4 (a). The three resonant bands achieved by the C-shaped monopoles and the branches on the bottom side connected to the main antenna are 2.3–2.75 GHz, 3.4–3.75 GHz, 4.8–6 GHz. An ellipse ended stepped slot etched on the ground plane provides a coupling less than 18 dB over the whole frequency band. The current distribution shown in Fig. 4 (b) explains the significant reduction of coupling current after the introduction of slots in the ground plane.

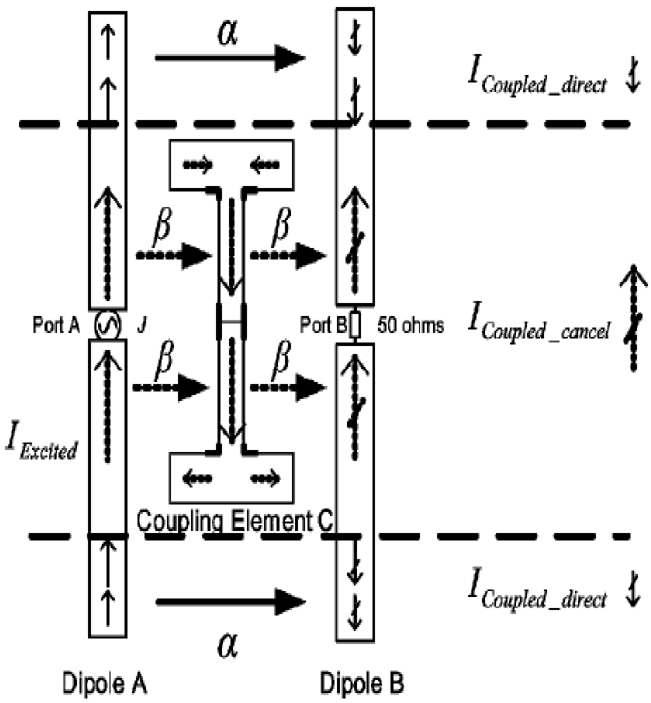


Figure 5. Coupling between two dipoles and parasitic element.

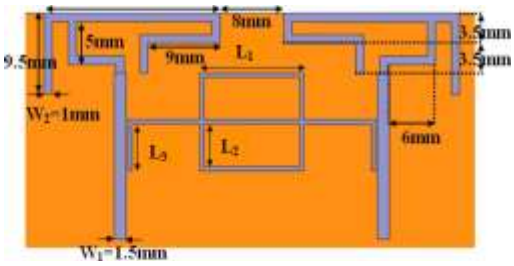


Figure 6. Parasitic elements inserted between two closely spaced IFAs

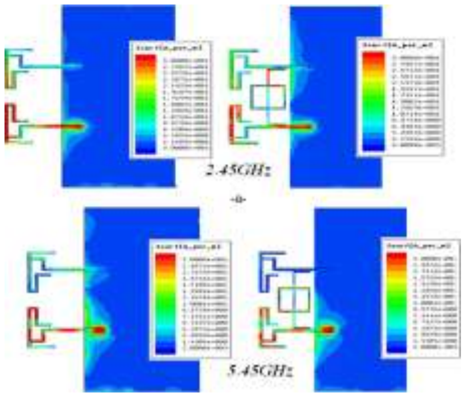


Figure 7. Current distribution with and without PE at resonating frequencies (a) 2.45 GHz and (b) 5.45 GHz

### 2.3 PARASITIC ELEMENT APPROACH

Introduction of coupling element called as parasitic element (PE) create reverse coupling to reduce mutual coupling [7]. Apart from the original coupling (direct coupling) an additional coupling path (indirect coupling) is created due to PE(s). The coupling element provides an additional 180 degree phase shift leading to the field cancellation as shown in Fig. 5 and reduction in mutual coupling [8].

High port-to-port isolation between two closely spaced IFAs by inserting a parasitic lossless radiating element (shown in Fig. 6) is obtained in a dual band diversity antenna present in [9]. The PE is able to radiate at the resonating frequencies of the IFAs and hence automatically attract the remaining non-radiated power from the antenna 1 and re-radiate it. This phenomenon explained in Fig. 7. reduces the S12 magnitude as there is not much signal left to enter port 2. Apart from providing port-to-port isolation, PEs employed in a microstrip patch antenna offers wide bandwidth [10]. Also a two strip patch as a PE etched on the bottom layer of the substrate in a microstrip slot tri-band antenna [11] is responsible for achieving third resonant frequency at 5.8 GHz. This is depicted in Case III of Fig. 8.

### 2.4 GROUND BRANCH UTILIZATION

Usually the ground plane is extended in the form of its branch between the two radiators to strengthen the isolation between them since it blocks the current from flowing from port 1 to port 2.

A compact tri-band MIMO antenna covering GSM850/900, DCS, PCS, UMTS and LTE 2500 is proposed in [12]. Fig. 9 shows the dual multi-patch monopoles are orthogonally placed on top layer (a) of the substrate and extension of ground plate in the form of a T-shaped branch placed in between the radiating monopoles on the bottom layer (b) of the substrate. Coupling below 15 dB is obtained due to the T-shaped ground branch and the reason is that antenna 1 induces coupling current on antenna 2 and T-shaped branch and the T-shaped branch also induces current on antenna 2. Now, the two induced currents on antenna 2 are reverse, so the isolation is enhanced. Another multiband MIMO antenna, with two inverted-L shaped branches and a rectangular slot with one circular end etched on the ground plane, is presented in [13]. The mechanism for decoupling is that the two inverted-L branches combined with the etched slot block the current flowing from the excited port to the coupled port. Thus, a coupling of -15 dB is obtained over all frequency bands.

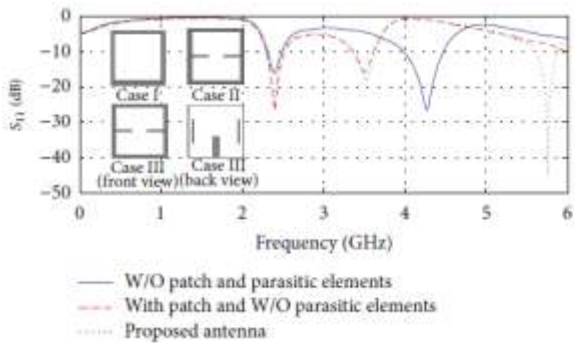


Figure 8. Design procedure of the triband microstrip antenna Case I: single band Case II: Dual band and Case III: Triband operation due to PE.

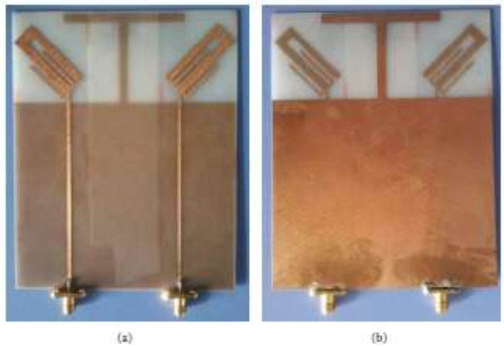


Figure 9. Fabricated Prototype of triband MIMO antenna (a) Top layer and (b) Bottom layer.

### 2.5 USE OF NEUTRALIZATION LINE (NL)

A Wideband MIMO antenna operating over 2.4-4.2 GHz band for WiFi/WiMAX applications is presented in [14]. As shown in Fig. 10 (a), the antenna comprises two crescent shaped radiators placed symmetrically with respect to a defected ground plane and a neutralization lines is connected between them to achieve good impedance matching ($S_{11}$< -10)and low mutual coupling ($S_{12}$ < -17 dB) as shown in Fig. 10 (b). By inserting the lines, the surface currents on both radiators are transferred to the neutralization lines and a current of similar magnitude in the top of the neutralization line cancels this feed line current. This tends to decouple the currents on the port 2 radiator and hence it enhances the isolation between the two radiator elements efficiently. Several solutions like inserting a suspended line between the PIFAs' feedings and/or shorting points are investigated to maximize the isolation in [15]. Initially the two PIFAs were designed separately to operate in DCS and UMTS band and later they were integrated on a common ground plane to build a MIMO antenna system where enhancing isolation becomes essential.

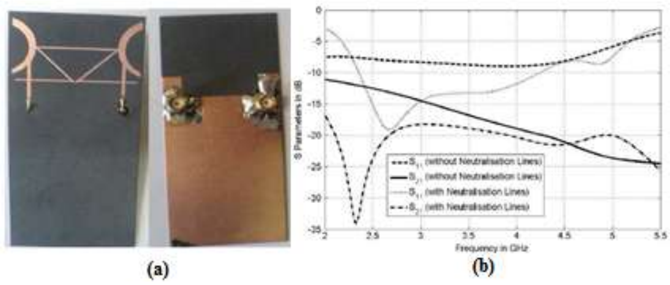


Figure 10. Dual-band MIMO antenna (a) Isolation mechanism in the form of folded strip (b) S-parameters.

**2.6 USE OF MULTIPLE ISOLATION TECHNIQUES**

High isolation antennas employing multiple isolation techniques, wherein the effect of each technique on the isolation parameter is studied, are also presented [16-17]. Two element dual-band MIMO antenna with 20 dB isolation stated in [16] have isolation mechanisms consisting of an elliptical slot and a parasitic patch. A dual element dualband MIMO monopole antenna employing extended ground plane, parasitic elements and ground slots as isolation technique offer isolation of 24 dB and 27 dB in the lower and the higher band respectively [17].

## III. Diversity Performance Metrics

To test the suitability of an antenna for MIMO applications certain diversity performance metrics like ECC, DG, MEG etc. are evaluated. ECC is degree of correlation measurement between the channels. For good diversity behaviour, the value of ECC should be less than 0.5 for mobile applications. Two approaches using which ECC is evaluated are viz., i. Using S-parameters given by (1). ii. Using the far-field characteristics of the radiating elements given by (2) [18].

$$\left|\rho_e(i,j,N)\right| = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}\right|}{\sqrt{\left|\prod_{k(=i,j)} \left[1 - \sum_{n=1}^{N} S_{i,n}^{*} S_{n,k}\right]\right|}} \qquad (1)$$

$$\rho_e = \frac{\left|\iint_{4\pi} \left[\vec{F}_1(\theta,\phi) \bullet \vec{F}_2(\theta,\phi)\right]\right|^2}{\iint_{4\pi} \left|\vec{F}_1(\theta,\phi)\right|^2 d\Omega \iint_{4\pi} \left|\vec{F}_2(\theta,\phi)\right|^2 d\Omega} \qquad (2)$$

Diversity Gain dependent on correlation is obtained using (3) [19]

$$DG = 10e_\rho \text{ with } e_\rho = \sqrt{1-|ECC|} \qquad (3)$$

An improvement in fading can be achieved when the signals received from the antenna satisfy (4) [18]

$$\frac{MEG_i}{MEG_j} \cong 1 \qquad (4)$$

where, MEG is called as the mean effective gain and is given as follows (5)

$$MEG = \int_0^{2\pi}\int_0^{\pi} \left[ \begin{array}{l} \left\{ \left( \frac{XPD}{1+XPD} \right) G_\theta(\theta,\phi) P_\theta(\theta,\phi) \right\} \\ + \left\{ \left( \frac{XPD}{1+XPD} \right) G_\phi(\theta,\phi) P_\phi(\theta,\phi) \right\} \end{array} \right] \sin\theta d\theta d\phi \qquad (5)$$

Every technique has its own advantage and disadvantage which is very well listed in [20]. Table 1 summarizes the referred papers with respect to the design type whether multiband or wideband, isolation technique used and bandwidth offered.

**Table. 1:** Summary of referred paper for each technique

| Ref | Design Type | Technique | Bandwidth (GHz) | Imin (dB) |
|---|---|---|---|---|
| [1] | Multiband | MTM | 0.827-0.853 2.3-2.98 | 9.8 |
| [5] | Wideband | DGS | 1.8-2.9 | 15 |
| [6] | Multiband | DGS | 2.3–2.75, 3.4–3.75, 4.8–6 | 18 |
| [11] | Multiband | PE | 2.3–2.52, 3.4–3.62, 5.6–5.95 | |
| [12] | Multiband | GBU | GSM850/900, DCS, PCS, UMTS, LTE 2500 | 15 |
| [14] | Wideband | NL | 2.4-4.2 | 17 |
| [17] | Multiband | EGP+PE+ DGS | 2.1-2.85, 5-6 | 24 |

**GBU: Ground branch utilization, Imin: Minimum isolation, NL: Neutralization Line, EGP: Extended Ground Plane**

## IV. Conclusion

MIMO technology in antennas is employed to overcome the problems faced by the SISO antennas. Also, in order to cater to the requirement of modern telecommunication standards, designing multiband/wideband antennas becomes a necessity. One of the challenges encountered in the design of compact high diversity multiband/wideband antenna is achieving high isolation. Various isolation enhancement techniques employed by such antennas are described in this paper. Moreover, the criteria required to satisfy the MIMO eligibility are also presented.

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