A Decoupling method using Split Ring Resonator (SRR) for Tri-band MIMO Antenna for WLAN LTE Band and 5G applications

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ABSTRACT MIMO antenna design has always been a topic of interest in wireless technology. Although it has many benefits, the key challenge is to minimize mutual coupling between antenna elements. The concept of metamaterial is an ongoing technique used for isolation enhancement between antenna elements. This study presents a decoupling technique between two tri-band antennas for LTE, WLAN, and 5G applications. For 3.5GHz, a monopole is initially created; the other two resonant frequencies are produced by changing the partial ground plane. Then, a MIMO antenna system is created using two tri-band monopoles. The resonators of low band can minimize the mutual coupling for two higher bands by suppressing surface wave propagation. Finally, coupling is reduced in the low band by using a Split Ring Resonator (SRR) to cancel out the original coupling. The reported MIMO antenna spans the 2.4, 3.5, 5.8 GHz covering LTE, 5G and WLAN bands, with maximum return loss of -22, -35 ,-38 dB and with a mutual coupling of -25, -18 and -32 dB. The envelope correlation co-efficient is less than 0.01 and the total active reflection co-efficient is less than -10 dB which are within the acceptable limits. The realized gain for the antenna is 1.02, 1.89, and 1.43 dB at 2.4, 3.5 and 5.8 GHz respectively.

INDEX TERMS MIMO, Return loss, Isolation, WLAN, 5G, Mutual coupling, ECC, LTE, TARC, SRR (split ring resonator).

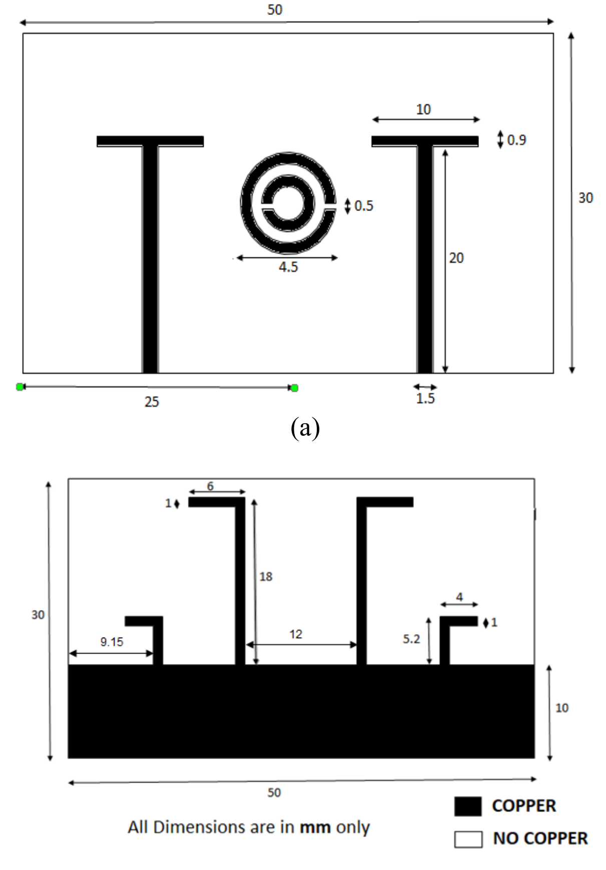
I. INTRODUCTION

Because of its numerous advantages, such as increased channel capacity, low signal loss, decreased multipath fading, and connection quality, multiple-input and multiple-output (MIMO) technology has received a lot of interest in researching [1]. However, when several antennas are combined closely in a small space at compact terminals, the strong coupling between antenna elements degrades MIMO performance extremely. As a result, the development of compact MIMO antennas with minimal coupling has always been a priority in research. Many works on MIMO antenna design have recently been published; mutual coupling is generally reduced by introducing a parasitic element or structure that acts as a band-stop filter [2], utilizing a defected ground structure [3] or a modified ground plane [4] to restrain surface wave propagation, using metamaterial technology to control propagation characteristics [5, 6], and using a neutralization line to eliminate the initial current [7, 8, 9]. However, the majority of the proposed MIMO antennas only work in a single band. Dual-band or tri-band MIMO antenna design is more challenging than single-band MIMO antenna design due to a reduction of the reflection coefficient created by decoupling structures. When two slots are etched on the ground and two transmission lines are added at the top surface of the substrate, coupling among the dual-band is reduced [10]. Reference [11] shows a MIMO antenna that operates in three bands. The coupling is reduced for three resonating frequencies by making a T-shaped slot in the ground and inserting a meandering-line resonator between the two components. However, more than one decoupling structure is added [10, 11], which may result in a complex design and a huge amount of occupied space. However, combining the two decoupling structures may enhance the system's complexity.

However, a Ω shaped decoupling structure is placed between the antennas, with complex length and width dimensions that are difficult to determine [12]. A band pass filter is created by using two Split Ring Resonators. These metamaterial structures have the potential to focus electromagnetic fields and currents around antenna structures rather than distributing them throughout the antenna ground [13], resulting in decreased coupling between the antenna elements. Pendry et al [14] suggested a twofold split ring resonator (SRR) that can provide high impedance and mutual coupling suppression between two densely packed antennas [15]. Metamaterials were extensively studied to realize a variety of miniature and multiband antennas over the recent years [16].

II. ANTENNA STRUCTURE

This paper describes how to build a MIMO antenna with tri-band features for WLAN and 5G applications. The tri-band antenna elements are a T-shaped monopole and two inverted-L ground stubs. Because it is fed by the T-shaped monopole, the longer inverted-L stub can be regarded an antenna at 2.4GHz. It can diminish mutual coupling at 3.5 and 5.8GHz by inhibiting surface wave propagation, which acts as a reflecting component. As a result, a self-contained low coupling characteristic at the medium and high bands can be produced. It denotes that a tri-band isolation design is reduced to a single-band problem through self-decoupling analogy, and mutual coupling at the lower band is achieved by placing a Split Ring Resonator (SRR) between the two monopoles. The split ring resonator is positioned exactly in the center of the two monopoles. In comparison to the previous work [12], the proposed metamaterial has a basic structure, is compact in size, and has high isolation in the lower band. The antenna structure is designed using HFSS (high frequency structure simulator) which is a numerical tool based on finite element method.



(a)

(b)

FIGURE 1. (a) Top view of the MIMO antenna (b) Bottom view of the MIMO antenna

Figure 1(a) depicts a 30×50 mm^2 FR4 substrate with a thickness of 0.8mm and two T-shaped monopole antennas symmetrically driven by a $50\ \Omega$ microstrip line to generate a 3.5GHz band. A Split Ring Resonator (SRR) is placed exactly in the center, with each ring separated by 1mm. Figure 1(b) depicts two inverted-L stubs on each side that operate as extra resonators and are fed by the T-shaped monopole. On both ends of the T-shaped monopole, one small and one large stub are organized and are responsible for 2.4 and 5.8 GHz resonances, respectively. The ideal lengths of the resonant structures are around a quarter-wavelength of the relevant frequency.

A. Single Antenna Structure

The half structure of the entire antenna is originally constructed and simulated for the outcome given in Figure 2. The partial structure facilitates the analysis of the MIMO antenna. At three resonant frequencies (2.4, 3.5, and 5.8 GHz), the return loss characteristics are less than -10 dB.

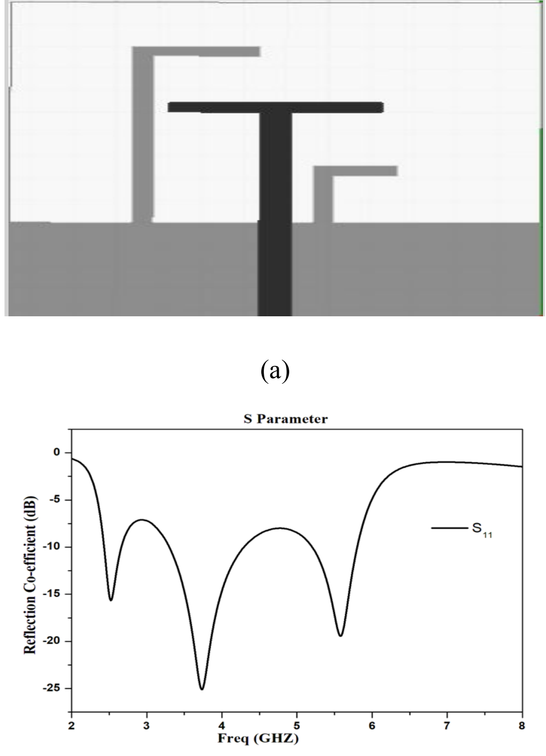


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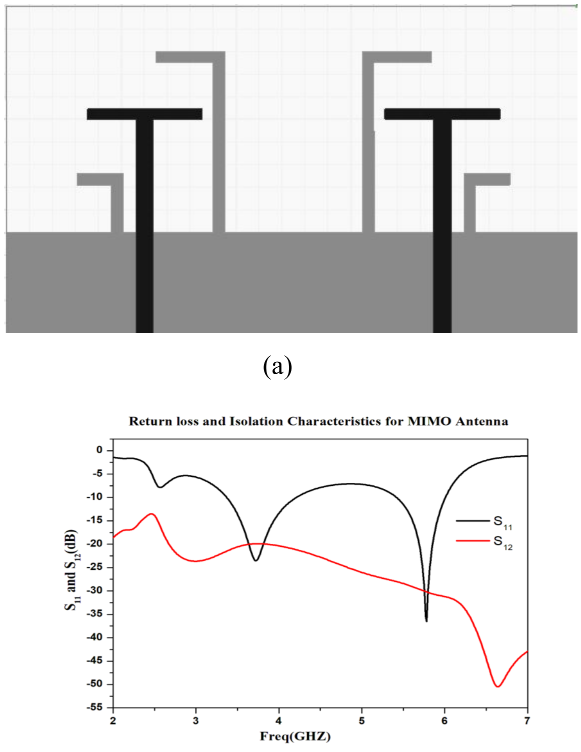
FIGURE 2. (a) Single antenna (b) Return loss characteristics of singe antenna (S_{11})

B. MIMO Antenna Structure

In Figure 3(a), the longer inverted-L stubs are at the center of MIMO, while the shorter ones are positioned on both ends. The impedance of two input ports is same due to the symmetrical arrangement.



(a)

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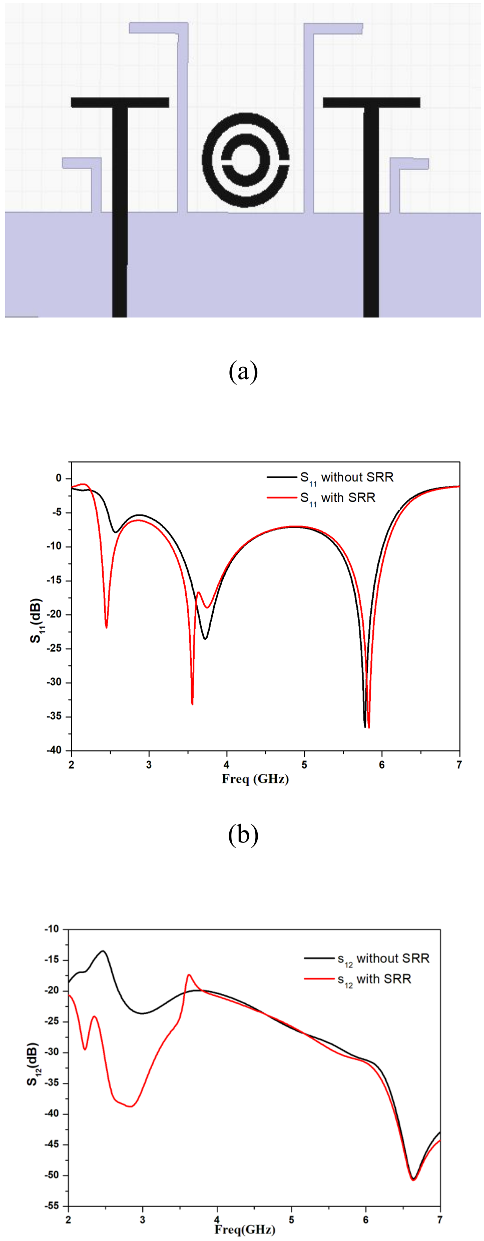
FIGURE 3. (a) MIMO antenna (b) S_{11} &S_{12} for MIMO antenna without SRR

Only S_{11} and S_{12} are presented for clarity. The MIMO antenna performs well in terms of impedance matching and decoupling characteristics at the two upper bands around 3.5 and 5.8 GHz. This is due to the larger stub's ability to lessen mutual interaction between the two higher bands. However, the significant mutual coupling degrades the impedance matching characteristic in the low band.

C. MIMO Antenna with Decoupling Structure

To address this issue, a Split Ring Resonator is placed between the two tri-band monopoles in order to concentrate electromagnetic fields and currents around antenna structures rather than distributing them over the antenna ground, resulting in reduced coupling between the two tri-band antennas. Figure 4(a) depicts the proposed mimo antenna with SRR constructed with hfss. Based on the data, we can conclude that S_{11} at 2.4GHz is improved by -3 dB to -22 dB. At 2.4 GHz, the isolation improves from -10 dB to -25 dB.



(a)

(b)

(c)

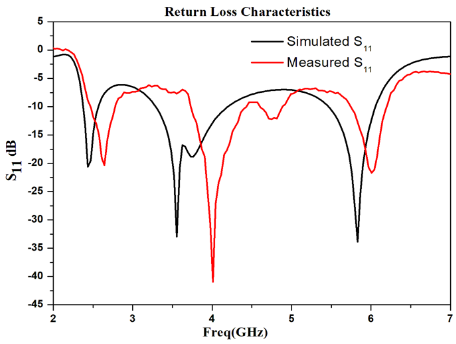
FIGURE 4. (a) MIMO antenna with SRR (b) Comparison of return loss characteristics with and without SRR (c) Comparison of isolation characteristics with and without SRR

III. RESULTS AND DISCUSSION

A. Return Loss characteristics

The suggested MIMO antenna has a total size of 30x50mm^2, which is fairly small in comparison to many previous designs. The planned MIMO antenna operates in frequency ranges 2.3-2.6GHz, 3.2-4.1GHz, and 5.6-6.1GHz, with return loss of -22, -35 ,-38 dB and mutual coupling values of -25, -18, and -32 dB, respectively. The operating frequency spectrum includes the majority of the frequency bands used by 5G, WLAN, and LTE. Figure 5(a) depicts the antenna's hardware implementation. As a result of the data acquired from both simulation and hardware, we can conclude that they are almost equivalent and that the proposed antenna can be used in practice.

FIGURE 5. (a) Fabricated MIMO Antenna front and back view



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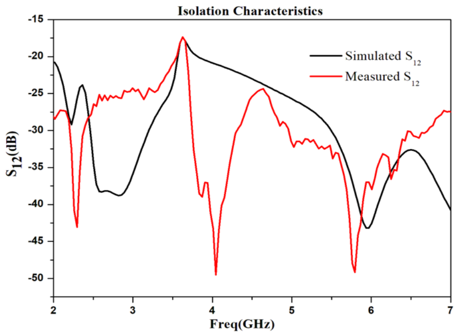


(c)

FIGURE 5. (b) measured vs simulated return loss characteristics (c) measured vs simulated isolation characteristics

B. Radiation Patterns

The measured radiation patterns with one port excited at 2.4, 3.5, and 5.8 GHz are shown. Figure 6(a), (b), and (c) show the antenna's radiation pattern for the three resonating frequencies. Peak antenna gains are around 1.02, 1.89, and 1.43 dB at 2.4, 3.5, and 5.8 GHz, respectively. The E plane has a dipole pattern, whereas the H plane is omnidirectional.

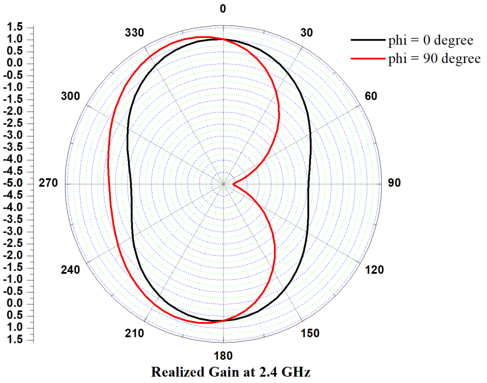
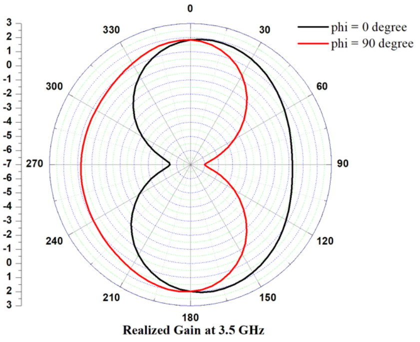


FIGURE 6. (a) Realized Gain at 2.4 GHz



(b)

(c)

FIGURE 6. (b) and (c) Realized Gain at 3.5 and 5.8 GHz

C. Current Distribution

Figure 7(a), 7(b), 7(c) depicts the current distribution across the antenna when power is given through one of the ports. The plot shows that field from port 2 is not entering into port 1. The split ring resonator (srr) aids in preventing radiation from accessing the other port, thereby enhancing isolation. Without SRR, we can observe there is interference of surface waves entering the nearby port.

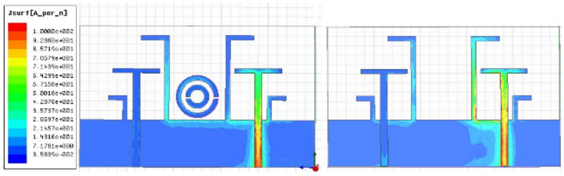


FIGURE 7. (a) Current distribution at 2.4 GHz with and without SRR

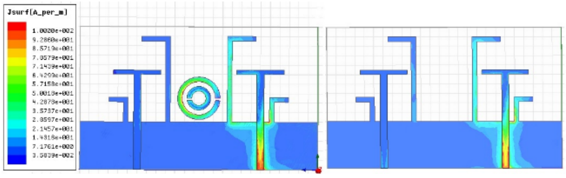


FIGURE 7. (b) Current distribution at 3.5 GHz with and without SRR

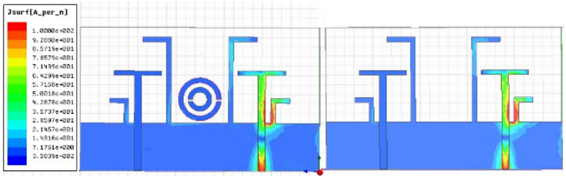


FIGURE 7. (c) Current distribution at 5.8 GHz with and without SRR

D. Envelope Correlation Co-efficient

The ECC (envelope correlation coefficient) can be used to efficiently measure the diversity performance of a MIMO antenna. Figure 8 shows that a low ECC value is the foundation for good diversity gain and high channel capacity. The following formula can be used to compute it from the efficiency and S-parameters [16, 17, 18, 19]. The ECC of the proposed MIMO antenna calculated using both S parameters and radiation pattern are less than 0.01.

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

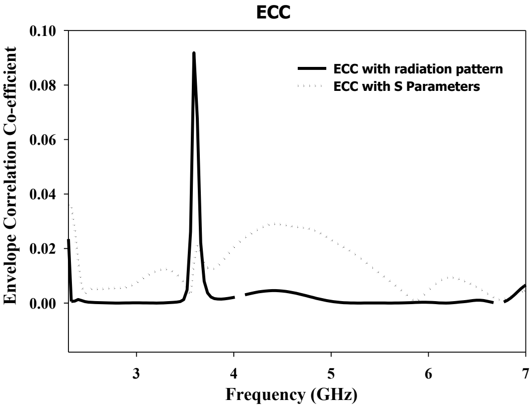


FIGURE 8. Envelope correlation coefficient using S parameters and from radiation pattern

E. Total Active Reflection Coefficient (TARC)

TARC is a metric for measuring MIMO efficiency. It is calculated by dividing the square root of the total reflected power by the square root of the total incident power [16] as shown in Figure 9. To establish the overall antenna system's resonance frequency and impedance bandwidth for a given phase stimulation between the ports.

$$\Gamma_a^t = \frac{\sqrt{(|S_{11} + S_{12}e^{j\theta}|^2) + (|S_{21} + S_{22}e^{j\theta}|^2)}}{\sqrt{2}}$$

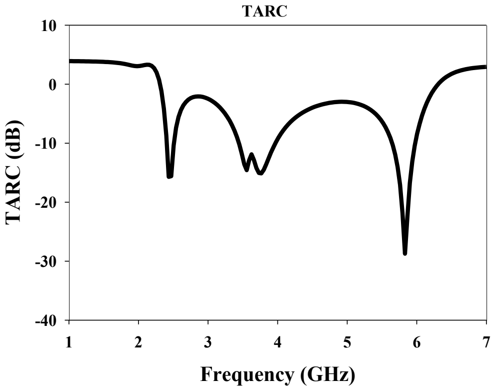


FIGURE 9. Total Active Reflection coefficient

IV. CONCLUSION

This study describes a decoupling mechanism for a tri-band MIMO antenna. The suggested decoupling approach is compact in size and has a simpler structure than most traditional multiband MIMO antennas due to the dual purpose of a longer inverted-L stub and the little occupied space of a split ring resonator, which is straightforward to design and install. The suggested MIMO antenna has good performance in terms of return loss, isolation, current distribution, and gain, and it is small enough to be integrated into a variety of terminals operating in LTE, WLAN, and 5G bands with maximum return loss of -22, -35 ,-38 dB and with a mutual coupling of -25, -18 and -32 dB. The envelope correlation co-efficient is less than 0.01 and the total active reflection co-efficient is less than -10 dB which are within the acceptable limits. The realized gain for the antenna is 1.02, 1.89, and 1.43 dB at 2.4, 3.5 and 5.8 GHz respectively.

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