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CSRR Loaded 2×1 Triangular MIMO Antenna for LTE Band Operation

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Abstract

A Compact 2×1 multiple input multiple output (MIMO) antenna system is designed to operate in the LTE band 7 (2.5 – 2.57) GHz. The proposed antenna consists of two triangular patches fed using microstrip line. In this work, complementary split ring resonator (CSRR) is loaded in the ground plane. The unloaded triangular patch antenna resonates at 5 GHz; whereas after loading it with CSRR, the same antenna resonates at 2.5 GHz. Size reductions of 72% compared to conventional patch antenna is obtained after the inclusion of CSRR in the ground plane. The designed antenna covers a bandwidth of (2.42 to 2.57) GHz with a maximum return loss of -26.5 dB at 2.5 GHz and isolation of -17.3 dB between the ports with close inter element spacing of 0.17λ. The simulated correlation co-efficient is 0.0212 and the total active reflection co-efficient is 0.56 at the resonating frequency.

1. Introduction

In wireless communication systems, long term evolution (LTE) represents the fourth generation solution providing higher throughput, wider bandwidth and improved handoff capabilities compared to third generation networks. LTE wireless devices are expected to operate over different frequency bands in the range from 400 MHz up to 4 GHz [1, 2]. LTE uses MIMO technology to improve the efficiency of using radio spectrum. MIMO antenna is expected to be a key element to support LTE systems. MIMO depends on the use of multiple antennas on the transmitting and receiving sides thereby increasing the channel capacity without the need of additional bandwidth or power. There is an increasing demand for making new MIMO antenna systems that are compact and compatible with user terminals and other wireless portable devices. The integration of multiple antennas on the user mobile terminals is a design challenge that has been given considerable attention by researchers, due to the inherent size and inter-antenna coupling limitations. Hence it is important to make antennas that have enhanced channel capacity, bandwidth, gain, and diversity performance. These requirements make the design of MIMO antenna systems challenging.

There are a number of techniques available in the literature for isolation [3] and antenna miniaturization. Material loading is to use a substrate with high relative permittivity or loading high permittivity bar on a low permittivity substrate. As the length and width of the patch are inversely proportional to the square root of ε_r, use of high permittivity substrate results in miniaturization at the cost of reduced efficiency and lower bandwidth due to increased surface wave excitation within the substrate [4]. Loading of high dielectric substrate requires expensive material. Miniaturization up to four times can be achieved by reshaping the antenna by using fractal antenna or by cutting slots on the patch. This method suffers from high ohmic losses leading to low radiation efficiency with complex geometry and poor polarization purity [5, 6]. Miniaturization up to four times can be achieved by folding the antenna and by using shorting posts. This technique suffers from decreased directivity and gain in addition to complex antenna geometry [7, 8]. By introducing slots, the current path within the patch area is increased lowering the resonant frequency leading to 40–75% of side reduction. It provides wide bandwidth, but affects the radiation characteristics and provides poor polarization purity [9]. By introducing defects or slots in the ground plane, size reduction up to eight times is achieved but with lower efficiency, increased back lobe level and narrow bandwidth [10, 11].

Metamaterials such as ENG, MNG or DNG inspired antennas provide high degree of miniaturization with limited bandwidth, low efficiency and complex geometry [12–17]. Metamaterials (MTM) are also used for isolation enhancement between adjacent elements due to the presence of a band gap in their frequency response [18, 19]. In this paper, a novel design of compact 2 × 1 (two-element) MIMO patch with two identical triangular patch antennas with CSRRs in the ground plane is proposed. The operating band of the proposed antenna is the LTE band 7 with a resonant frequency of the antenna elements centered at 2.5 GHz. 72% reduction in the size of the individual patch is achieved through CSRR loading, thus allowing the accommodation of the two patch antennas in an area of 50×50 mm^2 with 10mm spacing between them. The total size of the proposed MIMO antenna system board is 50 ×50×0.8 mm^3. The paper is structured as follows. Section 2 discusses the design of antenna. Section 3 presents and associates the simulation and measured results and Section 4 concludes the paper.

2. Design of the Antenna

The triangular patch is etched on FR4 substrate with $\varepsilon_r = 4.4$ and thickness t = 0.8 mm. The dimensions of the patch antenna were chosen in such way that when two of such elements were duplicated for MIMO antenna design, they fit well within a 50×50 mm^2 area with a 10 mm gap between the elements. Patch of area 18.5×16 mm^2 was selected. Such a patch resonates at 5 GHz in normal operating mode. To reduce the resonant frequency of the patch antenna, a single CSRR was etched out from its ground plane at its center.

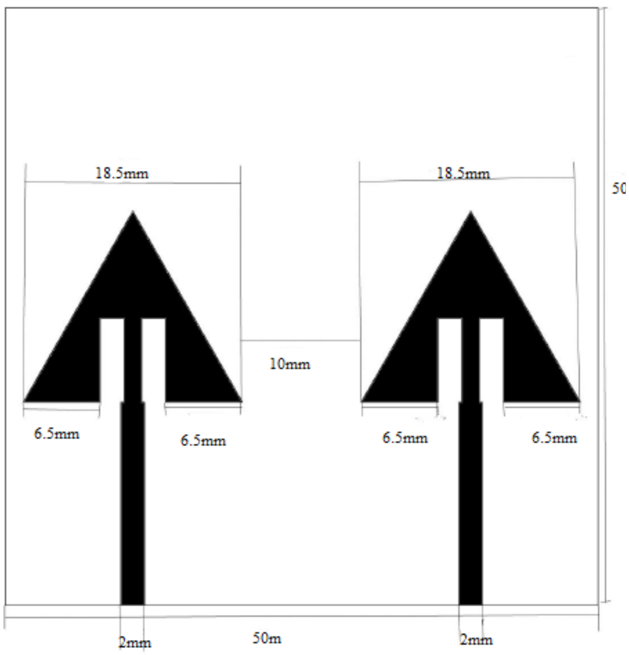

Figure 1: Geometry of the MIMO CSRR loaded patch antenna (a) top view

In the design of the single patch, the dimension of the CSRR was varied and the antenna was tuned to resonate at 2.5 GHz using the commercial software HFSS. A two element MIMO antenna system was made using the same patch design covering an area of 50 × 50 × 0.8 mm^3 with spacing of 10 mm. The top and bottom layers of the proposed design are shown in Fig. 1(a), (b). The outer radius '*r*' of the CSRR was 8.3 mm, the width '*w*' of each ring was 0.3 mm, the spacing '*s*' between the inner and outer ring was 0.3 mm, and the slit '*g*' in each ring was 0.5 mm which is shown in Fig.1 (b). The feed line width was 2 mm, which gives a characteristic impedance of 50 Ω. The CSRR is a resonant structure which behaves as an LC tank circuit [20]. CSRR underneath the patch in the ground plane interacts with the electric field and provides effective negative permittivity and makes the patch act as band pass filter at the resonant frequency.

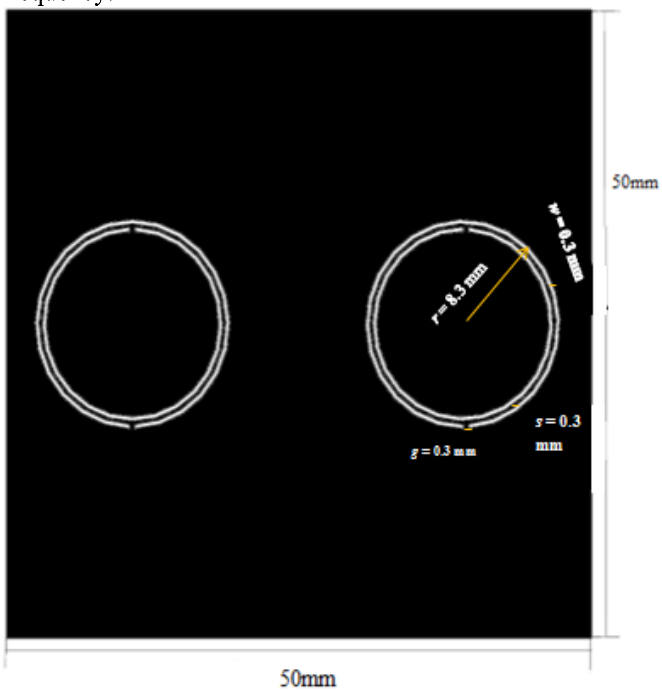

Figure 1: Geometry of the MIMO CSRR loaded patch antenna (b) bottom view

CSRR changes the characteristics of antenna cavity, and thus its resonance frequency is shifted. The antenna without CSRR resonated at 5 GHz and with CSRR resonated at 2.5 GHz providing a miniaturization of 72%. The dimensions of the antenna designed for 5 GHz is 16×18.5 mm^2 and the dimensions of the antenna for 2.5 GHz would be 29×36 mm^2, hence providing miniaturization.
Nicolson Ross Weir had demonstrated the extraction of relative permittivity and permeability using S parameters [21-23] and is given by,

$$V_1 = S_{11} + S_{21} \; --- (1)$$
$$V_2 = S_{21} - S_{11} \; --- (2)$$

$$\varepsilon_r = \frac{2c(1 - V_1)}{\omega d i(1 + V_1)} --- (3)$$
$$\mu_r = \frac{2c(1 - V_2)}{\omega d i(1 + V_2)} --- (4)$$

Where ω is the frequency in radian, c is the velocity of light in m/s, d is the thickness of the substrate, i correspond to imaginary part and V_1 is the voltage maxima and V_2 is the voltage minima.
To study the effect of CSRR on MIMO antennas, permittivity and permeability are computed using Nicolson Ross Weir technique and both are negative.
The plot is done using equations (1-4) and is shown in Fig 2 for the antenna structure clearly explaining the concept of band pass filter at the resonant frequency of 2.5 GHz.

Negative values of permittivity and permeability is the characteristic for band pass filter.

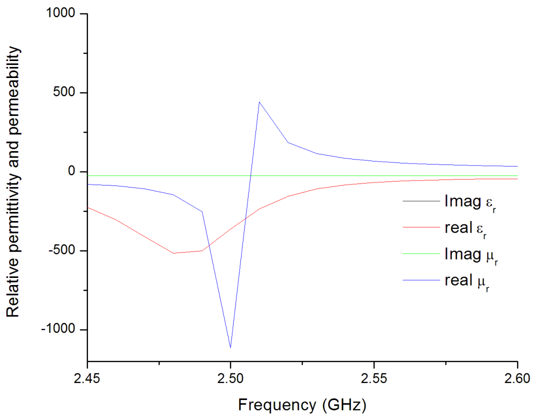

Figure 2: Relative permittivity and relative permeability vs. frequency for the antenna with CSRR

3. Results and Discussion

The design of CSRR is discussed followed by the return loss characteristics for single patch antenna and the return loss and isolation characteristics of MIMO antenna. Also the MIMO parameters such as ECC, TARC and gain are discussed for MIMO antenna in the following subsections.

3.1. Effect of CSRR Design Parameters

While tuning the antenna to resonate at 2.5 GHz, the dimensions of the CSRR were changed. These dimensions included the radius '*r*'of the outer ring, the width '*w*' of each ring, the spacing '*s*' between the inner and outer ring and the slit '*g*' in each ring. Slits do not have much effect on the resonant frequency. Thus, the width of the slits was kept at 0.5 mm. As the radius of the CSRR, was increased, the resonant frequency of the antenna decreased. Increasing the width of the rings *w* and the spacing between the two rings *s* resulted in an increase in the resonant frequency of the antenna. Thus, by changing these parameters, the antenna was tuned at 2.5GHz.

3.2. Single Patch Reflection coefficient with and without CSRR

The reflection co-efficient (dB) for the antenna without CSRR is -14 dB around 5 GHz and with CSRR loaded patch is -28 dB as shown in Fig. 3. The antenna resonates around 2.5 GHz with a 10 dB bandwidth of approximately 50 MHz, clearly indicating the miniaturization.

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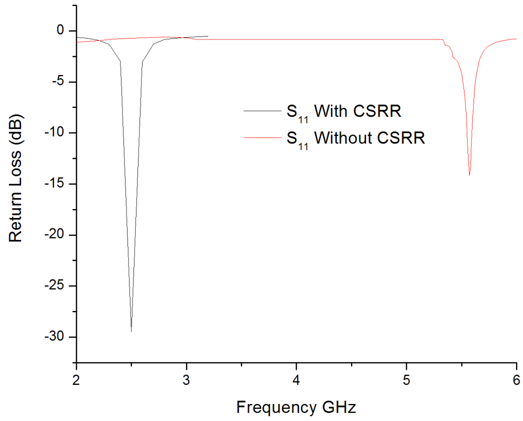

Figure 3: Comparison of reflection coefficient with and without CSRR loaded patch

3.3. Return Loss and Isolation for MIMO Antenna

Fig.6 shows the MIMO antenna system with CSRR loaded patches. Fig. 4, 5 shows the comparative plot for simulated and measured return loss and isolation characteristics. There is a slight shift in the resonant frequency from 2.5 GHz to 2.7 GHz compared to the simulation result due to fabrication losses. The simulation results for the return loss were observed to be -26.5 dB at the resonant frequency of 2.5 GHz and -38 dB during measurement at the resonant frequency of 2.7 GHz. The simulation result for the isolation was observed to be -17.3dB at the resonant frequency of 2.5 GHz and the measured result for the isolation is -15.1 dB at the resonant frequency of 2.7GHz, as shown in Fig. 5. The designed antenna covered a bandwidth of 2.42 to 2.57 GHz using simulation whereas 2.64 to 2.74 GHz for the measurement.

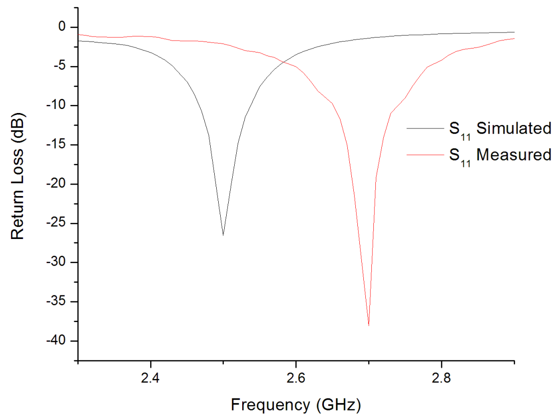

Figure 4: Simulated and measured return loss (dB)

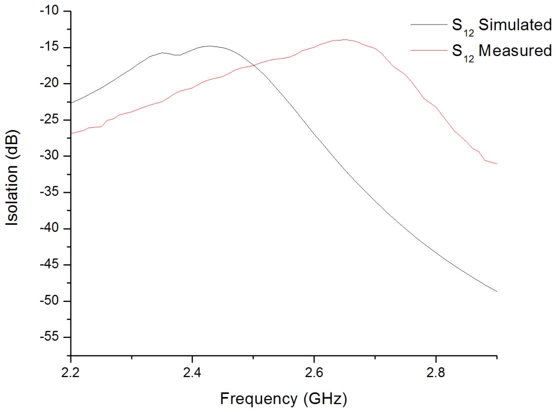

Figure 5: Simulated and measured Isolation (dB)

The proposed antennas described in the previous section were first designed and tuned in HFSS. They were then fabricated for the MIMO configuration as shown in Fig.6 (a), (b) showing the top and bottom layer.

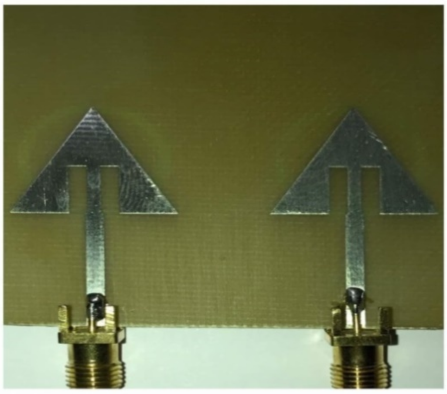

Figure 6: Fabricated antenna (a) Top layer.

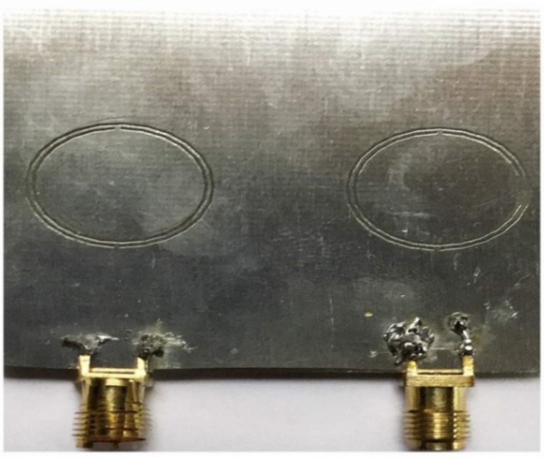

Figure 6: Fabricated antenna (b) bottom layer.

3.4. MIMO Performance Parameters

To properly characterize the efficiency and bandwidth of the MIMO antenna system, the scattering matrix is not enough [24].Thus, for better characterization of the MIMO antenna system, the total active reflection coefficient (TARC) and correlation co-efficient are computed.Total Active Reflection Coefficient (TARC) is defined as the square root of the ratio of the sum of the power available at all the ports minus the radiated power to the total available power [25]. It is a real number between 0 and 1 [26]. When its value is zero, this means that all the available power is radiated. The proposed antenna has a TARC value of 0.56 which is within 0 to 1 as shown in Fig. 7.

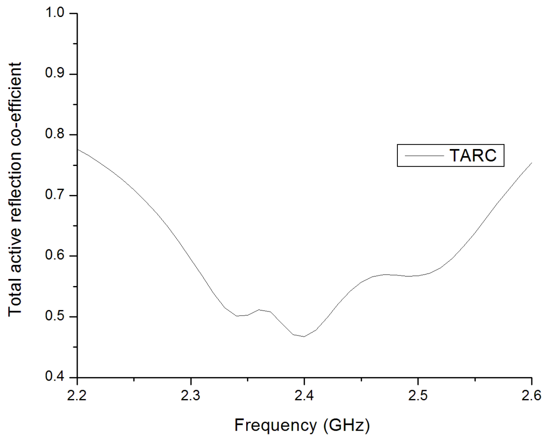

Figure 7: Simulated total active reflection co-efficient

The correlation coefficient ρ is a measure that describes how the communication channels are isolated or correlated with each other. High isolation and low correlation coefficients are required for a MIMO antenna system to provide good diversity performance [25]. The square of the correlation coefficient is the Envelope Correlation Coefficient (ECC). The correlation coefficient can be computed by using *S* parameters. An envelope correlation coefficient value of 0.5 has been set as an acceptable value for diversity conditions .The proposed LTE-MIMO provides the envelope correlation coefficient below 0.0212 over the LTE frequency band as shown in Fig.8.

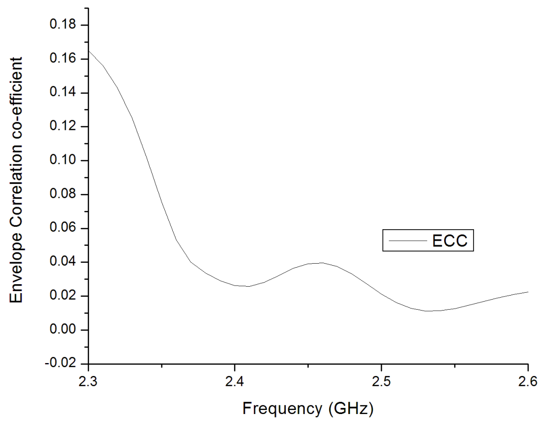

Figure 8: Simulated envelope correlation co-efficient

The realized gain was found to be 0.2148 dB at the resonating frequency of 2.5 GHz and is shown in Fig. 9.

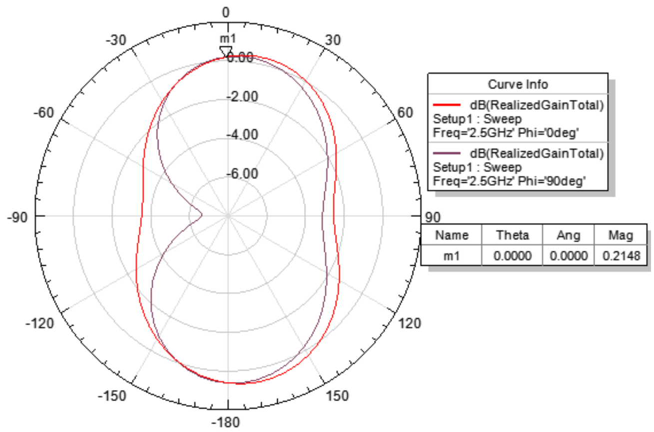

Figure 9: Simulated Realized Gain

The realized gain gets reduced to -29 dB without CSRR.

4. Conclusion

In this paper, compact 2 × 1 MIMO antenna system was presented. The antenna was fabricated on FR4 substrate and occupied a total size of 50 × 50 × 0.8 mm^3. Antenna miniaturization of 72% was achieved by loading the patches with CSRRs. The antenna was characterized for MIMO antenna parameters such as TARC and correlation coefficient. The MIMO antenna elements had good isolation thus good diversity performance. Due to its compact size and good performance, the design can be easily employed in a number of wireless portable devices operating in the (2.5 - 2.57) GHz LTE band 7 operation.

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