A 2X2 MIMO Antenna System Loaded with CSRRs for ISM-band Applications

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***Abstract*—A 2x2 (four-element) multiple-input multiple-output (MIMO) patch antenna system is designed for 2.5-GHz ISM band operation. It uses complementary split-ring resonator (CSRR) loading on its ground plane for antenna miniaturization. This reduces the single-element antenna size by 76%. The software used for this design is Advanced Design System. The proposed antenna has been designed using dielectric substrate FR4 and CSRR etched on ground plane with improved bandwidth and minimal return loss suitable to be effectively utilized for ISM applications. The total board size of the proposed MIMO antenna system, including the GND plane is 100x50x0.8 mm^3 , while the single-patch antenna element has a size of 14x18mm^2. The antenna is tested in Agilent HP8510C network analyzer. Measured results are in good agreement with simulations. The maximum measured gain for a single operating element is 0.8 dBi.**

Index Terms* — *Complementary split-ring resonator (CSRR), long-term evolution (LTE), MIMO antennas, WLAN.

1. INTRODUCTION

The evolution of technology for transmitting and receiving information by means of electromagnetic wave propagation has gone a long way. Instead, the scope of this introduction is mainly focused on a core technology, multiple-input multiple-output (MIMO) wireless communication, which is an integral part of both new and upcoming mobile communication systems. In modern wireless communications devices, there is a continuous demand for increasing the number of services that these devices can provide with compact size. This may result in increasing the data rate requirements and reliability of data.

These services include high-quality audio/ video calls, online video streaming, video conferencing and online gaming. These demanding features require wide operation bandwidth or covering several frequency bands. This can be accomplished by employing reconfigurable MIMO antenna systems in these mobile terminals. While designing compact antennas, antenna miniaturization techniques are used that can yield low antenna bandwidth, efficiency, and gain. Similarly, in a compact design, the antenna elements are placed close to each other, resulting in high correlation between the antenna elements and therefore poor diversity performance. Thus, in the design of a MIMO antenna system, it is important to employ antenna miniaturization techniques that keep the antenna design simple and its compromise with the other antenna parameters is at a minimum.

The study illustrates that a multi-antenna system can be exposed to severe spatial correlation if the interaction between the antennas and the propagation channel is not properly exploited. It also suggests the need of other techniques for obtaining linearly independent channels, since it is not always possible to accommodate large spatial separation among antennas in some applications, especially where the size of the overall antenna system is constrained. A double split ring resonator (SRR) is a highly conductive structure in which the capacitance between the two rings balances its inductance. A time-varying magnetic field applied perpendicular to the rings surface induces currents which, in dependence on the resonant properties of the structure, produce a magnetic field that may either oppose or enhance the incident field, thus resulting in positive or negative effective μ. In other words, the operation of a SRR represents an 'over-screened, under-damped' response of material to electromagnetic stimulation. For a circular double split ring resonator in vacuum and with a negligible thickness the following approximate expression is valid.

We present characteristics of microstrip patch antennas on metamaterial substrates loaded with complementary split-ring resonators (CSRRs). The proposed antenna utilizes CSRRs in the ground plane altering the effective medium parameters of the substrate. To characterize the performance of the CSRR loaded microstrip antenna, the metamaterial substrate has been modeled as an effective medium with extracted constitutive parameters. Simulation results were verified by experimental results. The experimental results confirm that the CSRR loaded patch antenna achieves size reduction and maintaining the same bandwidth as well. Metamaterials are finding numerous applications for novel antennas. One such application is the use of artificial materials for compact antennas. Miniaturization of microstrip antennas has been attempted for a long time using various different methods.

2. LITERATURE REVIEW

MIMO antenna system provides a higher data rate than a single antenna system without any increase in power or bandwidth [2]. Theoretically, a linear increase in data rate is achieved with the increase in the number of uncorrelated antennas at the transmitter and receiver ends [1]. MIMO antenna systems can be easily integrated at the base station of a mobile service. However, designing MIMO antenna systems for the user devices has many challenges.

Among them is to design compact MIMO systems with reasonable gain and other characteristics so that they can be easily integrated with small wireless mobile devices. Since the increase in the data rate due to MIMO antenna system is directly related to number of uncorrelated antennas, high isolation is required between the antennas of a MIMO antenna system. This becomes a serious challenge when antenna elements are placed very close to each other due to the limitation of mobile terminal size. Thus isolation between antenna elements is a parameter which requires consideration in MIMO antenna design. The 2.4 GHz ISM band is widely used and many applications operate in this band.

Recently, some four element MIMO antennas were presented in literature which cover this band [3]-[6]. These included planar inverted-F antenna (PIFA) array [3],[4], quarter wavelength slot antenna array [5] and 4-shaped antenna array designs [6]. The MIMO antenna system presented in [3] was made by the combination of PIFA and slot antenna elements.

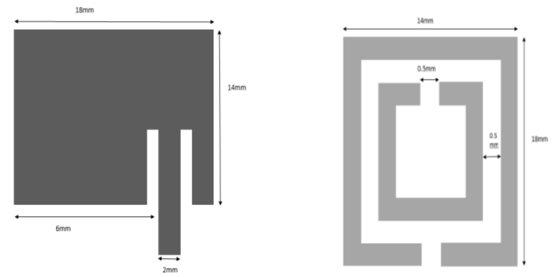
The antenna occupied a space of $40\times40\times1.6$ mm^3. The antenna operated at 2.48 GHz with a maximum gain of 2.4 dBi. In [4], the MIMO antenna system was made by a modified PIFA. The antenna dimensions were $120\times120\times16.4$ mm^3. The antenna had a broad operating bandwidth of 400 MHz covering the range of 2.4-2.8 GHz. The MIMO antenna system described in [5] occupied a space of $80\times80\times1.52$ mm^3. This antenna also had a wide bandwidth covering 1.63-2.05 GHz. In [6], a MIMO antenna made up of four-shaped elements was presented. The antenna had a dual band operation. Its upper band was covering the ISM band where the gain of antenna was 4.5 dBi. The dimensions of antenna was $58\times110\times1.56$ mm^3. In this paper, a compact four element (2×2) MIMO antenna system is presented.

The antenna operates in the 2.4 GHz ISM band. Apart from a high miniaturization achieved in this design, the proposed MIMO antenna is different from the previously presented antennas as it consists of simple patch antennas as its elements loaded with the complementary split ring resonators (CSRR). Patch antennas are easy to fabricate, inexpensive and can be easily integrated with accompanying electronics. The CSRR is a metamaterial element which is used with the patch antenna to reduce its size. A size reduction of 76% is achieved by loading a CSRR with the patch antenna. The total space occupied by the MIMO antenna system is $100\times50\times0.8$ mm^3 where only 50% space is used by four antenna elements.

The rest of the paper is organized as follows. The design of the proposed MIMO antenna system is presented in section III. Measured and simulated results for the MIMO antenna system are discussed in section IV and conclusions are given in section V.

3. PROPOSED WORK

Patch antennas have been widely used due to their ease of design and fabrication. However, they are seldom used as elements of MIMO antenna systems due to their large dimensions. Several methods have been presented to reduce the size of patch antennas. A CSRR is a negative image of a split-ring resonator (SRR).It is made by removing the copper in the shape of an SRR from a copper sheet, which is usually a ground plane. The CSRR interacts with the electric field and provides effective negative permittivity around its resonance frequency. The resonant frequency of a CSRR is the same as that of an SRR of the same dimension, and it is modeled as an *LC* circuit. The lumped element model for an SRR and a CSRR, which also gives quasi-analytical equations for finding the resonant frequency of the SRR and the CSRR. In an empirical model for the resonant frequency of the SRR is given, which is easy to implement.



(a) (b)

Fig.1.A single patch antenna: (a) top view and (b) bottom view

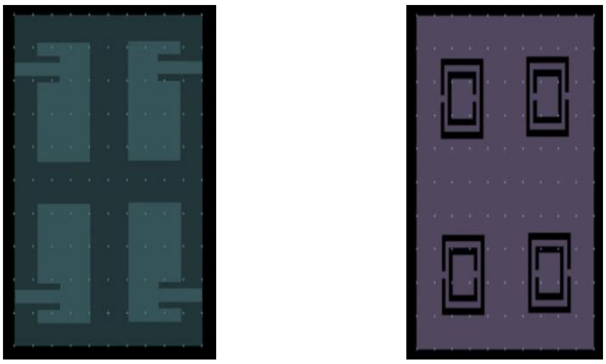
This paper presents a novel design of a 2X2 (four-element) MIMO patch antenna system, which has highly compact patch elements. The elements of the proposed MIMO antenna system consist of four identical patch antennas loaded with CSRRs. The operating band of the proposed antenna is the ISM band with a resonant frequency of the antenna elements centered at 2.5 GHz. A 76% reduction in the size of the individual patch is achieved through CSRR loading, thus allowing the accommodation of the four patch antennas in an area of 50X50 mm with 10 mm spacing between them. The total size of the proposed MIMO antenna system board is 50X100X0.8 mm^3 .

In all of the previous work, CSRR loaded miniaturized patch antennas were used in applications that require only a single antenna. Such patch antennas were never extended and analyzed for MIMO antenna systems. Also in many of the recently proposed MIMO antennas, most of them did not utilize patch antenna elements. Those designs that used modified patches had dimensions that were not very compact, thus making them not useful for mobile applications. In our design, the CSRR loaded patch antenna elements are easy to fabricate and can be easily integrated with other systems. The total dimensions of the design were kept to a minimum so that it conforms to the dimensions of handheld wireless mobile sets and other wireless portable devices including laptops and tablets.

A CSRR etched out underneath a patch antenna actually changes the characteristics of antenna cavity, and thus its resonance frequency is shifted. Since a CSRR is an anisotropic element, its orientation has a profound effect on the resonant frequency of the antenna apart from its dimensions. For different shapes of DGS substrate, we compare the results with various enhancements like bandwidth, isolation, gain and directivity. The main aim is to enhance the isolation.

4. DESIGN METHODOLOGY AND RESULTS

The proposed antennas described in the previous section were first designed and tuned in ADS. They were then fabricated. The scattering parameters of the MIMO antennas were measured using the Agilent HP8510C network analyzer. The two dimensional gain measurements of the MIMO antennas were carried out at an outdoor antenna test facility. The simulated results can be discussed in section 1V. Calculating and optimizing the both patch, inner and outer to get the required resonant frequency, which as radiating element. The length of inner rectangular ring and both of small rectangular patches has been optimized to control the bandwidth of microstrip antenna.



(a) (b)

Fig.2. A 2x2 MIMO system (a) top view and (b) bottom view

A steps involved in designing a substrate can be shown in figure. Connect a pin at the feed point of the antenna as shown below. Go to the EM setup window and click on Substrate and click on New to accept the 1.6 mm FR4.

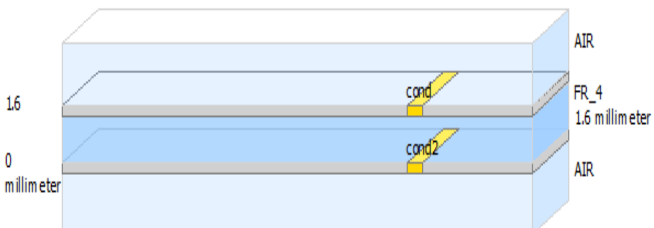


Figure.3. Substrate for two layers.

In this design the front and ground plane contains two different conductors, therefore the substrate can be fixed to cond and cond2 layers and the substrate can be chosen as FR4. Set the Simulation Frequency range as 0GHz to 20GHz.Click on Simulate.

While designing compact antennas, antenna miniaturization techniques are used that can yield low antenna bandwidth, efficiency, and gain. Similarly, in a compact design, the antenna elements are placed close to each other, resulting in high correlation between the antenna elements and therefore poor diversity performance. Thus, in the design of a MIMO antenna system, it is important to employ antenna miniaturization techniques that keep the antenna design simple and its compromise with the other antenna parameters is at a minimum.

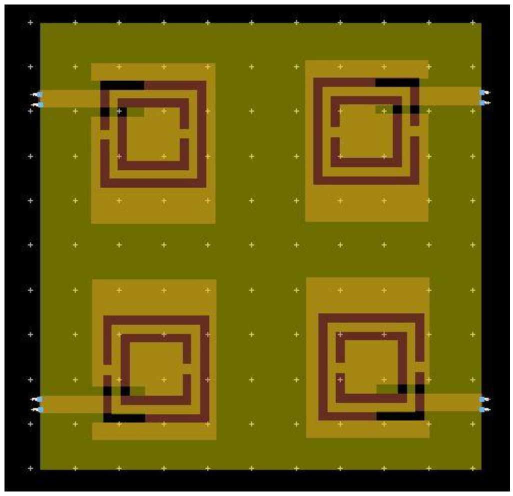


Figure 4:2x2 MIMO Antenna System.

A 2x2 (four-element) multiple-input multiple-output (MIMO) patch antenna system is designed and fabricated for a 2.5-GHz ISM-band operation. It uses complementary split-ring resonator (CSRR) loading on its ground plane for antenna miniaturization. The single-patch antenna element has a size of 14x18 mm^2. The antenna is fabricated and tested. The Efficiency for the antenna design is reduced to be 60%. Fig.5. shows the simulation result of MIMO antenna system by generating the frequency at 2.5GHz.

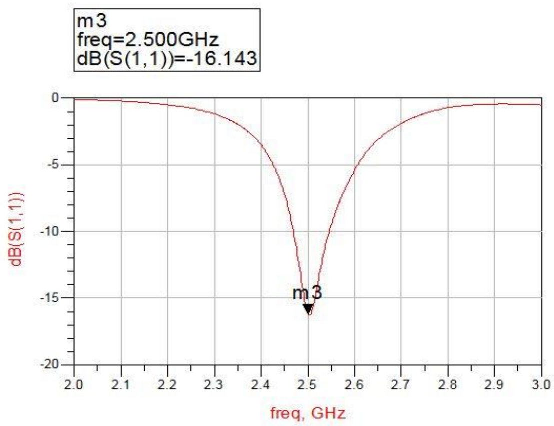


Fig.5.Simulated result for 2x2 MIMO antenna

The gain obtained for this MIMO antenna system is 0.849dBi and the directivity can be displayed as 2.46dBi.The efficiency obtained for a single antenna element is 70%.The antenna parameters for gain, directivity and the received parameters for this design can be maximum.

The gain of an antenna is an important measure in the calculation of its link budget, which determines the coverage area and achievable data rates of the system. In a mobile propagation environment, the directive gain of an antenna cannot be used to get the accurate results. In such environments, the mean effective gain (MEG) of the system is calculated. The MEG of an antenna is defined as the ratio of mean received power to the mean incident power. The MEG of an antenna operating in an urban mobile environment is determined by the mutual relation between the field patterns of the antenna and the statistical distribution of the signal in the environment.

5. CONCLUSION

In this paper, a novel compact 2x2 MIMO antenna system was presented. The antenna was fabricated on a conventional FR4 substrate and occupied a total size of 100x50x0.8 mm .The elements of the MIMO antenna were patch antennas, which are easy to fabricate. These simulations lead to the conclusion that the number of patches in an array is directly proportional to the efficiency of the antenna. Antenna miniaturization was achieved by loading the patches with CSRRs. The antenna was characterized for MIMO antenna parameters such as gain and directivity. 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 ISM band.

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