MIMO-CSRR Antenna for ISM Band Applications

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Abstract
For the operation of 2.45GHz ISM band, a 2x2 Multiple Input Multiple Output (MIMO) antenna system is designed and fabricated. Complementary Split Ring Resonator (CSRR) is used in the MIMO patch and loaded on its ground plane to miniaturize the single antenna element. The single patch antenna element of 14x18 mm\textsuperscript{2} is fixed in a board of the Designed MIMO antennae system measuring 100x50x0.8 mm\textsuperscript{3}. The antenna is tested by measuring radiation pattern, gain, VSWR, mutual coupling and return loss. The results of the Designed antenna systems are in good agreement with the simulations. In comparison to a conventional microstrip antenna, the Designed antenna achieves a 75% reduction in the resonant frequency.

Keywords - Complementary Split Ring Resonator (CSRR); Multiple Input Multiple Output; metamaterial; size reduction; split ring resonator

1 Introduction

Wireless In the field of wireless communication systems antenna plays a major role. Initially in the year 1950 microstrip antenna was first introduced [1]. After few years printed circuit board (PCB) was developed [2-5] the microstrip antenna gained advantage of being lightweight, small in size, small power for radiation, cost effective, suitable for array structure and simple for fabrication [6].

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Wireless communication system requires higher data rates for the present and future needs. In particular, wireless system needs multiple antennas both at transmitter and receiver end to reduce the space and remove the coupler, filter, power divider and so on. MIMO has emerged to be a practical technique for sending and receiving multiple data signals on the same radio link at the same time via multipath propagation. This makes MIMO an integral part of the new 4G LTE/5G wireless standards [7]. To make MIMO compatible to these standards it required high channel bandwidth, diversity, gain and hence designing the MIMO antenna suitably becomes more critical [8].

To Mitigate the issue in the size and cost of MIMO systems, antenna miniaturization techniques are used to yield low antenna bandwidth, efficiency and gain. To root case many MIMO paper have been reviewed [9-11]. The above-mentioned antenna are built for various frequency band including Industrial Scientific and Medical (ISM) covering 2.45 & 5.8GHz band, GSM and some are even developed for dual band operation systems. Isolation between the antenna parts and the gain are 8.5 dB and 2.4dBi respectively. The size reduction can be achieved by different techniques [12] using Reactive Impedance Surface (RIS), Split Ring Resonator (SRR) and high permittivity of the dielectric substrate without degrading the performance. Metamaterial elements have been used for antenna miniaturization which has the properties of electrically smaller size, high Directivity, operating frequency can be varied and improve the bandwidth efficiency [13].

CSSR is a negative image of Metamaterial is an unnatural material whose property could not be located in the environment. This material provides solution to reduce the resonating frequency without penalty in occupied volume operation. CSRR originates from Split Ring Resonator (SRR) which is achieved by removing the copper from its ground plane.

![Geometry of the single patch](image)

**Fig.1** Geometry of the single patch: (a) front view; (b) back view

### 2 Antenna Design

This work proposes a 2x2 MIMO antenna using inexpensive dielectric substrate FR4 with permittivity of 4.4 and height of 1.6 mm. The dimensions of the designed antenna are evenly distributed and are followed as 100x50x1.6mm³. The antenna structure has been simulated in Advanced Design System (ADS) using Finite Element Method (FEM). The FEM solver is a full 3D EM field solvers and the 3D structure is partitioned into a mesh of tetrahedrons. Simulation is performed at adaptive frequency; the Mesh is refined where signal energy is the greatest process and completed when error tolerance is met between consecutive passes.
Fig. 2 Geometry of the 2x2 MIMO Antenna: (a) front view; (b) back view

The resonating frequency of Antenna is derived by length and other dimensions of the patch. The center Frequency of Antenna is given by the equation.

\[ f_c = \frac{c}{2l/\sqrt{\varepsilon_r}} \]  \hspace{1cm} (2.1)

By the above equation, resonating frequency of the patch is derived as 5GHz. By varying the CSRR notched out from its ground surface, the new resonating frequency of the antenna is achieved. Hence the microstrip antenna is operating at frequency of about 2.45 GHz with 50Ω characteristic impedance on unlicensed band and which is also the operating frequency of MIMO antenna. Figure 1 shows the front and back view of the patch antenna dimension of 50x50mm² area. Figure2 shows the front and back view MIMO antenna, it has four identical patch antennas mounted with proper spacing. The dimension of MIMO patch antenna is 18x14mm which is operating in the frequency of 5GHz.

In order to reduce the resonating frequency of the antenna CSRR was introduced. To achieve the desired frequency, the antenna was tuned to resonate at 2.45 GHz by modifying the dimensions of CSRR that is notched out from its ground at its center. From the above equation (2.1) the length and width of the microstrip patch is calculated and is shown in the table.

In the recent years, metamaterial CSRR is used in antenna for miniaturization which interacts with electric and magnetic fields produces negative permittivity and permeability around its resonant frequency.
The dimensions of CSRR is same as that of SRR which is achieved by removing copper from its conducting strip under the ground plane of each elements. The important parameter of split ring resonator is shape of the ring, radius of the outer width of the rings, spacing between the rings, width of the slit and feeding width.

Table I  Comparison of Patch Parameters

| Patch Parameters | Without CSRR(mm) | With CSRR(mm) |
|------------------|------------------|---------------|
| Width of the Patch (w) | 37 | 18 |
| Length of the Patch (l) | 29 | 14 |
Fig 2 shows the geometry of the Designed MIMO antenna system. The dimensions of the antenna are 100x50mm$^2$, in this top 50x50mm$^2$ is used for the radiating patch and the bottom 50x50mm$^2$ is free to mount other components. The spacing between each element is of about 10mm which provides a good isolation between the antenna elements. In this design, the CSRRs were oriented in such way that slits were placed perpendicular to the radiating edges of the antenna. Table II shows the dimensions of the CSRR radius of the outer ring,

| Parameter                     | Symbol | Value  |
|-------------------------------|--------|--------|
| Outer ring Radius             | $r$    | 6mm    |
| Ring width                    | $w$    | 0.5mm  |
| Spacing Between the ring      | $b$    | 0.5mm  |
| Slit width                    | $s$    | 0.5mm  |
| Feed line Width               | $f$    | 2.98mm |

Table II  CSRR Dimensions for the Designed Antenna

3 Results And Discussion

The Designed Antenna can be Analysis by its parameters such as return loss, VSWR, radiation pattern and mutual coupling between antenna elements. The Patch Antenna is shown in the Fig. 1 which is operating at a frequency of about 2.45 GHz based on the ISM band and Fig. 3 shows the measured and simulated return loss of an antenna, it is nothing but frequency at which the reflection is minimum and the radiated power is maximum. The Designed antenna is resonating at a center frequency of about 2.48GHz.
Fig. 6 Radiation pattern of single path

Fig. 7 Radiation pattern of MIMO path
**Fig. 8** Current Distribution of the Single Patch (a) front view (b) Back view
A 2x2 patch loaded with CSRR is resonating at a center frequency of about 2.48 GHz shown in the Fig 5. For simplicity, without altering the dimension of the patch, a metamaterial based complimentary split ring resonator is varied according to band of interest. The bandwidth of the antenna is defined as upper cutoff frequency minus the lower cutoff frequency at 10 dB where the loss will be minimum, so the bandwidth of the antenna is about 140 MHz@-10dB. Current distribution of single and 2x2 mimo patch antenna is shown in the figures 8 and 9 which gives an overall picture of how the antenna is radiating and the mutual coupling between the elements. A higher current level indicates a maximum radiation pattern at the antenna. The bottom element shows the maximum current due to the presence of CSRR loading. The current level is shown for a maximum resonating frequency at 2.48GHz.

![Current Distribution of MIMO Antenna](image)

**Fig.9 Current Distribution of MIMO Antenna** (a) Antenna port 1 front view is active (b) Antenna port 4 front view is active (c) Antenna port 2 back view is active (d) Antenna port 3 back view is active

Mutual coupling plays an important role in order to evaluate the performance of MIMO antenna. It reduces the antenna radiation efficiency as the distance is identical and place close to each other. When applying the voltage at port 1 some part of the energy is transfer between surrounding element of the antenna (2, 3 and 4). The minimum isolation between the antenna element can reduce the mutual coupling between the MIMO elements. The voltage standing wave ratio is nothing but the reflection coefficient where the power is reflected from the antenna. For an antenna to work efficiently, it should have a VSWR in the range of between 1 and 2, Fig 4 shows the measured and simulated VSWR of the patch antenna.
Fig. 10 Mutual coupling of MIMO Antenna

The antenna is fabricated using FR-4 copper on both the side of material with a female SMA adapter is mounded on the antenna in order to measure the radiation characteristics of antenna. Rosenberger coaxial cable (DC to 18GHz) is connected between the E5080A and the DUT. The results were measured using keysight ENA Network Analyzer E5080A, and the calibration is performed for open, short and load conditions in order to have a proper alignment in the analyzer E5080A. Finally cable antenna test is used to verify the electrical performance of the antenna using distance to fault method to estimate the physical location of a fault in cable or antenna.

The 3D radiation pattern of the antenna is used to characterize the radiation pattern. Generally radiation pattern can be classified into three types as Omni directional, Directional and isotropic antenna. The radiation pattern as in this research work is Omni directional for single patch and directional for MIMO patch radiation pattern which have the gain in particular direction. Fig 6 and 7 shows the 2D radiation pattern of single path and MIMO path respectively.

4 Conclusion

A miniature antenna is designed by loading CSRR in a FR4 substrate 2 x 2 MIMO patch antenna system to operate in a 2.45GHz ISM band. The simulated results obtained by measuring radiation pattern, gain, VSWR, mutual coupling and return loss are analyzed. This analysis demonstrates that using CSRR, the size of the MIMO antenna can be reduced by 75% for operations at 2.45GHz.
ISM band and a good diversified performance can be achieved due to isolation of the antenna elements. Thus, the designed antenna due to its small size and diversified performance can prove to be a better element in wireless applications, working in the ISM band.

Fig.11 Fabricated structures (a) front view (b) back view

5 References

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