A Novel SRR inspired CPW-Fed Dual Band MIMO Antenna for Sub-6 GHz 5G Application

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A Novel SRR inspired CPW-Fed Dual Band MIMO Antenna for Sub-6 GHz 5G Application

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Abstract

The metamaterial inspired novel CPW fed MIMO antenna design works based on the principle of Non Bianisotropic- Split-Ring Resonator and amalgamation of Hexagonal Open Ring Resonator(Hex-ORR) thereby resulting in a miniaturized antenna with dimensions of 47.4 × 31.7 × 1.6 $\boldsymbol{mm^3}$.This antenna holds decent for the Sub-6 GHz 5G application covering bandwidth of 983.5 MHz (3.7887 - 2.8052 GHz) and 551.6 MHz (6.3834 - 5.3818 GHz) with center frequency of 3 GHz and 6 GHz, respectively. The lower frequency band is produced using hex-ORR, and a higher frequency band is provided using NB-SRR. The size of the antenna is optimized by considering the Non Bianisotropic-SRR size minor than the resonant wavelength.The proposed MIMO antenna parameters such as ECC, CCL, and TARC are also examined, and the results indicate that the proposed antenna design is a good candidate for sub-6GHz 5G applications.

Keywords: Dual band antenna, Hexagonal Open ring resonator, Non Bianisotropic Split Ring Resonator (NB-SRR), multiple input multiple output (MIMO) .

1 Introduction

MIMO (Multiple input multiple output) antenna configuration paves way for advancements in wireless communication that deploys multiple antennas at both the source and the destination. To minimize errors and maximize data speed, the antennas through each extreme of the communications circuit are combined. Because of progressions in wireless communication systems and their applications, a multi-frequency band of surprisingly small printed CPW-fed antennas is of recent research interests. In the context of the research domains like design of filters, wireless sensors and RFID communications metamaterial Antennas are of great necessity.These metamaterial Antennas acquire the nature of negative refractive index by the split ring resonators (SRRs) and complementary SRRs (CSRRs) structures which go hand in hand with the recent requirements like easy of integration , compactness in size and weight of the antenna. The orientation and position of the SRR's gap with regard to transmission line has a worth remembering impact on the general performance of Antenna. The left-handed metamaterials (LHM) have sparked a lot of interest in recent decades because of its unique characteristic. The electromagnetic (EM) response of any material is dependent on two key modalities : dielectric permittivity (ϵ) and magnetic permeability (μ). In most ordinary materials, both are positive. However, for few synthetic structures, the permittivity (ϵ_{eff}) and permeability (μ_{eff}) are said to be negative. Because the left-handed (LH) coordinate are the resultant combination of electric, magnetic, and their wave vector components which in turn forma a system, hence the name "LH material" is used to describe them. Because the index of refraction for LHMs is less than zero, the phase velocities and group velocities are oriented in opposite directions, causing the transmission direction to be reversed in accordance with the direction of energy flow. A synthetic negative magnetic permeability medium (NMPM) split ring resonators (SRR) are made up of replicas of electrically small resonant particles which in turn forms the array as proposed in the survey [1] . It also states that the SRs are dependent on simple and well-known reliably cheaper technologies such as photo-etching. SRs retain the non-bianisotropic behaviour of other antenna structures, like broadside coupled SRR, while making and controlling their electrical properties much easier. A single-layered actually massive MIMO antenna operating in the 5G spectrum is equipped with compact planar technology inspired by metamaterial structures best suited for millimeter-wave applications[2].The split ring resonators and the units cells of different operating structures such as the hexagonal shaped cells helps in covering a wide range of spectral bandwidth and also ensures the (NZRI) property[2] and the near zero index properties. The substrate integrated waveguide (SIW) Antenna, which is designed for use in mm Wave sensing applications [3], is also conformality-friendly and can be used in military protective gear made of ballistic components. A compact triple band antenna that supports the IEEE 802.11a/b/g and IEEE 802.16e standards at frequencies of 2.4, 3.5, and 5 GHz, respectively. The resonant modes are caused by the rectangular slot and a split ring structure inspired by metamaterials [4]. Low cross polarisation and higher antenna gain are the results of the established radiation patterns. A low profile CSRR based monopole antenna with additional slots[5] aids in the applications like GSM, WiMAX and C band solicitations. It also has a miniaturized structure and better impedance matching. SRR implementation in the rearmost flank of the substrate is to achieve a wideband casing from 3.87 to 7.63 GHz, which covers the 5 GHz WLAN and 5.8 GHz RFID enactments[6].The antenna modelling technique with enhanced gain can be done using the negative permeability characteristics of the metamaterial loaded antennas[7].Complementary Folded Triangle-SRR helps in achieving additional resonating bandwidths for multiband applications and improvising the gain requirement[8].The deployment of MIMO antenna arises the problem of interference between the adjacent antennas and this could be overcome by the perfect isolation metric as discussed in the MIMO antenna design[9].The CSRR antennas with offset feed can help in relocating the multiple resonant bands in case of monopole congiguration[10].The meta antenna exclusively for Ultra wide band characteristics with good band notch characteristics with MIMO configuration results in coupling reduction parameter[11].Metamaterials are artificially organized structures constructed on a size scale smaller than the wavelength of external stimuli, and they can show excellent field localization and enhancement, which could enable novel tools to significantly improve sensor sensitivity and resolution, as well as open new degrees of freedom in sensing design[12].

This paper is organized in a manner that it shows the working of a squashed CPW fed antenna which is operating on the dual band from 3.7887 - 2.8052 GHz and 6.3834 - 5.3818 GHz with a Hexagonal shapped-CRR and Non Bianisotropic-SRR. To eliminate the bianisotropic property of the split ring resonator which produces the effect of anisotropy and cross polarization the NB-SRR is proposed in which the rings are aligned together from end to end of the metal strip, which helps in improvising the bandwidth to a higher frequency . It primarily helps to improve the limited magnetic response in other directions.

2 Antenna Design

The proposed non-biaisotropic split ring resonator (NB-SRR) is designed with the FR-4 substrate whose dielectric constant varies from 3.8 to 4.8 with the dimension of $47.4 \times 31.7 \times 1.6$ mm^3.The hexagonal –CRR and the non-biaisotropic-SRR are associated to the overall working performance of antenna like operating bandwidth and gain. The Ring radius in the resonators is mentioned by the r_1, r_2 , r_3,r_4, r_5 and r_6 from the Center point. The splits across the rings of improves bandwidth in non-biaisotropic SRR.

The novel approach for improvising the impedance matching is to design the ground plane by merging the CPW feed and impedance transformation

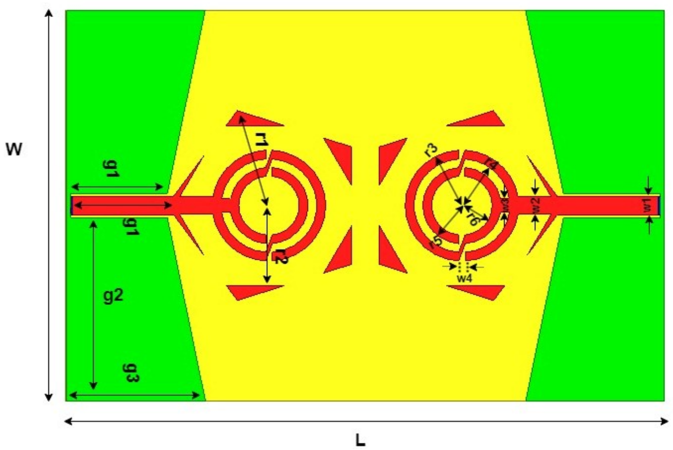

Fig. 1: Schematic representation of proposed antenna.

line. The dimensions of the ground plane are as follows g_1=8 mm, g_2=14.85 mm, g_3=11 mm and u=0.3 mm signifying the symmetric ground plane, height of ground, length and spacing between the feed and the ground respectively. The scopes of the antenna designed is represented in the Table.1. The significant width of the feed at the junction is represented as w1.These width calculations are derived from

$$t_n = \alpha^n \times w_1 \qquad (n = 1, 2) \tag{1}$$

The premeditated width of the tapered transmission lines from the above equation is 1.5mm, 1.4 mm, 1.12mm and 0.5 mm corresponding to the notations w1, w2, w3 and w4.

The resonant frequency for a Hexagonal- CRR is given by equation 2.

$$f_{Hex-CRR} = \frac{1.8412 \times C}{2\pi S\sqrt{Re(\varepsilon_r)}} \tag{2}$$

Where C denotes the speed of light and S corresponds to sides of the hexagonal length . The resonant frequency of NonBiaisotropic-SRR is same as SRR which is represented by euation 3.

$$f_{NB-SRR} = \frac{C}{2\pi^2}\sqrt{\frac{3(r_1 - r_2 - w)}{Re(\pi_r)r_1^3}} \tag{3}$$

Table 1: Dimensions of the proposed antenna

Parameter	Value(mm)
W	31.7
L	47.4
g_1	8
g_2	14.85
g_3	11
r_1	8.1
r_2	7.5
r_3	4.5
r_4	4.5
r_5	3.1
r_6	2.4
W_1	1.5
W_2	1.4
W_3	1.12
W_4	0.5
S_1	0.3
S_2	0.2
S_3	0.25

2.1 Results and Discussion

The software tool used for simulation of the MIMO antenna structure is High Frequency Structure Simulator (HFSS) electromagnetic simulator software. The tools helps us in analyzing the return loss characteristics of S11 and S22 across the frequency as depicted in the figure 2. The recommended structure hold good for dual band configuration which represents the first band from 2.8056 - 3.8000 GHz and second band ranges from 5.8400 - 6.3806 GHz with the middle frequency located at 3.2GHz and 6.05 GHz, respectively. The impedance bandwidth due to the higher frequency is handled by the small metal stripe in charge of the NonBiaisotropic-SRR. Out of the two bands the Hexagonal CRR is responsible for WLAN coverage.

The ratio of reflected and incident waves are the factors determining the Voltage Standing Wave Ratio (VSWR). Figure 3 shows the resultant value of 0.15 and 1.63 as VSWR. The proposed antenna has near to the ground VSWR when compared to the other meta antennas surveyed in the literature.

Radiation pattern: An antenna pattern is the linear representation that depicts the variance in real electromagnetic field strength at all sites at an equivalent gap from the antenna. E-plane and H-plane pictorial representations are the end results of the antenna. The former one represents the plane holding the electric-field vector and its radiation for a linearly polarised antenna, while the latter one represents the plane having the magnetic-field vector and its greatest radiation. Fig. 6 and Fig 7 are the respective representation of the field pattern which holds the corresponding values phi=0 and phi=90 .

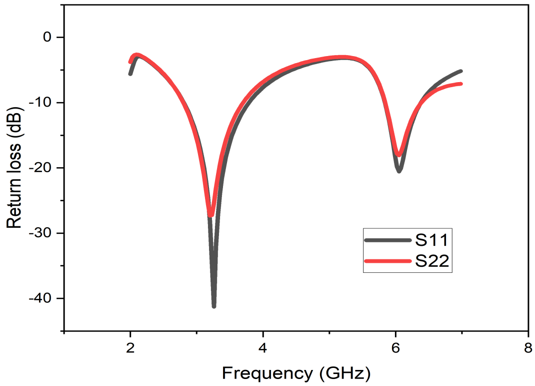

Fig. 2: Return loss of S_{11} and S_{22} (dB).

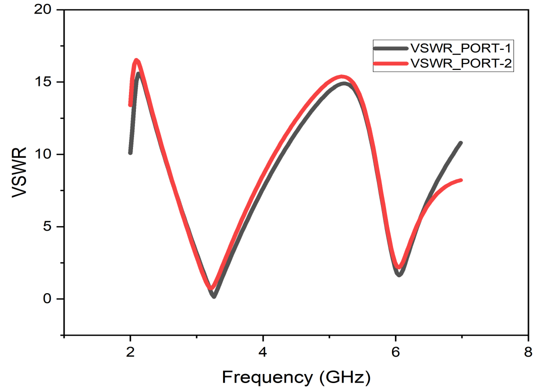

Fig. 3: Voltage Standing Wave Ratio [VSWR]-(dB).

3 Parameters Extraction of Non Bianisotropic split-ring Resonator

The band characteristics of Non-Bianisotropic Split Ring Resonator is examined by the classical waveguide theory method. The reflection coefficient (S_{11}) and transmission coefficient (S_{21}) are found, and from this S-parameters, permeability characteristics are extracted. The S-parameters (S_{11} & S_{21}) are plotted against as a function of frequency as depicted in Fig. 8.

Inference from the figure 8 shows the Notch band characteristics 2.9 GHz and pass band performance at2.5GHz. Thus, the pass band is responsible for obtaining higher resonance frequency of 6 GHz. The retrieved negative

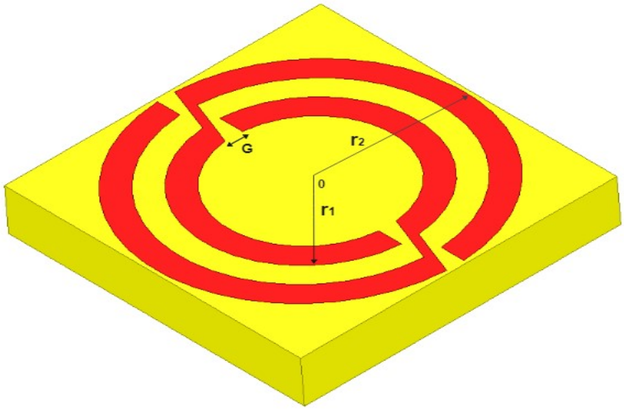

Fig. 4: Band Characteristics of NB-SRR.

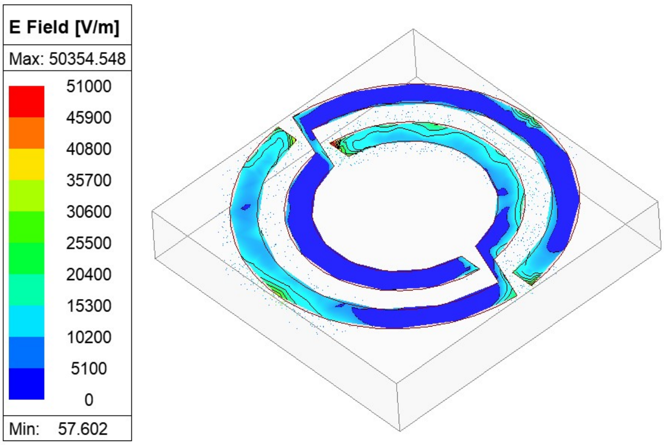

Fig. 5: Negative Permeability characteristics of NB-SRR at 5.6 GHz.

permeability characteristics of NB-SRR is shown in Fig. 7. Negative-index metamaterial characteristics is shown at the frequency of 5.6 GHz Which settles with notch band characteristics. The parameters (S_{11} & S_{21}) extraction and their negative permeability clearly indicates that the proposed Non Bianisotropic-SRR satisfies the metamaterial property and paves way for a new resonance frequency due to pass band. Also, this paves a way for the gain and bandwidth upgradation in the higher frequency region.

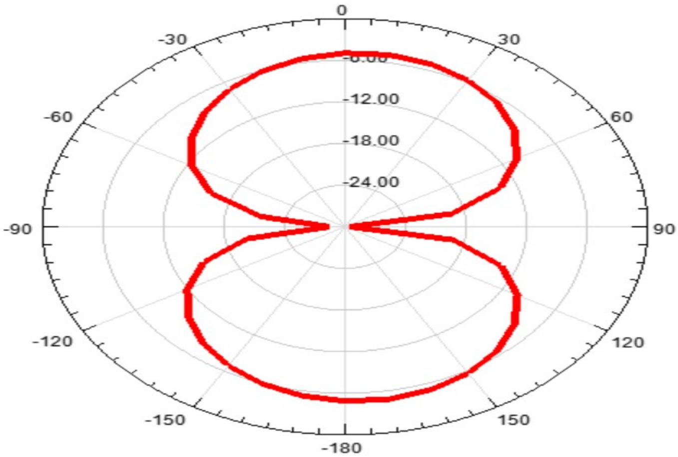

Fig. 6: Radiation Pattern for E plain.

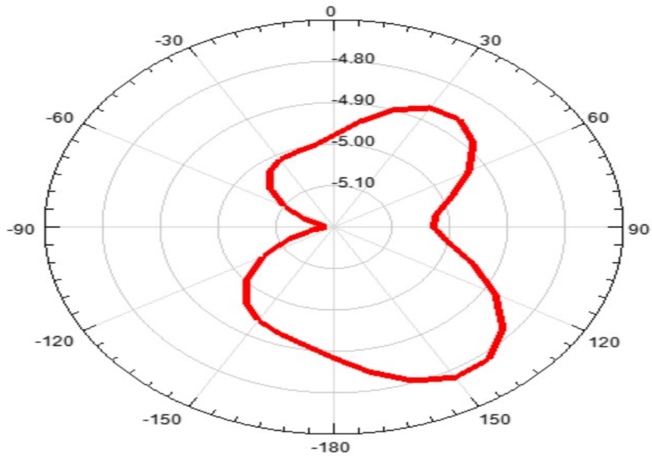

Fig. 7: Radiation Pattern for H plain.

4 Performance Metrics of MIMO Antenna

The performance metrics of MIMO [13] can be evaluated using diverse number of methodologies like performing the parametric study in terms of frequency of wide range of spectrum, space diversity, antenna and polarization diversity.This study describes the performance analysis by extracting the S-parameter.

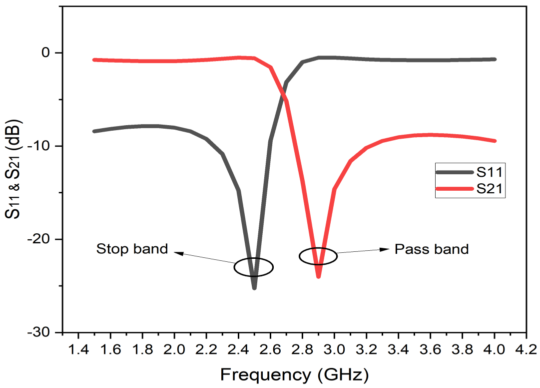

Fig. 8: Band characteristics of NB-SRR.

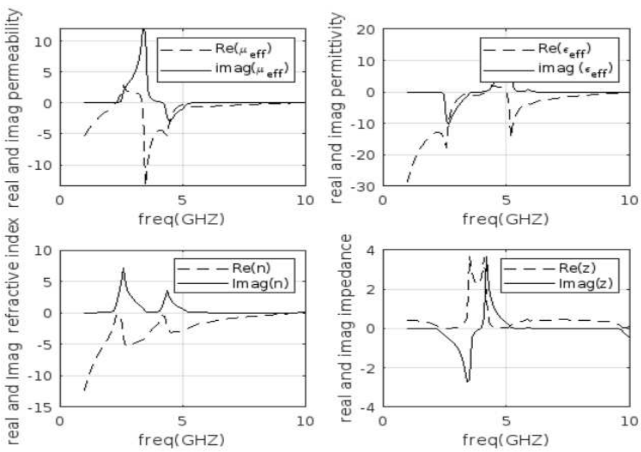

Fig. 9: Negative Permeability characteristics of NB-SRR.

4.1 Negative permeability and permittivity of meta material loaded structure

The permeability and permittivity values[14] of the antenna gets altered due to the accumulation of artificially induced structure which cause an addition in the inductive and capacitive components of the basic design. This change in the ELC structures gives rise to the negative permeability and permittivity component at the different bandwidths of the resonating meta-material antenna. The fig.9 shows the effective permeability and permittivity characteristic graphs. The negative permeability across the 3 GHz band is nearer to -10dB and in the next operating band of 6.3834 - 5.3818 GHz it is close to zero. The negative permittivity across the 2.5GHz band is nearer to -20dB and across 5.1 GHz it is nearing -10dB.

4.2 The Envelope Correlation Coefficient(ECC)

The deployment of multiple antennas or MIMO configuration paves way for additional parametric analysis to optimize the performance. The correlation coefficient is named as ACC or ECC which deals with the independency between the adjoining antennas. If the antennas are said to be uncorrelated then then they are not suited for real time propagation. When the more than one antennas operate at same time the radiation pattern of one has an impact[15] on the other this is measured with the help of Envelop correlation coefficient (ECC) by using the below formula (4)

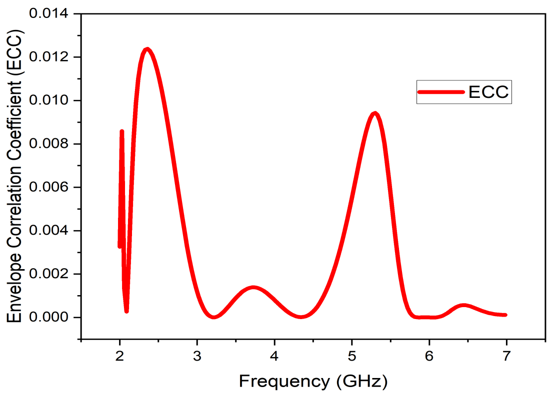

Fig. 10: Envelope Correlation Coefficient [ECC]

$$ECC = \frac{(S_{11} * S_{12} * S_{21} * S_{22})^2}{(1 - s_{11}^2 - s_{21}^2)(1 - s_{22}^2 - s_{12}^2)} \quad (4)$$

The maximum allowable limit of ECC(e) ≤ 0.5 under ideal condition of communicating devices [15].The ECC value for the proposed MIMO structure for the first passband is 0.012 and the second pass band is 0.09 as per the figure.10 which shows the plot between ECC and frequency.

4.3 Diversity Gain (DG)

The smart antenna evolution has put forth the need of diversity gain concept which is the reduction in fading margin as these re-configurable antennas are used. The expression for diversity gain of the MIMO[16] configuration is expressed by the formula (5)

$$DG = 10\sqrt{1 - ECC^2} \tag{5}$$

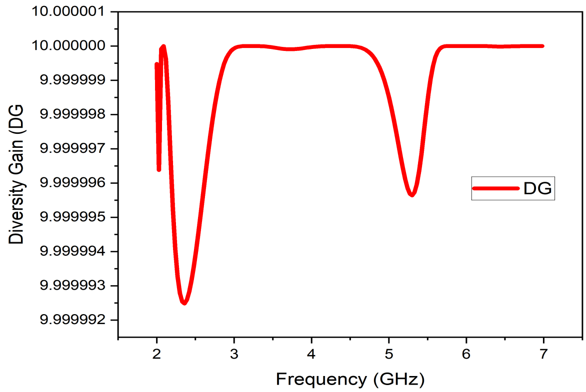

Fig. 11: Diversity gain (dB).

Fig.11. shows the Diversity plot of the MIMO antenna.The acceptable range of the diversity gain is about 10dB [15]. The diversity gain obtained for the two passbands are not up to 0.1 over the impedance bandwidth as a result of better ECC performance.Hence the designed antenna exhibits better correlation with the adjacent antenna and has a good diversity performance.

4.4 Total Active Reflection Coefficient (TARC)

If the design uses a single antenna then return loss parameter is considered as the evaluation factor when MIMO configuration comes into role then TARC acts as the evaluation parameter by considering the return loss of whole MIMO proposed design by taking into account the mutual coupling effect of the antenna.Equation (6) gives the TARC value.

$$TARC = \frac{\sqrt{(S_{11} + S_{22})^2 + (S_{21} + S_{22})^2}}{\sqrt{2}} \tag{6}$$

The ideal condition for Total Active Reflection Coefficient is basically less than zero dB [15]. The TARC constant in dB for the suggested antenna design is depicted in the Fig. 12, which is less than 0.15 dB thoroughout the passband range.

4.5 Channel Capacity Loss (CCL)

The channel capacity decides the transmitter and receiver configuration in the multipath environment of MIMO antennas.This may serve as the additional

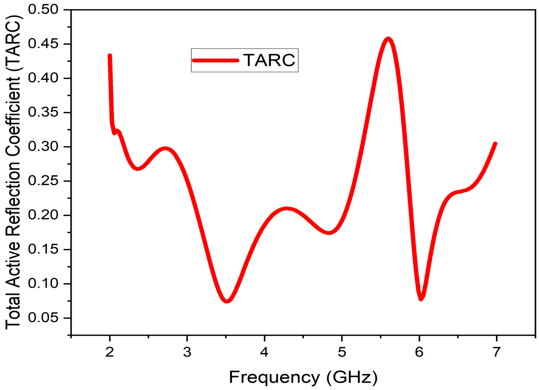

Fig. 12: Total Active Reflection Coefficient(TARC)

factor used for analysing the signal deprivation.This channel capacity loss is also dependent on the S parameter metrics which is mentioned by the equation (7)

$$CCL = -log_2(1 - |S_{11}^2| - |S_{12}^2|) \tag{7}$$

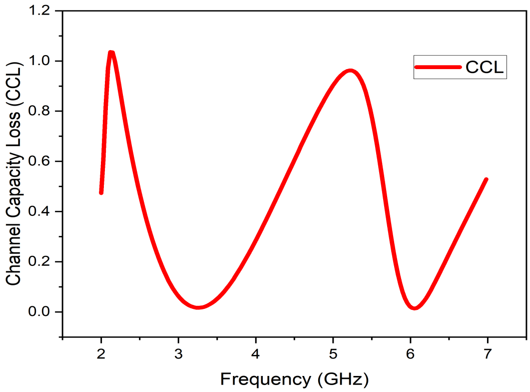

Fig. 13: Channel Capacity Loss(CCL)

The graphical representation of CCL is plotted across the frequency in the Fig.13 . The epitome of CCL is $\leq$ 0.5, for portable devices working based on MIMO configuration. The designed NB-SRR MIMO configuration has the

CCL value less than 0.10 bits/sec/Hz for both the (3.7887 - 2.8052 GHz) and (6.3834 - 5.3818 GHz) frequency bands. Henceforth the probable values of the MIMO parameters can be estimated to hold good for Sub-6 GHz Band applications.

5 Measurement Results and Discussions

The Simulated and the fabricated antenna is tested with the Vector Network Analyzer(VNA) as shown in the figure 13. The simulation results of the Non Bianisotropic-SRR antenna measuring the S_{11} parameter is compared with the fabricated antenna by means of E5063A Vector Network Analyzer which is a product from the of keysight technologies. The fabricated antenna structures top view is represented in the Figure 14.The return loss S11(db) for the first pass band is -45 dB near the centre frequency of 3.2Ghz and -22dB for the second pass band at the frequency of 6Ghz .This antenna parameters is also best suited for the MIMO configuration operation at sub-6 GHz frequency range with optimal parametric results like ECC, Diversity Gain, TARC and CCL.

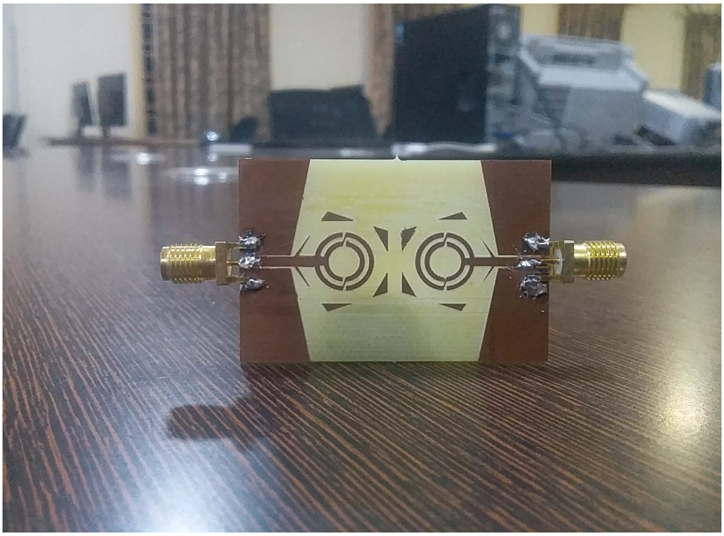

Fig. 14: Final Fabricated Overview of Antenna

6 Conclusion

The dual band antenna designed for Sub-6 GHz 5G application can give the optimal characteritics like negative permeability and negative permittivity curves as discussed in the earlier parametric studies. This Non Bianisotropic-

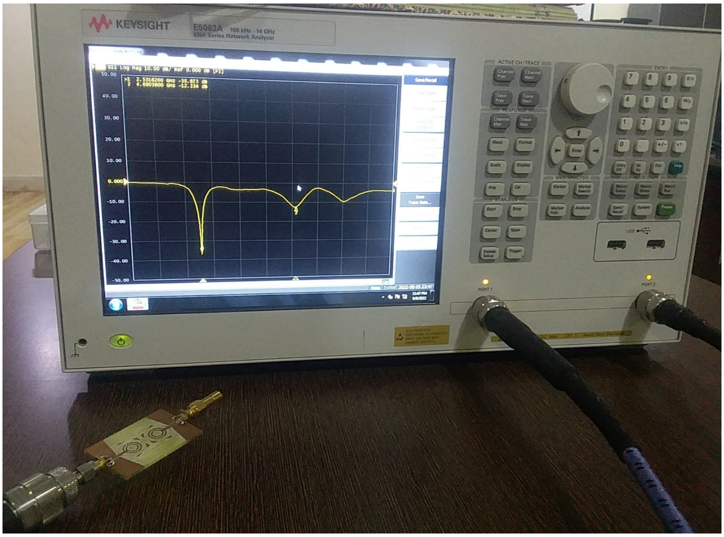

Fig. 15: Image of measuring the output

Split-Ring Resonator based MIMO has the better impedance matching , band pass and band notch characteristics.The proposed Non Bianisotropic-SRR creates a higher frequency band and enhances the bandwidth.

Declaration

The authors declare that they have no conflicts of interest.

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Availability of data and material

Data sharing not applicable to this article as no datasets were generated during the current study.

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