Four-port dual-band MIMO antenna for LTE and sub 6-GHz 5G applications

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Abstract: This manuscript presents a novel ring resonator (RR) based coplanar waveguide (CPW) fed four-port MIMO antenna, working around LTE 1.8 GHz and sub-6-GHz 5G applications. The presented MIMO antenna is a based on the microstrip technology and RRs are located on the upper and bottom side of plane of the designed antenna for achieving high isolation and wider bandwidth. The bandwidth and isolation can be adjusted by changing dimension of RR. The total prototype size of proposed MIMO antenna is 30 × 30 × 1.6 mm^3 and measured B. W. ($S_{11} \leq$ -10 Db) of 0.46 GHz (1.77-2.23 GHz) and 2.45GHz (4.09-6.54 GHz) respectively. The presented MIMO design offers high isolation of -18 dB at both resonating bands. For the purpose of validating the results, planned MIMO antenna design is made-up and tested. A comparison among simulated and tested values of designed antenna has been carried out, and it has been found that they are in good agreement with one another.

Keywords: Dual-band, MIMO antenna, LTE 1.8 GHz, sub 6-GHz, wireless communication

1. INTRODUCTION

5G is sure to have a major influence, enabling the lives of millions of people to be better, on defense, agriculture, health and the automotive sector. In the year 2018, the frequency band in the majority of the sub-6 GHz range became named 5G New Radio (NR) bands, which stands for 5th Generation New Radio. For high data rate transmission in wireless communication, especially in 4G and future 5G technology need a multiple band with multiple-input–multiple-output (MIMO) antenna system to fulfill above demands and it moves beyond the standard SISO systems (Pirinen pekka 2014, Ghosh amitabha et al. 2019). In past decade, a number of wireless network access devices were designed with the use of multiband MIMO techniques as a complement to the high-speed network. In a MIMO system, antenna separation is often set to more than λ/2to avoid mutual coupling among the ports. But due to λ/2 separation between antenna elements, it increases the size of MIMO antenna system. Now, today scenario most of the equipment's are portable and compact in nature. So, size of MIMO antenna is one of the major concerns. Further, in contrast to MIMO technology, which offers not only fast data transfer speeds but also required compact multiband MIMO antenna with high isolation among the antenna ports (Mao chun xu et al. 2014, Anitha R. et al. 2016, Kumar sanjeev et al. 2021). A dual-band with modified ground plane MIMO antenna is projected for WLAN and UWB claims in (Deng jing Ya et al. 2017, Peristerianos andreas et al. 2015, Kunal srivastava et al. 2020). For obtaining a high isolation among the antenna element, a T-slot is used into the ground plane. Another for WLAN application based, a dual-band MIMO antenna is designed in (Birwal amit et al. 2020). A 2-element F-shaped monopole MIMO antenna design is proposed for WI-MAX and WLAN uses in (Nirmal pratima et al. 2018) and elliptical slot with rectangular parasitic strip is used for improving isolation between antenna elements. Demo-shaped monopole antennas are used for LTE/Bluetooth/Wi-Fi/WLAN applications in (Tiwari rakesh et al. 2020) using a T-shaped stub on the ground plane. In (Kumar sanjeev et al. 2018), a T-structured and complementary split ring resonator (CSRR) are combined to improve the separation of 4-element MIMO antenna for LTE/UWB band. (Morsy Mohamed 2019) proposes an indoor multiband MIMO antenna with exceptional isolation. One recently presented4-port multiband MIMO antenna for 5G applications is (Krishnamoorthy R. et al. 2021). The design uses a connected ground plane with symmetrical structure. Compact multiband MIMO antenna configuration for GSM and WLAN bands has been designed using AT-shape electromagnetic band gap and fractal approach (Soliman ahmed M. et al 2015). In (Kiem nguyen khac et al. 2018), transmission line is used to improve isolation and design is proposed for LTE 1.8 GHz and 3.5 GHz Wi-MAX band claims. Most of the above reported MIMO antennas are having either poor isolation or large size or none of them operating in 1.8 GHz LTE including 5G applications. Because nowadays, GSM and sub-6 GHz 5G band along with four-port MIMO for high data rate is very attractive future for upcoming era.

In this article, a new four-port MIMO antenna for 1.8 GHz LTE and sub-6GHz 5G applications is proposed with low ECC and TARC, small in size, high DG and low MEG.A rectangular spiral shape element is used to design MIMO antenna. The presented MIMO antenna could be used for dual-band applications in wireless communications such as LTE and sub-6-GHz 5G NR.

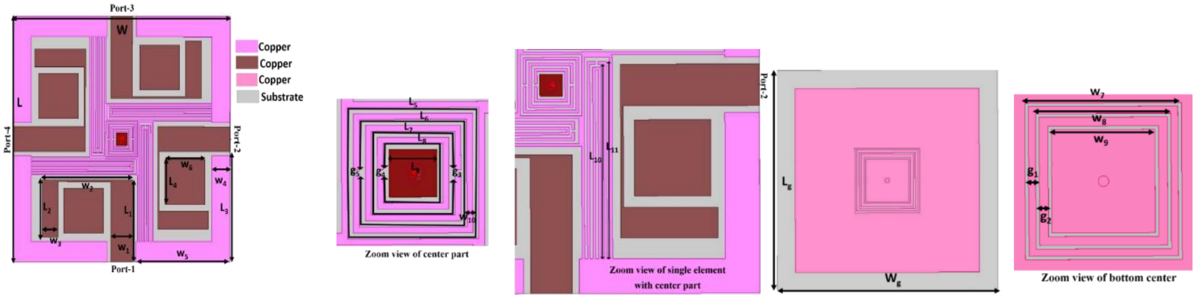
2. INVESTIGATION OF PROPOSED MIMO ANTENNA

2.1 Design structure

Presented MIMO antenna is intended on price effective FR-4 material, having dielectric constant 4.4 with tangent loss 0.02. Complete dimension of presented antenna is 30 × 30 × 1.6 mm^3. The optimized dimension of presented MIMO antenna is given in table 1.

Table 1: Designed MIMO antenna's values

Parameters	W	L	L_1	W_1	L_2	W_2	W_3	L_3	W_4	L_4
Dimensions (mm)	30	30	10	3	7	12.5	2.2	13	2.5	5.5
Parameters	W_6	W_7	W_8	W_9	L_5	L_6	L_7	L_8	L_9	W_5
Dimensions (mm)	5.5	8.8	7.6	6.2	17.6	14.2	11.0	7.8	1.6	13
Parameters	L_{11}	W_g	L_g	W_{10}	L_{10}	g_1	g_2	g_3	g_4	g_5
Dimensions (mm)	14.5	30	30	0.2	14	0.2	0.2	0.2	0.2	0.2



(a) (b) (c)

(b) Figure 1: (a) Top view of designed MIMO antenna, (b) Zoom view of center part (c) Bottom and zoom view

2.2 Design steps

In step-1, a co-planer waveguide structure use 50Ω strip line as radiator, having length 10 mm and width 3 mm excited by SMA connector as shown in figure 2. It resonates at 7.63 GHz with impedance bandwidth of 3.69 GHz (5.69 GHz - 9.48 GHz) as shown in fig 3(a). In step-2, a 90° tilted second strip is added to the first strip. Size of strip is 7.3mm x 0.2mm as shown in figure 2. Due to addition of second strip in antenna 1 shows the multiple resonance at frequency 2.70GHz and 4.75GHz with bandwidth 0.19GHz (2.58GHz-2.77GHz) and 1.1GHz (3.8GHz-4.9GHz) respectively as shown in fig 3(a). In step-3, at the edge of second strip a 90° rotated third strip is added. The size of the third strip is 7mm x 1.2mm. The physical length of design antenna after adding third strip is 24.3mm as shown in figure 2. After adding third strip in antenna, It shows multiple resonating frequency at 1.8GHz and 8.94 GHz with impedance bandwidth of 0.154GHz (1.66GHz-1.814GHz) and 1.03GHz (8.49GHz-9.52GHz) respectively as shown in fig 3(a). In step-3 desired lower frequency band (GSM 1.8GHz) is achieved but second desired sub 6GHz 5G band is not yet achieved. To get second desired band need improvement in impedance matching of antenna. In step-4, an optimized square patch is added in between the bended strip line as shown in figure 2.

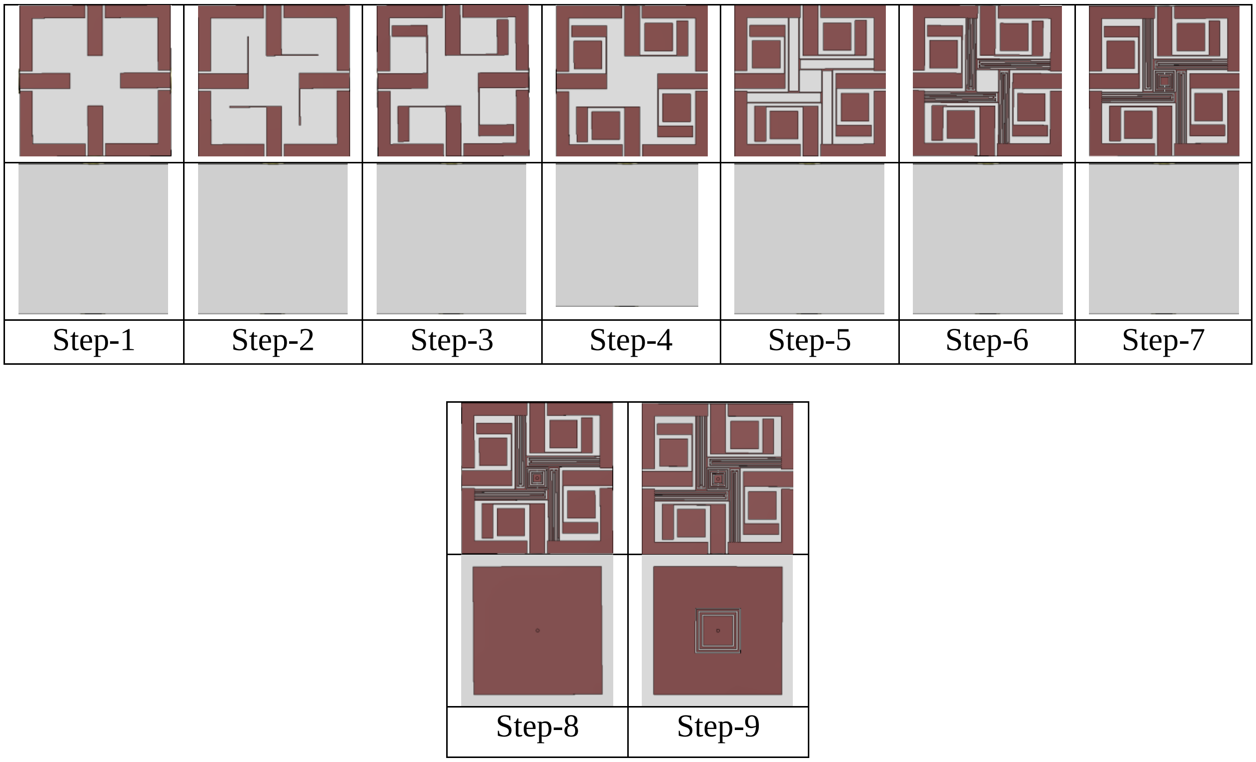
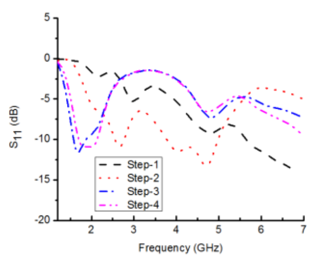
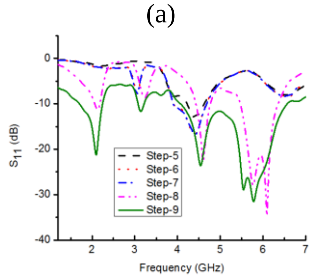


Figure 2. proposed antenna designing steps.

Due to this, coupling takes place between strip line and square patch. It shows a very small effect on lower frequency but a drastic change is occurred at higher frequency side. The higher frequency is shifted approximately 1.5GHz toward lower frequency side as compared to previous step. Till step-4 desired lower frequency band is achieved. However, the second desired band (sub 6GHz 5G) and isolation between the ports is still poor. To further improve these parameters in step-5 to step-9, work on isolation between the port and impedance matching at second desired band is done. In step-5, a rectangular ring is placed in between patch elements, whose one end is connected to the ground plane and other end is connect to other rings as shown in figure.2. Inserted rings width and length are optimized up to certain extends. Because of inserted rings, its effects on impedance matching at both the band is seen. In step-6, two more rings are further added inside the step-5 designed ring structure. Both ring's one side is connected to the ground plane and another end is spilt by the 0.2mm gap as shown in figure2. Due to addition of further rings structure in the design antenna, now it started resonating at two different frequencies is 3GHz and 4.4 GHz. In step-7, at center of the substrate three ring resonator is added with a square shape conducting plate as shown in figure 2. As indicated in Figure 2, three rings are fitted onto the reflecting sheet in Step-9. In this case, the optimum value is 2mm for the spacing and width. The top side gap is also optimised. With this ring design and optimization in design, suggested antenna exhibits first resonating band at 2.07GHz, second resonating band at 3.12GHz, and third resonance band at 4.54GHz, as shown in fig 3. (b). Between port#1 and port#2, isolation is roughly 20dB, while between port#1 and port#3, it is around 18dB.

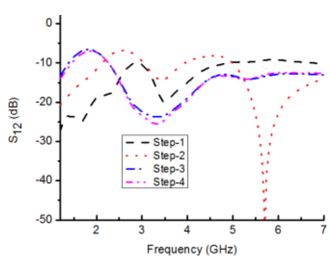


(a)

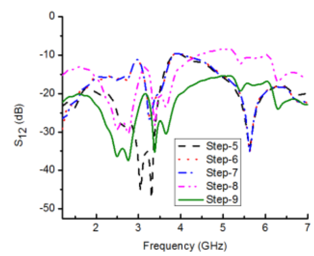


(b)

Figure 3. Impedance bandwidth of designed MIMO antenna (a) step-1 to step-4 (b) step-5 to step-9.

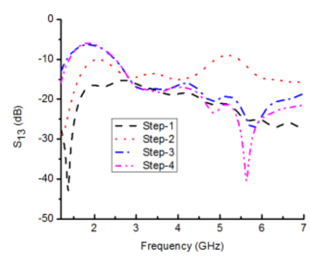


(a)

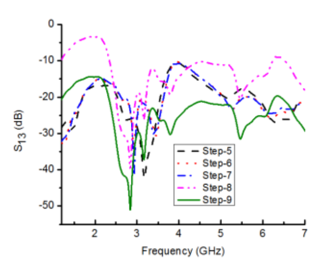


(b)

Figure 4. Isolation betweenports 1 and 2 of designed MIMO antenna (a) step 1 -4 (b) step 5-9

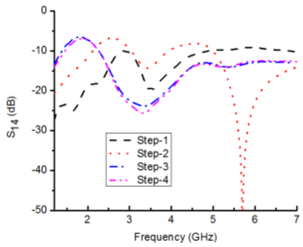


(a)

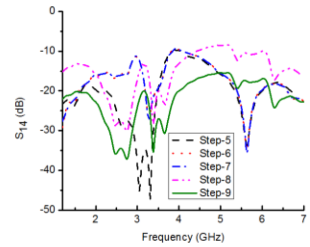


(b)

Figure 5. Isolation between ports 1 and 3 of designed MIMO antenna (a) step 1 -4 (b) step 5-9



(a)



(b)

Figure 6. Isolation between ports 1 and 4 of designed MIMO antenna (a) step 1 -4 (b) step 5-9

Based on the figures 4(b), 5(b) and 6, the isolation between ports 1 and 4 is approximately 20dB for the first frequency band, 20dB for the second resonating band, and 18dB for the third resonating band (b). Figure 1 depicts the final four-port MIMO antenna.

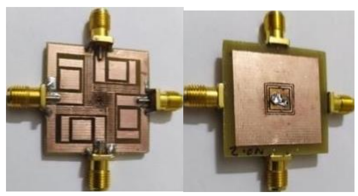
3. PROTOTYPE, RESULTS AND DISCUSSION

3.1 S- parameter and isolation

This segment shows the validation of replicated with practical results of the presented 4-port MIMO antenna and its prototype is illustrated in figure 7. Simulated and measured scattering outcomes are presented in figure 8. Figure 8(a) shows that simulated (S_{11}) result good agreement with measured results. The simulated and measured dual frequency band are 0.6 GHz (1.70-2.30 GHz), 2.92 GHz (3.9-6.82 GHz) and 0.46 GHz (1.77-2.23 GHz), 2.43 GHz (4.09-6.54 GHz) respectively and isolation more than 18 dB while simulated isolation is better than 16 dB throughout entire working band as shown in Figure 8(b). The gain and efficiency of the designed antenna is illustrated in Fig. 9. The measured radiation efficiency varies between 82 to 91 % and gain (measured) also varied in between 4.24dBi to 4.65 dBi. In this case, the observed highest efficiency and peak gain in all interested bands are significantly 91 % and 4.65 dBi respectively. It's a tad different in measured result which is due to test set up error. A comparative analysis of presented four-port MIMO antenna with different parameters, such as size of antenna, bandwidth, isolation and gain is given in Table 2 and it can be observed that presented MIMO antenna having improved performance as compare to reported antenna.

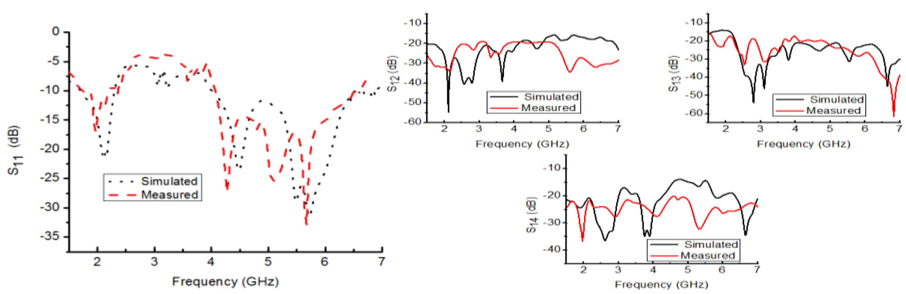
3.2 Radiation Pattern

The radiation characteristics of designed antenna has been calculated in XZ and YZ planes by exciting one port-1 and terminated other ports with 50Ω load and the results in E and H planes are found at 2.0GHz and 5.0 GHz as shown in figure 10.



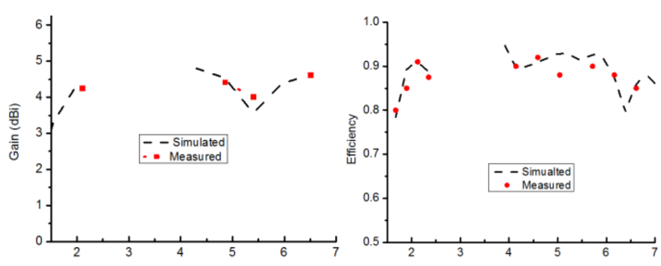
(a)   (b)

Figure 7: Pictures of invented MIMO antenna (a) Front view (b) Back view



(a) (b)

Figure 8: Simulated and measured results (a) $S_{11}$and (b) Isolations

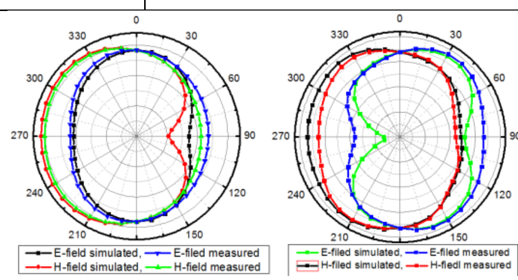


(a) (b)

Figure 9: Replicated and measured graph of (a) gain (b) efficiency

Table 2: Observation of the presented MIMO antenna with other reported antennas

Ref.	Number of elements	Size (mm^2)	Working range (GHz)	Isolation (dB)	Gain (dBi)
[12]	2	89 × 86	2.1-2.8, 4.85-6.6	-19	4
[13]	2	30 × 26	3.2-3.8, 5.7-6.2	-20	2.8
[14]	2	20 × 34	2.11-4.19, 4.98-6.81	-21	4.19
[15]	4	32 × 38	2.3-2.62, 3.46-10.3	-18	3.1
[16]	2	120 × 120	0.69-.79, 1.76-2.12	-13	3.4
[17]	4	32 × 32	3.72-3.82, 4.65-4.76, 6.16-6.46	-16	2.5
[19]	2	65 × 55	1.71-1.88, 3.4-3.6	-15	…….
Prop.	4	30 × 30	1.77-2.23, 4.09-6.54	-18	4.65



(a) (b)

Figure 10: Replicated and measured radiation graph of projected MIMO radiator at (a) 2.0 GHz and (b) 5.0 GHz

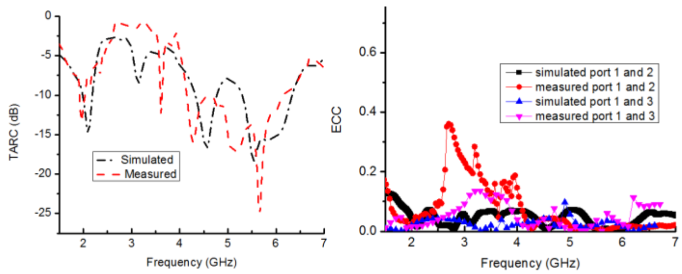
3.3 MIMO Parameters for diversity analysis

3.3.1 TARC

In a multi-port antenna arrangement, when antenna elements of the MIMO operate simultaneously. In this case, among antenna elements affect one another and the overall performance of the MIMO antenna will influence in terms of TARC, isolation, and efficiency and TARC of the plannedfour-port MIMO configuration can be evaluated through equation (1) (Manteghi majid et al. 2005)

$$\Gamma_a^T = \sqrt{\sum_{i=1}^{N} |b_i|^2 / \sum_{i=1}^{N} |a_i|^2} \ldots\ldots\ldots\ldots\ldots (1)$$

Where, $a_i$and b_i are the incident and reflected signal from respective ports. The simulated and measured TARC are presented in Fig. 12(a) and found -7 dB for the entire operating range.



(a) (b)

Figure 12: Replicated and measured graph of(a) TARC (b) ECC

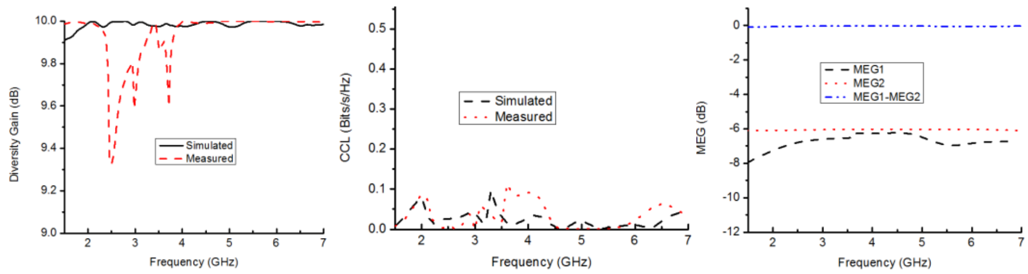
3.3.2 ECC and DG

The relationship among the antenna elements demonstrated by ECC. Therefore, for higher diversity between the antenna elements, Ideally, ECC should be zero, however in an uncorrelated MIMO antenna configuration, practical acceptable value is less than 0.5and its theoretical value is calculated by equation (2) (Blanch Sebastian et al. 2003).

$$ECC = \frac{\left|S^*{}_{ij} + S^*{}_{ji}S_{jj}\right|^2}{\left(1 - |S_{ii}|^2 - \left|S_{ji}\right|^2\right)\left(1 - \left|S_{jj}\right|^2 - \left|S_{ij}\right|^2\right)} \ldots\ldots\ldots\ldots. (2)$$

Where i and j shows the respective ports of MIMO antenna and ECC value below than 0.012 as shown in Fig. 12(b). The increased value of the signal to interference ratio is denoted by DG and it can be mathematically calculated using ECC as given in Eq. (3).Fig. 13(a) shows that DG >9.98 dB in the entire operating band (Rosengren kent et al. 2005).

$$DG = 10\sqrt{1 - ECC^2} \ldots\ldots\ldots\ldots..(3)$$



(a) (b) (c)

Figure 13: Replicated and measured graph of (a) DG curve (b) CCL (c) MEG

3.3.3CCL

One of the most important parameters of the MIMO performance is the CCL. It is also important, during the impact of the correlation, to offer specifies of the capacity losses of the MIMO antenna system. The formula to express CCL is given in (4) (Choukiker yogesh kumar et al. 2013).

$$C\ (loss) = -det(\beta^R) \ldots\ldots\ldots\ldots\ldots(4)\ , \quad \beta^R =$$

$$[R_{11}\ R_{12}\ R_{13}\ R_{14}\ R_{21}\ R_{22}\ R_{23}\ R_{24}\ R_{31}\ R_{32}\ R_{33}\ R_{34}\ R_{41}\ R_{42}\ R_{43}\ R_{44}\,]$$

Where $R_{ii} = 1 - \left(\sum_{j=1}^{N} \quad |S_{ij}|^2\right)$ and $R_{ij} = -(S^*{}_{ii}S_{ij} + S^*{}_{ji}S_{ij})$. Fig. 13(b) shows that the simulated and measured value of CCL for the presented MIMO antenna is less than 0.3 bit/s/Hz as required. It is specifying a high performance for practical applications.

3.3.4 MEG

MEG is another key parameter for performance assessment of diversities and it can be described as the power received relationship between diversity antenna and an isotropic antenna. The MEG can be evaluated using Equation (5) (Nasir jamal et al. 2015) and from Fig. 13(c), the measured MEG_1 and MEG_2 values lies in between -6 to -10 dB and $MEG_1 - MEG_2$ value lies below than 0 dB.

4. CONCLUSION

A novel planar CPW-fed dual-band four-port printed MIMO antenna has been designed, made-up and verified for wireless communications applications. The 1.9 GHz and 5.2 GHz resonant frequencies of the antenna design and working range of this antenna is 1.77 GHz to 2.23 GHz and 4.09 GHz to 6.54 GHz, respectively. However, the ports' measured mutual coupling is less than -18 dB. The measured maximum gain and efficiency observed for proposed MIMO antenna are 91% and 4.65 dBi respectively. Further, MIMO parameters are evaluated and studied for conforming diversity behavior of presented MIMO antenna. The findings of all measurements and simulations are compared and found to be in good agreement. The planned four-port MIMO antenna is one of the best candidates forsub-6-GHz 5G NR along with LTE band applications.

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