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Design and Performance Studies of a MIMO Antenna With Circular Polarization Diversity for 5G Applications

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***Abstract*— An innovative 2-element multiple input multiple output (MIMO) antenna with the circular polarization (CP) diversity is proposed in this paper with an intention to use in the sub−6 GHz spectrum (3.6–3.8 GHz) for 5G wireless applications. A microstrip line fed slot antenna is working as a single element for the MIMO arrangement. An elliptical shaped slot and the unequal feed lines mechanism are used to sense CP for every element. For CP diversity, mirror operation between the antenna elements is performed. A rectangular slot line in the ground plane is inserted to realize better isolation between the antenna elements. The MIMO antenna provides good isolation < −25 dB between the antenna elements in 5G operating frequency band of 3.6−3.8 GHz. Considering 5 dBic gain as well as axial ratio (AR) less than 0.5 dB, this antenna shows promising CP radiation pattern. Moreover, result of envelope correlation coefficient (ECC) (< 0.002) and channel capacity loss (CCL) less than 0.3 b/sec/Hz make it suitable for fifth generation wireless applications.**

Keywords— 5G, MIMO, circular polarization, ECC, CCL.

I. INTRODUCTION

These days, microstrip patch antennas having various advantages like low cost, low profile, light weight, less complexity in integration with active components and radio frequency (RF) devices draw the devotion of the manufactures and hence, widely used in the arena of communication, RF, biotelemetry, and wireless satellite applications [1]. But these antennas also have some drawbacks such as low gain and efficiency, lower handling capability of power. So, researchers have devoted their valuable time to overcome the weakness by discovering some methods like array concept and multiple input multiple output (MIMO) system. For the requirement of higher data rates within limited power in the present wireless communication system, a comparatively talented choice is the MIMO antenna. To increase channel capacity with limited power, MIMO antenna provides multiple channels for transmission of data by using numerous antennas at both transmitting and receiving side.

In last three decades, a remarkable revolution has happened in the telecommunication system started from single band 1G, then 2G dual-band, after 2G systems comes 3G and nowadays, 4G systems prevail [2]. Because of great accomplishment in mobile communication using MIMO arrangement, a higher number of users has been engrossed. However, the profuse usage of telecom system creates a gigantic challenge for telecom industries for providing multi-gigabits per second (Gbps) of connectivity in the allocated bandwidth of 4G along with the problem of restricted size of communication devices. Due to lots of other challenges like described above, telecom industries are moving towards 5G. In recent years, quite a lot of 5G MIMO antennas are operating in the sub-6 GHz frequency band. Planar Inverted F-shaped Antenna (PIFA) for multiband pattern reconfigurable for 5G MIMO mobile applications is proposed [3]. A promising 8×8 antenna array is represented in [4] for 5G multi-band applications by covering the GSM1900 (1880–1920 MHz), LTE band 38 (2540–2620 MHz) and LTE band 40 (2300–2400 MHz). However, it cannot cover the crucial LTE band 43 (3.6–3.8 GHz) which is forthcoming sub-6 GHz band for 5G. A dual band 10-elements massive MIMO system has been reported in [5] for 5G applications and it works in LTE bands 42/43 (3.4–3.8 GHz) and LTE band 46 (5150–5925 MHz).

All the research works described above are linearly polarized MIMO antennas. However, linear polarization (LP) has some weakness like multipath distortion, polarization mismatches between transmitter and receiver antennas [1]. Circular polarization (CP) removes the disadvantages for wireless communications along with mitigation of the weather condition effect [6]. A few research works have been carried out in CP antenna for 5G applications in recent years. Among them, hepta band two-element swastik shaped arm MIMO antenna is illustrated in [7] with CP at 3.66–3.7 GHz, 5.93–6.13 GHz along with other LP bands though it does not cover CP in the respected whole band in the sub−6 5G spectrum. A Fabry-Perot resonant cavity for broad band CP antenna is proposed in [8]. Planer aperture antenna with CP is projected in [9]. However, it is designed for millimeter wave (25−33 GHz). In this communication, CP diversity MIMO antenna for sub-6 GHz 5G applications is introduced.

Minimum mutual coupling must be maintained while designing a MIMO antenna. In order to attain this, diverse techniques of isolation enhancement are discovered such as the utilization of neutralization lines [10], decouple elements of tree structures [11], right-angled feeding system [12] etc. Utilization of such techniques has some weakness like the addition of complexity of the system and increase of antenna's footprint. To achieve better isolation between the antenna elements of MIMO system, a talented key is to choose an antenna having polarization diversity without containing complex structures [13]. A MIMO system having polarization diversity, realized by using planar inverter F shaped antenna and sleeve antenna along with ground trace, has been designed for achieving low correlation between antenna element in [14].

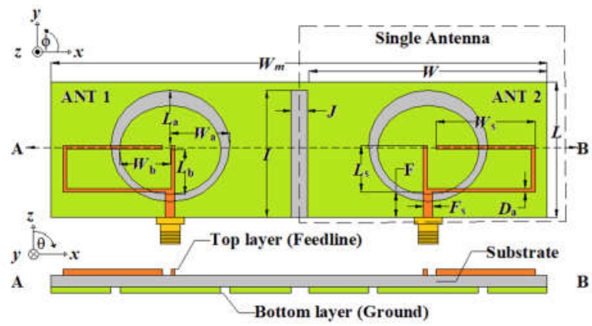

Fig. 1. Overall view as well as cross-sectional view of the proposed 2-element MIMO antenna.

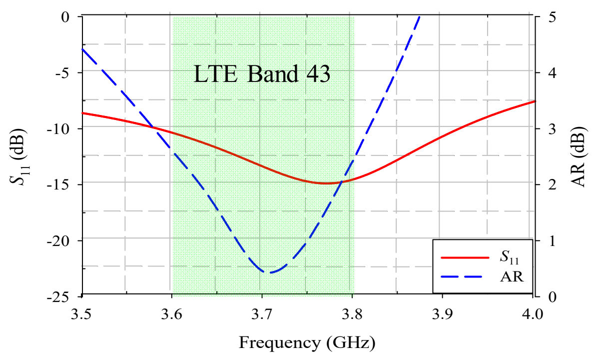

Fig. 2. S_{11} and AR of single antenna element.

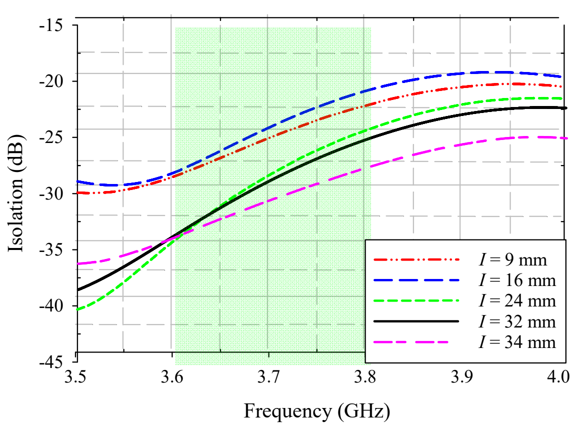

Fig. 3. Isolation for different values of height of the rectangular slot.

A three element MIMO array with both pattern and polarization variety is projected in [15] while only single CP is accomplished.

In this communication, a 2-element MIMO antenna with CP diversity is designed at LTE band 43 (3.6−3.8 GHz) for 5G wireless communication. A microstrip line fed unequal width elliptical slot is used as radiating element for each antenna element. Unequal feed lines mechanism is used to excite CP. Besides, the CP diversity of the proposed antenna is achieved by making one of the antenna elements mirror of another antenna element along the vertical axis. Moreover, using defected ground structure (DGS) method, a rectangular slot line is introduced in the ground plane for attaining improved isolation. The MIMO antenna shows a good CP radiation pattern with moderate gain and lower cross-polarization (XP)

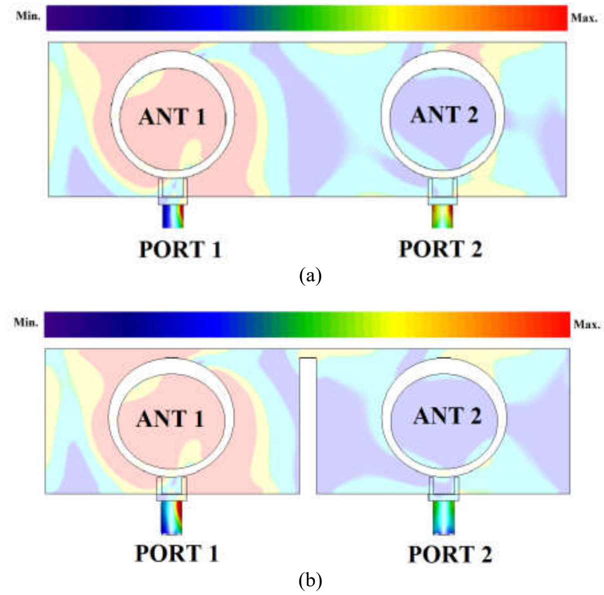

Fig. 4. Surface current distribution of MIMO antenna (a) without slot and (b) with slot at 3.7 GHz.

level. Furthermore, good ECC and channel capacity loss (CCL) make the proposed antenna more attractive for 5G applications.

The segmentations of the rest of the communication are as follow: the development of the design process of the antenna is described in section II. Antenna simulation and result analysis are covered in Section III. Segment IV covers the conclusion for the MIMO antenna.

II. Design of the MIMO Antenna

Fig. 1 shows the complete view of the MIMO antenna with cross section. There are two single antenna elements as showing in the figure where one antenna element is denoted as ANT 1 and the other element is denoted as ANT 2. A 0.8-mm thick Teflon with dieelectric permitivity of 2.15 and losstangent of 0.001 is used as a substrate.

A. *Single Element Design*

The single antenna element is the combination of slot antenna as radiating element and microstrip feed line. The slot antenna consists of a non-uniform width elliptical shaped slot. The elliptical shaped slot generates two orthogonal electrical field components required for producing CP. But, due to the unequal magnitude and improper phase difference of them, CP was not achieved in broadside direction of both *xz*-plane and *yz*-plane. To overcome this problem, unequal feed lines mechanism is used. The main feed line is divided into two unequal arms. The shorter arm is I-shaped which is situated along the *y*-axis and the other arm is U-shaped. To achieve proper magnitude and phase difference between the two electrical field components for realizing CP, the relation between the electrcial length of I-shaped and U-shaped arms should be odd multiple of a quarter wavelength.

Fig. 2 exhibits the result of reflection coefficient, S_{11} and AR of single antenna. From this figure, S_{11} is achieved less than −10 dB in the whole LTE band 43. 3-dB AR bandwidth is accomplished in the frequency range of 3.6−3.8 GHz along with minimum AR value of less than 0.5 dB at 3.7 GHz.

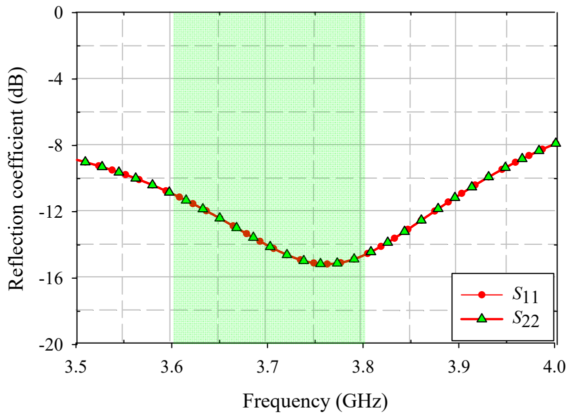

Fig. 5. Reflection coefficient of the MIMO antenna.

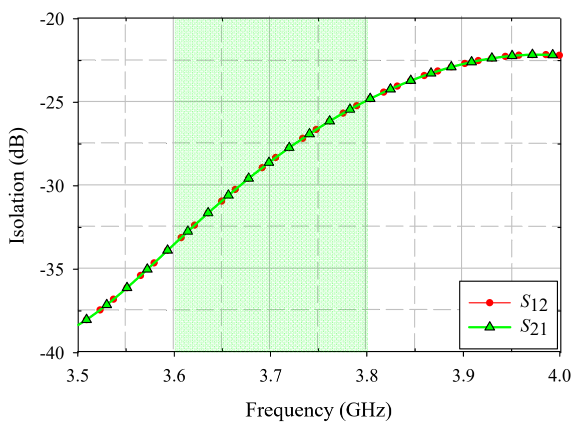

Fig. 6. Isolation of the MIMO antenna.

B. *MIMO Antenna Design*

At this point, two single element antennas are used to realize MIMO antenna. The ANT 2 is the mirror structure of the ANT 1 with respect to the *y*-axis. The purpose of the mirror operation is to find the different CP from different antenna element along with achieving better isolation between elements. In this situation, isolation and ECC of the MIMO antenna is satisfactory for MIMO operation. To further enhancement of the MIMO operation, improvement of the isolation is necessary. For achieving high isolation, the DGS method is performed. A rectangular slot line is designed in the ground plane where height of the slot line performs an inevitable role to increase isolation between the antenna elements.

Fig. 3 represents isolation variations with respect to the frequency for different heights. It is evident that for the heights, $I \geq 32$ mm, isolation is less than −25 dB and for $I = 34$ mm maximum isolation is attained in the whole band of 5G. But, at $I = 34$ mm, both antennas are electrically isolated from each other. To keep a common ground between the antenna elements, $I = 32$ mm is chosen where isolation between the antenna for the value of I is also promising.

Fig. 4 illustrates the surface current distribution of the MIMO antenna with and without slot in the ground plane while PORT 1 is excited. The surface current distribution of the MIMO antenna elucidates the improvements of the isolation. From the Fig. 4(a), it is noticed that there is a current flow in ANT 2. Fig. 4(b) displays the surface current

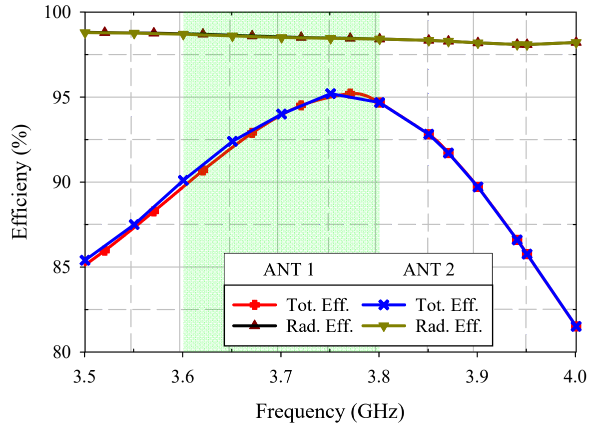

Fig. 7. Efficiency of ANT 1 and ANT 2.

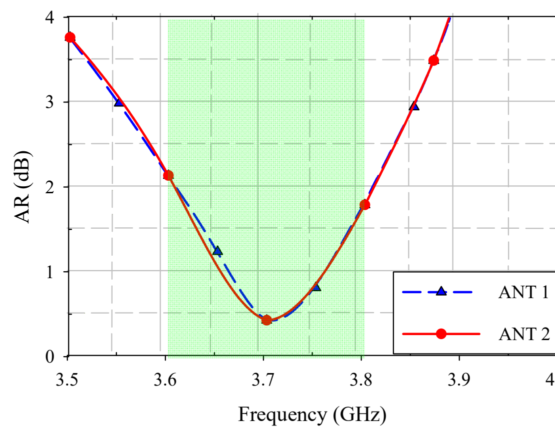

Fig. 8. AR vs frequency of ANT 1 and ANT 2.

TABLE I. FINAL DIMENSIONS OF THE PROPOSED MIMO ANTENNA (unit: mm)

W	60	W_a	15	W_b	12.8	L_s	11.6	W_m	125
L	34	L_a	14	L_b	11.2	I	32	F	6.4
F_s	2.4	W_s	25	D_a	0.9	J	4.0		

distribution of the antenna with slot. The current flow is reduced by inserting the slot line in the ground as shown in Fig. 4(b). Due to the small current, the isolation between antenna elements is increased. Table I is populated by the final value of every parameter that is used to design the antenna.

III. SIMULATION RESULT ANALYSIS

For the simulation purposes, the CST microwave studio simulation software is used. Extensive simulation and scrupulous analysis have been performed to find the best result to meet the requirement of the desired applications.

Fig. 5 shows the final results of both S_{11} and S_{22}. From this figure, it is evident that impedance bandwidths of the both antennas are more than 350 MHz which covers the LTE band 43 (3.6−3.8 GHz).

Isolation should be less than −15 dB for the MIMO antenna. Fig. 6 illustrates the result of both S_{12} and S_{21} and both are found less than −25 dB in the entire band (3.6−3.8 GHz). Hence, a good isolation is achieved between the antenna elements.

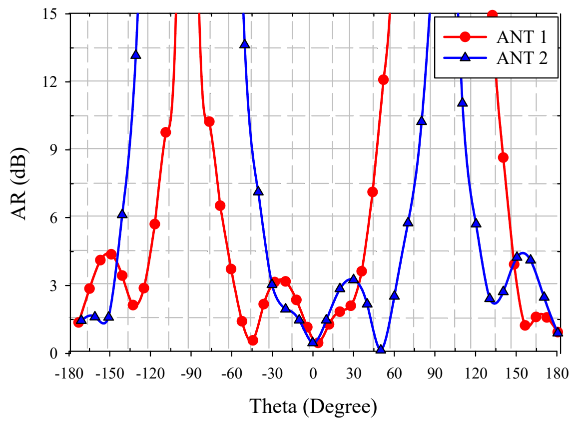

Fig. 9. AR for ANT 1 and ANT 2 at 3.7 GHz (phi = 0°).

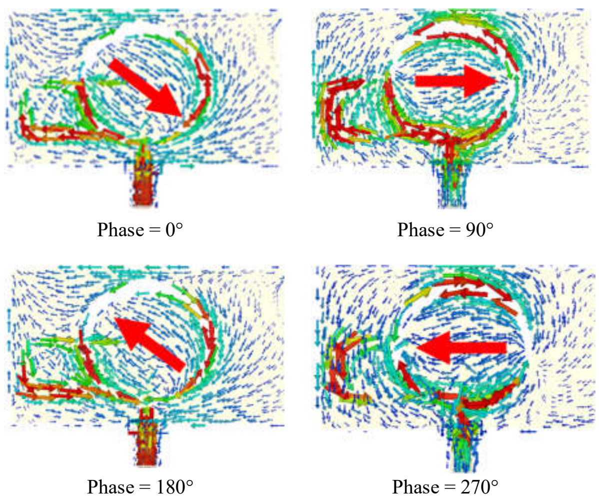

Fig. 10. Surface current distribution of the ANT 1 at 3.7 GHz.

Fig. 7 shows the both radiation and total efficiency of ANT 1 and ANT 2. Both total and radiation efficiency is achieved more than 90% for antenna elements.

To find the polarization of the antenna, analysis of the result of AR is essential. In Fig. 8, the AR vs frequency is shown. From the Fig. 8, it is obvious that the AR is less than 3-dB from the frequency 3.55 GHz to 3.85 GHz with minimum AR of less than 0.5 dB at the frequency 3.7 GHz. Hence, the antenna is working as a CP antenna for 3.6−3.8 GHz. Fig. 9 displays the results of AR vs theta at 3.7 GHz for both ANT 1 and ANT 2. Both antennas working as a CP antenna at phi = 0° and theta = 0°, 180° as shown in Fig. 9.

To explore more about CP of MIMO system, the current distribution of the antennas must be scrutinized. In Fig. 10, the surface current distribution of ANT 1 at 3.7 GHz is shown while PORT 1 is excited. From Fig. 10, it is realized that the current direction is anti-clockwise direction which reveals that the polarization of this antenna element is RHCP. Furthermore, as the ANT 2 is mirror of ANT 1, the polarization for ANT 2 must be LHCP while PORT 2 is excited.

In Fig. 11(a) and Fig. 11(b), the CP radiation pattern of ANT 1 in *xz*- and *yz*-planes are realized, respectively. The

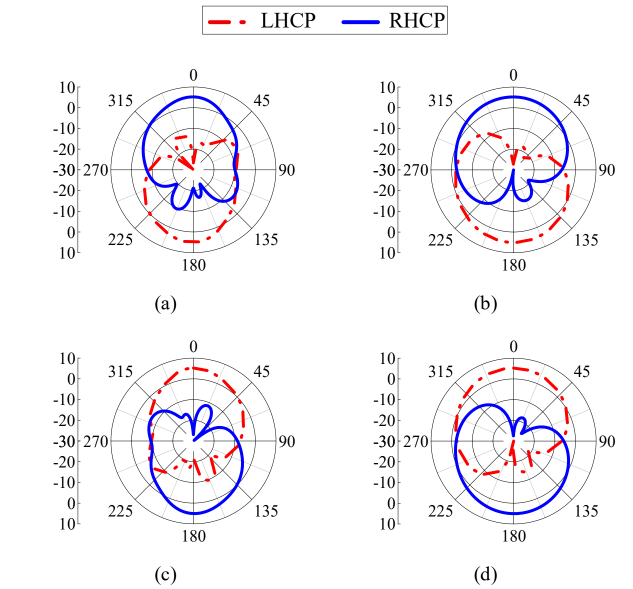

Fig. 11. CP radiation pattern of ANT 1 at 3.7 GHz in (a) *xz*-plane as well as (b) *yz*-plane and ANT 2 in (c) *xz*-plane as well as (d) *yz*-plane.

polarization of ANT 1 is RHCP in both planes and again LHCP is found at theta = 180° which is a common phenomenon of a slot antenna. Moreover, Fig. 11(c) and Fig. 11(d) show CP radiation pattern of ANT 2 in both *xz*-plane and *yz*-plane, individually. Co-pol is LHCP for ANT 2 which is opposite of radiation pattern of ANT 1. Moreover, XP level of both elements is attained less than −30 dB.

Fig. 12 exhibits the outcomes of gain vs frequency for both ANT 1 and ANT 2. The CP gain is nearly uniform in the whole LTE band and around 5 dBic gain is accomplished.

To judge the performance of multiple ports of the MIMO antenna, ECC of the antenna is the main key. Lower ECC is suitable for obtaining more diversity patterns and an acceptable standard of ECC is less than 0.5 for MIMO operation [5]. From Fig. 13, ECC is less than 0.001 in the whole LTE band ensuring better diversity patterns of the MIMO action of the antenna. Diversity gain (DG) provides information of the SNR (Signal to noise ratio) improvement of the MIMO antenna. The ideal value of DG is 10 dB. In Fig. 14, the DG of the MIMO antenna is realized and DG is achieved around 10 dB which shows a good SNR improvement of the MIMO arrangement.

During the transmission of a message through the communication channel, there will be transmission losses. CCL provides the information about maximum transmission rate without any loss and it should be less than 0.4 b/sec/Hz. The CCL parameter can be calculated by using equation (1) [7].

$$\text{CCL} = -\log_2 \det \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \quad (1)$$

where $\beta_{11} = 1 - (|S_{11}|^2 + |S_{12}|^2)$

$$\beta_{22} = 1 - (|S_{22}|^2 + |S_{21}|^2)$$

$$\beta_{12} = -(S_{11}^* S_{12} + S_{21}^* S_{12})$$

$$\beta_{21} = -(S_{22}^* S_{21} + S_{12}^* S_{21})$$

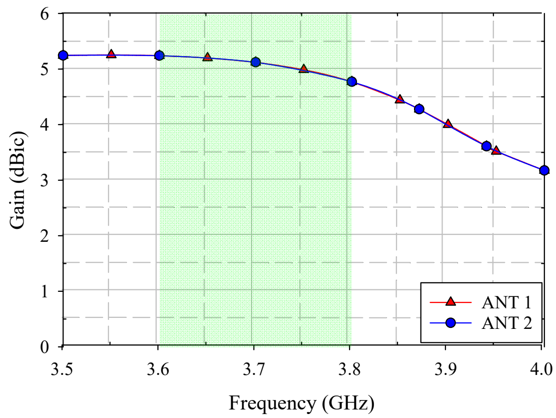

Fig. 12. Gain vs frequency for the antenna.

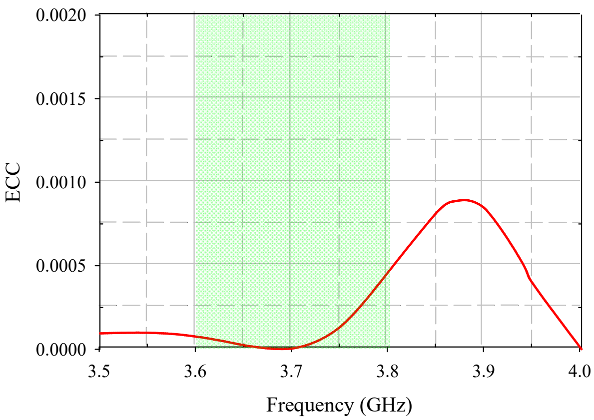

Fig. 13. ECC vs frequency for the MIMO antenna.

Fig. 15 illustrates the result of CCL of the MIMO antenna with respect to the frequency. The CCL is realized less than 0.3 b/sec/Hz in the desired LTE band which is promising result.

TABLE II represents a comparison among the proposed MIMO antenna and other 5G MIMO antennas. From this table, the isolation of the proposed antenna is more than the isolation of the other antennas. This work attains larger 10-dB impedance and 3-dB AR bandwidth than the CP antenna reported in [7]. Moreover, the isolation and ECC parameter of the antenna provide a promising MIMO performances in the desired frequency band.

IV. Conclusion

A 2-element MIMO antenna with CP diversity has been described in this paper. An elliptical shaped slot antenna is used as a single element. Mirror orientation of antenna elements is performed to find different CP sense for different antenna element. Finally, DGS is used to achieve better isolation between the elements. The MIMO antenna provides a promising isolation result, 10-dB impedance bandwidths and 3-dB AR bandwidths in the overall LTE band 43 (3.6−3.8 GHz). The antenna shows brilliant CP radiation with minimum AR of less than 0.5 dB. Moreover, around 5 dBic gain is attained in the overall frequency band. The antenna offers a good ECC value (less than 0.001) and CCL less than 0.3 b/sec/Hz. DG result shows the promising SNR improvement of the proposed antenna. These performances

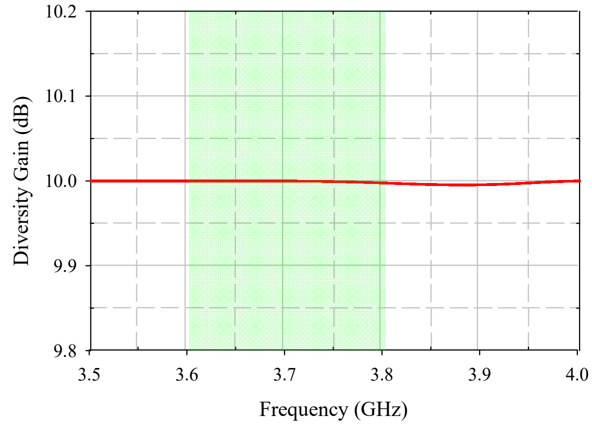

Fig. 14. Diversity gain vs frequency for the MIMO antenna.

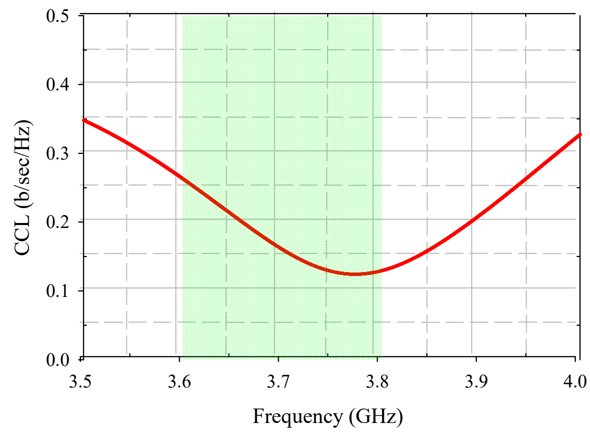

Fig. 15. CCL of the antenna.

TABLE II. Comparison among the proposed antenna with other reference antennas

Ref.	10-dB Imp. Bandwidth (GHz)	CP/ LP	S_{12} (dB) (<)	Gain (dBic)	ECC (<)	3-dB AR Bandwidth (GHz)
[5]	3.4–3.8 (< –6 dB)	LP	–11	---	0.15	---
[7]	3.66–3.7	CP	–17	2.98	0.05	3.66–3.7
[16]	3.4–3.8	LP	–15	5 dBi	0.01	---
[17]	3.4–3.8	LP	–12	---	0.15	---
This work	3.6–3.8	CP	–25	5	0.001	3.55–3.85

p ... wireless communication field.

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