A 4-element MIMO antenna with orthogonal circular polarization for sub-6 GHz 5G cellular applications

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Abstract

A multiple-input-multiple-output (MIMO) antenna with orthogonal circular polarization (CP) is proposed in this paper with an intention to use the antenna in sub-6 GHz 5G applications. The single antenna consists of a radiating slot and feed line. The non-uniform width elliptical ring slot in the ground plane and unequal feed line technique are used to produce CP. The benefit of using ring slot antenna is that this type of antenna can radiate orthogonal CP at the front and back direction, simultaneously. The operating band of single antenna is (3.6–3.8 GHz). The MIMO antenna has 4 single antenna elements where each antenna element is surrounded by the mirrored antenna elements. As a result, MIMO structure provides orthogonal CP. Moreover, this MIMO antenna can also radiate both LHCP and RHCP on the both directions ($\theta = 0^\circ$ and 180°) simultaneously. Three interconnected strip lines on the ground plane are designed to connect the individual grounds of the antenna elements. The MIMO antenna provides good isolation and CP gain in the whole band (3.4–3.8 GHz). The envelop correlation coefficient and channel capacity loss are evaluated to judge the MIMO performances and promising result is achieved. To analyze the impacts of user hand, various performance studies are done for the antenna in the vicinity of left hand and right hand phantom model and satisfactory results are achieved. These performances prepare the antenna more attractive to use in 5G cellular applications.

Keywords 5G · MIMO · Circular polarization · Orthogonal polarization · Cellular applications

1 Introduction

Multiple-input-multiple-output (MIMO) antenna is the talented choice of modern cellular communication systems, at present. Without MIMO antennas, it is difficult to provide higher data rates and profuse channel capacity that are required for modern telecommunication systems.

In recent years, the telecommunication industries have observed an evolution in telecom sector. Mobile communication systems started with 1st generation (1G). After 1G, then 2G, 3G and now 4G prevails. At now, 5G is knocking

at the door. Many countries have already taken initiative to start the 5G system. There are two promising spectrums for the 5G wireless communication. One is sub-6 GHz spectrum and the other is mm-wave spectrum.

As sub-6 GHz spectrum is already available in global wireless communication systems and can be used for the 5G without large changes in the hardware systems, service providers are considering to use it for easier and smooth implementation of the 5G systems for initial purpose. There are lots of frequency band those are allocated for future 5G cellular communication like LTE band 42

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(3.4–3.6 GHz), LTE band 43 (3.6–3.8 GHz), and LTE band 48 (3.55–3.7 GHz).

There are quite researches going on in sub-6 GHz spectrum for the 5G systems. A 4×4 MIMO antenna has been proposed to use in the 3.4–3.8 GHz band [1] where circular shaped slot along with arc-shaped strip is used as radiator and rectangular feed line is used to feed the antenna element. A four-element inverted L-shaped monopole antenna has been designed in [2] where symmetric MIMO configuration is employed to increase the frequency range (2.7–4.96 GHz).

A four-port vector synthetic dipole (VSD) antenna with dual polarization has been reported in [3] for 5G wireless applications. There are also some massive MIMO antennas for the 5G applications in sub-6 GHz such as dual polarized 8×8 MIMO antenna [4], 10×10 MIMO antenna [5], and 8×8 MIMO array for 5G smart phone applications [6]. All the above described antennas are linearly polarized (LP) antenna.

On the other hand, circularly polarized (CP) antenna has two electric fields rather than one electric field of LP antenna. Because of the two orthogonal electric fields, CP antenna provides extra advantages like freedom of orientation and better mobility of the antenna. Moreover, the polarization of the transmitter and receiver antenna have a great impact on the strength of the received signal [7].

Slot antennas have benefits compared to the patch antennas like easier multiband implementation, wider bandwidth, and less fabrication errors [8]. Various types of slot antennas are available at present. An open-slot antenna whose total size is 50×60 mm², has been designed for dual band CP in [9]. In this work, three slots (one T-shaped slot and two L-shaped slots) and bent feed line structure are used to produce broadband CP. In [10], a D-shaped slot and modified ground plane are used to generate CP. The size of the antenna is 40×54 mm². An antenna (47×50 mm²), which consists of a hook shaped feed line and defected ground, has been reported in [11]. The defect of the ground plane has been achieved by creating three slots in the ground. Above described works have larger size antenna and complex geometry. In this communication, an elliptical slot antenna is proposed where the size of the antenna is 30×60 mm².

There are few works on CP MIMO antenna for 5G applications. A Fabry–Perot resonant antenna with broadband CP has been demonstrated in [12] for mm-wave application. In [13], 8-element CP MIMO antenna has been reported for mm-wave applications. Furthermore, the user impacts on the antenna have been experimented. A hepta band MIMO antenna has been discussed in [14] where two CP bands (3.66–3.7 GHz) and (5.93–6.13 GHz) are achieved.

For CP antennas, axial ratio (AR) is an essential parameter. But during the array and MIMO operation, due to

mutual coupling, AR has been greatly affected. The effect of mutual coupling on AR has been explained in [15]. The effect of mutual coupling can be reduced by introducing strip line between the antenna elements [16]. The strip line creates high impedance that opposes the current to flow from one antenna element to another. On the other hand, by placing the antenna elements in diagonal position, the isolation between the antenna elements can be improved [17]. But in above-described antennas, there is no common ground plane between the antenna elements though common ground plane is useful for practical applications [2].

In this paper, a 4-element MIMO antenna with CP diversity is proposed for 5G cellular applications. This MIMO antenna covers a frequency band of 3.4–3.8 GHz. A ring slot as radiating element and feed lines are used to design the single antenna. The ring slot is elliptical shaped with non-uniform width. For MIMO arrangement, four single antenna elements are placed in such a manner where each antenna element is in mirror position from nearby antenna elements. Because of mirror operation, every single element is surrounded by two different polarization antenna elements. Hence, the orthogonal CP polarization is achieved. Due to polarization diversity at the front and back radiation of the slot antenna and orthogonal CP for mirror operation among MIMO elements, the coverage area of the antenna can be increased, significantly. Moreover, the proposed MIMO antenna can be integrated in a device easily along with other components because it is realized on a common ground. Defected ground technique on the common ground of the antenna elements is applied to reduce mutual coupling among the elements that causes better isolation. Every single antenna element has large 10-dB impedance and 3-dB AR bandwidths which cover the interested band. The MIMO antenna provides promising MIMO diversity performance in the whole band. The user hand impacts on the MIMO antenna are also studied and satisfactory results are achieved. Considering the outcomes of the antenna, the MIMO antenna is more feasible in interested band.

The organization of the paper is as follows: the design and parametric analysis of the single antenna are described in first section. The second section covers MIMO antenna design and performance analysis. Finally, the user impacts on the MIMO antenna are discussed.

2 Single antenna design

Figure 1 shows the overall view of the single antenna. The antenna is the combination of elliptical ring slot on the ground plane and microstrip feed line. The Teflon dielectric as substrate with permittivity of 2.15 is used to design the

antenna where the thickness is 0.8 mm. The width (W) of the slot is non-uniform because the center of the outer ellipse, having major axis and minor axis lengths of c and d respectively, is not aligned with that of the inner ellipse whose major and minor axis lengths are a and b , respectively. The center of the inner ellipse is the overall center point of the antenna's geometry. The center of the outer ellipse is moved along the positive y -axis by a distance of e . The reflection coefficient of the single antenna is affected very much with the variation of the position of the center of the outer ellipse that is described later. Moreover, the length of the major axis of the slot is equivalent to the quarter wavelength (14.8 mm) of the frequency 3.7 GHz.

Fig. 1 Structure of the single antenna used for proposed MIMO configuration **a** top view, **b** bottom view and **c** cross-sectional view (AA')

The slot is fed by a microstrip feed line (denoted as Main Feed line). The feed line is divided into two secondary feed lines. The right-angled feeding method is implemented to position the secondary feed lines. Hence, one of the secondary feed lines denoted as I-shaped feed line is positioned along the y -axis. Another secondary feed line which is C-shaped, is situated along the x -axis. The length difference of the I-shaped and C-shaped secondary feed line is odd multiple of quarter wavelength. The impedance of the main feed line is 50Ω . At first, the impedance of secondary feed lines is chosen 100Ω by using power divider rule. After final optimization, the impedance of the secondary feed lines is equivalent to 90Ω .

3 Parametric analysis of the single antenna

Figure 2 shows the impact of the slot width (W) along the major axis of the inner ellipse on the S_{11} . The slot width is changed by varying only a while other parameter are kept unchanged. The impedance matching of the antenna is proportional to the W . Furthermore, the resonance is shifted to the higher frequency with the increase of the W . When W is equal to 2.2 mm, the minimum reflection coefficient is -25 dB at 3.7 GHz, which is the resonance frequency. But when the slot width along the major axis of the inner ellipse is greater than 2.2 mm, the resonance point is shifted to the higher frequency.

Figure 3 displays variation of the AR with the variation of the parameter W . The AR reduces during the increase of W . When W is more than 2.2 mm, AR increases. At $W = 2.2$ mm, minimum AR value is achieved at the resonance frequency.

Fig. 2 Impact of the slot width on the S_{11}

Fig. 3 Impact of the slot width on AR

Fig. 5 Reflection coefficient result for the different values of e

Fig. 4 Effect of major axis (a) of the inner ellipse on reflection coefficient at optimal value of W

Figure 4 displays the influence of the major axis (a) of the inner ellipse on the reflection coefficient at the optimum value of W . The optimum value of the slot width (W) is 2.2 mm. For keeping the parameter W fixed, the parameter a and c are changed by using the following equation:

$$c = a + W \quad (1)$$

The center of the operating frequency varies with both a and c while proper impedance matching is remained. The antenna is tuned at 3.7 GHz at $a = 14.8$ mm ($c = 16.0$ mm) because at this point the a is nearly equivalent to the quarter wavelength (14.9 mm) of 3.7 GHz. Moreover, increasing the major axis (a) of the inner ellipse, the resonance is occurred in the lower frequency and vice versa.

Fig. 6 AR result for the different values of e

Figure 5 shows the impact of the vertical distance (e) between the center of the inner and outer ellipse on the S_{11} . When e is increased, the impedance matching is improved with a little change of the resonance frequency. Though at $e = 1.5$ mm improved impedance matching is found, the resonance point is shifted to the higher frequency.

In Fig. 6, similar types of coincidence are happened in AR because of the variation of e . Increasing the value of e , the lowest AR point is moved to lower frequency. At $e = 1$ mm, the minimum AR is found at 3.7 GHz which is the tuned frequency of the antenna.

Figure 7 illustrates the impact of the g on AR. The AR is reduced with the g . The lowest AR is found when g is 2.3 mm. At $g = 0.3$, both secondary feed lines couple each other. Therefore, the result is deteriorated.

Fig. 7 Variation of AR with g Fig. 8 Variation of AR with F_a

Figure 8 shows the influence of the length of the C-shaped secondary feed line on AR. The feed line is changed by varying the only two arms of the C-shaped feed line positioned along the x-axis. The length (F_a) of one of the arms is altered while the length (F_{a1}) of the other arm is varied with F_a through the following equation:

Table 1 Numerical data of the antenna parameters

Parameter	Dimension (mm)	Parameter	Dimension (mm)
a	14.8	F_a	26.4
b	13.5	F_{a1}	24.1
c	16.0	g	2.3
d	15.8	W	2.2
e	1.0	W_1	0.9
f	6.4	W_2	0.75

$$F_{a1} = F_a - g \quad (2)$$

Minimum AR point varies in the range 3.6–3.8 GHz while maintaining uniform AR bandwidth. At $F_a = 26.4$ mm, the length difference (50.5 mm) between the C-shaped and I-shaped secondary feed lines is approximately three times of quarter wavelength (14.9 mm) at 3.7 GHz. Because of the length difference, both feed lines create two orthogonal electric fields that are required to generate CP at 3.7 GHz.

Table 1 is occupied by the final value of the parameters that are used to design the single antenna.

4 Single antenna performance analysis

Figure 9 displays the simulated S_{11} and AR results. Reflection coefficient is tuned at 3.7 GHz and achieved less than -24 dB. 10-dB impedance bandwidth is achieved around 13%. Furthermore, lowest AR is attained less than 0.5 dB. 3-dB AR bandwidth is achieved around 8.2%. Both 10-dB impedance and 3-dB AR bandwidths are realized in 3.6–3.8 GHz.

Figure 10 demonstrates the CP gain and efficiencies of the antenna. More than 4 dBic CP gain is achieved in the operating bandwidth. Moreover, variation of the gain is negligible in the region of interest. The radiation efficiency and total efficiency are more than 90%. Moreover, the total efficiency is less than radiation efficiency as input port loss is included in the total efficiency.

The Fig. 11 shows the radiation pattern of the antenna in both xz- and yz-planes at 3.7 GHz. The polarization sense is right hand circular polarization (RHCP) at $\theta = 0^\circ$. The RHCP gain is found more than 4 dBic in both planes. The cross-polarization level is realised more than 30 dB. On the other hand, due to the ring slot, the antenna radiates left hand circular polarization (LHCP) in back direction ($\theta = 180^\circ$). The LHCP gain is also greater than 4 dBic. More than 30 dB cross polarization suppression is found. As a result, both radiations ($\theta = 0^\circ$ and 180°) with different CP senses can be used for data transmission and receiving purposes. Moreover, similar types of radiation pattern is achieved in the whole band. Therefore, the proposed antenna is suitable to use in the frequency band (3.6–3.8 GHz) for 5G cellular applications.

5 MIMO antenna design

The overall view of the MIMO antenna is delineated in Fig. 12. The MIMO antenna consists of four single antennas. Rotational mirror fashion is used to place the antenna

Fig. 9 Simulated S_{11} and AR of the single antenna

Fig. 10 Simulated gain and efficiency of the single antenna

Fig. 11 Radiation pattern at 3.7 GHz

Fig. 12 The overall view of the 4-element MIMO antenna. The MIMO antenna parameters: $j=4$ mm, $k=1$ mm, $p=1$ mm, $q=10$ mm, and $R=61.5$ mm

elements for MIMO arrangement. At first, two mirrored single antenna elements (ANT. 1 and ANT. 2) are placed along x -axis and they are separated by a slot having a width of j . Hence, the polarization sense of the elements is opposite of each other. A single strip line (denoted as S_1) is inserted between them to connect the individual grounds [18]. The strip line S_1 has a width of k . Then, a copy of this combination is positioned side by side along the y -axis where both combinations are mirror to each other. The vertical slot distance for separation between the two combinations is q . Again, a single vertical strip line (denoted as S_2) where width of the strip line is p , is designed between them to provide common ground among the antenna elements. The width of the strip line, p provides a great impact on the AR of each antenna element. Finally, the following parameters: b and F_a of single antenna and center of the outer ellipse have been optimized to find better result. The center of the outer ellipse is moved by distance of 0.75 mm along the negative x -axis. The final value of b and F_a are 14 mm and 25.9 mm, respectively.

Figure 13 shows the impact of the p on the AR. From the figure, it is obvious that AR is satisfactory when p is 1 mm. The change of AR is happened due to the mutual coupling of the MIMO antenna. The reason can be elucidated by the surface current distribution of the MIMO antenna. Figure 14 shows the surface current distribution of the MIMO antenna at $p=128$ mm and $p=1$ mm. From Fig. 14a, when ANT. 1 is excited, it is noticed that maximum current is around the slot of the antenna element ANT. 1. But, some of the current flows through the antenna element ANT. 4 and small amount of current flows through the antenna elements ANT. 2 and ANT. 3. Hence, there is interference between the antenna elements that degrades the AR of

Fig. 13 Impact of p on AR

Fig. 15 Variation of AR with the number of the antenna elements

(a) $p = 128$ mm

(b) $p = 1.0$ mm

Fig. 14 Surface current distribution at 3.65 GHz when PORT 1 is excited

Fig. 16 E-phi and E-theta of the single and MIMO antennas

the ANT. 1. The current flow is reduced at $p = 1.0$ mm as shown in the Fig. 14b. There is a high impedance microstrip line among the antenna elements at $p = 1.0$ mm that prevents the current flow and reduces the interference.

Furthermore, the orientation and number of the elements affects the AR of the antenna elements which is shown on Fig. 15. The AR is improved when there are four elements. The reason is that the two electric fields that are required to generate CP are affected as shown in Fig. 16. Figure 16 shows the effect of the MIMO arrangement on E-theta and E-phi of the ANT. 1. Both E-theta and E-phi are affected by the other single antenna elements. Especially, E-theta is affected tremendously. Therefore, the amplitude difference between the E-theta and E-phi of the MIMO antenna is smaller than that of the single antenna. As a

result, the 3-dB AR bandwidth is improved in the MIMO antenna compared to the AR bandwidth of the single antenna.

Figure 17a shows the variation of AR of ANT. 1 with the parameter j . The large AR bandwidth is found at $j=0$ mm and 4 mm but a promising AR performance is found at $j=4$ mm considering the minimum value of AR and 3-dB AR bandwidth. The reason can be easily comprehending from the Fig. 17b. The figure shows the influence of j on S_{21} . The better isolation (S_{21}) is found in the interested band for $j=4$ mm than that of other values of j . Therefore, comparatively good AR performance is found at $j=4$ mm.

(a) Change of AR of the ANT. 1 with the parameter j

(b) Effect of j on isolation

Fig. 17 Influence of the parameter j on the performances of the MIMO antenna

Fig. 18 Influence of the parameter q on AR of the ANT. 1

Figure 18 displays the variation of AR of ANT. 1 with the vertical distance (q) between the antenna elements. When vertical distance between the antenna elements is zero, the AR is degraded. Because, at this situation, the slot of the one element is so close to slot of the other elements along y -axis. and both antenna elements are affected by each other. The AR is improved when the value of q is increased. After $q=6$ mm, the change of AR with q is small. At $q=10$ mm, lowest AR is found though the AR bandwidth is approximately same as the AR bandwidths of the q greater than 4 mm.

6 MIMO antenna performances and discussion

Figure 19 shows the reflection coefficient and AR of the ANT. 1 of the MIMO antenna. It is noted that the similar results of S_{11} and AR are found in other elements. The

Fig. 19 Simulated S_{11} and AR of the MIMO antenna

Fig. 20 Isolation of the MIMO antenna

Fig. 21 Gain and efficiencies with respect to the frequency

10-dB impedance and 3-dB AR bandwidths are attained more than 14% and 15%, respectively. Hence, both bandwidth covers the 3.4–3.6, 3.55–3.7 GHz and 3.6–3.8 GHz frequency bands.

Figure 20 illustrates the isolation between the elements of the antenna array. All the isolation parameters are less than -15 dB in the bands of the interest.

Figure 21 shows the CP gain and efficiency with respect to the frequency. The gain is more than 4 dBic in the overall range. The radiation efficiency is found more than 95%. Furthermore, the total efficiency is more than 80%. Hence, the MIMO antenna provides high efficiency in the region of interest.

Figure 22 displays the radiation patterns of the all antenna elements in both xz - and yz -planes at 3.65 GHz. The polarization of the ANT. 1 and ANT. 3 is RHCP. On the contrary, ANT. 2 and ANT. 4 have LHCP. The broadside gain of every element is found 5 dBic. The main lobe of every

Fig. 22 Radiation pattern of the MIMO antenna at 3.65 GHz

element provide strong radiation performance. Besides, cross-polarization level of every antenna element is more than 30 dB. Moreover, radiation pattern of every antenna element is symmetrical.

From the Fig. 22a, b, it is evident that the back radiation of the ANT. 1 is RHCP and the radiation has the same levels of gain and cross-pol suppression of the front radiation (LHCP). Since, all the antenna elements are ring slot antenna, likewise to the ANT. 1, other antenna elements have different polarization in the front and back sides

Fig. 23 ECC of the proposed MIMO antenna

Fig. 24 CCL of the proposed MIMO antenna

that are shown in the Fig. 22. So, both RHCP and LHCP are achieved by using front and back radiation from each antenna element in the MIMO organization. Therefore, it is possible to get all CP sense from the MIMO antenna. As a result, the total coverage area of the MIMO antenna is increased.

To analyze the diversity performance of the MIMO antenna, envelop correlation coefficient (ECC) and channel capacity loss (CCL) performances of the antenna have been studied. The result of ECC evaluates the multiple ports performances of the MIMO antenna. On the other hand, the CCL provides the information about the maximum data transmission rate for transferring data in the transmission line without loss.

Figure 23 shows the ECC of the MIMO antenna. The every ECC of the MIMO antenna is less than 0.010 and very low comparing to the standard value (< 0.5).

Figure 24 represents the CCL of the antenna. Each CCL parameters of the MIMO antenna is less than 0.2 b/s/Hz and showing quite CCL performances compared to the standard value (< 0.4). Both ECC and CCL result show that the antenna provides a good diversity performance.

A comparison among the proposed MIMO antenna and other previously reported works is presented in Table 2. Apparently, most of the antennas are LP MIMO antenna and the proposed antenna is one of the few CP MIMO antennas in sub-6 GHz spectrum. In this work, MIMO antenna is realized by applying mirror rotation technique where each antenna element is surrounded by the elements that radiate opposite CP sense. This technique helps to enhance the diversity capability of the antenna by using orthogonally polarized CP elements. Moreover, as like as [18], ECC of the MIMO antenna is improved significantly for dual CP arrangement. Another interesting benefit of the proposed antenna is that dual CP sense from individual

Table 2 Comparison among the proposed antenna with other previously reported MIMO antennas

Refs.	Polarization	10-dB Imp. BW (GHz)	Isolation (dB)	3-dB AR BW (GHz)	Gain (dBic)	ECC
[1]	LP	3.4–3.8	−11	–	4 dBi	0.09
[2]	LP	2.70–4.94	−11	–	4 dBi	0.08
[4]	Dual LP	3.4–3.8	−15	–	5 dBi	0.01
[5]	LP	3.4–3.8	−11	–	–	0.15
		5.150–5.925 (< -6 dB)				
[14]	CP	3.66–3.7	−17	3.66–3.7	2.98	0.05
[16]	CP	1.8–2.6	−21	2.1–2.6	2	0.01
[18]	Dual CP	3.6–3.8	−25	3.55–3.85	5	0.001
[19]	LP	3.4–3.8, 5.150–5.925	−12	–	–	0.15
This work	Dual CP	3.4–3.8	−20	3.35–3.85	5	0.004

element can also be achieved by changing the radiation direction from front to back. This is happened because of using slot antenna as it is obvious that if a slot antenna radiates LHCP in front direction ($\theta = 0^\circ$), then back radiation ($\theta = 180^\circ$) polarization sense of the antenna will be RHCP. On the other hand, the proposed MIMO is designed employing common ground structure where DGS mechanism is used to achieve high isolation and moderate gain. As a result, it is found from Table 2 that, the proposed antenna provides better isolation and gain than most of the referenced antennas. In addition, the proposed MIMO antenna has larger AR bandwidth than [13, 17]. The good isolation and ECC performance of the proposed antenna make the more attractive for sub-6 GHz 5G applications.

7 User impact on MIMO antenna

Since the cellular devices would be close contact with the human body, the effect of the human body should be studied. To study the impacts of the human body on the proposed MIMO antenna, various result analysis is done

Fig. 25 The MIMO antenna with the human phantom hand in **a** LHM and **b** RMH

Fig. 26 Reflection coefficient at different modes

in the left hand mode (LHM) and right hand mode (RHM). Figure 25 demonstrates the overall view of the MIMO antenna with human phantom hands.

Figure 26 shows the reflection coefficient of every element in LHM and RHM, respectively. The bandwidths of every element cover the band (3.4–3.8 GHz), if 6-dB impedance bandwidth is considered. From the figure, it is obvious that the reflection coefficient of every element depends on the position of the MIMO antenna with respect to the human hand. The reflection coefficient of the ANT. 1 in LHM (S_{11}) and ANT. 4 in RHM (S_{44}) are deteriorated significantly as the antenna is too close to the index finger in both modes.

Figure 27 displays the impact of human hand on AR of every single antenna. The AR of the ANT. 3 and ANT.

(a) LHM

(b) RHM

Fig. 27 AR of the antenna in RHM

2 are more than 3 dB for LHM and RHM, respectively. It is observed during the simulation studies that the AR of both elements is affected by the little finger of the respective hand phantom because the antenna elements are too close to the finger. The AR is improved when the little finger is not close from the antenna elements. Except those antenna elements, the other antennas are working as a CP antenna in the respective modes. The AR bandwidth of the ANT. 4 is increased while the AR bandwidth of other elements (ANT. 1 and ANT. 2) are reduced in LHM. In RHM, the ANT. 1 has wider bandwidth whereas the 3-dB

Fig. 28 Total efficiency of the antenna in LHM

Fig. 29 Radiation efficiency of the MIMO antenna in LHM

AR bandwidth of the ANT. 3 and ANT. 4 have abridged. Consequently, it is evident from the figure that the bandwidths of the AR depend on the position of the antenna. In both modes (LHM and RHM), it is evident that three of four antenna elements are working as CP antennas.

Figures 28 and 29 illustrate the efficiency of the MIMO antenna at LHM. The total and radiation efficiencies are reduced because the human body is a lossy material though the both efficiencies are more than 50%. Similar result is obtained for the RHM.

8 Conclusion

A 4-element dual CP MIMO antenna has been presented in this paper. An elliptical ring slot and unequal feed-line mechanism are used to realize CP for every element.

Every antenna element is a mirror of other neighboring elements along horizontal and vertical directions. As a result, orthogonal polarization is achieved. Using defected ground structure mechanism, three strip lines are used to keep a common ground among the antenna elements. Both 10-dB impedance and 3-dB AR bandwidths cover the frequency band of (3.4–3.8 GHz). The isolation among the antenna element is achieved more than 20 dB. The MIMO performances in terms of ECC and CCL are also promising. Satisfactory outcomes (reflection coefficient, AR and efficiencies) are achieved in antenna result analysis in the vicinity of the human phantom hand. Considering the above studies, the proposed MIMO antenna is feasible to operate in the desired frequency band for 5G wireless applications.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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