JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

RESEARCH ARTICLE - ENGINEERING

A Design of CP-MIMO System with Elements of a Diamond-Ring Slot for 5G Mobile-Phone

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Article Info.

Article history:

Received
03 May 2021

Accepted
12 June 2021

Publishing
30 June 2021

Abstract

This paper proposed a Circular Polarization (CP) smartphone antenna Multiple Input Multiple Output (MIMO) system with elements of a diamond ring slot for next-generation (5G). The model's composition contains four elements. Each element has a dual-fed diamond ring slot arranged at the four smartphone corners Printed Circuit Board (PCB). A cheap FR-4 substrate with using a size of 75 x 150 mm^2 as the design dielectric mater. 50-Ohm microstrip-lines T-shaped feeds the antenna ports. The orthogonal positioning of microstrip feed lines is used to achieve polarization and diversity characteristics. The paradigm results show that each port operated with an operating frequency of 3.74 GHz, with the overall system running at 3.84 GHz. Also, the results show that the MIMO system is suitable for operation in a sub-6 band that qualified for 5G smartphone applications.

Keywords: MIMO Antennas; CP; ECC; 5G; diamond-ring slot

1. Introduction

For 5G communications, the MIMO systems are a crucial enabler. On the other hand, the MIMO technology represented a form of spatial diversity [1]. Diversity/MIMO techniques can raise wireless channel capacity in rich scattering environments by expanding the number of transceiver antennas of the wireless link [2],[3]. However, due to its limited space of small mobile devices, MIMO antenna elements' correlation coefficients are usually very high [4]. The overall efficiencies of MIMO elements will be significantly degraded severely due to mutual couplings [5]. To outclass the above issue, a polarization technique is used in a MIMO systems array with an alternate small PCB to efficiently deal with many antennas array in a little space [6]. The slot antenna type is one of the multi-antenna models which deal with 5G applications. A slot antenna is a vital antenna type that has been extensively investigated for several decades for various wireless systems due to its appealing features, included lightweight, low cost, and a facility of integral with Radio Frequency (RF) circuit [7],[8],[9]. Using the orthogonal placement of micro-strip feed concerning each other can show polarization and radiation pattern diversity [10].

Furthermore, CP antennas have recently gained prominence due to their enhanced signal propagation properties as compared to Linearly Polarized (LP) antennas [11]. On the other hand, CP can combine with the orthogonal dual-feed to obtain high isolation [12], so the present study attempts to use such a strategy. Many pieces of research deal with a slot microstrip-line to create the dual-polarized antenna with different shapes to slot such as in [13], [14], proposed V and L- shaped slot antenna for dual-polarization respectively to obtain Ultra-Wide Band (UWB). In this paper, a dual-polarized MIMO system with CP is presented for 5G applications. The MIMO antenna consists of the four-diamond ring slot radiator elements with T-shaped microstrip feed lines arranged at the four PCB corners. The length and width of micro-strip feed lines are tuned to achieve high isolation. This design has unique features such as an essential band for 5G application, high return loss, and a very low correlation coefficient.

Nomenclature

CP	circular polarization	SMA	sub-miniature
MIMO	multiple input multiple output	CST	computer simulation technology
5G	fifth-generation	VSWR	voltage standing wave ratio
PCB	printed circuit board	AR	axial ratio
FR-4	flame retardant	3D	three-dimensional
RF	radio frequency	dB	decibel
LP	linearly polarized		
DG	Diversity Gain	**Symbols**	
UWB	ultra-wideband	ρ_eij	envelope correlation coefficient
ECC	envelope correlation coefficient	Sij	S-Parameters

2. Single Antenna Design

The schematic of the proposed dual-polarized CP antenna configuration is with dimensions of 24 x 24 mm^2, shown in Fig. 1. The antenna was designed on an FR-4 substrate with 1.6 mm thickness, 4.3 relative permittivity, and 0.02 loss tangent. Its composition includes a diamond-ring slot radiator with inner and outer radiuses of r1 and r2, respectively. The proposed feeder types are a pair of microstrip-lines T-shaped are placed on orthogonal positions. For both antenna feeding ports, 50Ω Sub-Miniature Version A (SMA) connectors are used. The submitted design approach aims to build a dual-polarized with a high return loss antenna and a suitable size. Also, four elements will be integrated into a PCB smartphone. All elements were accomplished by using the micro-strip feed lines T-shaped with the diamond-ring slot antenna. We proposed a T-shape in this paper to achieve an elevation radiation pattern and good return loss [15]. Designed antenna configuration parameter values are listed in Table 1.

3. MIMO Antenna Model

The MIMO antenna is integrated on a cheap FR-4 substrate with a total size of 75 x 150 x 1.6 mm^3. Four dual-polarized diamond ring slot elements used at the different corners of the PCB smartphone. In addition to showing sufficient bandwidth, slot radiators on the proposed 5G porotype will provide nearly symmetrical radiation patterns to cover the PCB's top and bottom regions. Figure 2 shows the geometry of the MIMO antenna.

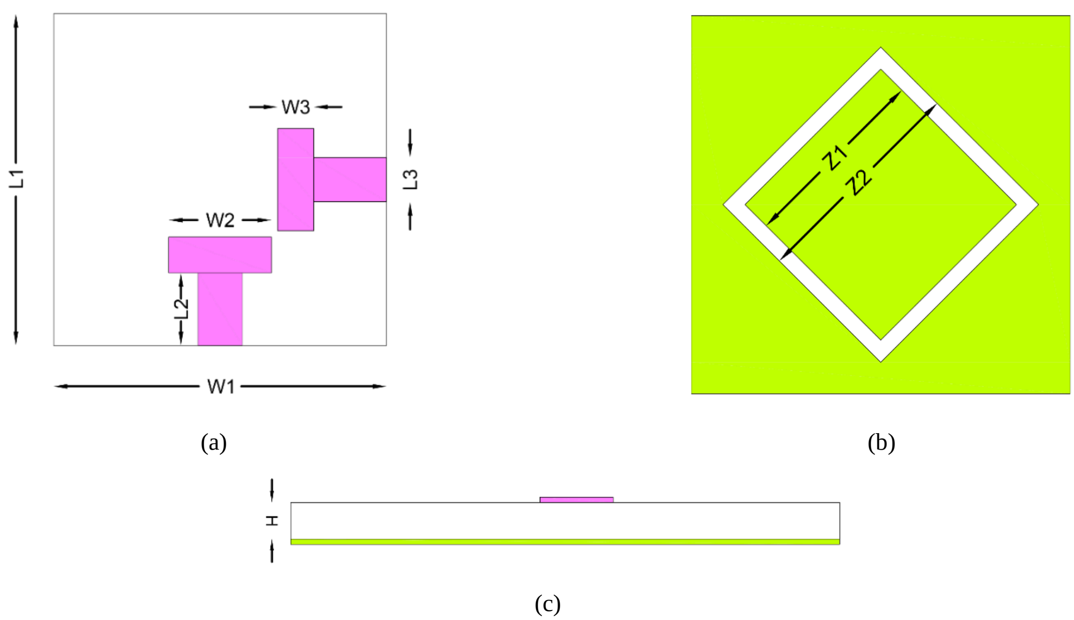


Fig. 1 The antenna geometry, (a) top layer, (b)bottom layer, and (c) side view

Table 1 Parameter values of the antenna design

Parameter	Value (mm)
L1	24
W1	24
L2	5.25
W2	7.4
L3	3.2
W3	2.6
Z1	12.16
Z2	14.14
H	1.6

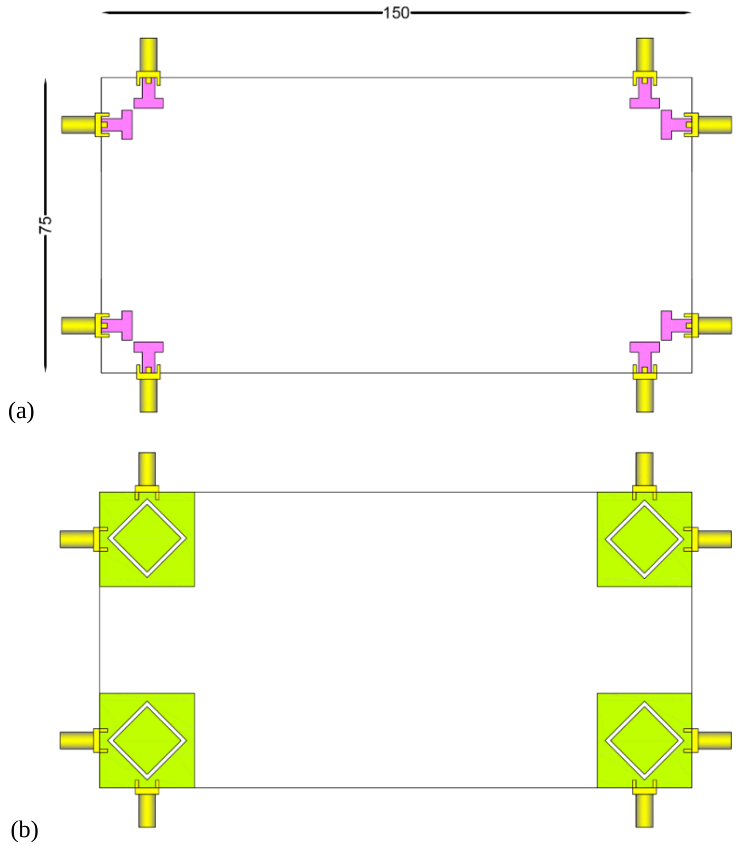


Fig. 2 Designed smartphone antenna (a) top layer and (b) the bottom layer

4. The Results of Simulation

The proposed model of a single and MIMO are simulated using CST.STUDIO 2020 to evaluate their performances. Such a model is achieving after many trying with various dimensions that lead to the final proposed scheme. The microstrip-line feeder's width and length and the PCB dimension were all modified to produce the best performance.

4.1. Single Antenna Simulation

Fig. 3 illustrates the return loss and isolation for the proposed diamond-ring slot radiator antenna. The operating frequency range is 3.3 to 4.8 GHz at (-10 dB), with a resonance frequency of 3.74 GHz and return losses of (-63 dB). Furthermore, it was achieving high isolation through a band of (3.1-4.7 GHz). The Voltage Standing Wave Ratio (VSWR) characteristic of the proposal is represented in Fig. 4. The resultant value of VSWR at operating frequency did not exceed 2 dB, which matches its condition according to [16].

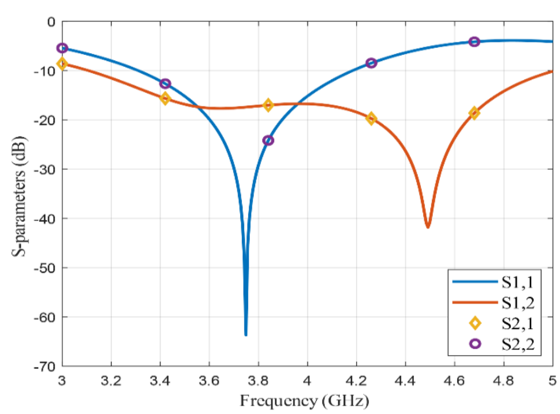


Fig. 3 S-Parameter for single antenna element

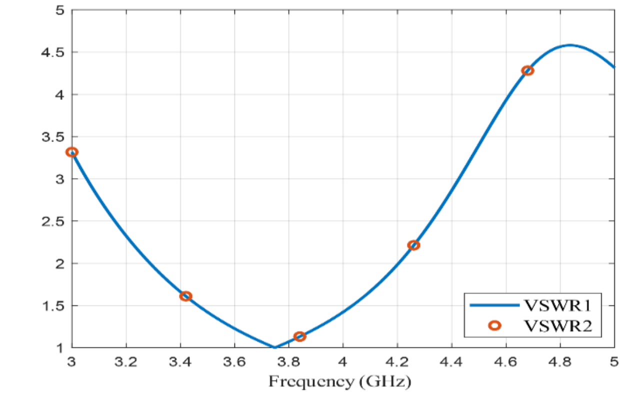


Fig. 4 The VSWR for a single antenna element

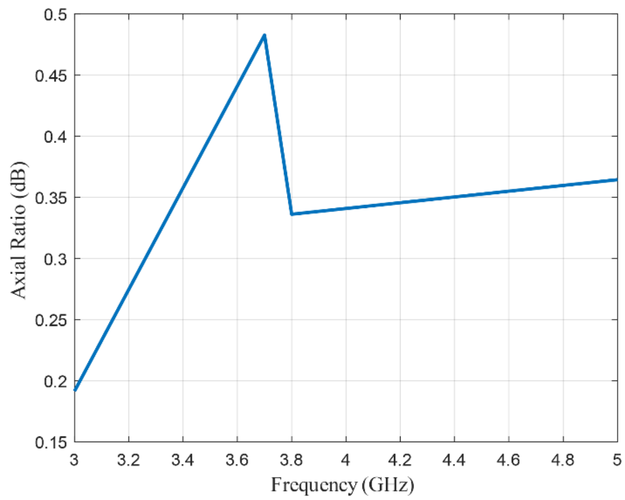
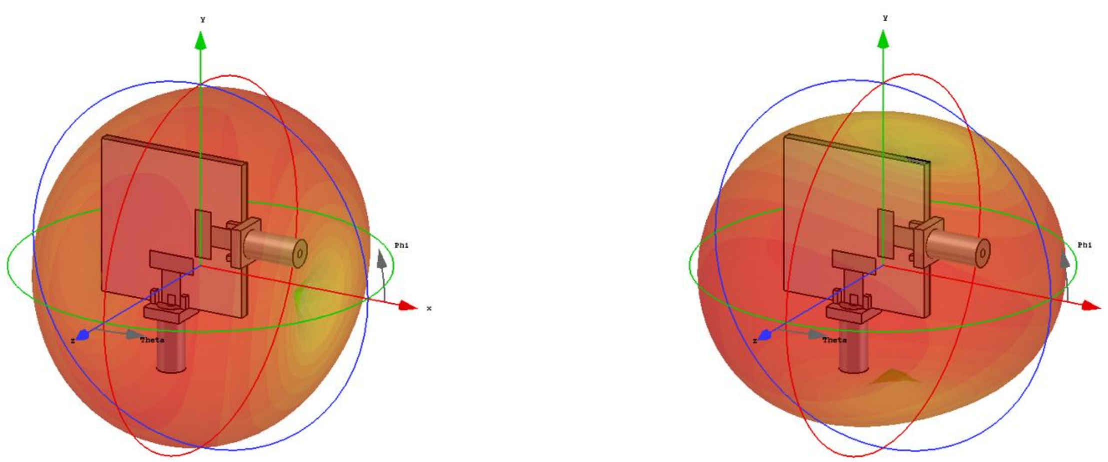


Fig. 5 AR for single antenna element

The Axial Ratio (AR) is an essential parameter for CP antennas that should not exceed -3dB, as the decision of [11], as shown in Fig. 5. In addition, Fig. 6 illustrates the 3D radiation pattern at the operating frequency, and it is noted that port-1 has an omnidirectional radiation pattern along the xz-plane. In contrast, the port-2 radiation pattern has an omnidirectional radiation pattern along the yz-plane.

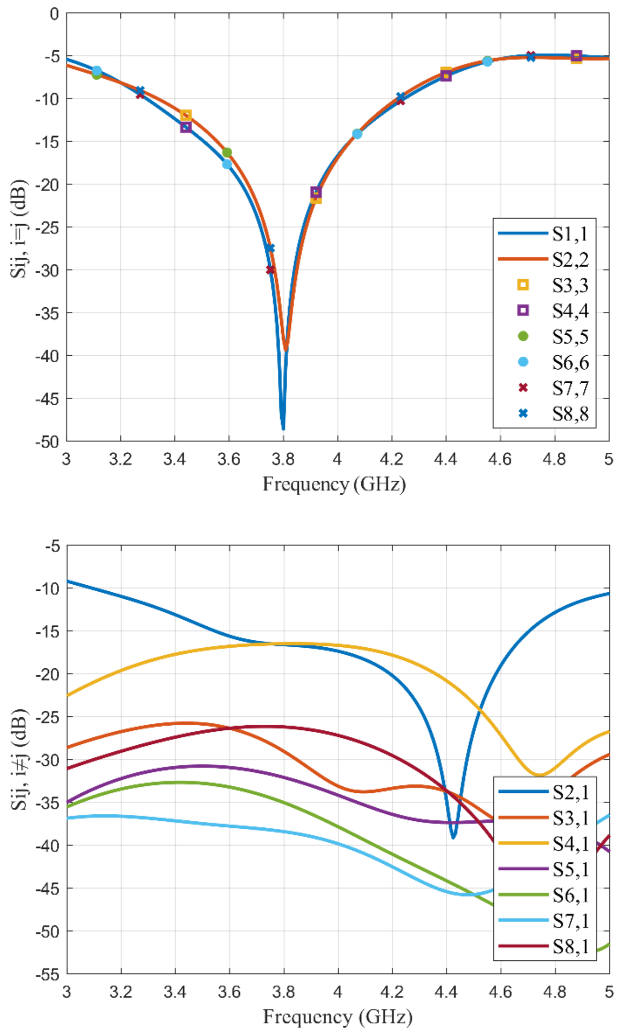


(a) (b)

Fig. 6 The 3D radiation patterns of the dual-polarized (a) port-1 and (b) port-2

4.2. MIMO Antenna Simulation

The MIMO model simulation discusses three performance criteria: S-Parameter, diversity performance, and radiation patterns. In terms of the S-Parameters (($Sij, with\ i = j$): S11–S88 and ($Sij, with\ i \neq j$): S21–S81) are demonstrated in Fig. 7, with the desired frequency range. The proposed MIMO model achieves good S-parameters with appropriate impedance bandwidth (900 MHz) and high isolation features.



(a)

(b)

Fig. 7 The S-Parameters for MIMO system (a) $Sij, with\ i = j$ and (b) $Sij, with\ i \neq j$

The VSWR performance of the suggested MIMO system of all ports shown in Fig. 8 indicates that the value does not exceed 2.

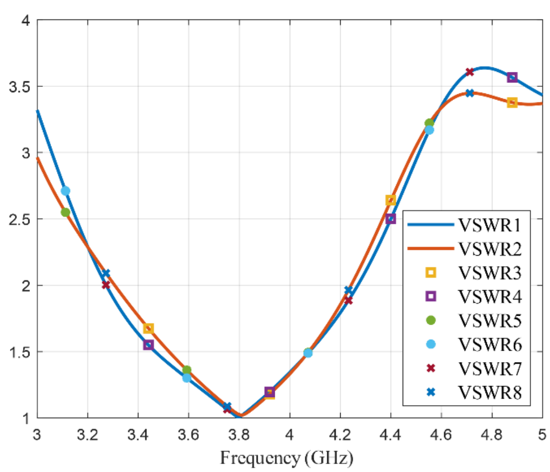


Fig. 8 VSER of MIMO antenna system

The third performance is the AR which illustrates in Fig.9. AR simulated for the proposed MIMO at the operating frequencies <3 dB the broadside direction (θ =0° and φ =0°).

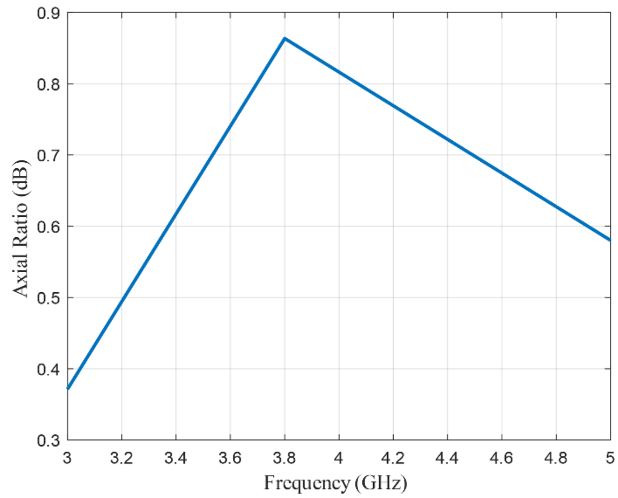


Fig. 9 AR of MIMO antenna

In terms of diversity performance, the first significant parameter used to calculate the diversity of the antenna's performance is the Envelope Correlation Coefficient (ECC). They are used to calculate the similarity degree between two beams pattern. The lower correlation can mean that the two beam patterns have less overlap [9]. By using the S-parameters of the following equation (1):

$$\rho_{eij} = \frac{|s_{ii} * s_{ij} + s_{ji} * s_{jj}|^2}{(1 - |s_{ii}|^2 - s_{ij}{}^2)(1 - |s_{ji}|^2 - s_{jj}{}^2)} \tag{1}$$

Figure 10 shows the results of the correlation coefficient of the proposed antenna less than 0.01 in its operating frequency. It is confirming that such a coefficient is very low compared to a standard value (< 0.5) [17].

Diversity Gain (DG) is the second significant parameter that indicates the antenna efficiency in terms of the diversity gain set. The results are illustrated in Fig. 11, which can be calculated using equation (2) [18]:

$$DG = 10\sqrt{1 - |\rho_{eij}|^2} \tag{2}$$

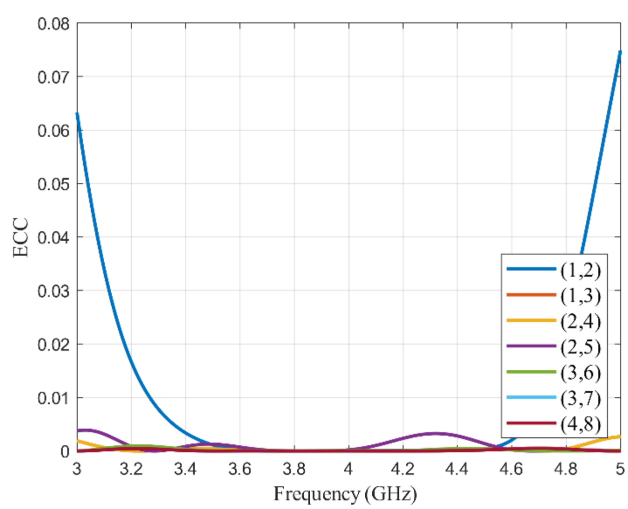


Fig. 10 ECC of MIMO antenna system

Finally, the simulation of 3D radiation pattern performances shows in Fig. 12 all ports deployed in the suggested 5G smartphone PCB. It shows that the radiation patterns of radiators can cover each side of the PCB smartphone. Simultaneously, different polarizations can be achieved for each PCB region due to the antenna component dual-polarized characteristics, making the proposed MIMO antenna system proper for future mobile applications.

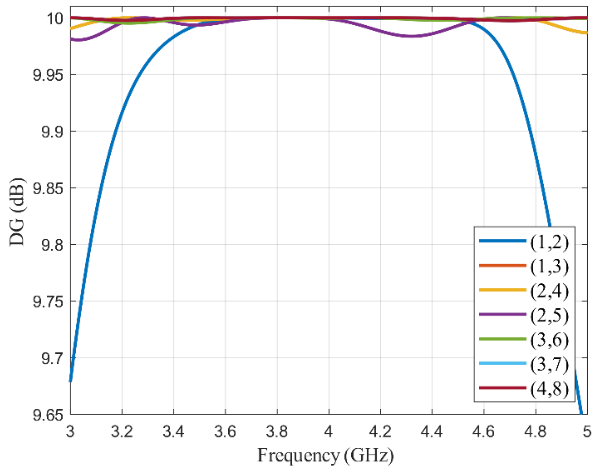
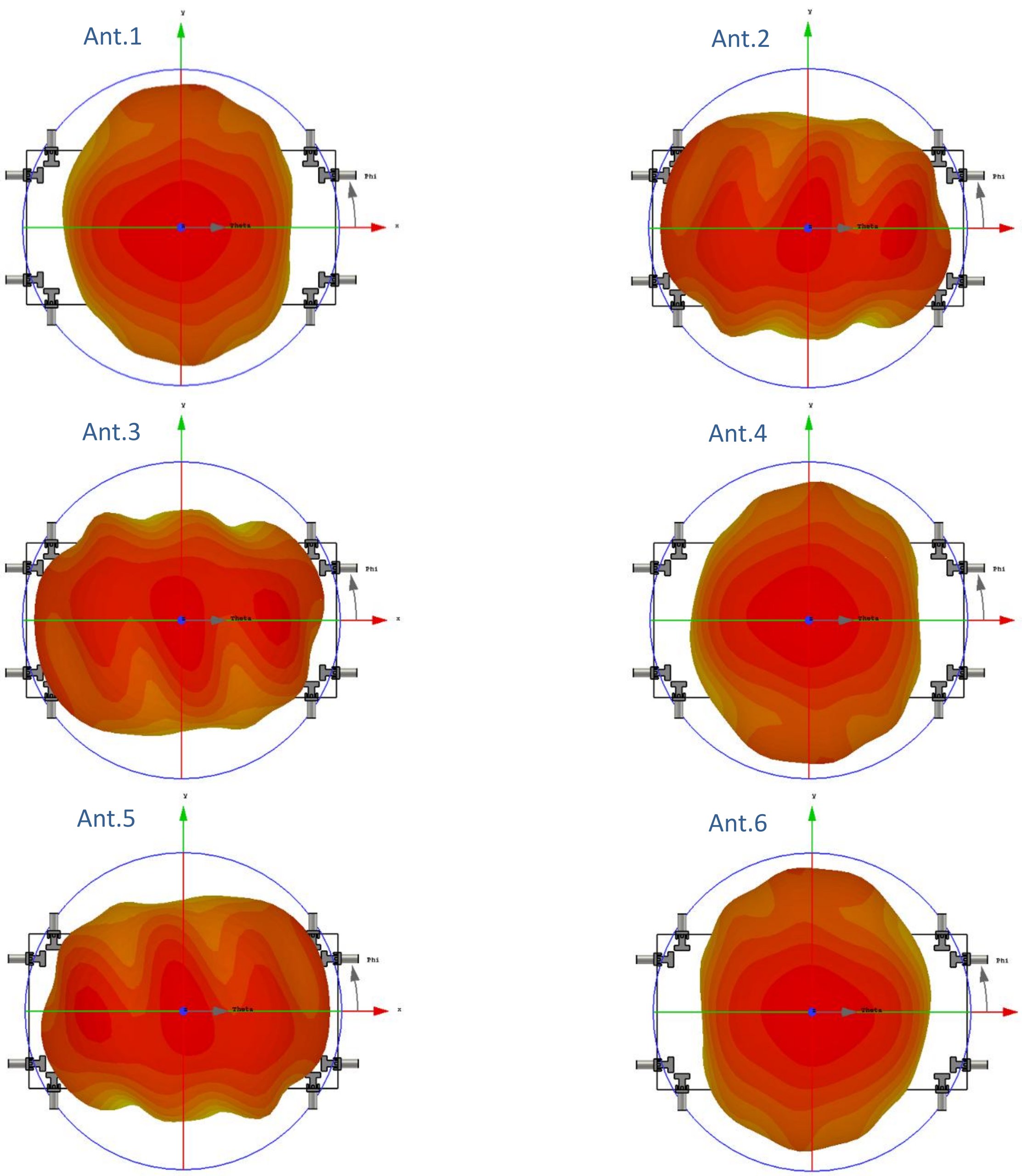


Fig. 11 DG of MIMO antenna system



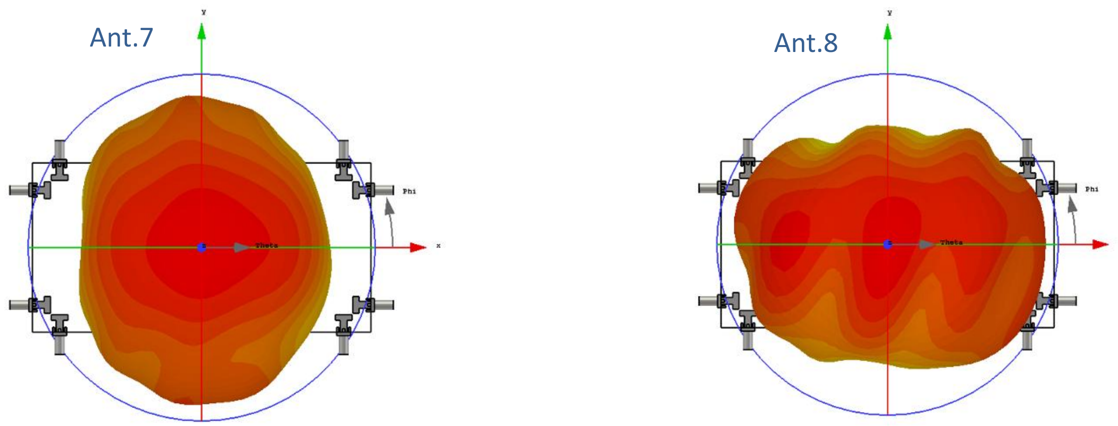


Fig. 12 3D radiation patterns of 5G smartphone antenna

5. Conclusion

In this paper, a CP dual-polarized antenna design is proposed for a 5G MIMO system. The antenna schematic consists of four elements; each one contains a dual-port with T-shaped microstrip feed lines arranged at the four PCB corners with a dimension of 75 x 150 mm^2. The antenna's orthogonal orientation of microstrip feed lines provides polarization diversity with a very low correlation coefficient without using decoupling structures. High impedance matching (around -63 dB reflection coefficients) is achieved by tuning the length and width of microstrip feed lines. The results showed that the proposed antenna of the smartphone has good properties and meets future mobile applications' criteria.

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