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Multi Antenna Systems for 5G Mobile Phones

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Abstract**—**With the increasing demand of bandwidth and data rate, there is a dire need to implement antenna systems in mobile phones which are able to fulfill user requirements. A monopole antenna system with multi-antennas configurations is proposed considering the feasibility and user demand. The multi-antenna structure is referred to as multi-input multi-output (MIMO) antenna system. The multi-antenna system comprises of 4 antennas operating below 6 GHz frequency bands for 4G/LTE and 4 antenna for 5G applications at 28 GHz and the dimension of board is $120 \times 70 \times 0.8mm^3$. The suggested designs is feasible with a structure of low-profile planar-antenna and is adaptable to smart cell phones and handheld devices. To the best of our knowledge, this is the first design compared to the literature by having integrated antenna system for two standards, i.e., 4G and 5G. All MIMO antenna systems are simulated on commercially available software, which is high frequency structures simulator (HFSS).

Keywords**—**High frequency structures simulator (HFSS), mutli-input multi-output (MIMO), monopole antenna, slot antenna.

I. Introduction

THE current era has faced a quick development in the field of new communication technologies. Transmitters/receivers (i.e., antennas) are a crucial component for communicating information and the cell phone is main application. A number of multi-antenna systems have been proposed to accomodate the fast developing technologies and current needs. It was addressed and observed that MIMO-antenna systems have proved to be suitable for the emerging technogies, i.e., long term evolution (LTE), worldwide interoperability for microwave access (WiMAX), and wireless local area networks (WLANs). These evolving technologies and the advanced systems, i.e., GSM/UMTS/WLAN have been integrated towards the future of communication technologies, i.e., LTE/4G/5G. The future technology is being made to introduce a diverse system, which have great advantages in terms of great coverage, huge capacity and better performance [1]–[3].

The highly increased demand of data throughput has motivated the researchers and antenna designers to choose MIMO antennas to enhance the capacity and provide the high data rates in 4G and 5G within the limited bands. They are a key technology used in 4G and 5G for high data rates within limited bandwidth. They support multiple bands including lower band of 4G LTE [3], [4]. Multi-antenna systems incorporate with greater merits including the high data rate with efficient bandwidth utlization and less power requirement and it is done by have more and more quantity of antennas [5]–[7]. It offers multi-antennas at both sides (i.e., transmitter and reciever) and by doing this, we can get high channel capacity and also the data rate for various channels. It is suggested that by increasing the number of antennas, we can get better channel capacity and the relationship of which is given by [8],

$$C = M_t N_r B \log_2(1 + \gamma). \quad (1)$$

where, C is the channel capacity (bps), B is the bandwidth (Hz), and M_t and N_t are the number of transmitter antennas and receiver antennas, respectively, and γ is the signal-to-noise ratio (absolute value). From (1), we can see that the capacity can also be increased by enhancing the bandwidth. But the problem is to integrate the large number of antennas within the size of a mobile phone because the energy can be coupled easily through the adjacent ports and can degrade the system performance [9]–[12].

An analysis of system coverage and capacity on millimeter-wave band for 5G mobile communication systems is reported in [12]. Millimeter-wave band in the 30-300 GHz range can significantly improve the capacity of the central network for 5G mobile communication. Through system level simulation, the system coverage and capacity according to the configuration of MAS (massive antenna structure) was evaluated.

Three kinds of MIMO antenna systems for mobile handheld devices are investigated in [13], [14]. They were compact in size and covered GSM1900, LTE2300, LTE2500 and WLAN 2.4 GHz for 5G handset applications. The PCB size was $136 \times 68.8 \times 1mm^3$ consisted of four or six three dimensional PIFA elements with a dielectric cube of $10mm \times 10mm \times 5mm$. The isolation was higher than 10dB and the envelop correlation coefficient was very small. Efficiency was examined by increasing number of elements and decreasing the spacing. It degraded in both cases.

An Omni-directional antenna in MIMO arrangement is presented in [15], [16] which covered S band (2.2-2.4 GHz) and C band (4.4-5.0 GHz). For each of the two bands, a pair of PIFA like radiating structure was used. The value of effective correlation coefficient computed by using S parameters was 0.005 for lower band and 0.001 for high band. The value of the mean effective gain ratio between the two antennas was less than 3 dB. In [17], two very compact designs of miniaturized four element planar inverted F antennas were reported. The operating frequency was 2.45 GHz. The proposed dimensions for antenna design were $105 \times 55mm^2$ while each antenna occupied volume of 0.455 cm^3. Mutual coupling was less than 10dB. Measurements and results showed that the proposed

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TABLE I
ANTENNA PARAMETERS

Parameters	Value
Dielectric constant of the substrate ϵ_r	3
Resonance frequency f_r	2.6 GHz
Height of the substrate (h)	0.8mm

design was able to achieve the channel capacities close to the ideal theoretical limit.

The main objective of this research work is to come up with 4 antenna elements MIMO system, which is created using the modified version of monopole-antenna within a smart cell-phone and the size of back-plane is $120 \times 70mm^2$, frequency range of below 6GHz bands. Moreover to come up with mm-Waves MIMO antenna system within a smart phone size backplane with $120 \times 70mm^2$, and covering 5G 28GHz band and to simulate, measure and characterize the 2 antenna systems for 4G/5G applications. In this work, we propose 4-element L shape MIMO antenna system for 4G and 4-element slot antenna based MIMO antenna system for 5G on the same substrate. The unique features of the design are compact in size, dual standard (can be used for 4G and 5G at the same time) and 8 antennas are integrated on a single substrate.

II. SYSTEM MODEL

The main parameter of interest is to enhance the capacity and provide the high data rates in 4G and 5G within the limited bands and limited size with controlled coupling. Multi-antenna systems have been proved to be higher data rate with efficient bandwidth and power utilization also proposed by [18]. The size of design is the main concern in this regard because the purpose of the work is to design an antenna system within the size of a mobile phone of size $120 \times 70 \times 0.8mm^3$.

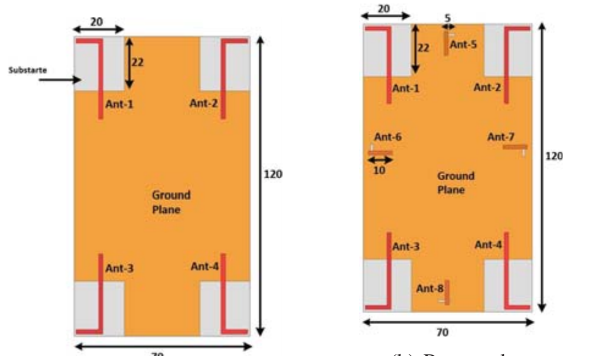
Antenna is designed with the help of few parameters as shown in Table I.

The geometry of monopole antenna is shown in Fig. 1 (a). It consists of 3 main parts such as resonating element, ground plane and feed. The antenna is vertical L shaped. This shape was chosen to reduce the space. The total length of antenna is 25mm which around quarter of wavelength $(\lambda/4)$ at 2 GHz. It is modeled using high frequency structured simulator (HFSS). The FR4 substrate is used to design the antenna with the total size of $120 \times 70 \times 0.8mm^3$. The dielectric constant constant and loss tangent values are 4.5 and 0.02, respectively.

A slot antenna is designed for 5G 28 GHz applications. The size of the slot antenna is 5mm which is around half of wave length at 28 GHz. To make it in MIMO configurations 4 slot antennas are etched in the ground plane and feed from the top of the layer using 50Ω microstrip feed lines as shown in Fig. 1 (b). Four slot based 5G antennas (Ant-5 to Ant-8) are integrate between 4 monopole based 4G antennas (Ant-1 to Ant-4) to make this structure suitable for 4G and 5G applications. This structure is compact in size and can integrate in the mobile handsets to fulfill data requirements.

III. RESULTS AND DISCUSSIONS

The simulations of the proposed designs are performed using HFSS ver. 2015. The S parameters, gain, efficiency



(a) Monopole antenna geometry (b) Proposed antenna geometry (for 4G & 5G)

Fig. 1 Geometry of antennas

and the radiation patterns are also measured using the same software. The simulated S-Parameters of the 4G MIMO antenna and 5G MIMO antenna designs are shown in Figs. 2 (a) and (b).

Since the design of the 4-port MIMO antenna is symmetrical, the simulated S-parameters for all input ports are almost identical and covering 2005-2121 MHz frequency band which centred around 2100 MHz for 4G and covering 23.9-28.9 GHz frequency band which centred at 28 GHz for 5G applications.

Isolation or coupling curves for 4G and 5G systems are shown in Figs. 3 (a) and (b) respectively. The minimum isolation between any two ports is higher than 6 dB which is enough for MIMO antennas for 4G with 4-port systems as shown in Fig. 3 (a). In Fig. 3 (b).The minimum isolation between any two ports is higher than 35 dB which is enough for MIMO antennas for 5G with 4-port systems.

The current distributions are shown in Figs. 4 (a) and (b). In case of 4G, When Antenna1 is active and others are terminated with matched load of 50Ω. It can be seen in Fig. 4 that a little current is coupled with adjacent element. But it is still acceptable for MIMO applications.

For 5G, the current distribution can be seen in Fig. 4 (b), when Antenna5 is active and others are terminated with matched load of 50Ω. It can be seen that a very low current is coupled with adjacent element and it shows high isolation between all 4G and 5G antennas.

The radiations patterns in the form of peak gain of the proposed 4G MIMO antenna system are shown in Fig. 5. Total gain is observed for Antenna 1 to Antenna 4 is 5dBi at 2.1 GHz. They are directional antennas to cover 4 independent channels to increase channel capacity or data rates. These patterns are directional in the x-z plane and omni-directional in x-y plane to satisfy requirements for 4G applications. The total efficiency was found to be more than 92% for all antennas.

The radiations patterns (2D and 3D) in the form of peak gain of the proposed 5G MIMO antenna system are shown in Fig. 6. Total gain is observed for Antenna 5 to Antenna 8 is 10dBi at 28 GHz. They are directional antennas to cover 4 independent channels to increase channel capacity or data rates. The total efficiency was found to be more than 92% for

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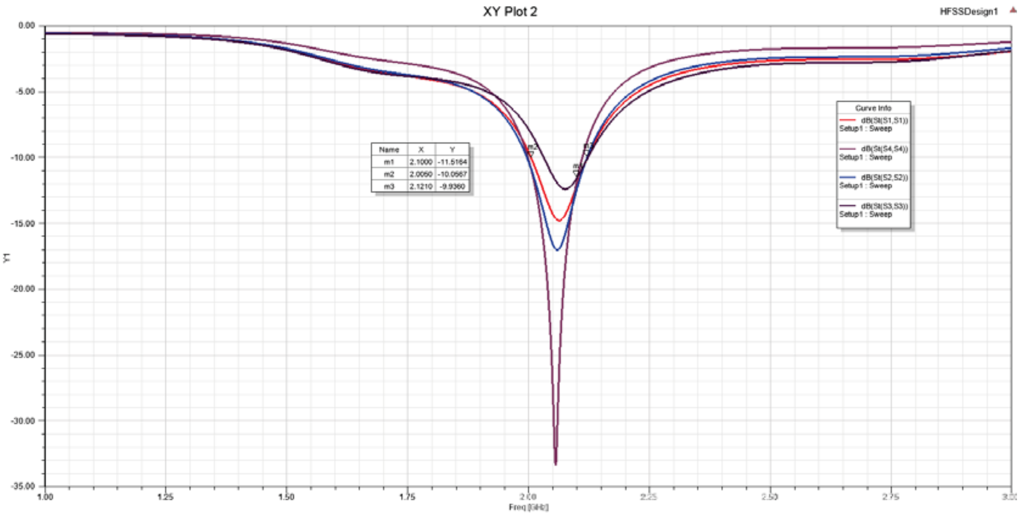
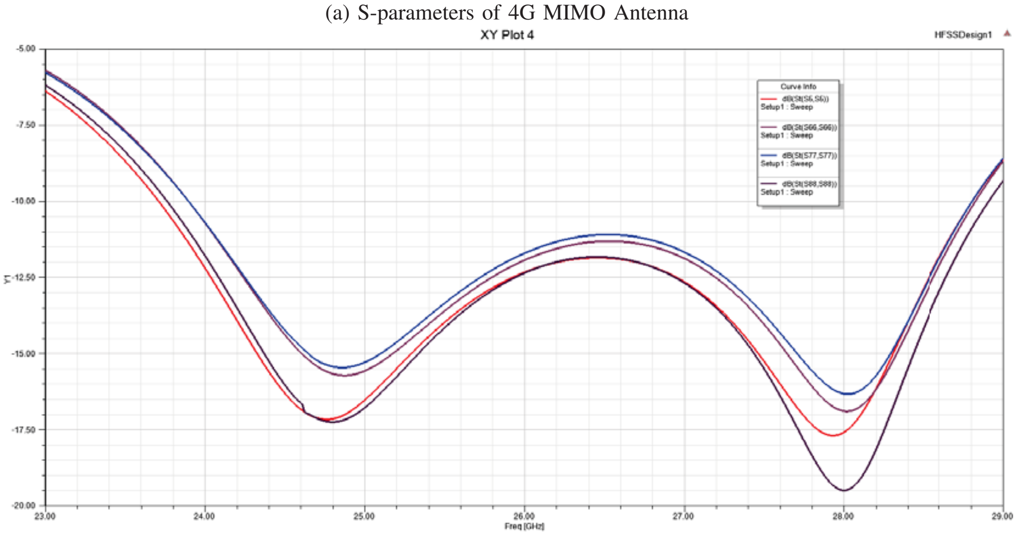


(a) S-parameters of 4G MIMO Antenna



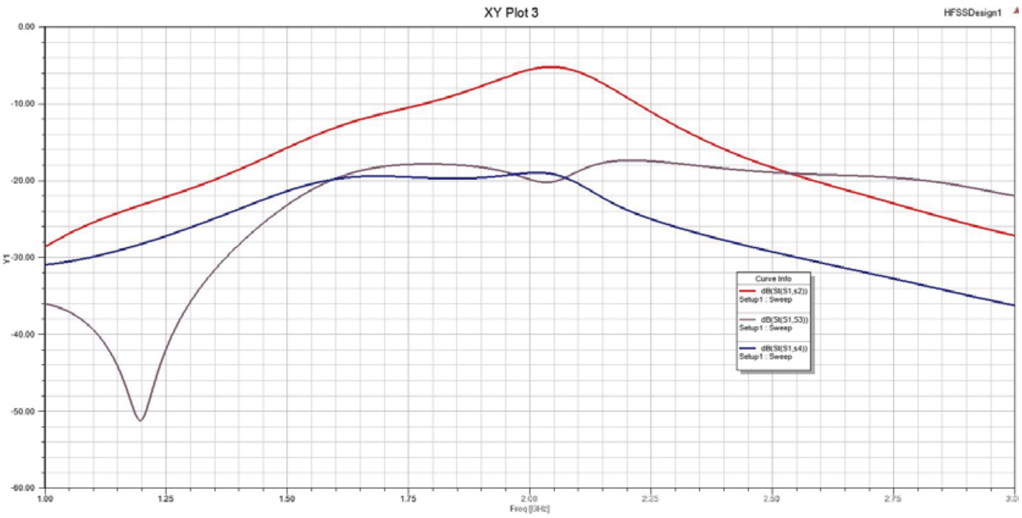
(b) S-parameters of 5G MIMO Antenna

Fig. 2 S-Parameters for 4G and 5G

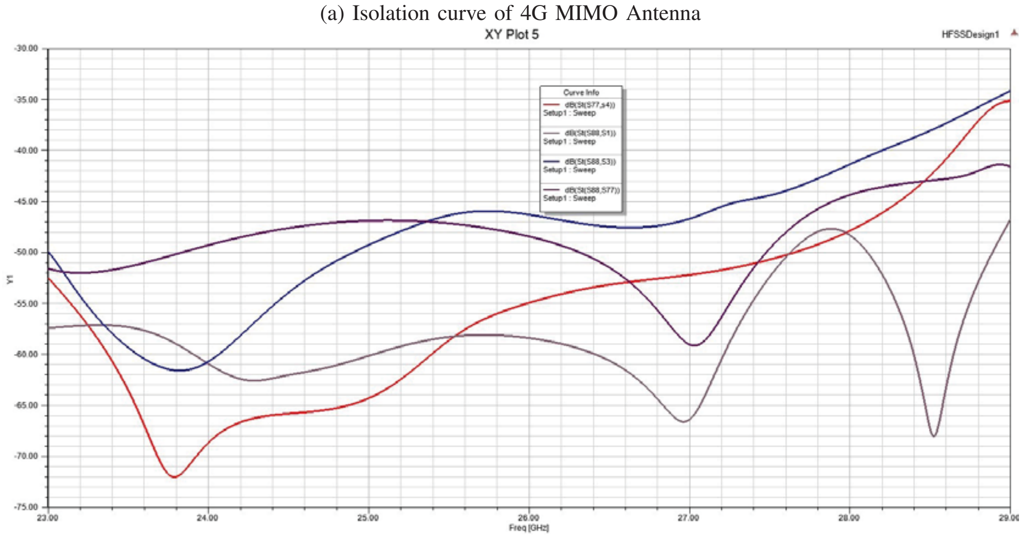
all antennas. 2D and 3D patterns were drawn to show tilts in the radiation patterns which ultimately enhance the spatial diversity performances.

IV. Conclusion

In this article, 4- element L shaped Monopole MIMO antenna system is proposed for 4G which operates at 2.1GHz and 4-element slot antenna based MIMO antenna system is proposed for 5G which operates at 28GHz. All the 8 antennas are integrated on a single substrate of a mobile phone of size $120 \times 70 \times 0.8mm^3$. The MIMO antenna system is compact in size and the most important feature is that it is dual standard; operates on both 4G and 5G frequencies. The MIMO antenna system is suitable for future mobile phones. The S parameters, coupling curves and the current distributions showed that the single design can fulfill the requirements of both 4G and 5G communication systems.

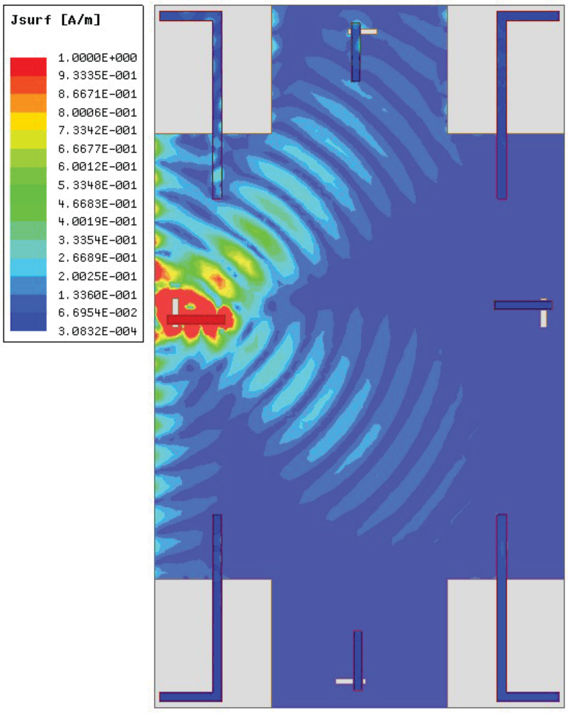


(a) Isolation curve of 4G MIMO Antenna

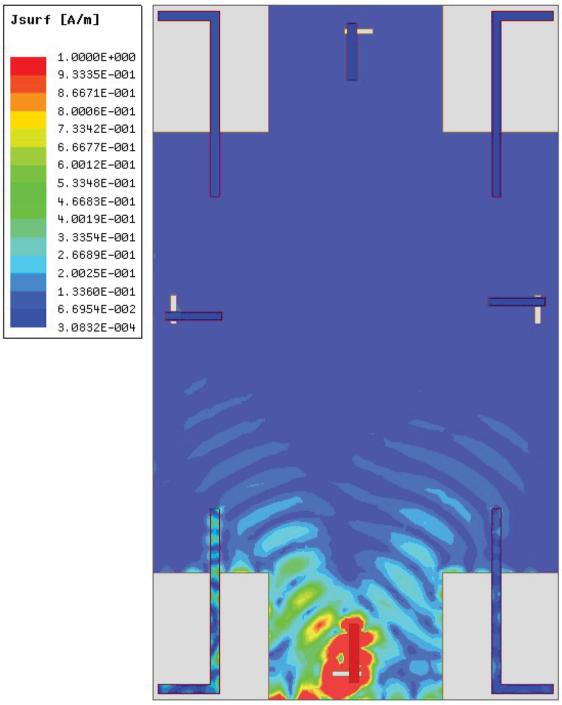


(b) Isolation curve of 5G MIMO Antenna

Fig. 3 Isolation curve for 4G and 5G

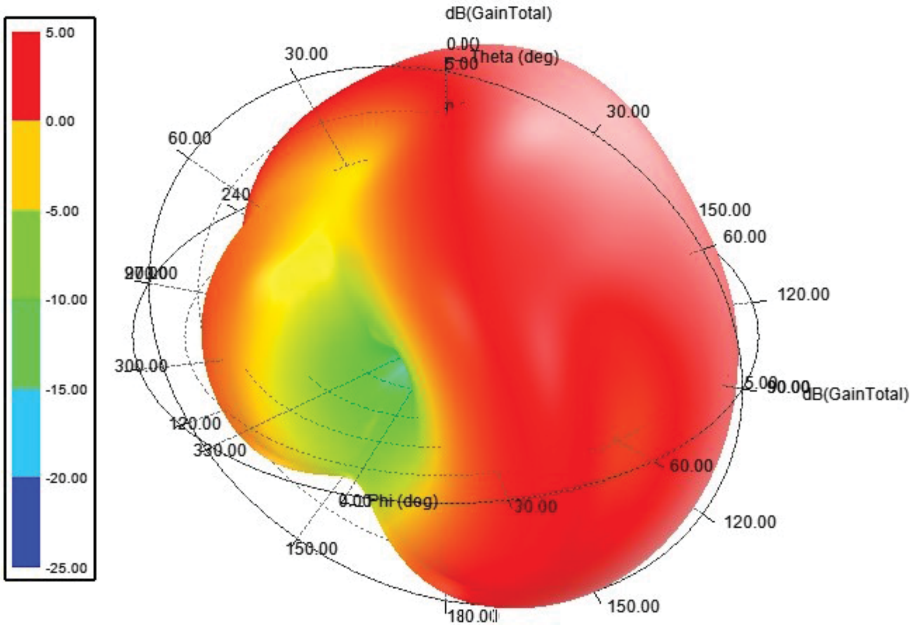


(a) Current distribution of 4G MIMO when antenna 1 is active

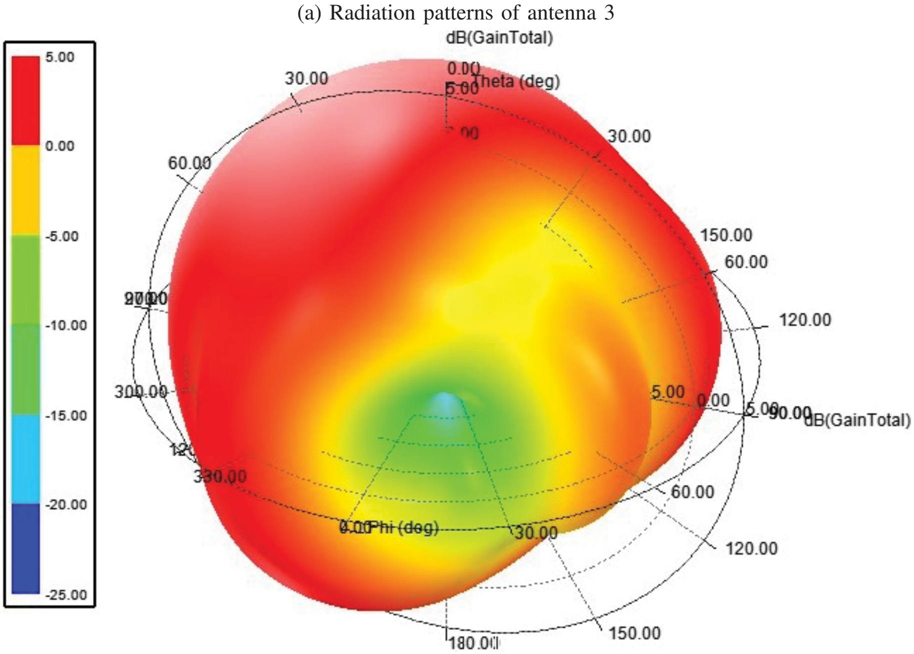


(b) Current distribution of 5G MIMO Antenna when antenna 5 is active

Fig. 4 Current distributions for 4G and 5G

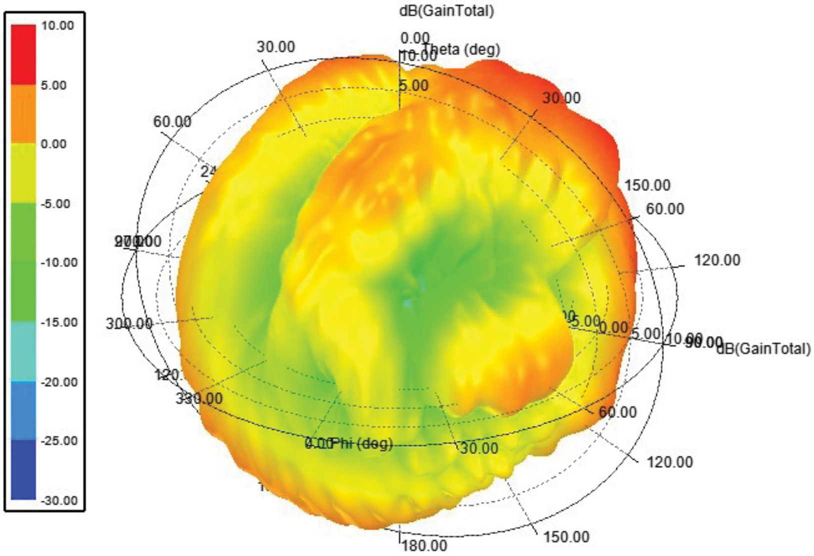


(a) Radiation patterns of antenna 3

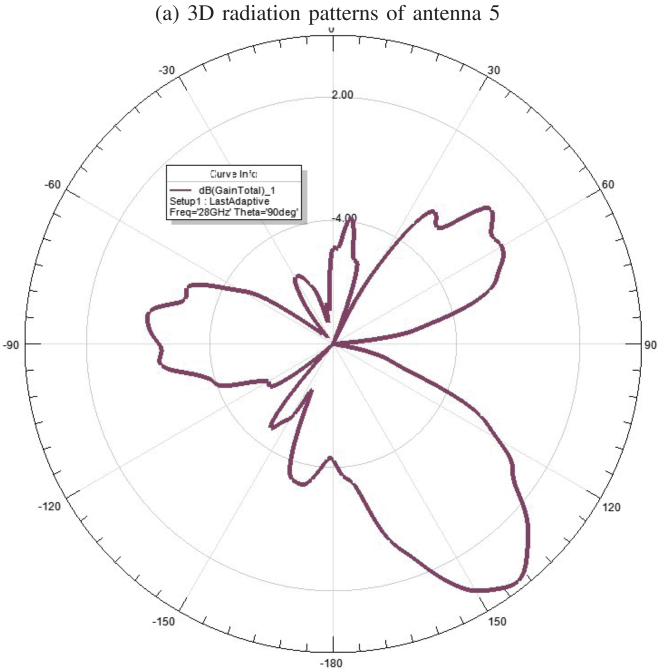


(b) Radiation patterns of antenna 4

Fig. 5 Radiation patterns for 4G



(a) 3D radiation patterns of antenna 5



(b) 2D radiation patterns of antenna 5

Fig. 6 Radiation patterns for 5G

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