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A Design of Beam-Steerable Antenna Array for Use in Future Mobile Handsets

Naser Ojaroudi Parchin, Atta Ullah, Haleh Jahanbakhsh Basherlou, Raed A. Abd-Alhameed, Peter S. Excell

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***Abstract*—**A design of beam-steerable antenna array for the future cellular communication (5G) is presented. The proposed design contains eight elements of compact end-fire antennas arranged on the top edge of smartphone printed circuit board (PCB). Configuration of the antenna element consists of the conductive patterns on the top and bottom copper foil layers and a substrate layer with a via-hole. The simulated results including input-impedance and also fundamental radiation properties have been presented and discussed. The impedance bandwidth ($S_{11} \leq$ -10 dB) of the antenna spans from 17.5 to 21 GHz (more than 3 GHz bandwidth) with a resonance at 19 GHz. The antenna exhibits end-fire (directional) radiation beams with wide-angle scanning property and could be used for the future 5G beam-forming. Furthermore, the characteristics of the array design in the vicinity of user-hand are studied.

***Keywords*—**Beam-steering, end-fire radiation mode, mobile-phone antenna, phased array.

I. Introduction

IN line with the abbreviations of the past and current mobile communication standards (for instance 1G, 2G, 3G, and 4G), the term 5G, used here denotes the next-generation mobile communication systems after current 4G systems [1], [2]. Due to the growing need of higher data rate communication, the evolution from 4G to 5G is started which requires new techniques and careful consideration in different wireless communication systems [3]-[5].

Different from the design of antennas for 4G, increasing the operation frequency of the future wireless systems (beyond 10 GHz) would bring new challenges in the designs of antennas for the future handheld devices which need new techniques [6]-[10]. The smaller antennas arranged as an array can be used at different sides of the smartphone mainboard to form beam-steerable antenna arrays with directional/end-fire radiation beams [11]-[15].

This paper focuses on the design and characteristics of a beam-steerable antenna for 5G cellular communications. The antenna is composed of a linear phased array with eight compact end-fire radiators on the top side of the PCB. *Rogers RT 5880* dielectric has been used as the antenna substrate. The proposed phased array design is working in the frequency range of 17.5-21 GHz and providing good beam-steering, sufficient efficiency, and high realized gain/directivity characteristics. The radiation beams of the array can easily cover the scanning angles of -75 to +75 degree. Moreover, the radiation behavior of the designed 5G array in the vicinity of the user's is investigated and good results have been obtained.

Naser Ojaroudi Parchin*, Atta Ullah, and Raed A. Abd-Alhameed are with the Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, UK (*e-mail: N.OjaroudiParchin@Bradford.ac.uk).

Haleh Jahanbakhsh Basherlou is with the Bradford College, Bradford, West Yorkshire, BD7 1AY, UK.

Peter S. Excell is with the Engineering Division, Glyndwr University, Wrexham LL11 2AW, UK.

II. Antenna Design

The configuration of the proposed beam-steerable array antenna, designed on a Rogers RT5880 substrate (ε = 2.2 and δ = 0.0009) is depicted in Fig. 1.

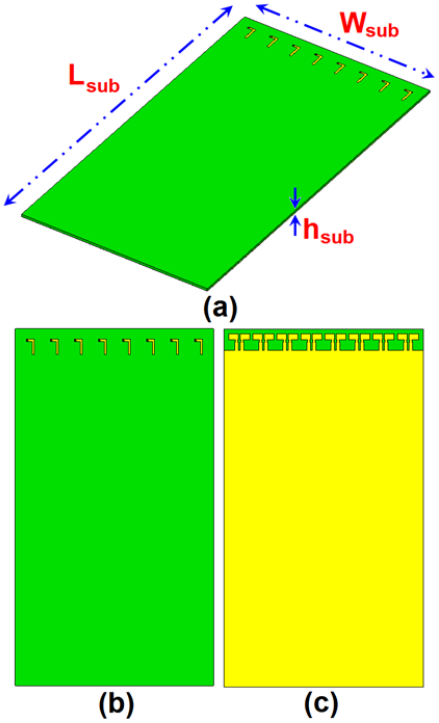


Fig. 1 The Proposed 5G mobile-phone antenna schematic, (a) side, (b) top, and (c) bottom profiles

As can be observed eight elements of compact end-fire antennas are located on the top side of the smartphone PCB to form a beam-steerable array and also to exhibit the required radiation coverage of 5G cellular systems. Another set of the embedded linear array with the same performance and size could be used at the bottom side of the PCB [16]-[18].

III. Single-Element Antenna Characteristics

Fig. 2 displays the schematic of the designed end-fire antenna element. As illustrated, the antenna configuration consists of the conductive patterns on the top and bottom copper foil layers and a middle dielectric layer. In addition, a

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metalized via-hole is used to make a connection between top and bottom copper-foil layers. The rectangular arms of the ground plane work as dipole arms to provide an end-fire radiation pattern. The parameter values of the designed antenna are specified in Table I.

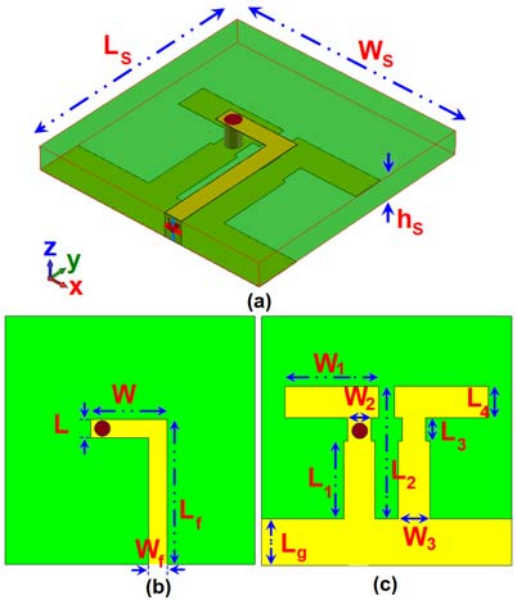


Fig. 2 Single element antenna configuration, (a) transparent view, (b) top view, and (c) bottom view

TABLE I
DIMENSIONS OF THE DESIGN PARAMETERS

Parameter	W_S	L_S	h_S	W_f	L_f	W	W_{sub}
Value (mm)	8	8	0.8	0.6	4.7	2.45	60
Parameter	L	W_1	L_1	W_2	L_2	W_3	L_{sub}
Value (mm)	0.6	3	2.5	0.75	4.25	1	110
Parameter	L_3	L_4	L_g	W_a	L_a	d	h_{sub}
Value (mm)	0.75	1	1.5	8	58	7.25	0.8

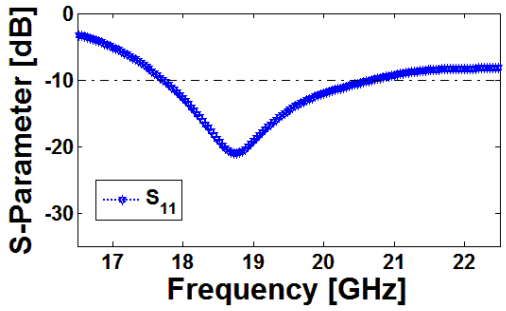


Fig. 3 S_{11} characteristic of the antenna

Fig. 3 displays the S_{11} characteristic of the antenna. As shown, the antenna has good impedance matching and wide bandwidth around 19 GHz. In addition, the simulated current distribution of the antenna at 19 GHz is displayed in Fig. 4. As can be observed, the current flows are dominant around the antenna arms [19], [20]. The antenna radiation pattern in 3D and 2D (polar) forms are depicted in Fig. 5. More than 4.85 dB realized gain with well-defined end-fire mode have been achieved for the antenna radiation pattern at 19 GHz [21],[22].

The radiation characteristics of the antenna including maximum gain, radiation, and total efficiencies are plotted in Fig. 6. As seen, the antenna has good radiation performance in the frequency range of 17.5 to 20.5 GHz.

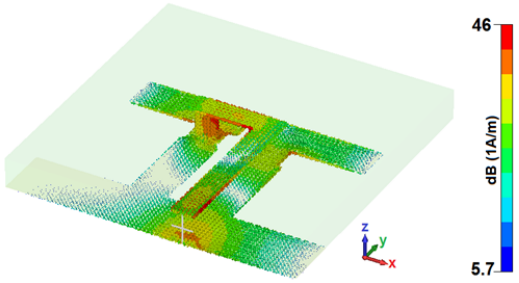
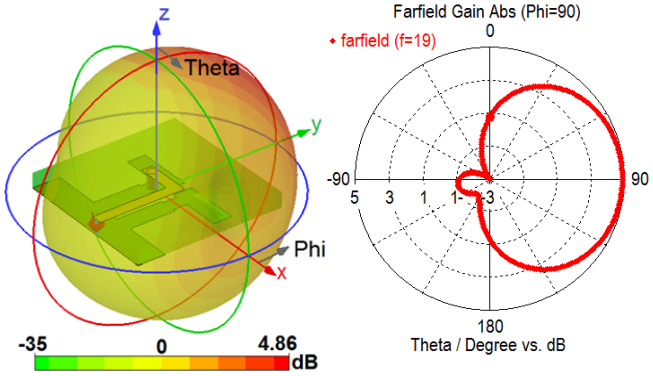


Fig. 4 Simulated current distribution at 19 GHz



(a) (b)

Fig. 5 (a) 3D and (b) 2D radiation patterns at 19 GHz

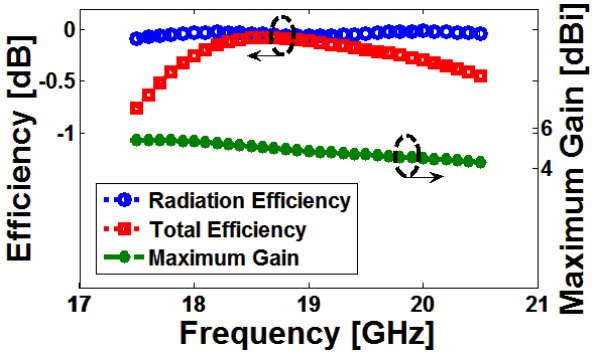


Fig. 6 Fundamental properties of the single-element antenna

IV. CHARACTERISTICS OF THE BEAM-STEERABLE 5G ANTENNA ARRAY

The schematic of the antenna array is displayed in Fig. 7. As can be observed, eight elements of the designed antennas with end-fire radiation are arranged in a linear form. As mentioned before, the designed array has a compact size which makes it suitable for use on the top of mobile phone PCB. However, in order to cover the required beam-scanning of the 5G cellphone, another set of the array is needed to use at the bottom portion of the PCB. Due to the same performance of the phased array at different sides of the PCB, the radiation characteristics of the 5G mobile phone with one

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set of the array have been investigated in this section. Fig. 8 shows a phased array system architecture which can be used in feeding a linear antenna array antenna for 5G communications. Different feeding networks such as parallel and series can be implemented using phase shifters for beam steering. For the proposed beam-steerable array design, a 1×8 uniform linear array could be used and each radiator with equal magnitude must be excited [23]-[25]. There are various techniques of feed network design for this purpose: parallel, series, etc.

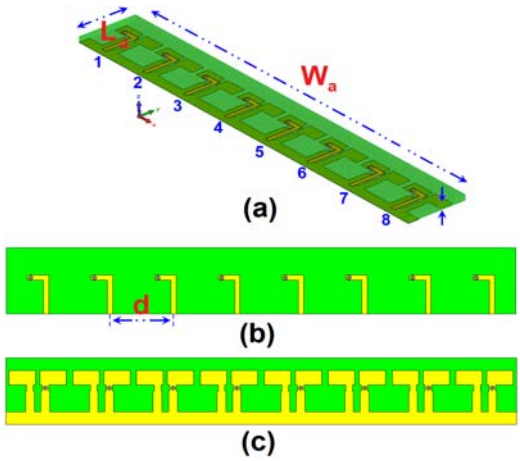


Fig. 7 (a) 3D, (b) top, and (c) bottom views of the linear array

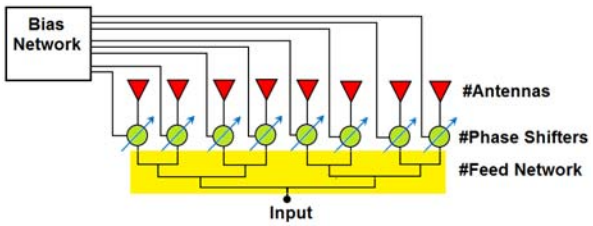


Fig. 8 Phased array architecture for the proposed array

Fig. 9 illustrates the S parameters of the final design (5G mobile phone antenna). As illustrated, the antenna is working the frequency range of 17.5-21 GHz (more than 3 GHz bandwidth). The mutual coupling characteristic of the radiation elements is shown in Fig. 9, as well. There is good isolation between the radiators of the proposed design (less than -14 dB) which make the antenna suitable for phased array and scanning applications.

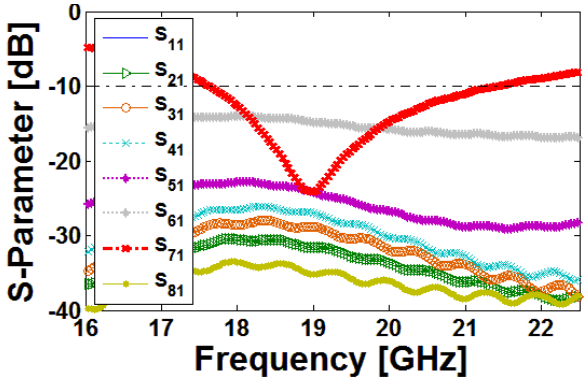
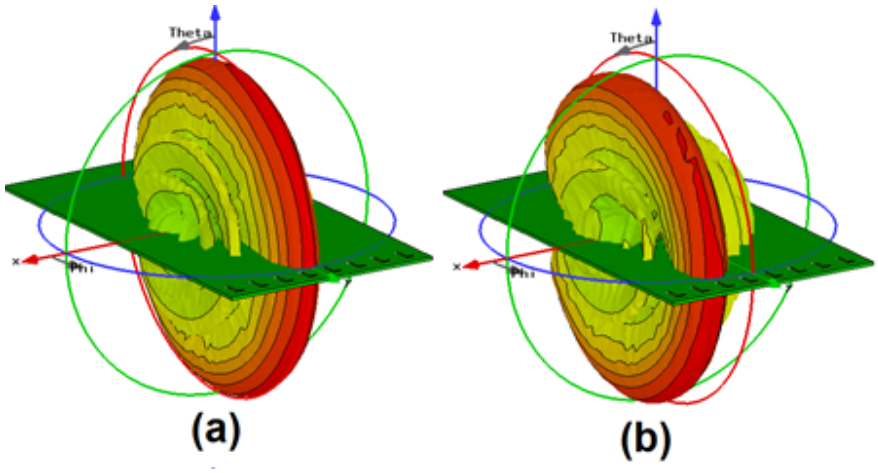


Fig. 9 S parameters of the designed 5G antenna

3D-directional radiation beams of the proposed phased array antenna at the scanning range of 0-75 degree are displayed in Fig. 10. It can be observed that the proposed antenna has wide-scan and well-defined radiation beams with sufficient gain levels. The antenna beams have end-fire behavior and can cover more than half-space in H-plane as shown in Fig. 10. They also have low sidelobes and maximum gains of the beams are concentrated in the desired scanning angles [26], [27].

The fundamental properties of the antenna beams including directivity and efficiency (radiation and total) characteristics are shown in Fig. 11. From these results, it can be found that the antenna has good radiation behavior with high-directivity/ high-efficiency properties. The realized gains of the antenna in the Cartesian mode for plus/minus (+/-) angles of scanning have been represented in Fig. 12. Similar performances with almost the same gain values are obtained for the proposed phased array antenna [28].



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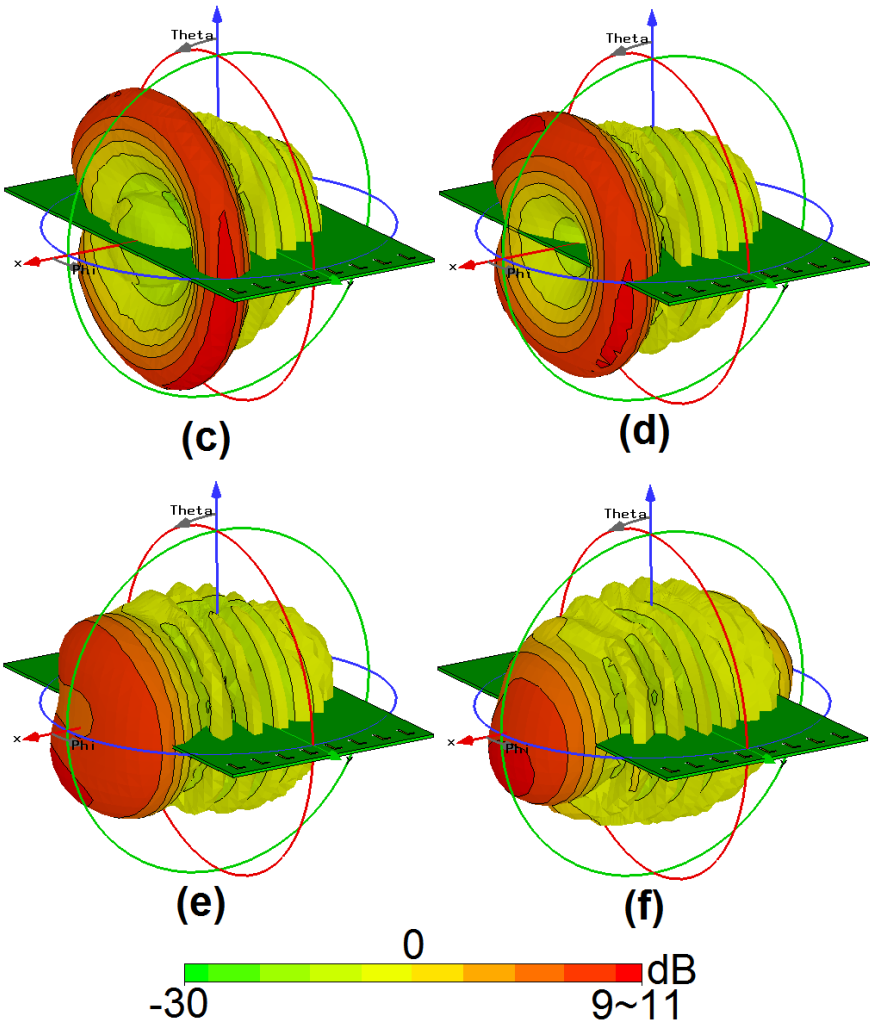


Fig. 10 Simulated array beams at (a), 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 75°

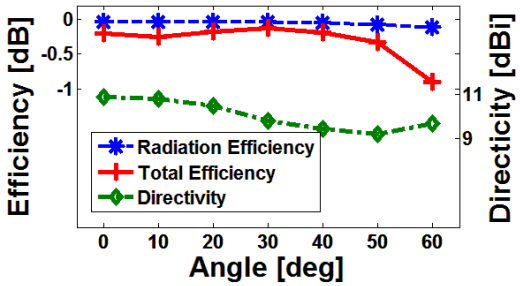


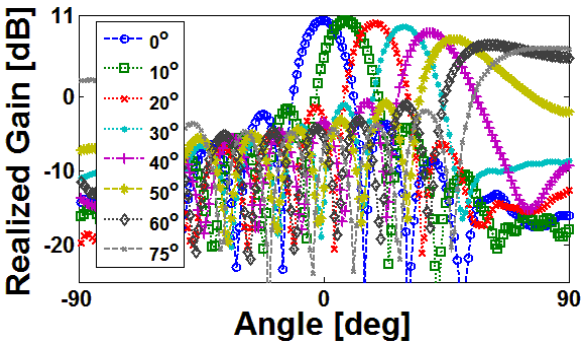
Fig. 11 Fundamental radiation properties (efficiency & directivity) of the 5G antenna at different angles

V. Array Performance in the Vicinity of the User-Hand

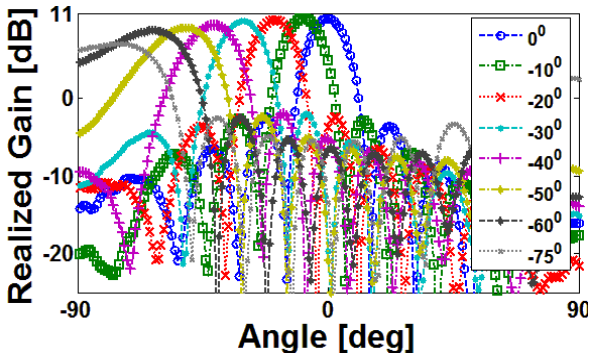
In this section, the radiation performance of the antenna in terms of efficiency, scanning, and gain values in the presence of human-hand are discussed. Generally, we should expect a negative impact of the hand on the antenna radiation performance. It can also have the influence of the impedance-matching and frequency response of the antenna. In addition, by changing the position of hand the amount of the loss would be increased/decreased [29], [30].

TABLE II
Propertied of the Antenna Array with User-Hand Impact

Param. / Angle	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*
Rad. Effic. (dB)	-1.4	-1.6	-2	-2.2	-2.35	-2.5
Tot. Effic. (dB)	-1.7	-1.9	-2.2	-2.4	-2.75	-3.2
Directivity (dBi)	10.8	10.8	10.4	8.65	8.52	8
Rlzd. Gain (dB)	8.98	8.85	8.18	6.21	5.72	4.7



(a)



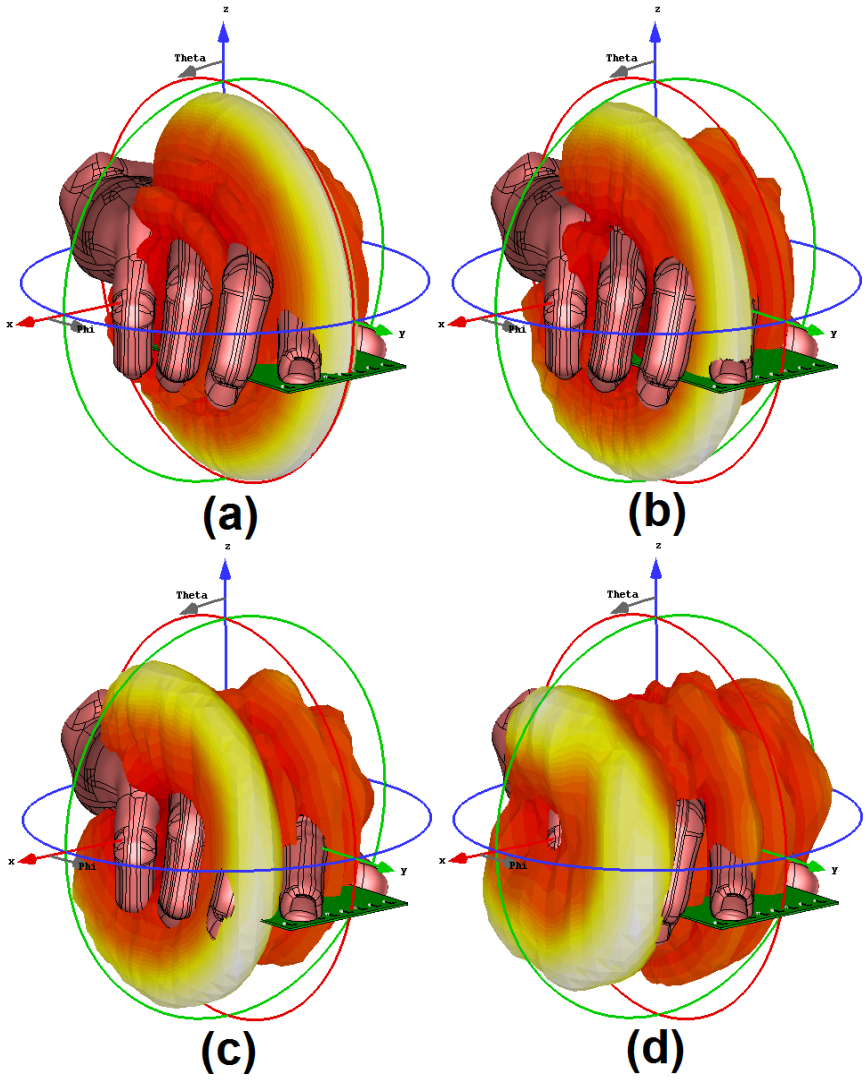
(b)

Fig. 12 Realized gains of the antenna at (a) plus and (b) minus scanning angles

Fig. 13 displays the 3D directional radiation beams of the antenna in the vicinity of human-hand at 19 GHz. It can be observed that the antenna has a good scanning function with sufficient directivity values in the presence of the human-hand. The fundamental radiation characteristics of the antenna beams at different angle are specified in Table II. The total losses of antenna parameters in terms of radiation efficiency, total efficiency, directivity, and realized gain, are about -2 dB, -2 dB, 1 dBi, and 3.5 dB, respectively.

VI. Conclusions

In this study, a design of wide-scan beam-steerable 5G mobile phone antenna array is presented for cellular communication applications. The antenna configuration consists of a 1×8 beam-steerable array antenna placed on the top portion of smartphone PCB with the size of 60×120 mm^2. The radiation elements of the employed array are designed to work at 19 GHz and have compact. Fundamental radiation characteristics of the 5G antenna along with hand-impact have been investigated study.



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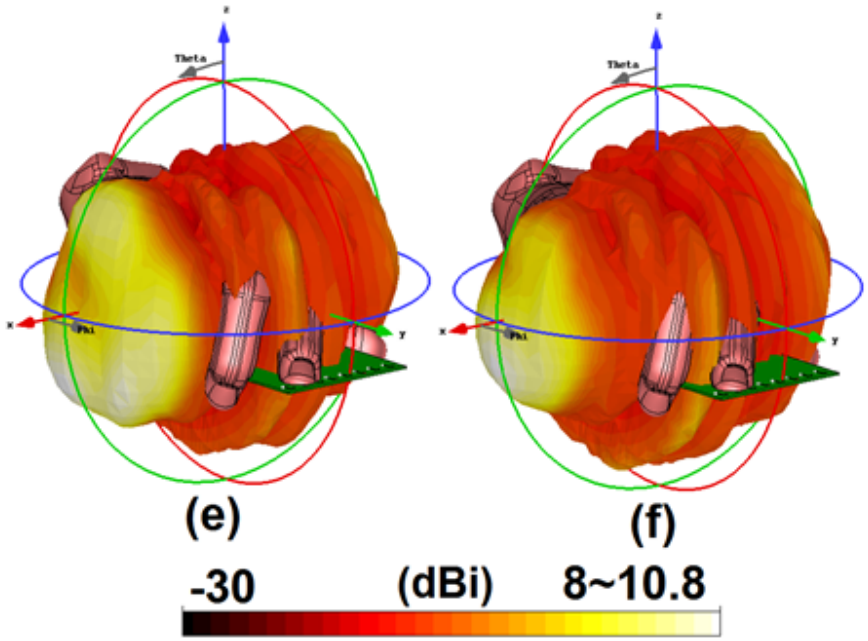


Fig. 13 Radiation beams of the antenna in the presence of user's hand at (a) 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 75°

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