International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:14, No:5, 2020

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

***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.

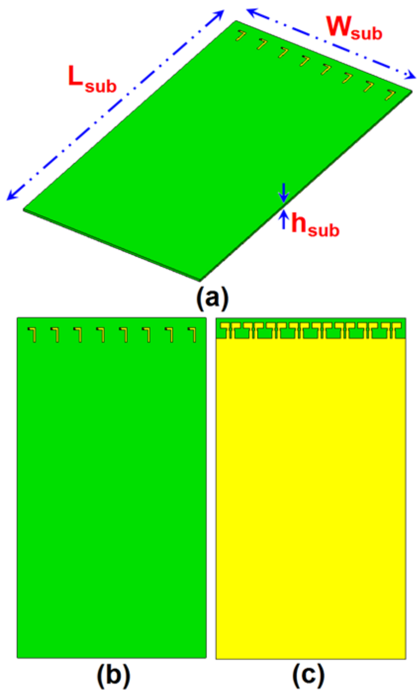


Fig. 1 The Proposed 5G mobile-phone antenna schematic, (a) side, (b) top, and (c) bottom profiles

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 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.

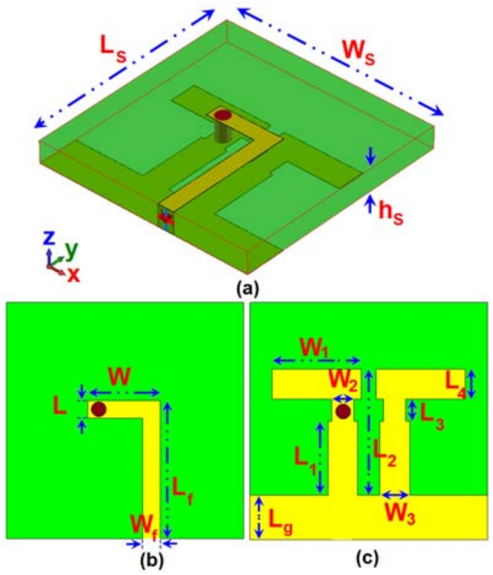


Fig. 2 Single element antenna configuration, (a) transparent view, (b) top view, and (c) bottom view

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

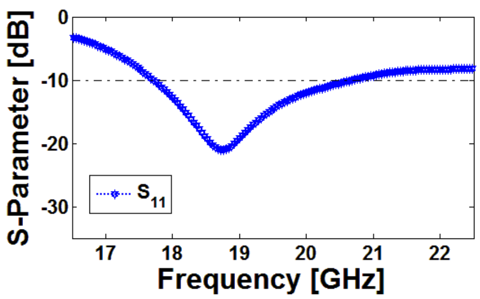


Fig. 3 S_{11} characteristic of the antenna

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.

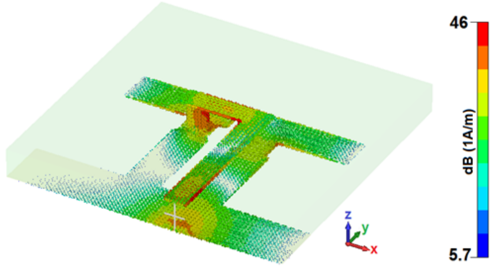


Fig. 4 Simulated current distribution at 19 GHz

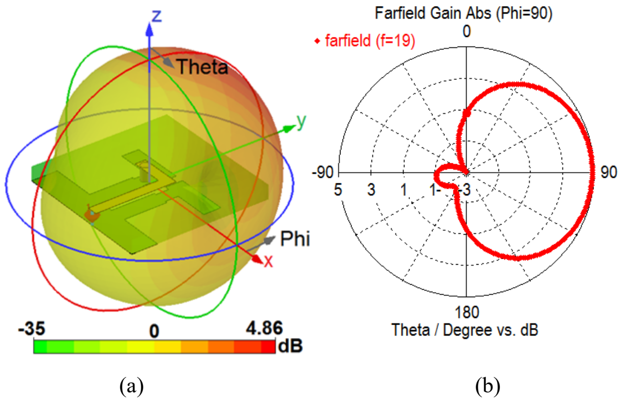


Fig. 5 (a) 3D and (b) 2D radiation patterns at 19 GHz

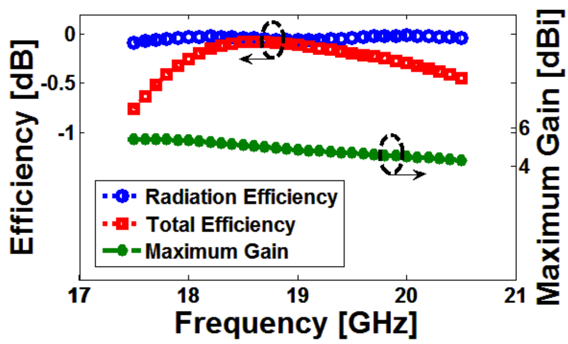


Fig. 6 Fundamental properties of the single-element antenna

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 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.

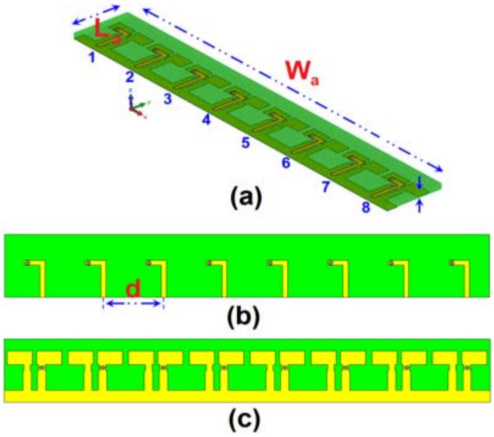


Fig. 7 (a) 3D, (b) top, and (c) bottom views of the linear array

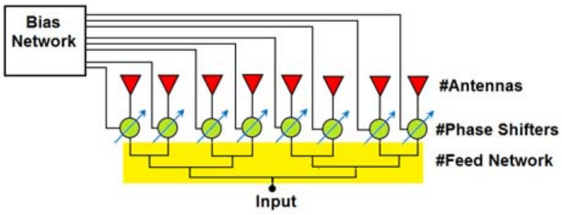


Fig. 8 Phased array architecture for the proposed array

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.

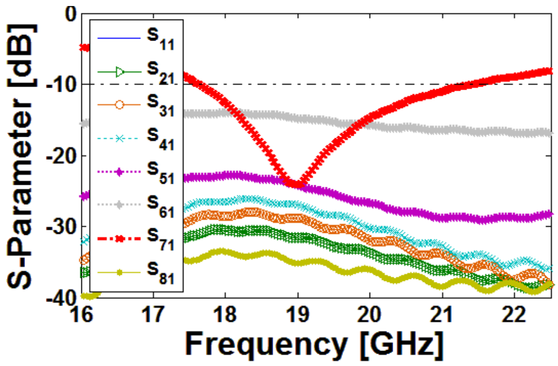
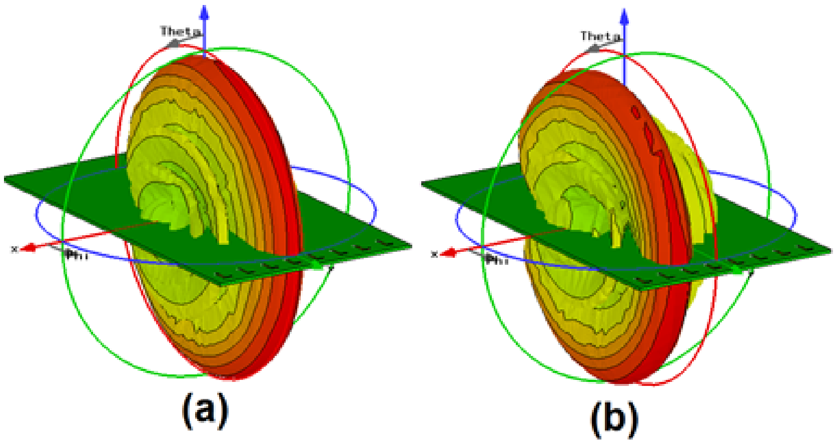


Fig. 9 S parameters of the designed 5G antenna

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].



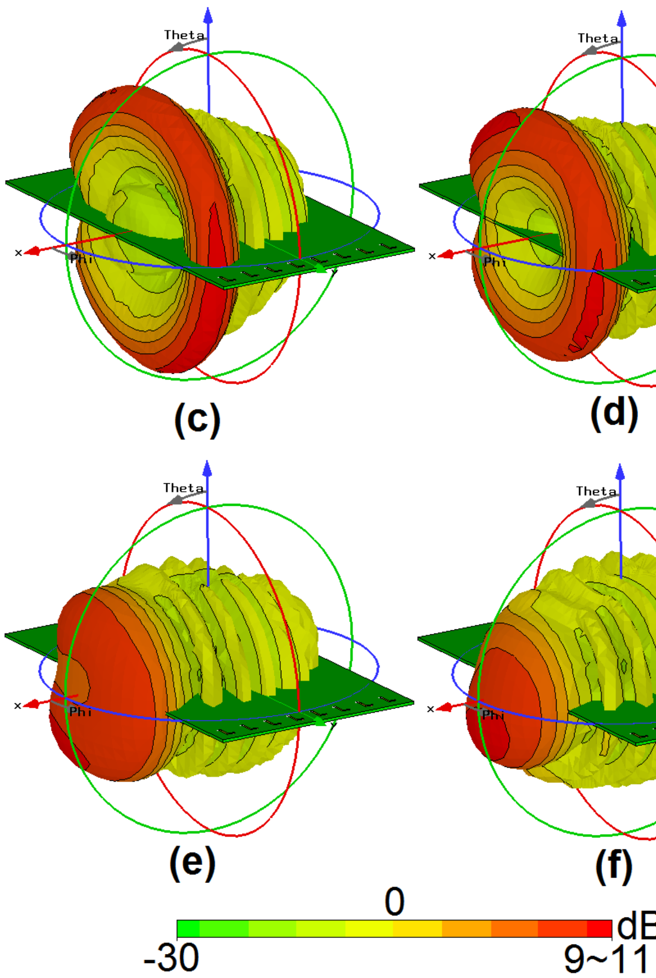


Fig. 10 Simulated array beams at (a), 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 75°

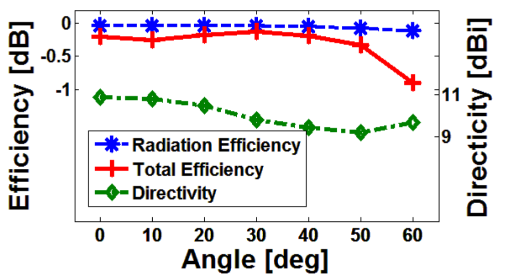


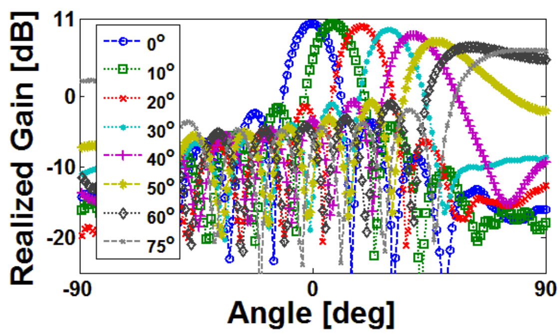
Fig. 11 Fundamental radiation properties (efficiency & directivity) of the 5G antenna at different angles

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

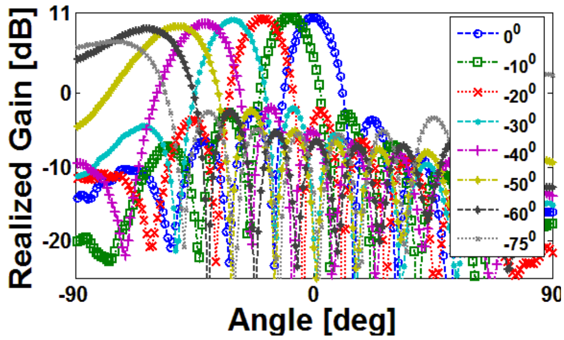
In this section, the radiation performance of the antenna in terms of efficiency, scanning, and gain values in the presence of human-hand are discussed. Generally, we should expect a negative impact of the hand on the antenna radiation performance. It can also have the influence of the impedance-matching 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)



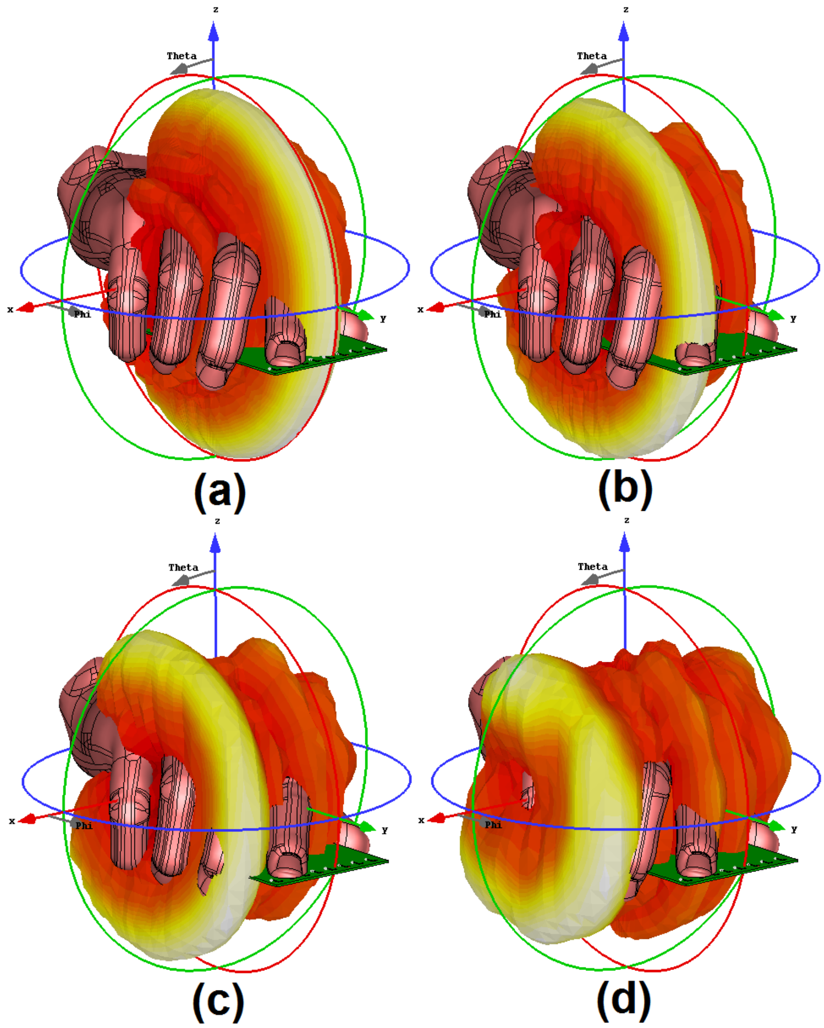
(b)

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.



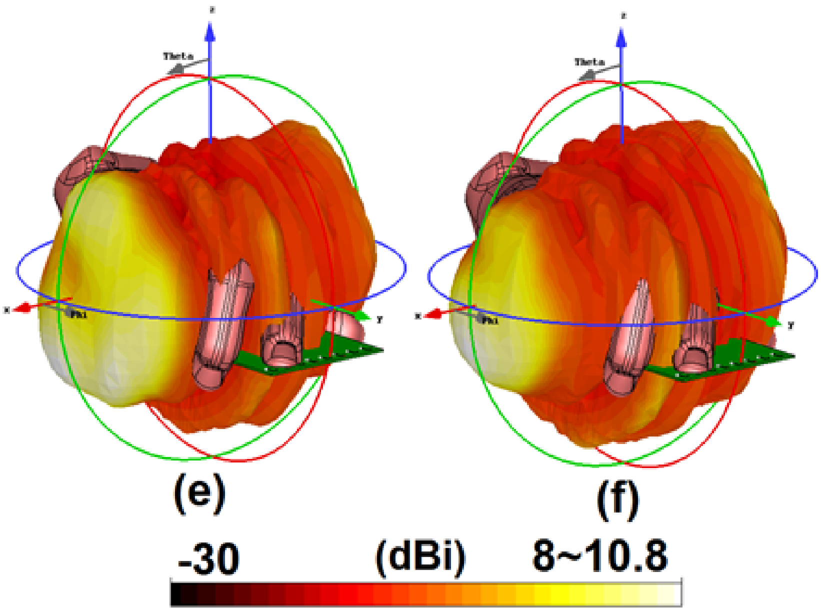


Fig. 13 Radiation beams of the antenna in the presence of user's hand at (a) 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 75°

ACKNOWLEDGMENT

This work is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement H2020-MSCA-ITN-2016 SECRET-722424.

REFERENCES

[1] P. Gupta, "Evolvement of mobile generations: 1G to 5G," International Journal for Technological Research in Engineering, vol. 1, pp. 152-157, Nov. 2013.
[2] Y. Wang, et al., "5G mobile: Spectrum broadening to higher-frequency bands to support high data rates," IEEE Vehicular Technology Magazine, vol. 9, pp. 39-46, 2014.
[3] H. J. Basherlou, et al., "MIMO monopole antenna design with improved isolation for 5G WiFi applications," International Journal of Electrical and Electronic Science, vol. 7, pp. 1-5, 2019.
[4] T. Bai, and R. Heath, "Coverage and rate analysis for millimeter wave cellular networks," IEEE Transactions on Wireless Communications, vol. 14, pp. 110-1114, 2015.
[5] N. O. Parchin, et al., "Design of low cost FR4 wide-band antenna arrays for future 5G mobile communications," International Symposium on Antennas and Propagation (ISAP), Xian, China, 2019.
[6] W. Roh et al., "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results," IEEE Commun. Mag., vol. 52, pp. 106–113, 2014.
[7] N. O. Parchin et al., "A radiation-beam switchable antenna array for 5G smartphones," Photonics & Electromagnetics Research Symposium (PIERS), Xiamen, China, 2019.
[8] Y. Al-Yasir, et al., "New radiation pattern-reconfigurable 60-GHz antenna for 5G communications," Modern Printed Circuit Antennas, IntechOpen, 2019.
[9] N. O. Parchin, et al., "Frequency-switchable patch antenna with parasitic ring load for 5G mobile terminals," International Symposium on Antennas and Propagation (ISAP), Xian, China, 2019.
[10] N. O. Parchin, R. A. Abd-Alhameed, "A compact Vivaldi antenna array for 5G channel sounding applications," EuCAP, London, UK, 2018.
[11] S. Rajagopal, S. Abu-Surra, Z. Pi and F. Khan, "Antenna array design for multi-gbps mmwave mobile broadband communication," Proc. IEEE GLOBECOM'2011, Houston, Texas, USA, pp.1-6, 2011.
[12] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Multi-layer 5G mobile phone antenna for multi-user MIMO communications," Telecommunications Forum, November 2015, Serbia.
[13] W. Hong, et al., "Design and analysis of a low-profile 28 GHz beam steering antenna solution for future 5G cellular applications," IEEE international microwave symposium, 1-6 June 2014, Florida, 2014.
[14] W. Hong, et al., "mmWave phased-array with hemispheric coverage for 5th generation cellular handsets," EuCAP, pp. 714-716, 2014.
[15] N. O. Parchin, et al., "Frequency reconfigurable antenna array for mm-Wave 5G mobile handsets," BroadNets, Faro, Portugal, 19–20, September 2018.
[16] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Beam-steerable microstrip-fed bow-tie antenna array for fifth generation cellular communications," EuCAP 2016, Switzerland, 2016.
[17] N. Ojaroudiparchin, et al., "Design of Vivaldi antenna array with end-fire beam steering function for 5G mobile terminals", 23rd Telecommunications Forum, Belgrade, Serbia, 2015, pp. 587–590.
[18] Y. Ojaroudi et al., "Circularly polarized microstrip slot antenna with a pair of spur-shaped slits for WLAN applications", Microw. Opt. Technol. Lett., vol. 57, pp. 756-759, 2015.
[19] N. O. Parchin, "Low-profile air-filled antenna for next generation wireless systems," vol. 97, pp. 3293–3300, 2017.
[20] Q. Chen, et al. "Design considerations for millimeter wave antennas within a chip package," IEEE International Workshop on Anti-counterfeiting, Security, Identification, Xiamen, pp. 13-17, 2007.
[21] A. Ullah, et al., "Coplanar waveguide antenna with defected ground structure for 5G millimeter wave communications," IEEE MENACOMM'19, Bahrain, 2019.
[22] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Investigation on the performance of low-profile insensitive antenna with improved radiation characteristics for the future 5G applications," Microw. Opt. Technol. Lett., vol. 58, pp. 2148-2158, 2016.
[23] N. Amitay, V. Galindo, C. P. Wu, "Theory and analysis of phased array antennas," Wiley-Interscience, New York, 1972.
[24] N. O. Parchin, et al., "UWB mm-wave antenna array with quasi omnidirectional beams for 5G handheld devices," IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), 2016.
[25] N. O. Parchin et al., "A substrate-insensitive antenna array with broad bandwidth and high efficiency for 5G mobile terminals," Photonics & Electromagnetics Research Symposium (PIERS), Xiamen, China, 2019.
[26] N. O. Parchin et al., "High-performance Yagi-Uda antenna array for 28 GHz mobile communications," 23^{th} Telecommunications Forum, TELFOR 2019, 25–27 November, 2019, Belgrade, Serbia.
[27] N. O. Parchin et al., "Reconfigurable phased array 5G smartphone antenna for cognitive cellular networks," 23^{th} Telecommunications Forum, TELFOR 2019, 25–27 November, 2019, Belgrade, Serbia.
[28] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "8 × 8 planar phased array antenna with high efficiency and insensitivity properties for 5G mobile base stations," EuCAP 2016, Davos, Switzerland, pp. 1–5.

[29] J. Ilvonen, et al., "Mobile terminal antenna performance with the user's hand," IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 772-775, 2000.
[30] N. O. Parchin, et al., "MM-wave phased array quasi-yagi antenna for the upcoming 5G cellular communications," Applied Sciences, vol. 9, pp. 1-14, 2019.