Small-Clearance Phased Array Antenna Design with Miniaturized Elements for 5G Communications

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Abstract. In this paper, highly miniaturized radiation elements organized in a linear phased array form is introduced for fifth generation cellular communications. The design structure is composed of eight low-profile folded-dipole in the x-y plane located at the top portion of the printed circuit board (PCB) with Rogers RT5880 substrate. The radiation elements of the design are etched on the same layer of the ground plane. The proposed array is highly compact which occupies only 0.5 mm (clearance) of the PCB plane. The critical properties of the introduced phased array are investigated. The designed antenna exhibits wide beam-steering, high efficiencies, and sufficient gain levels at 28 GHz, the main 5G band. In addition, the proposed phased array design has sufficient radiation behavior in the adjacency of user-hand phantom.

Keywords: 5G, folded-dipole antenna, miniaturized antenna, smartphone applications.

1 Introduction

The development of 5G technology has been an on-going process recently. It requires high data capacity and transmission speed. To support the increasing demand of high transmission rate with throughput for various fixed and mobile services, phased arrays with multiple antenna elements have been attracting much more attention for next-generation communication networks at mm-Wave frequency spectrum [1-4].

28 GHz is the most promising band for 5G wireless communications [5-8]. Increasing the operation frequency of the future wireless systems need novel and different techniques of the antenna design for future wireless devices [9-12]. Compact antennas can be arranged in linear or planar array form to be used in phased array structures with high-gain characteristics for 5G wireless communications [13-15].

Different from the conventional antennas (patch, monopole, PIFA and slot antennas) with omni-directional radiation, the end-fire resonators, such as Vivaldi and Yagi are more suitable for the communication between user and base station [16-20]. However, for smartphone applications, all these antennas could occupy huge space in the smartphone broad. Since one of the challenges of the antenna design for 5G smartphones is to reduce the size of the employed antenna elements; we propose here a new antenna array design with highly miniaturized elements for 5G cellular communications. The employed antenna elements occupy a very small

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clearance (L_a=0.5 mm) of the PCB ground plane. The structure of the proposed phased array contains eight folded dipole antennas with compact profiles and 1×8 linear form are arranged in the edge of the PCB. In order to excite the antenna resonators, the discrete feeding technique is employed [21-22]. The characteristics of the designed phased array in terms of S-parameters, radiation beams, efficiencies, beam-steering, and gain levels are studied, and sufficient outputs have been achieved. Besides, the proposed 5G antenna exhibits sufficient performance in adjacency of user-hand phantom at different scanning angles.

2 Schematic of the Phased Array

The schematic of the introduced phased array is illustrated in Fig. 1. The EM simulation CST software was used for the investigation [23]. The design procedure is simple and easy to accomplish. As can be observed, eight folded-dipole radiators with compact sizes have been arranged on the top side of the mobile-phone PCB with Rogers RT5880 substrate and overall size of 75×150×0.8 mm^3.

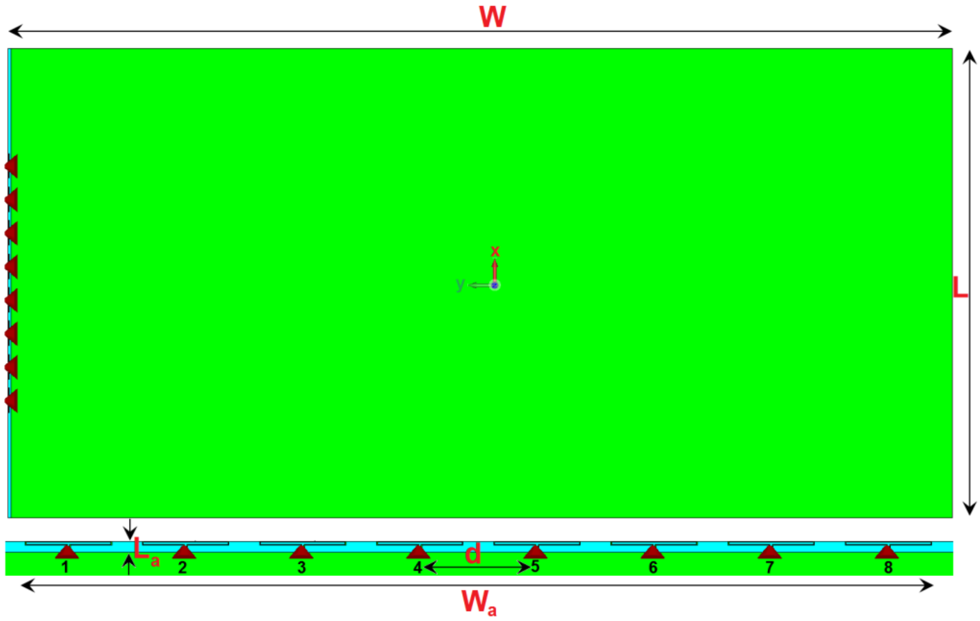


Fig. 1. Schematic of the phased array.

Table 1. Dimensions of the design parameters.

Param.	**W**	**L**	**h**	**W_a**	**L_a**	**W_1**
(mm)	150	75	0.8	41.4	0.5	3.95
Param.	L_1	W_2	L_2	W_3	L_3	W_4
(mm)	0.5	0.04	0.32	0.1	0.18	1.89

2 The Single-Element Folded-Dipole

Figure 2 (a) plots the transparent structure of the folded-dipole antenna. The folded-dipole antenna is low profile with simple structure and flexible in nature, and low-cost since the does not require any vias or walls and can be easily accomplished in a single-layer planar surface. In addition, it can be used for size reduction of the antenna resonator [24-26]. Figure 2 (b) shows the S_{11} function of the designed folded dipole. As shown, the it provides good performance with 2 GHz frequency bandwidth.

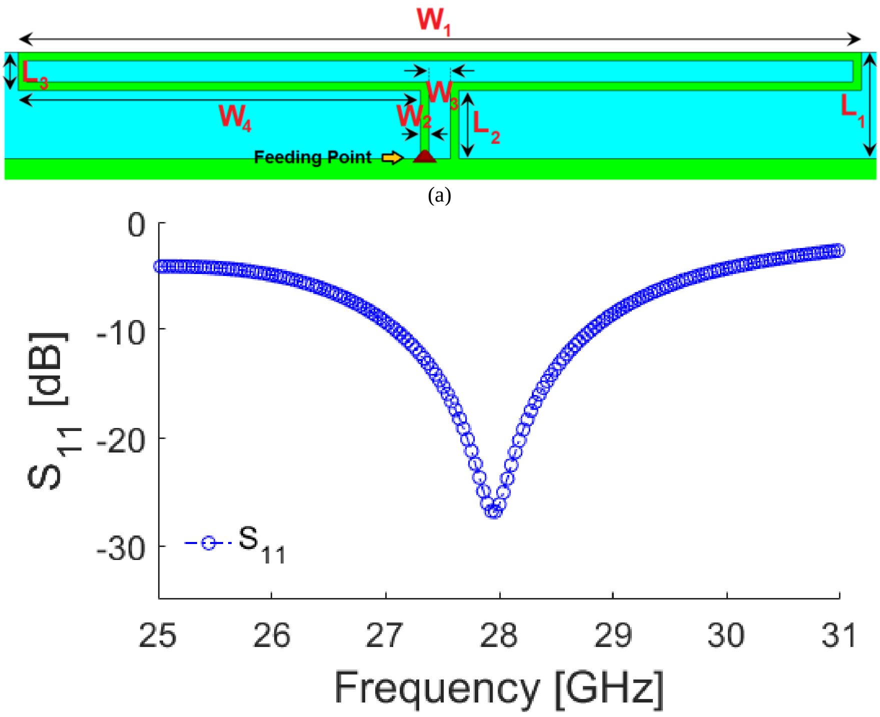


Fig. 2. (a) The folded dipole structure and (b) its S_{11} result.

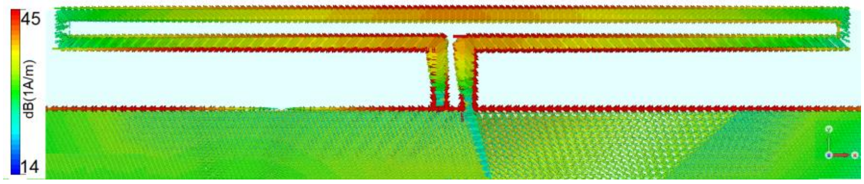
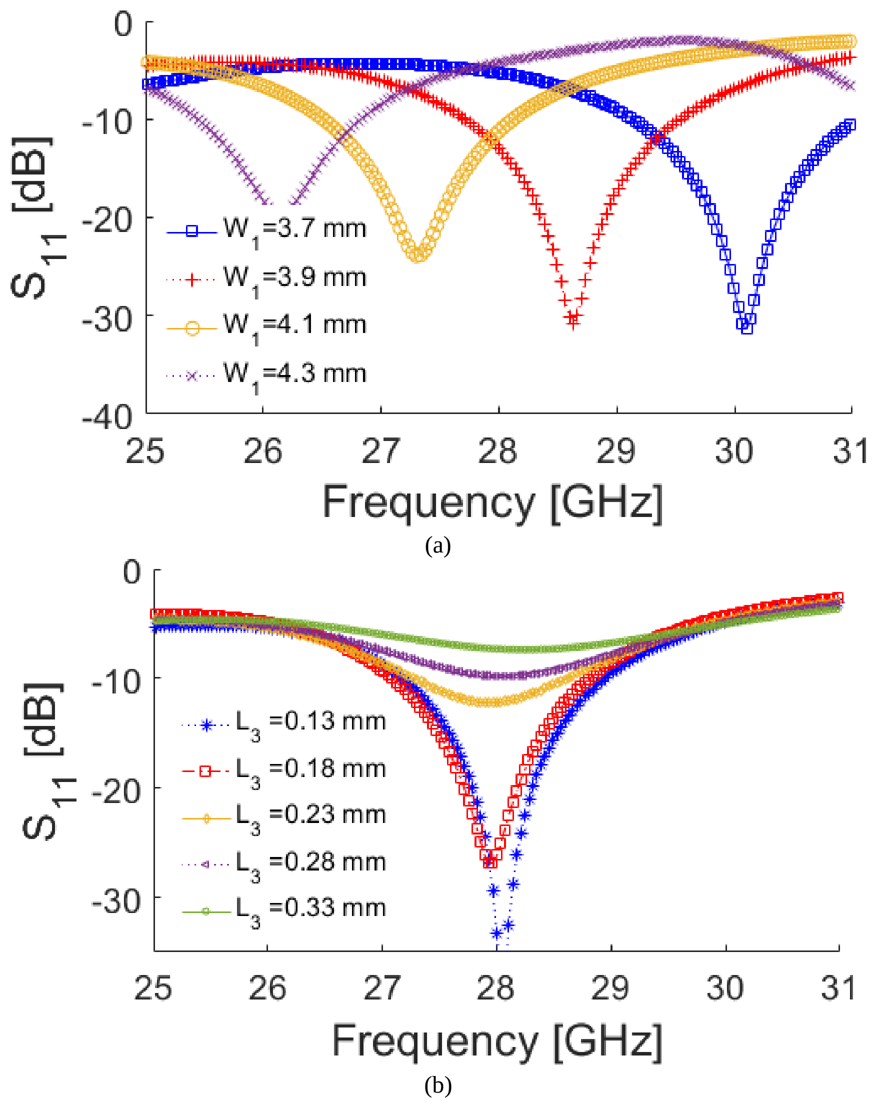


Fig. 3. The current density at 28 GHz.

Figure 3 plots the current distributions of the folded-dipole antenna at 28 GHz. It can be seen most of the currents with high densities are distributed around the folded resonator at the antenna resonance frequency. Various parameters of the folded-dipole antenna such as W_1 and L_3 have significant impacts on the operation frequency and the matching of the proposed compact design [27-30]. The S_{11} results for different widths of the antenna loop are plotted in Fig. 4 (a):

when its value changes from 3.7 mm to 4.3 mm, the resonance varies from 30 to 26 GHz while maintaining sufficient impedance matching function better than -20 dB. Another important design parameter that mainly tunes the impedance matching function is the outer length of the loop (L_3). As depicted in Fig. 4 (b), when the outer length of the loop changes from 0.33 to 0.13 mm, the matching function of the S_{11} can be varied from -5 dB to better than -35 dB. According to these results, it is evident that the proposed antenna is very flexible in terms of operation band and matching for different frequencies.



(b)

Fig. 4. The antenna S_{11} results for various values of (a) W_1 and (b) L_3.

2 The Performance of the presented Phased Array Mobile Antenna

The structure of the proposed 5G smartphone antenna is shown in Fig. 1 and described above. The radiation elements have been arranged in a linear configuration with a dimension of $W_a \times L_a$= 40×3 mm^2 with an equal distance of d=5 mm on the top portion of the PCB. Its S-parameters are plotted in Fig. 5.

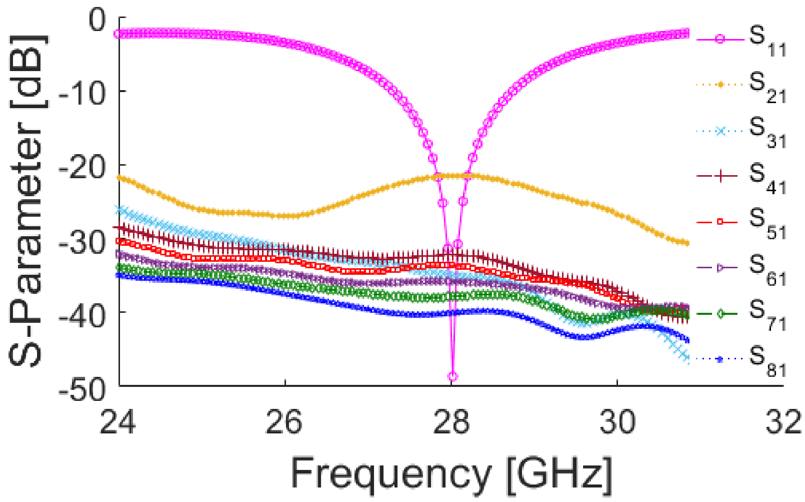


Fig. 5. S-parameter results.

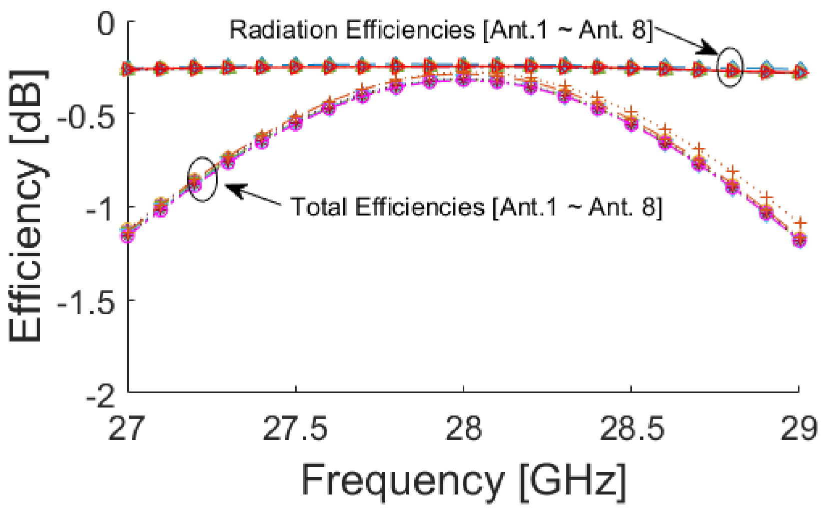


Fig. 6. Efficiencies of the elements over the frequency band.

The antenna elements of the introduced smartphone antenna exhibits high efficiencies. As clearly shown in Fig.6, the elements achieve more -0.25 (95%) radiation efficiency over the operation band. Furthermore, as seen, the antennas provide good total efficiency above -1dB (80%) with a maximum value of 95% at the resonant frequency,28 GHz. Figure 7 illustrates the

3D beams of the designed array 5G antenna for various angles from 0°~70°. As shown, the design provides excellent radiation beams that could cover the half-space of the required radiation coverage for the smartphone. Another set of the compact linear array can be placed at the bottom side of PCB to achieve a full radiation coverage [31-32].

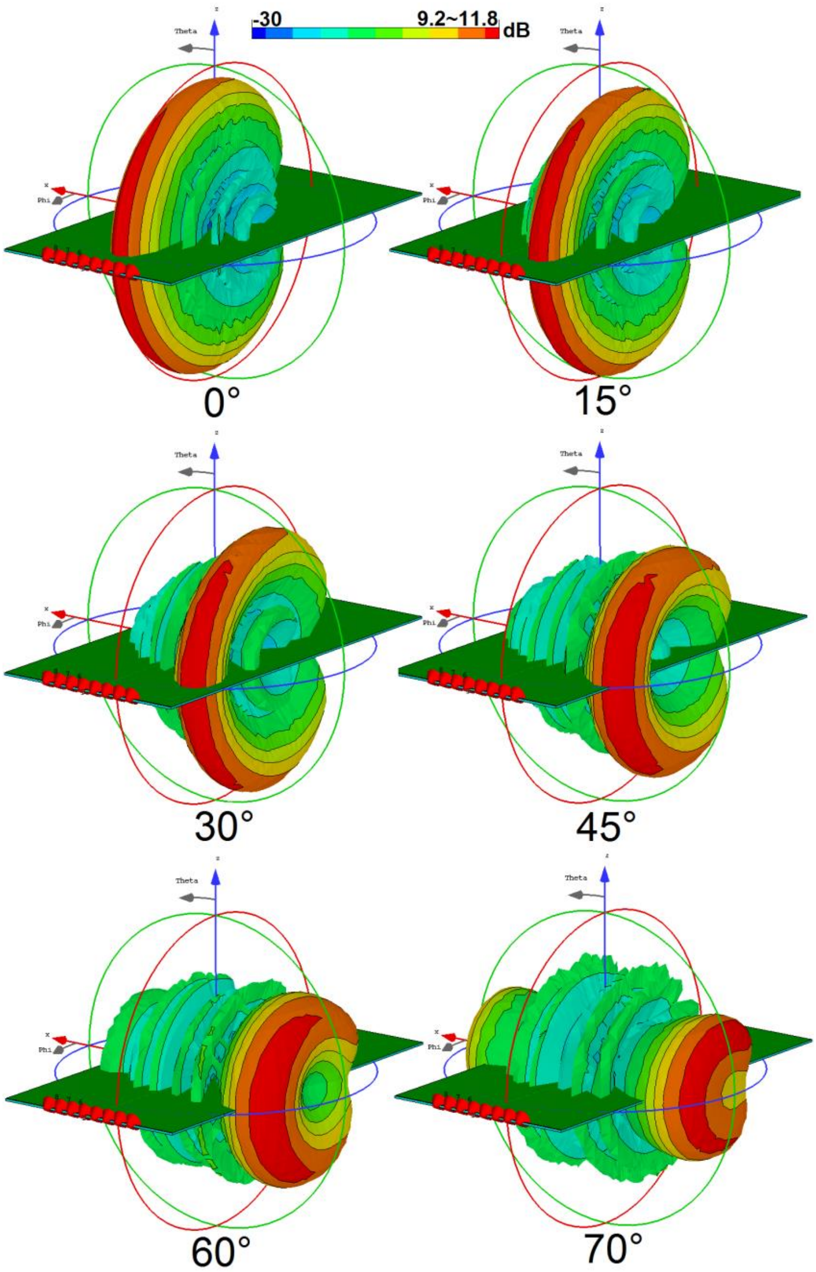


Fig. 7. 3D beams at different angles.

Figure 8 plots and also compares the gain characteristics of the element and the main design antenna over 27-29 GHz. It is seen that the element provides 4~5 dBi maximum gains. In addition, the main design (5G phased array) provides quite good maximum gain characteristic, better than 11 dBi, over the antenna band.

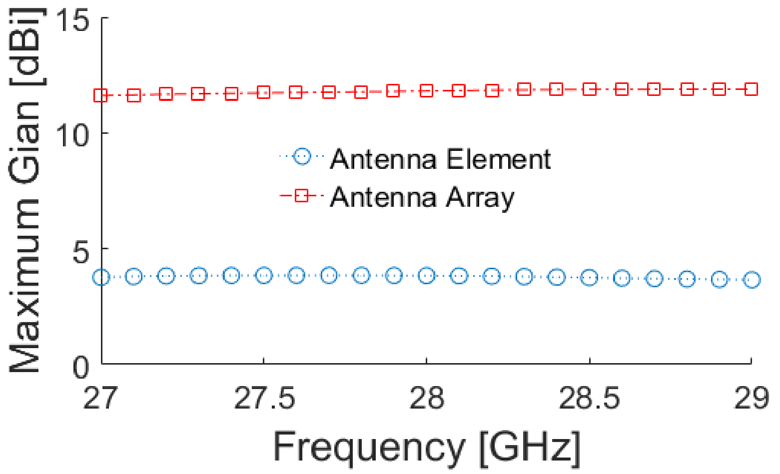


Fig. 8. Gain results of the element and the array antennas.

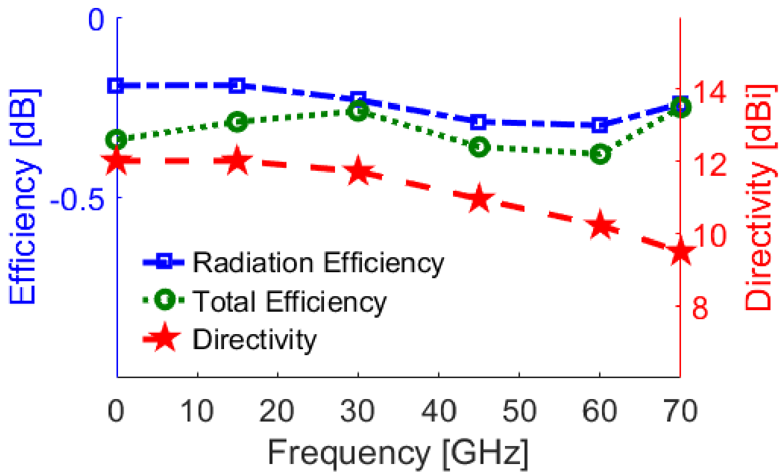


Fig. 9. Radiation characteristics at different angles.

The simulated fundamental properties including the directivity and efficiencies of the array beams over the scanning angles are represented in Fig. 9. As seen, it provides sufficient maximum gains varying from 9.5 to 12.5 dBi. In addition, the introduced phased array obtains more than 90% efficiencies over the scanning angles of 0°~70°. The 2D-cartesian beam-steering of the presented design over the scanning angle of -70°~70° plotted in Fig. 10. It is clear from the figure that the designed 5G phased array antenna exhibits symmetrical beam steering in minus/plus scanning angles [33-36]. In addition, it provides almost constant gain levels with value around 10 dB at different scanning angles.

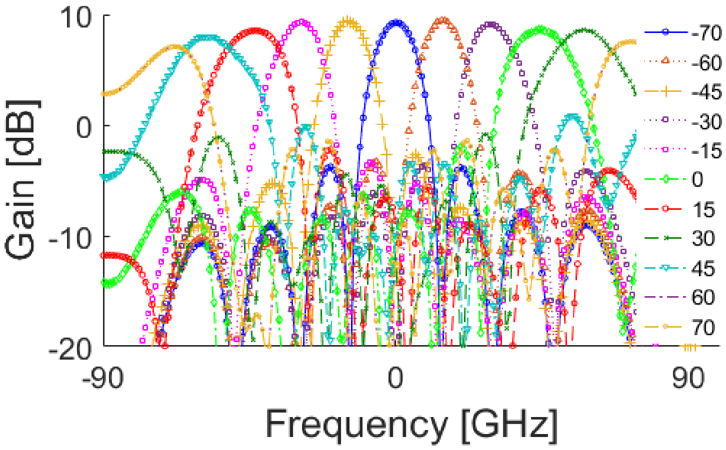


Fig. 10. 2D-cartesian beam-steerable gains for the various angles.

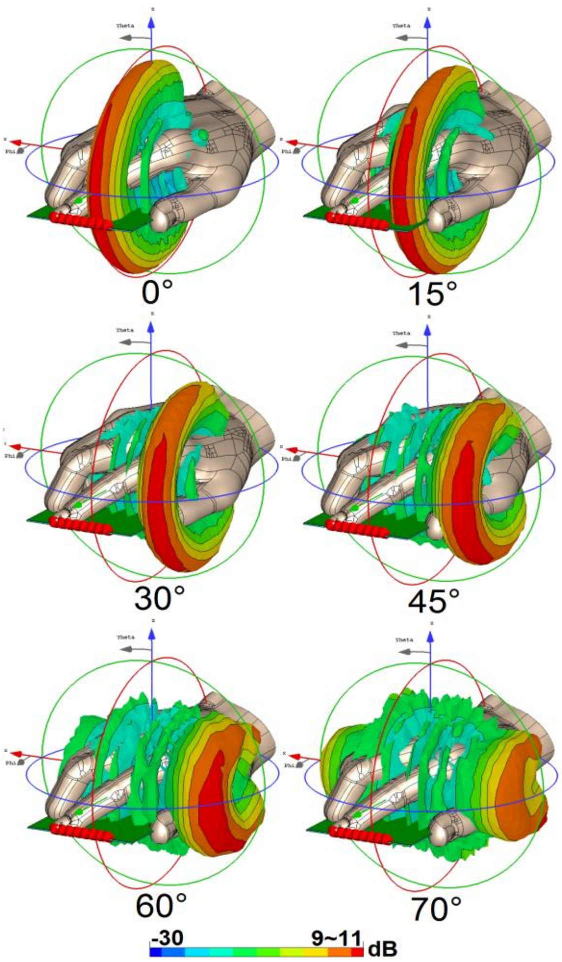


Fig. 11. 3D beams in data-mode.

The antenna characteristics in the adjacency of the user including the hand and head can be reduced. This also depends on the distance and placement of the antenna component [37-40]. Figure 11 investigated the performances in data-mode for different angles. As plotted, the antenna provides well-defined radiation beams and beam-steering at different scanning angles. This might be due to miniaturized and compact sizes of the employed element which not covered by user-hand. As can be seen, the gain levels of the beams are reduced but not significantly.

Conclusion

In this study, a compact phased array with miniaturized radiation elements is presented for 5G smartphone applications. It contains eight folded dipoles which have been linearly arranged to form a phased array on the PCB top side. The array design has a small clearance of 0.5 mm. Fundamental properties of the designed 5G antenna are investigated and quite good outputs have been achieved. It also exhibits sufficient performance in data-mode

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