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Multi-Layer 5G Mobile Phone Antenna for Multi-User MIMO Communications

Naser Ojaroudiparchin, *Student Member, IEEE*, Ming Shen, *Member, IEEE,* and Gert Frølund Pedersen, *Senior Member, IEEE*

***Abstract*— In this study, a new design of multi-layer phased array antenna for millimeter-wave (mm-Wave) fifth generation (5G) mobile terminals is proposed. The proposed linear phased array antenna is designed on four layers of the *Rogers RT5880* substrates to operate at 28 GHz which is under consideration for 5G wireless communications. Two identical linear sub arrays can be simultaneously used at different sides of the mobile-phone printed circuit board (PCB) for operation in diversity or multiple-input multiple-output (MIMO) modes. Each sub array contains eight elements of very compact off-center dipole antennas with dimensions of 5.4×0.67 mm^2. The feature of compact design with good beam-steering function makes them well-suited to integrate into the mobile-phone mock-up. The fundamental properties of the proposed antenna have been investigated. Simulations show that the proposed 5G antenna is effective for the required beam-coverage in multi-user MIMO communications.**

***Keywords*— 5G, MIMO antenna, mm-Wave applications, multi-layer antenna.**

I. Introduction

THE wireless systems for the future 5G cellular system are increasingly proposing the utilization of the mm-Wave spectrum due to growing need for wider bandwidths [1]. Some of the candidate bands for 5G communications in the frequency of 20-50 GHz [2] are specified in Fig. 1. It is expected that the deployment of 5G would be in the early of 2020s [3].

Moving to the mm-Wave frequencies for 5G mobile terminals requires new techniques in the design of antennas for mobile-station (MS) and base-station (BS) systems. In order to achieve an efficient beam-steerable phased array antenna, which is one of the most important blocks for 5G cellular systems, the smaller antennas arranged as an array can be employed [4-5].

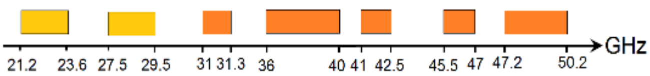

Fig. 1. The candidate bands for the future 5G systems in 20-50 GHz.

The usage of multiple-input–multiple-output (MIMO) systems at the BS and MS devices for cellular communications has received widespread attention over the past decade [6]. The architecture of multi-user MIMO mobile communications is shown in Fig. 2. This paper suggests a new multi-layer phased array with off-center dipole antenna elements for MIMO-5G mobile communication service. The proposed antenna operates in the frequency range of 27 to 29 GHz and has good realized gain, directivity, efficiency, and beam steering characteristics. The configuration and performance of the single-element off-center dipole antenna is described in Section II. Section III discusses the simulation results of the proposed phased array MIMO antenna. Last Section concludes this study.

Authors are with Antennas, Propagation, and Radio Networking (APNet) Section, Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University, DK-9220, Aalborg, Denmark (E-mails: naser@es.aau.dk, mish@es.aau.dk, and gfp@es.aau.dk).

Fig. 2. Architecture of the multi-user MIMO for 5G mobile communications.

II. Single Element Multi-Layer Dipole Antenna

The geometry of the single element off-center dipole antenna is shown in Fig. 3. The printed dipole antenna consists of two radiating arms with same length. One arm of the antenna is connected to the feeding strip-line through a feeding aperture using four layers of vertically connected vias. The other arm of the antenna is connected to the ground plane using three layers of connected vias. The antenna element has a very compact size (W_{sub}×L=5.4×0.65 mm^2) and can be used at the bezel sides of the mobile phone mock-up.

The final antenna is designed on the multi-layer *Rogers RT5880* substrate with h_{subs}, ε_r, and δ of 0.8 mm, 2.2, and 0.0009, respectively. The values of the antenna parameters are listed in Table 1.

Table 1: Values of the Antenna Parameters

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L
Value (mm)	5.4	5.5	0.2	0.65	2.5
Parameter	h_{subs}	W_f	d	r	r_1
Value (mm)	4×0.2	0.2	5.35	0.65	0.15

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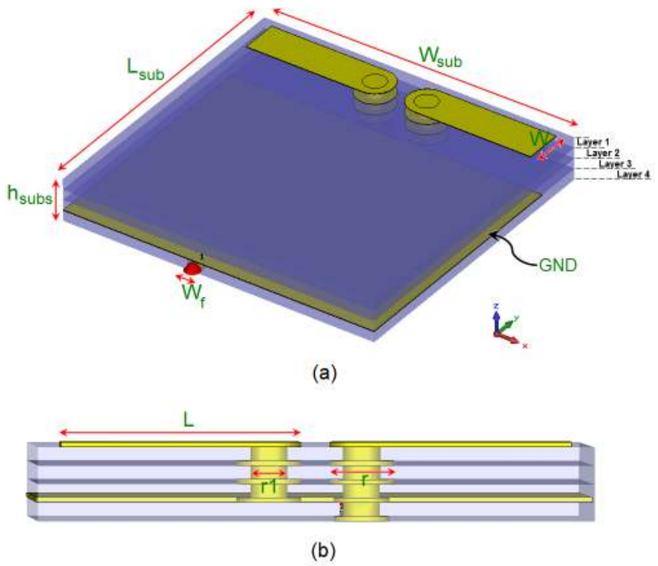

Fig. 3. The geometry of the single element antenna, (a) 3D view, (b) side view.

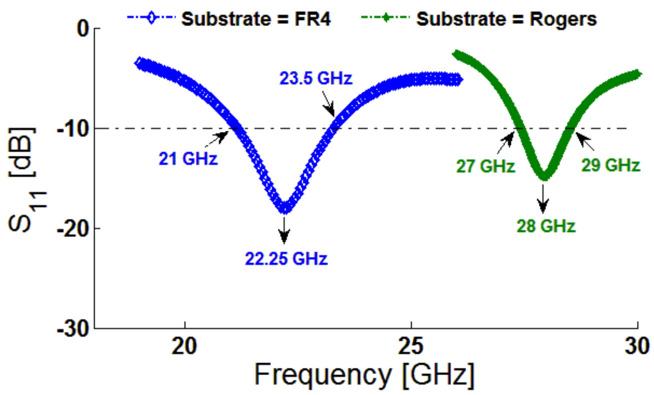

Fig. 4. Simulated reflection coefficient (S_{11}) characteristics of the antenna for different types of substrates (*FR-4 & Rogers*).

Figure 4 illustrates the simulated S_{11} characteristic of the antenna for different types of substrtaes (*FR-4 & Rogers RT5880*). As illustrated, the antenna can operate at the frequency ranges of 21-23.5 GHz and 27-29 GHz which both are the candidate bandes for the future 5G communications (Fig. 1). As the substrate is one of the most important materials in the design of microstrip printed antennas, its selection must be treated with care. A substrate with low loss tangent can increase efficiency and gain properties of the antenna and reduces microstrip losses.

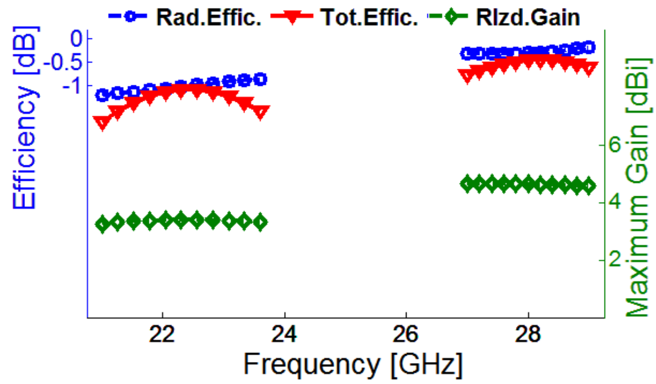

Fig. 5. Simulated radiation properties of the antenna for different types of substrates at 21-23.5 GHz (*FR-4*) and 28 GHz (*Rogers*).

Simulated radiation properties (maximum gain, radiation and total efficiencies) of the antenna for the different substrates have been illustrated in Fig. 5. As shown, the antenna with *Rogers RT5880* substrate (28 GHz) has a superior performance compared with *FR-4*. In order to have a high gain antenna with good performance, *Rogers RT5880* has been used to design the proposed 5G phased array antenna.

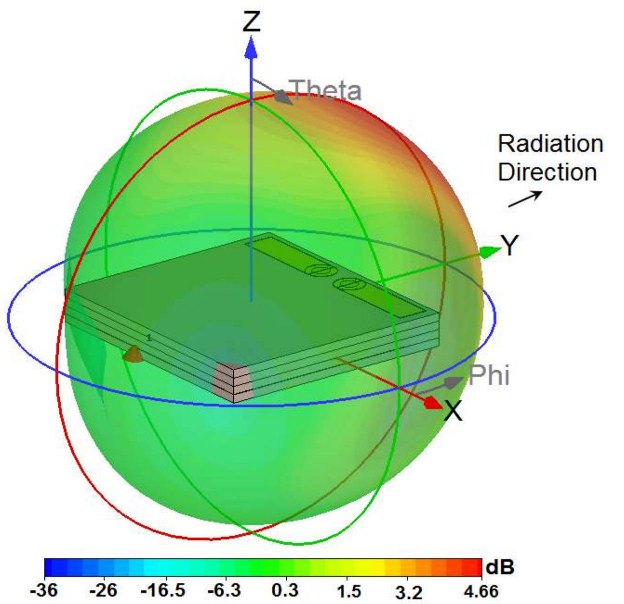

Fig. 6. 3D radiation pattern (simulated) of the antenna at 28 GHz.

The 3D radiation pattern of the single element multi-layer dipole antenna at 28 GHz is illustrated in Fig. 6. It can be seen that the antenna has a desirable radiation performance with directional (end-fire) pattern and 4.56 dB realized gain at its operating frequency. In addiation, Fig. 7 shows the simulated current distribution for the antenna at 28 GHz. As illustrated, most of the currents flow around the dipole antenna arms.

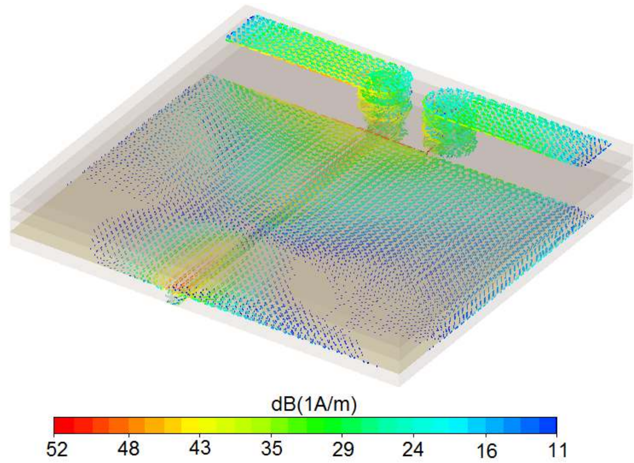

Fig. 7. Simulated current distribution of the dipole antenna at 28 GHz.

III. Proposed Beam-Streeable 5G Antenna

Figure 8 shows the schematic of the linear array with eight elements of the multi-layer dipole antennas. For uniformly spaced linear arrays, the distance between elements is calculated near λ/2 of the operation frequency (28 GHz). The values of the array parameters are listed in Table 2.

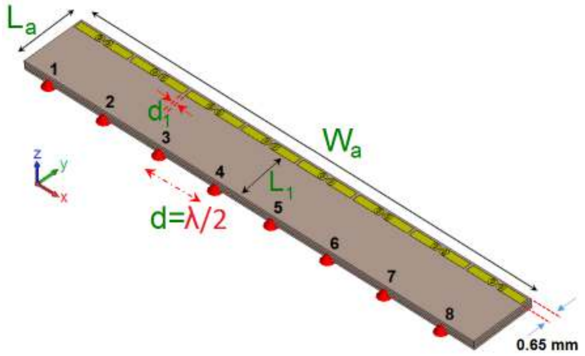

Fig. 8. Geometry of the antenna array.

TABLE 2: VALUES OF THE ARRAY PARAMETERS

Parameter	W_a	L_a	d	L_1	d_1
Value (mm)	42.5	5.5	5.35	4.68	0.25

The simulated S parameters for the array is illustrated in Fig. 9. As shown, the antenna operation frequeny is from 27 to 29 GHz with good impedance-matching and low mutual coupling characteristics.

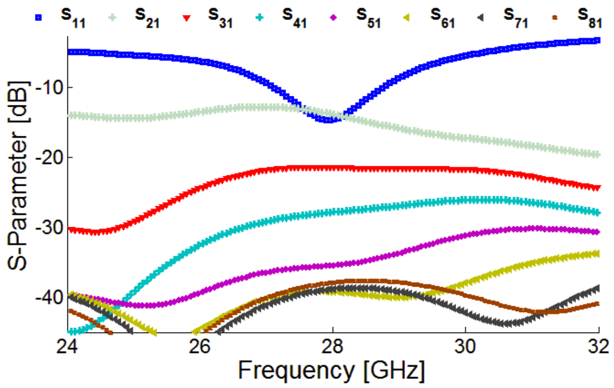

Fig. 9. Simulated S parameters of the designed array.

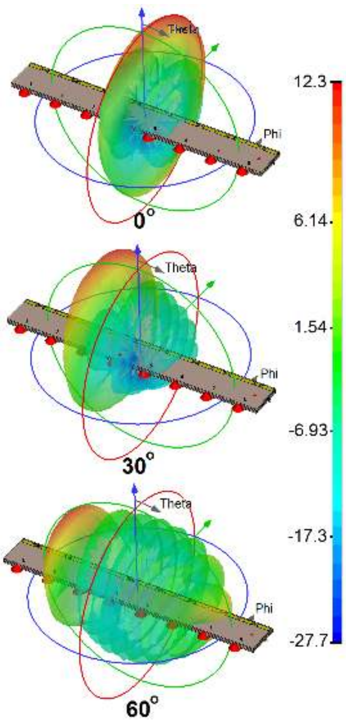

Fig. 10. Radiation patterns of the array with values of directivity for different scanning angles at 28 GHz.

The 3D radiation patterns of the array at 28 GHz when its beams are tilted to 0°, 30°, and 60° elevation are illustrated in Fig. 10, respectively. As seen, the proposed antenna has a good beam steering property with a wide range beam-coverage. It should be noted that the beam-steering characteristics of the linear antenna for plus and minus angles are almost symmetrical.

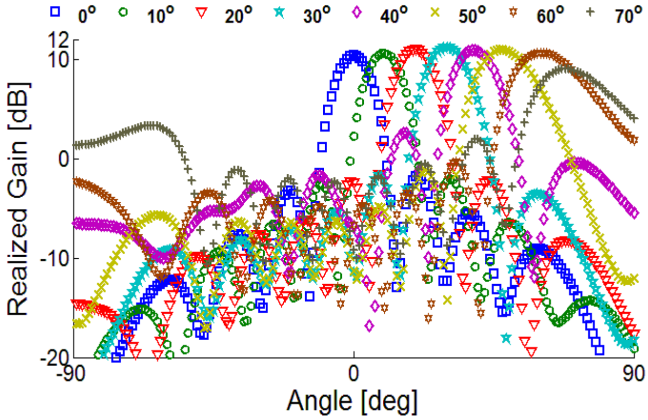

Fig. 11. Simulated realized gains of the linear array off-center dipole antenna at different scanning angles.

The simulated realized gains of the array in the scanning range of 0° to +70° are shown in Fig. 11. A stable gain with a value of 11 dB (7 dB higher compared to a single element dipole antenna) at 28 GHz is obtained for the designed array. It can be seen that the array has a good beam-steering characteristic with more than 11 dB realized gains in the scanning range of 0 to 60 degree.

The fundamental properties of the linear array beams for the scanning range of 0 to 70 degree are described in Fig. 12. As seen, for the scanning range of 10° to 60°, the antenna has more than -0.25 dB (95%) and -1 dB (80%) radiation and total efficiencies. Furthermore, as can be seen, when the scanning angle of beam-steering characteristic is ≤ +60°, the proposed antenna has more than 11 dBi directivity.

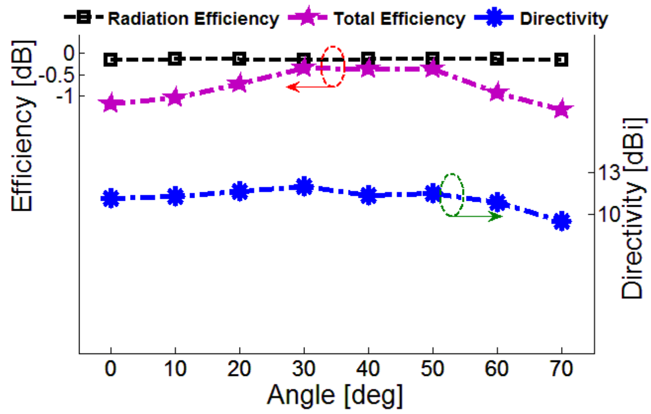

Fig. 12. Simulated directivity, radiation efficiency and total efficiency characteristics of the linaer over the scanning range of 0 to 70 degree.

Final configuration of the proposed 5G antenna is shown in Fig. 13. As it can be seen, two sets of the designed linear arrays (sub array 1 & sub array 2) with eight elements of 28 GHz dipole antennas have been used at different sides of a mobile phone PCB. The performances of the sub arrays at different sides of PCB are almost the same.

Figure 14 shows the surface current distributions of the proposed 5G antenna at 28 GHz when sub array 1 and sub array 2 are fed separately. For both of the sub arrays the currents have concentrated on the edge regions of the mobile phone PCB and the current flows are distributed around the arms of off-center dipole antennas.

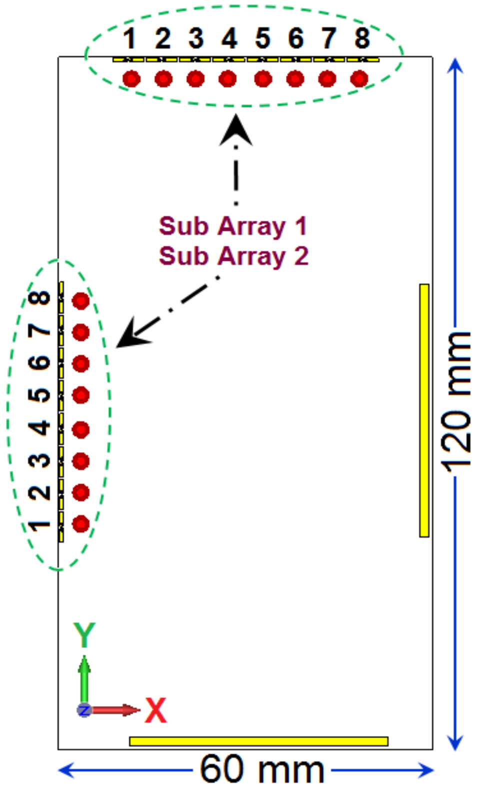

Fig. 13. Configuration of proposed 5G antenna with two sets of sub arrays.

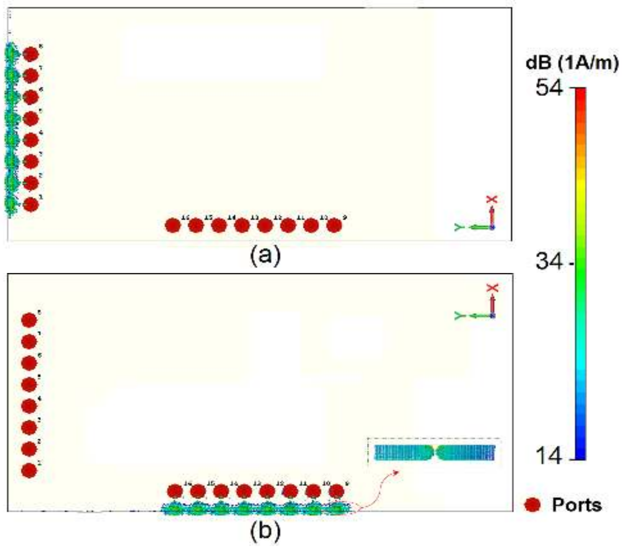

Fig. 14. Simulated current distributions of the proposed 5G MIMO antenna at 28 GHz for, (a) sub array 1, and (b) sub array 2.

The directional beam steering results of the antenna radiation patterns for the employed sub arrays at different scanning angles are illustrated in Fig. 15. As seen, in presence of mobile phone PCB with full ground plane, both of the sub arrays have good beam steering performance with high-gains and wide range coverage which are highly effective for the required beam-coverage in MIMO communications of 5G cellular handsets.

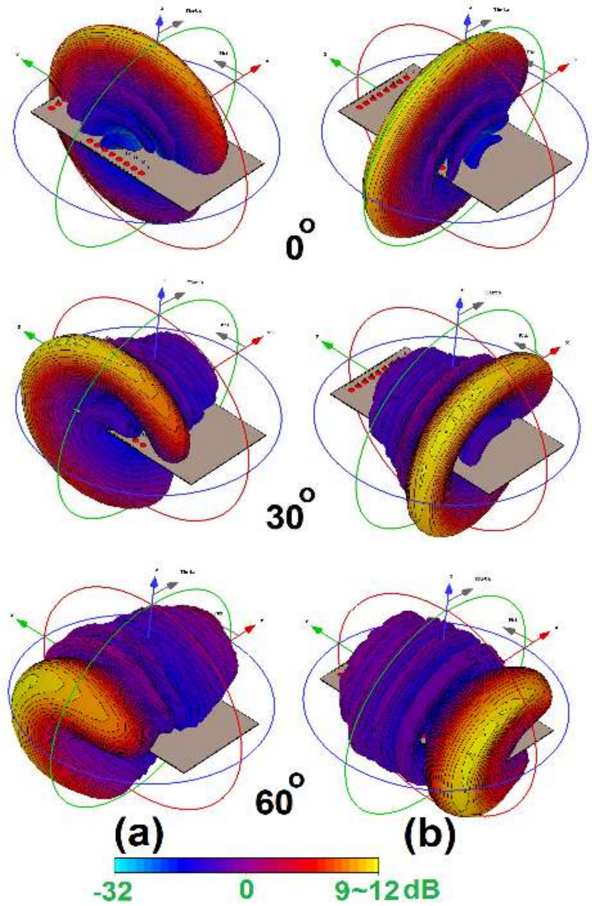

Fig. 15. 3D radiation beams of the proposed antenna at different scanning angles for, (a) sub array 1, and (b) sub array 2.

IV. Conclusion

The design of a phased array dipole antenna for multi-user MIMO communications has been presented in this paper. For the proposed design, two sets of off-center dipole arrays have been used on the top and side regions of the cellular handset PCB with a dimension 60×120 mm^2. The sub arrays can operate in diversity or MIMO modes of 5G communication. The simulations show that the proposed multi-layer design satisfies general requirements such as compact-size, high-gain, high-efficiency, and good beam steerable radiation beams for 5G cellular application.

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