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Wide-Scan Phased Array Antenna Fed by Coax-to-Microstriplines for 5G Cell Phones

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***Abstract*—The new design and analysis of a wide-scan phased array antenna for the future 5G cellphone platforms is proposed in this manuscript. The antenna is designed on a low-cost FR-4 substrate with 0.8 mm thickness, 4.3 permittivity, and overall size of $W_{sub}\times L_{sub}$=60×120 mm^2. Eight dipole antenna elements fed by coax-to-microstriplines have been used to form a linear array at the top portion of the cellphone PCB. The antenna is working at 24 GHz and has end-fire radiation beams with a wide-angle scanning capability. The simulated results in terms of different antenna specifications have been presented and discussed.**

Keywords—5G cellphones; dipole antenna; low-cost substrate; wireless communications

I. Introduction

Due to the growing need for wider bandwidths and higher data rates, fifth generation (5G) cellular systems are motivated to utilize higher frequency spectrums [1-2]. Different from the design of antennas for previous generation mobile networks, antenna designs for the future wireless systems at higher frequencies (beyond 10 GHz) would face more challenges [3]. The smaller antennas can be employed on the top/bottom portions of the cellphone PCB to form phased array antennas with end-fire beams [4-5].

Besides designing the antennas, feeding mechanism is also a challenge and a competitive research topic. In general, the end-fire antenna elements (such as Vivaldi, Yagi, dipole, and etc.) are fed by microstriplines. The measurement of these antennas can only be performed with a coaxial measurement system due to the big ground plane of cellphone PCBs [6].

In this work, we propose a design of dipole antenna array with a new feeding technique for 5G cellular systems. In the proposed design, eight dipole antenna elements fed by coax-to-microstriplines have been used to form a linear array at the top portion of cellphone PCB. In addition, in order to provide a much better transition, truncated crown of vias have been used around the feeding point and along the top/bottom layers of the radiators. The antenna is working from 23 to 25 GHz and has good beam-steering property with sufficient directivity values. It also has a wide-angle scanning property.

II. 5G Antenna Configuration

The proposed 5G antenna illustrated in Fig. 1 is designed using the low-cost/high-loss FR4 substrate with properties of h=0.8 mm, ε= 4.3, and δ=0.025. As shown in Fig. 1, eight elements of dipole antennas with coax-to-microstriplines feeding mechanism have been used at the top portion of the PCB. In order to obtain wide-angle scanning function, the distance between radiators is calculated slightly less than λ/2 of the resonance frequency.

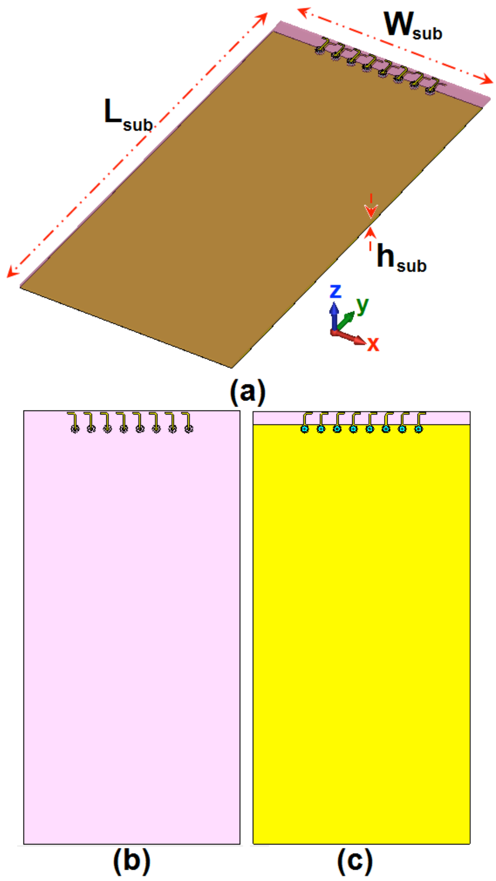

Fig. 1. Proposed 5G antenna, (a) 3D, (b) top, and (c) bottom views.

III. 24 GHz Dipole Antenna

Figure 2 displays the geometry of the single element dipole antenna. As illustrated in Fig. 2, the center conductor of the coaxial probe is connected with the microstrip-line of the dipole and also the outer conductor with the ground plane. A truncated crown of vias have been used along the top/bottom layers of the antenna. The antenna has a low profile with overall size of W×L. The final dimensions of the designed antenna parameters are listed in Table I.

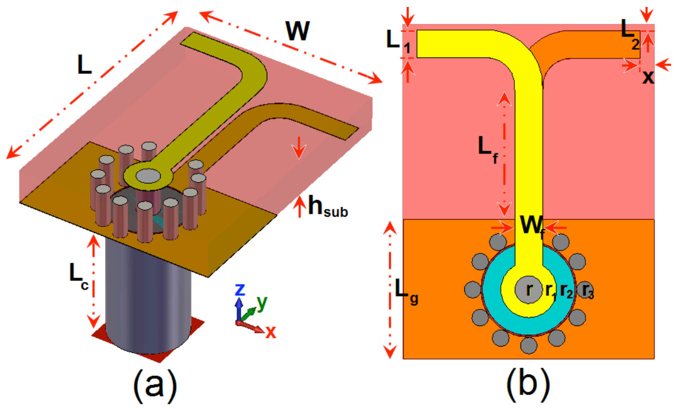

Fig. 2. Transparent (a) 3D and (b) top views of the coax-to-microstripline-fed dipole antenna.

TABLE I. Dimension Values of the Antenna

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L	W_f
Value (mm)	60	120	0.8	4.5	6	0.5
Parameter	L_f	L_C	L_1	L_2	W_a	L_a
Value (mm)	2.3	3	0.5	0.1	36	6.2
Parameter	x	r	r_1	r_2	r_3	L_g
Value (mm)	0.25	0.25	0.5	0.86	0.15	2.25

Figure 3 depicts the simulated frequency response (S_{11}) of the antenna. As illustrated, the antenna has 2 GHz bandwidth and operates in the frequency range of 23 to 25 GHz. The current distribution of the dipole antenna has been represented in Fig. 4. It can be observed at the resonance frequency (24 GHz), most of the currents are concentrated around the dipole arms. Therefore, due to the resonant properties of the antenna arms, the antenna impedance can be changed at this frequency and provides an operation band below -10 dB [7].

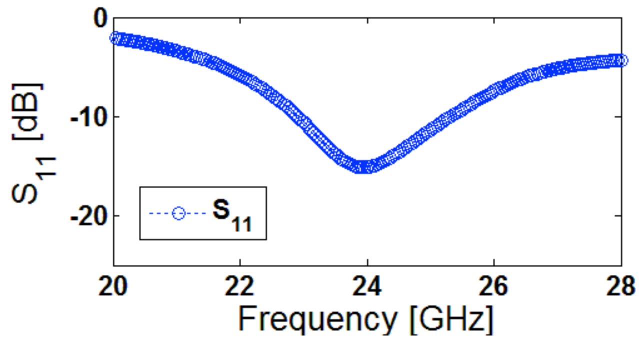

Fig. 3. Frequency response of the antenna.

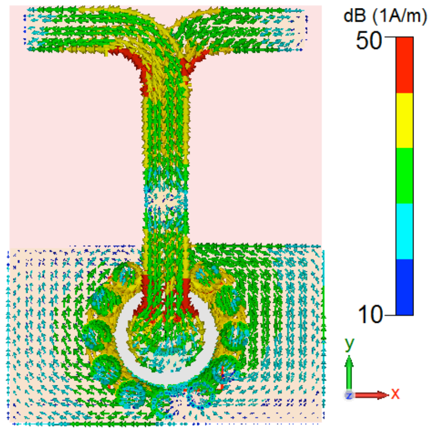

Fig. 4. Current distribution of the antenna at 24 GHz.

Based on the obtained results shown in Fig. 5, the frequency response and impedance-matching characteristics of the proposed dipole design can be optimized by adjusting the values of the critical parameters such as L_g, L_2, and x.

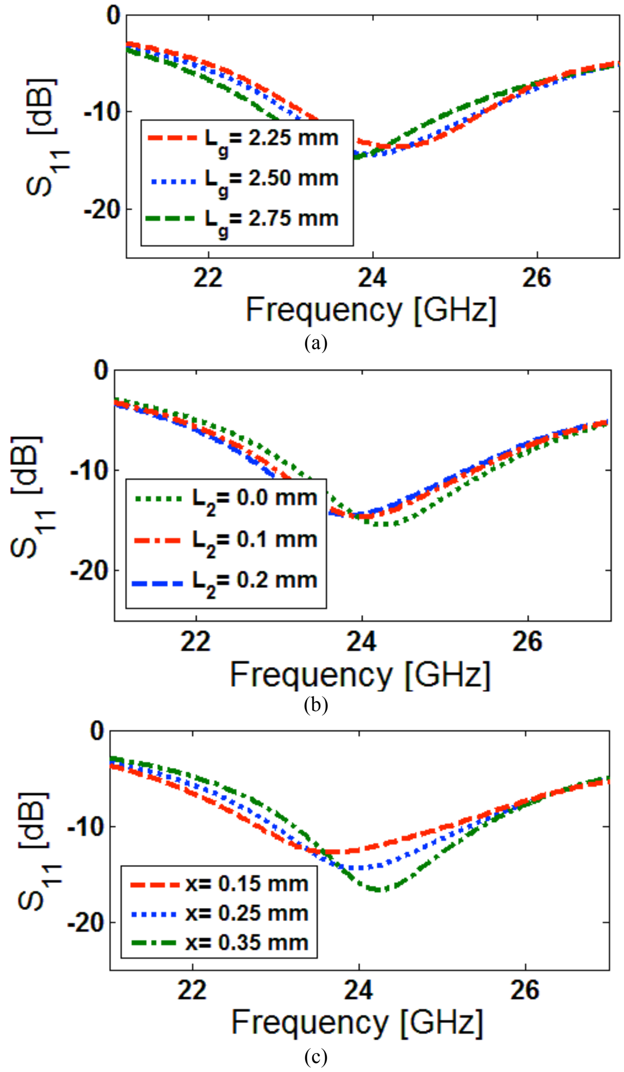

Fig. 5. Simulated S_{11} characteristics of the antenna due to different values of (a) L_g , (b) L_2, and (c) x.

As illustrated in Figs. 5(a) and 5(b), when the values of L_g (length of the ground plane) and L_2 (distance between dipole arms with top of the substrate) increase from 2.25 to 2.75 mm and 0.0 to 0.2 mm respectively, the center of the antenna resonance decreases from 24.25 to 23.75 GHz. In addition, the value variation of x (width of the dipole arms) has main effect on the impedance-matching characteristic of the antenna as shown in Fig. 5(c).

Figure 6 illustrates the 3D and 2D radiation patterns (simulated) of the antenna at 24 GHz. The obtained results show that the proposed coax-to-microstripline-fed dipole antenna has a good end-fire radiation behavior with sufficient gain levels at the center of the operation band. The simulated radiation and total efficiencies of the antenna are shown in Fig. 7. As seen, the antenna has good efficiency function, even though it has been designed on the high-loss FR-4 substrate.

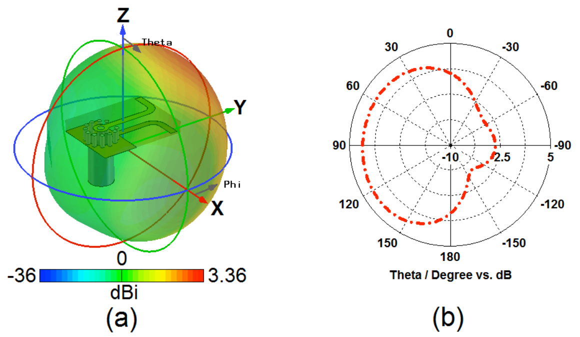

Fig. 6. (a) 3D, and (b) 2D views of the radiation pattern at 24 GHz.

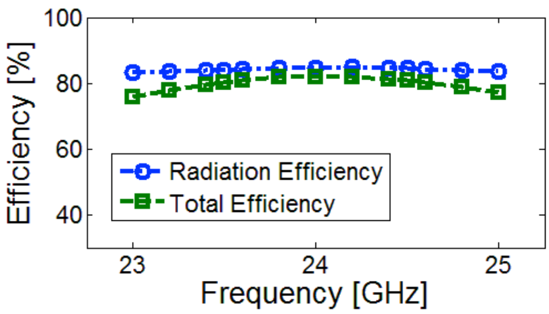

Fig. 7. Simulated efficiency characteristics over the operation band.

IV. The Proposed Phased Array 5G Antenna

Figure 8 shows the configuration of the linear dipole antenna array. It is composed of eight 24 GHz dipole antenna elements and has been used on top of the PCB. The illustrated array could be used in two sets of phased arrays in the top/ bottom portions of the PCB [8]. In order to obtain the wide-angle scanning function for the array beams, the distance between elements (d) is calculated less than λ/2 (d=4.5 mm). Figure 9 shows the S parameters (S_{11}~S_{81}) of the final design. As shown, the proposed phased array antenna has good impedance-matching and mutual coupling characteristics in the frequency range of 23 to 25 GHz. It should be noted to obtain the main resonance of the final design at 24 GHz, the value of L must be changed from 6 to 6.2 mm (because of the of PCB ground plane effect).

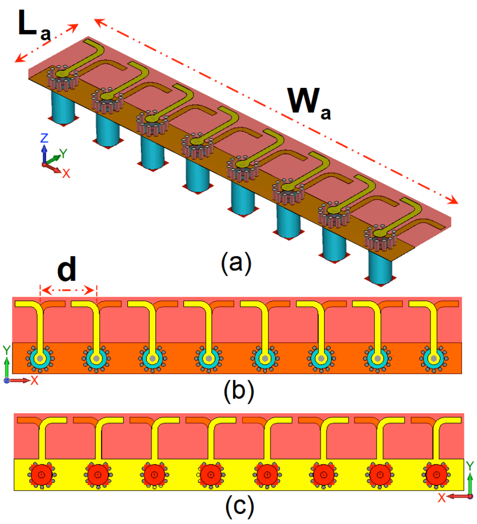

Fig. 8. Transparent (a) 3D, (b) top and (b) bottom views of the array.

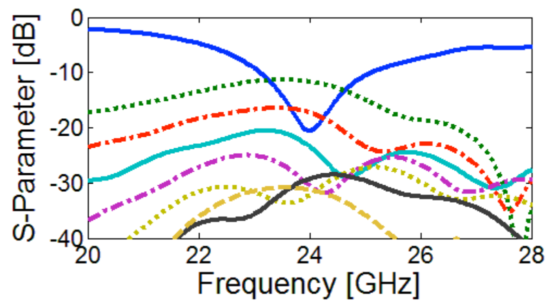

Fig. 9. Simulated S parameters of the proposed 5G antenna.

Surface-current distribution for the proposed antenna at 24 GHz is shown in Fig. 10. As illustrated, the current has concentrated on the edge regions of PCB and most of the current flows are distributed around the arms of the dipole antennas.

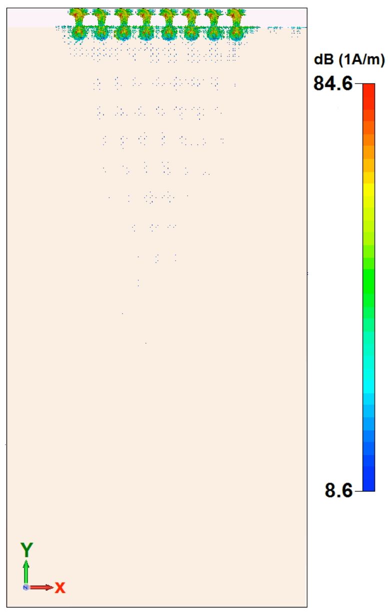

Fig. 10. Simulated current distribution of the proposed antenna at 24 GHz.

The 3D-directional radiation beams of the antenna at different scanning angles are illustrated in Fig. 11. In addition, the Cartesian realized gains (IEEE gain × mismatch losses) of the antenna are displayed in Fig. 12. As illustrated, the antenna has a good beam steering characteristic with end-fire mode and acceptable gain levels at different scanning angles. The antenna has a wide-angle scanning property with same performances for minus/plus (+/-) angles which could be effective to cover the desired beam-coverage of 5G cellular communications.

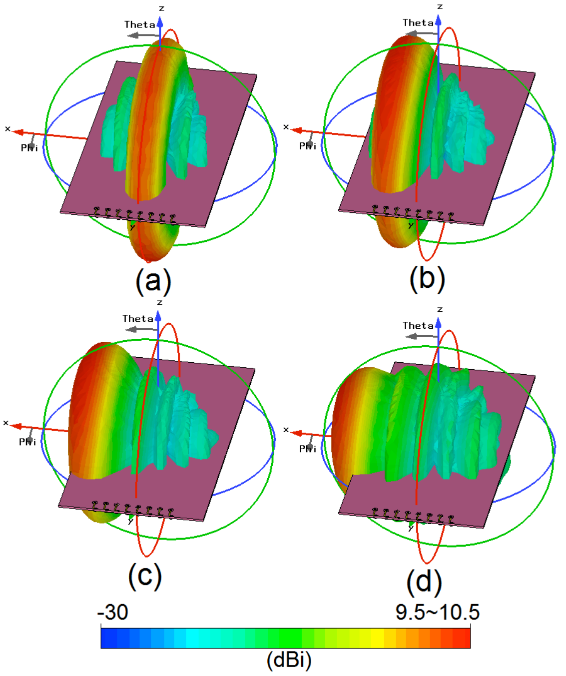

Fig. 11. 3D Radiation beams of the antenna with directivity values at, (a) 0°, (b) 20°, (c) 40°, and (d) 60°.

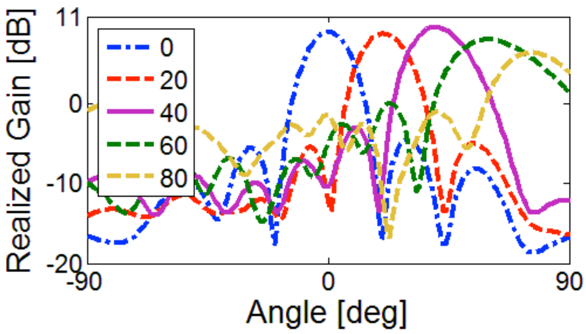

Fig. 12. Simulated realized gains of the 5G antenna.

V. Conclusion

In this paper, a coax-to-microstriplines fed dipole antenna array with end-fire and wide-scan radiation beams is designed and discussed. The input impedance and fundamental radiation properties of the proposed antenna are investigated. The investigated results show that the proposed 5G antenna provides several attractive features and therefore is suitable for the 5G cellular systems. Furthermore, eight elements of the proposed 24 GHz dipole antennas have been employed to form a linear array on the top region of the cellular handset PCB.

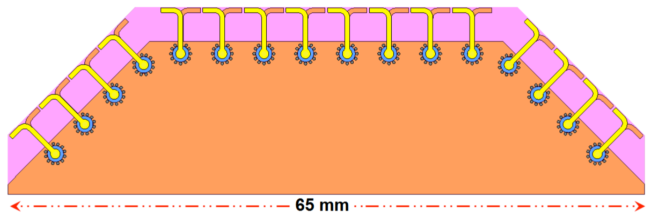

Fig. 13. New configuration of the proposed dipole array with 16 radiators.

Due to compact dimension of the employed radiation elements, there is a possibility to use more radiators on the top portion (shown in Fig. 13) of the PCB to increase the gain and directivity characteristics of the 5G antenna [8], which could be a suitable topic for further work.

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