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End-Fire Phased Array 5G Antenna Design Using Leaf-Shaped Bow-Tie Elements for 28/38 GHz MIMO Applications

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***Abstract*—In this paper, a new design of mm-Wave phased array 5G antenna for multiple-input multiple-output (MIMO) applications has been introduced. Two identical linear phased arrays with eight leaf-shaped bow-tie antenna elements have been used at different sides of the mobile-phone PCB. An Arlon AR 350 dielectric with properties of h=0.5 mm, ε=3.5, and δ=0.0026 has been used as a substrate of the proposed design. The antenna is working in the frequency range of 25 to 40 GHz (more than 45% FBW) and can be easily fit into current handheld devices. The proposed MIMO antenna has good radiation performances at 28 and 38 GHz which both are powerful candidates to be the carrier frequency of the future 5G cellular networks.**

I. INTRODUCTION

The fifth generation (5G) cellular communication systems are estimated to work at higher frequency bands (beyond 10 GHz) which would bring new challenges with careful consideration in the implementation of antennas into the future handheld devices [1-5]. In order to reduce the antenna size and to obtain wide bandwidth, we employ here the compact microstrip-fed leaf-shaped bow-tie antennas with end-fire radiation beams integrated into mobile phone PCB [6].

Bow-tie microstrip antennas have become the subject of much researches in the present day communication scenario due to their attractive characteristics compared to other printed structures. The bow-tie antenna comprises a pair of radiators etched on the opposite sides of the substrate [7].

In the proposed design, eight elements of leaf-shaped bow-tie antenna have been used to form a linear phased array. The antenna elements are fed by microstrip-lines with 50 Ohm discrete ports. They also have wide bandwidth from 25 to 40 GHz. Simulated results exhibit that the designed wideband array achieves the antenna directivity of better than 10 dBi at different scanning angles. Two sets of the designed linear arrays (array 1 & array 2) with same performances have been employed at different sides of a mobile phone PCB to work in multi-user MIMO mode. Radiation performances of the antenna at 28 and 38 GHz (5G candidate bands) have been investigated and good results are obtained. The proposed phased array antenna is effective for the required beam-coverage in 5G MIMO communications.

II. SINGLE ELEMENT INVESTIGATION

Figure 1 illustrates the geometry of the designed single element leaf-shaped bow-tie antenna. The antenna is designed using the Arlon AR 350 substrate with properties of h=0.5 mm, ε=3.5, and δ=0.0026. The antenna has a very compact size of $W_S \times L_S = 4.6 \times 4.6\ mm^2$. The values of the antenna parameters are specified in Table I.

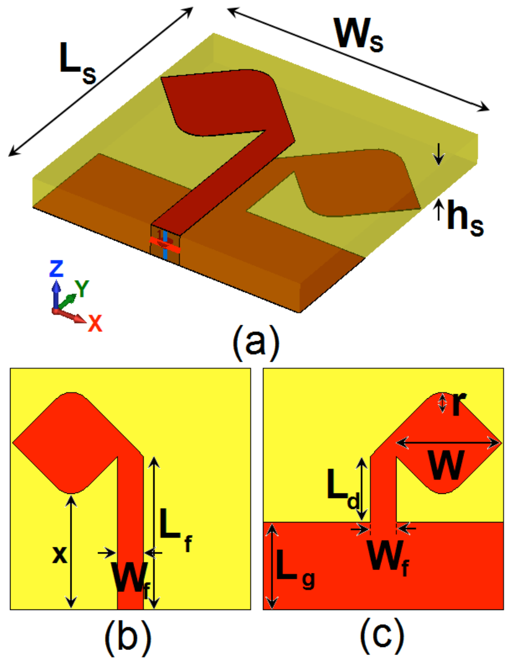

Figure 1. Configuration of the leaf-shaped bow-tie antenna, (a) side, (b) top, and (c) bottom profiles.

TABLE I
DIMENSION VALUES OF THE ANTENNA

Parameter	W_S	L_S	h_S	W_f	L_f	W
Value (mm)	4.6	4.6	0.5	0.5	2.9	2
Parameter	r	L_d	L_g	x	W_a	L_a
Value (mm)	0.4	1.25	1.7	2.25	36.8	4.6

The antenna has a vey wide bandwidth (25 to 40 GHz) with more tha 45% fractional bandwidth. The simulated frequency response (S_{11}) of the antenna is depicted in Fig. 2.

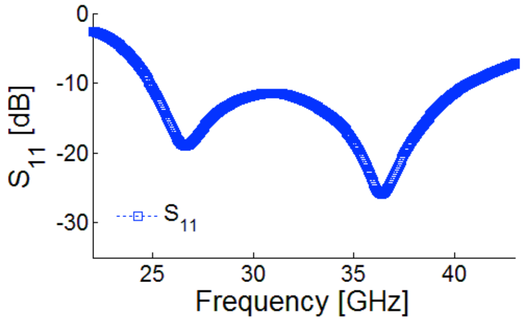

Figure 2. Simulated frequency response (S_{11}) of the antenna.

As illustrated in Fig. 3, the S_{11} and impedance-matching characteristics of the antenna can be controlled by using different values of x and L_g. However, there are some other parameters which can have impacts of the frequency response of the antenna. It can be observed form Fig. 3 (a), when the value of x increses from 2 to 2.5 mm, the antenna has relfection coefficient characteristics of -18, -14, and -11 at the center frequency. The impact of the ground plane size (L_g) is occurred at the upper frequency of the antenna badwidth. As shown in Fig. 3 (b), for different values of L_g (1.2, 1.7, and 2.2 mm), the upper frequency of the antenna badwidth increases from 37 to 45 GHz.

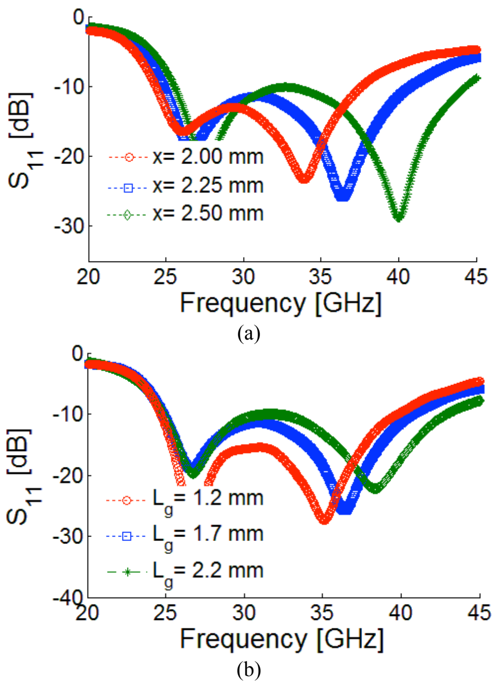

Figure 3. Simulated S_{11} characteristics of the leaf-shaped bow-tie antenna due to different values of, (a) x and (b) L_g.

Due to wide bandwidth of the proposed leaf-shaped bow-tie antenna, the antenna radiation patterns at lower, middle, and upper frequencies (27, 32, and 38 GHz, respectively) are studied and illustrated in Fig. 4. As shown, the antenna has a good radiation behavior with end-fire mode at different frequencies of the operation band. Furthermore, based on the obtained results shown in Fig. 5, the antenna has good efficiencies (more than 97% and 90% radiation and total efficiencies) and almost constant maximum gain values over the operation band (25 to 40 GHz).

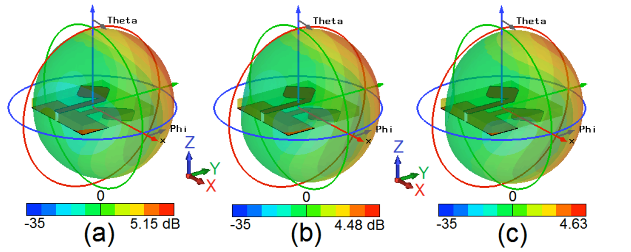

Figure 4. 3D views of the antenna radiation patterns at, (a) 27 GHz, (b) 32 GHz, and (c) 38 GHz.

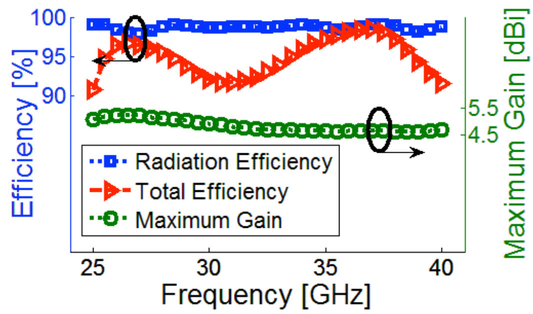

Figure 5. Simulated efficiency and maximum gain characteristics of the antenna over the operation band.

III. 5G Mobile Phone Antenna Configuration

Eight elements of the proposed leaf-shaped bow-tie antennas with distance of d=4.6 mm have been used to form a linear phased array shown in Fig. 6. The array has a compact size of $W_a \times L_a$ and has been used on the top side mobile phone PCB. Figure 7 shows the configuration of the 5G antenna.

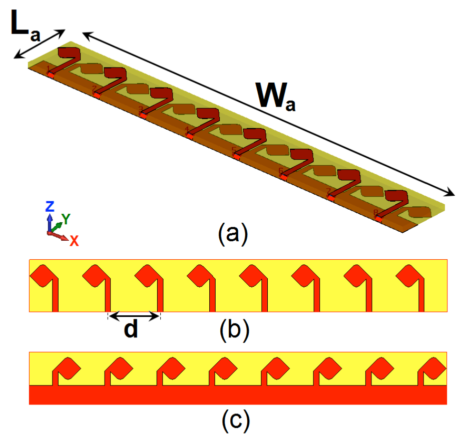

Figure 6. (a) 3D view, (b) top layer, and (c) bottom layer of the linear array.

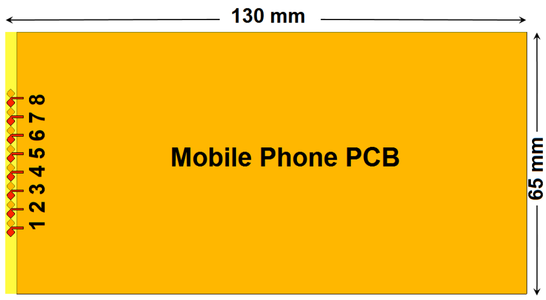

Figure 7. Schematic of the 5G mobile phone antenna.

Figure 8 shows the S parameters (S_{21} to S_{81}) of the proposed 5G mobile-phone antenna. As shown, the antenna has good performance with low mutual couplings in the frequency range of 25 to 40 GHz.

The 3D directional and 2D normalized polar beams of the proposed antenna at 0°, 45°, and 90° are illustrated in Fig. 9. It can be seen that the antenna has wide-angle scanning characteristic with end-fire mode [8]. It also has sufficient realized gain values at different scanning angles. As illustrtaed in Fig. 10, the designed 5G antenna has good directivity, radiation, and total efficieny properties at the desired scanning angles and could be effective to cover the required beam-coverage of the 5G cellular communications.

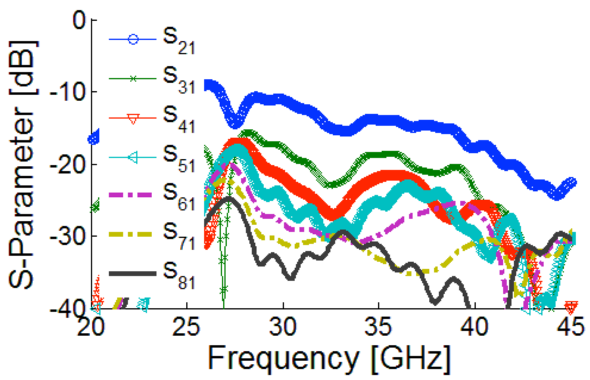

Figure 8. Simulated S parameters (S_{21} to S_{81}) of the proposed 5G mobile phone antenna.

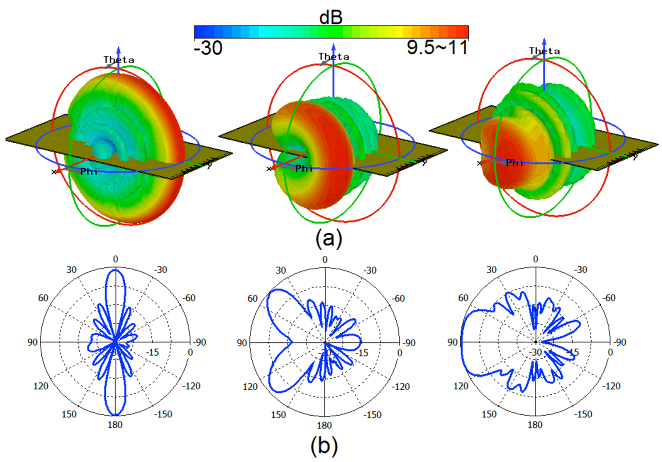

Figure 9. (a) 3D radiation beams with realized gain values and (b) 2D normalized polar radiation beams.

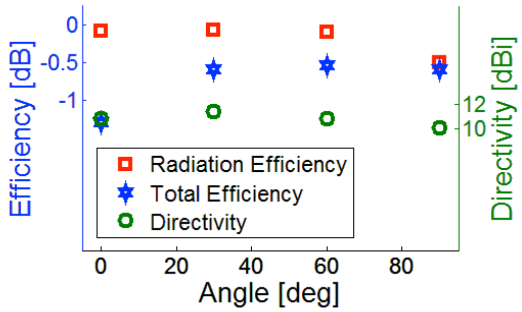

Figure 10. Efficiency and directivity properties of the antenna at 0°, 30°, 60°, and 90°.

IV. MIMO Configuration of the Proposed Design

Figure 11 illustrates the MIMO configuration of the proposed 5G antenna. As shown, two sets of the leaf-shaped bow-tie linear phased arrays are placed at different sides of the mobile phone PCB. The employed arrays have same dimension and performances. Due to importance of 28/38 GHz 5G bands, the radiation characteristics of the proposed MIMO antenna have been investigated at these frequencies.

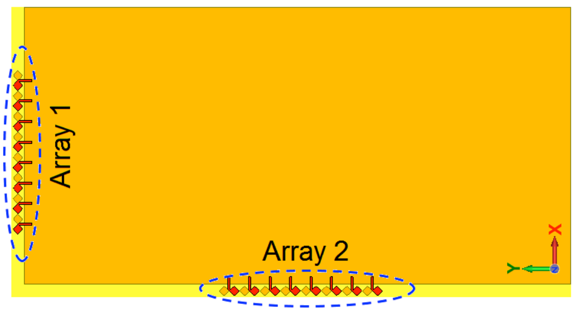

Figure 11. MIMO configuration of the proposed 5G antenna.

Figures 12 and 13 show the 3D radiation beams of the MIMO antenna with two sets of the array at 28 and 38 GHz, respectively. It can be seen that the antenna has good radiation behavior at both of the 5G candidate bands. As mentioned above, the employed arrays have similar performances with sufficient gain values at different scanning angles.

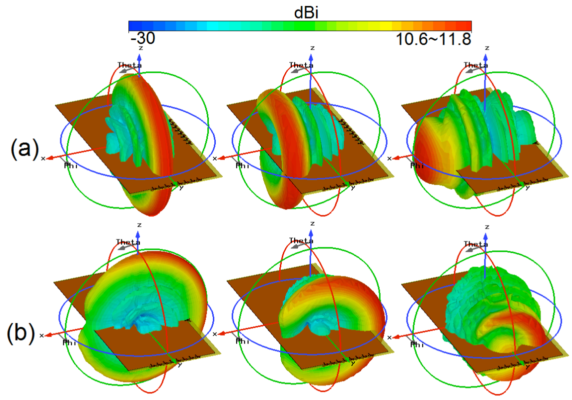

Figure 12. 3D radiation bemas of the MIMO antenna at 28 GHz for different scanning angles, (a) array 1 and (b) array 2.

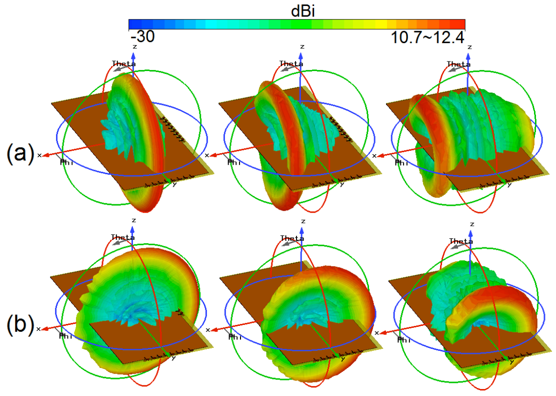

Figure 13. 3D radiation bemas of the MIMO antenna at 38 GHz for different scanning angles, (a) array 1 and (b) array 2.

The surface current distributions of the proposed 5G antenna at 28 and 38 GHz when the array are fed separately have been displayed in Fig. 14. As can be seen, current flows are distributed around the arms of the leaf-shaped bow-tie elemets which lead to maintain good radiation behavior, even thouth they have been montained on the PCB of mobile phone with a big ground plane.

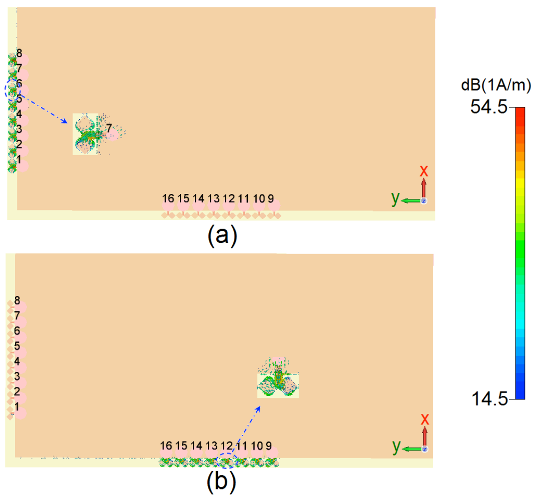

Figure 14. Current distributions at, (a) 28 GHz and (b) 38 GHz.

New geometries of the 5G MIMO antenna are shown in Fig. 15. In the presented design, two sets of 1×4 linaer array of the proposed wideband leaf-shaped bow-tie antenna elements have been used at different sides of mobile-phone PCB. They have same performances with more than 9 dB realized gain at 0°. Thay also have good beam-steering function and can work at MIMO/diversity modes.

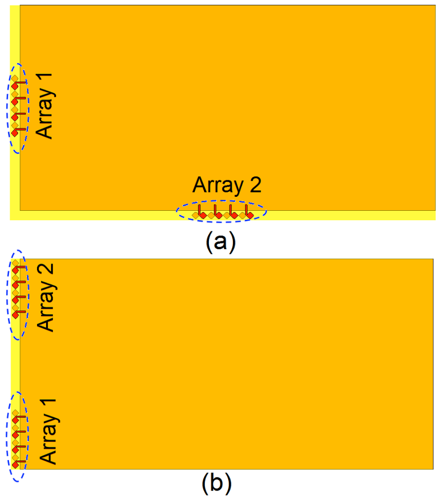

Figure 15. New geometries of the MIMO antenna with 1×4 arrays located at, (a) top-side portions and (b) top portion.

V. Conclusion

An end-fire phased array 5G antenna design using leaf-shaped bow-tie elements for MIMO applications is proposed in this paper. The fundamental properties of the antenna in terms of impedance-matching and radiation behavior have been investigated. The antenna has good performances at 28 and 38 GHz 5G bands and could be a candidate for the future handheld devices.

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