FR4-PCB Smartphone Phased Array with Improved Performance for 5G Beam-Steering Applications

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Abstract. In this paper, a high efficiency phased array antenna is introduced for fifth-generation (5G) smartphones. The configuration of the design is achieved by employing eight insensitive L-ring/slot-loop resonatorss with linear array form on the top of the handset mainboard. The design exhibits high radiation performances even though the beam-steerable array is implemented on a lossy FR-4 material. The proposed design exhibit a frequency bandwidth of 18-20 GHz with a single resonance at 19 GHz. The designed antenna exhibits wide beam-steering, high efficiencies, and sufficient gain levels at 19 GHz of 5G communications. In addition, the proposed phased array design has sufficient radiation behavior in the adjacency of user-hand phantom. Moreover, its characteristics are insensitive for various substrate types.

Keywords: 5G system, cellular networks, future smartphones, substrate-insensitive antenna.

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].

A critical challenge in antenna designing for MM-wave e5G is to implement phased arrays with high radiation properties. 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].

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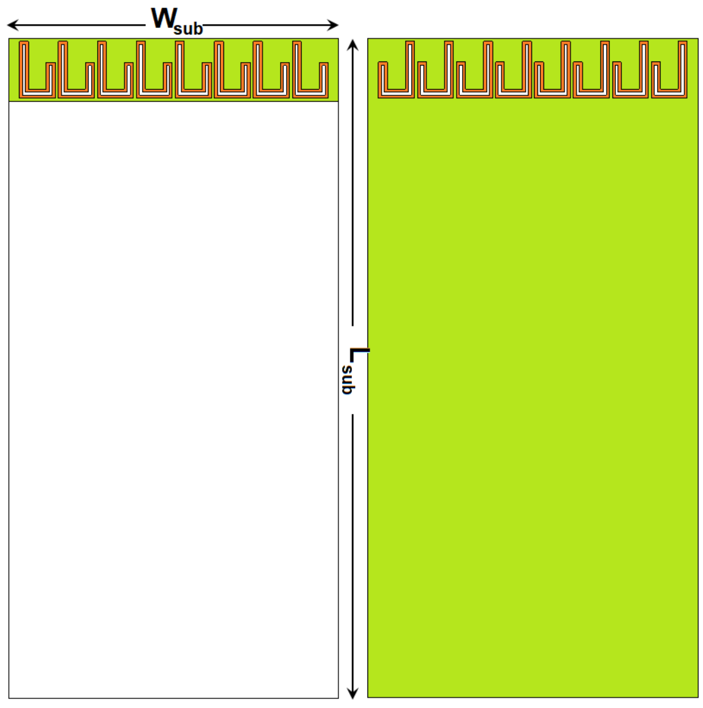
However, for smartphone applications, all these antennas could occupy huge space in the smartphone broad. Since one of the challenges of the antenna design for 5G smartphones is to implement antenna arrays with improved characteristics; we introduce here a new beam-steerable array with high radiation properties for future smartphone applications. Since the main dielectric is the vacuum with no losses, the resonator is able to provide high performances in terms of efficiency and antenna gain levels. furthermore, the antenna is insensitive for various dielectric constant and loss tangent values, which give a high flexibility to be used in different board. Characteristics of the single resonator and the phased array design are investigated.

2 Results and Discussions

The introduced phased array is arranged on a cheap FR-4 dielectric with characteristics of h_{sub}=0.8 mm, permittivity (ε_r)=4.3, and loss tangent (δ)=0.025. As illustrated in Fig. 1, eight substrate-insensitive antenna elements have been with linear array arrangment and with the size of $W_a \times L_a$ is placed in the top-edge of the board with the size of $W_{sub} \times L_{sub}$=55×110 mm^2. The arraned array has a low-profile of 8.5×43 mm^2. The EM simulation CST software was used for the investigation. The dimensions of the design parameters are listed in Table. 1.



(a) (b)

Fig. 1. (a) front and(b) back layers of the 5G array.

Table 1. Dimensions of the design parameters.

Param.	W_{sub}	L_{sub}	h_{sub}	W_S	L_S	W	L	W_1	L_1

(mm)	55	110	0.8	12	13.5	1.5	9.5	0.5	8
Param.	W_2	L_2	W_3	L_3	W_4	L_4	W_5	L_a	W_a
(mm)	5	4.5	3	6	1.5	0.5	0.5	10.5	51.5

2 The Single Insenstivite Radiator

Figure 2 plots the transparent structure of the single antenna. It has low profile with simple structure and flexible in nature, and low-cost for fabrication. The S_{11} of the simulated L-ring slot-loop antenna with discrete-port feeding technique is depicted in Fig. 3. As shown, the designed antenna operates at the frequency spectrum of 18-20 GHz (with 2 GHz bandwidth).

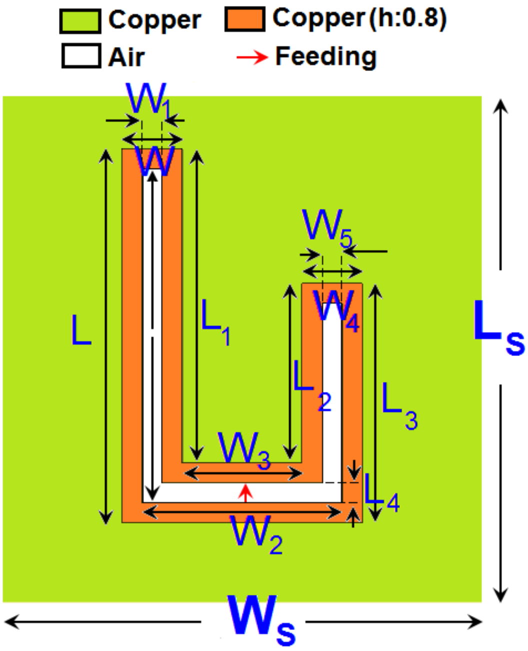


Fig. 2. The air-filled slot-loop element.

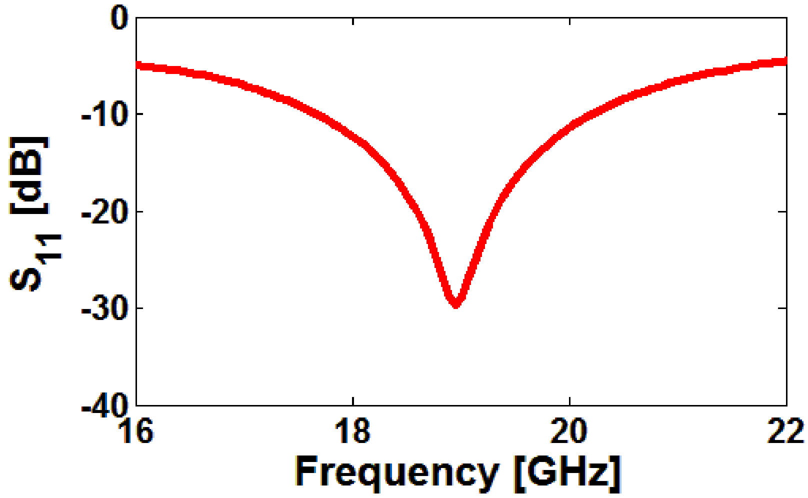


Fig. 3. S_{11} characteristic of the L-ring slot-loop antenna.

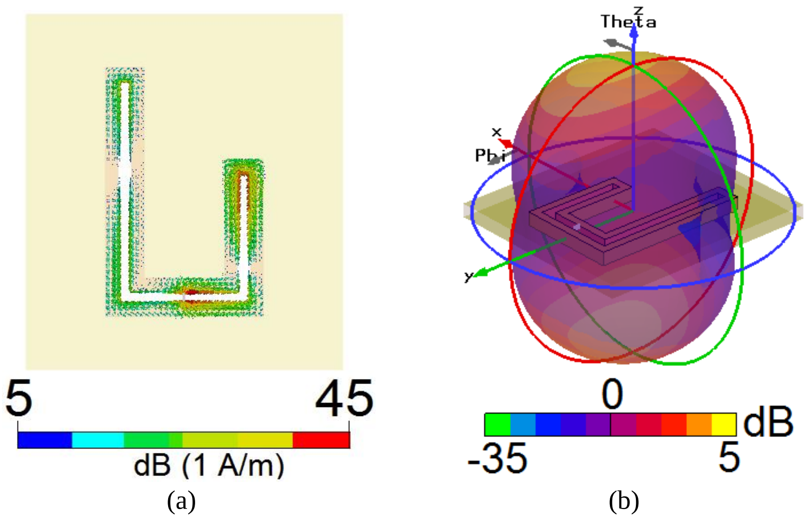


Fig. 4. (a) The surface current and (b) 3D radiation at 19 GHz.

The current density for the L-ring slot resonator at its resonant frequency (19 GHz) is plotted in Fig. 4 (a). As expected, the employed metal-ring radiator has maximum densities and behaves highly active [21-25]. The 3D radiation of the metal-ring design is represented in Fig. 4 (b). It is found that the antenna has well-defined radiation, covering the both sides of the FR-4 dielectric. In addition, it provides a high realized gain of 5 dB. As indicated before, the design characteristics of the are insensitive to varous substrate’s properties. To understand this function, the coefficient reflection (S_{11}) of the antenna element for different substrate-types including FR-4, Arlon Ad-320, and Rogers-5880 are studied in Fig. 5. It is cearly shown that unlike the conventional antennas, the proposed air-filled loop array exhibits similar results and its reflection coefficient does not change for different types of substrates [26-30].

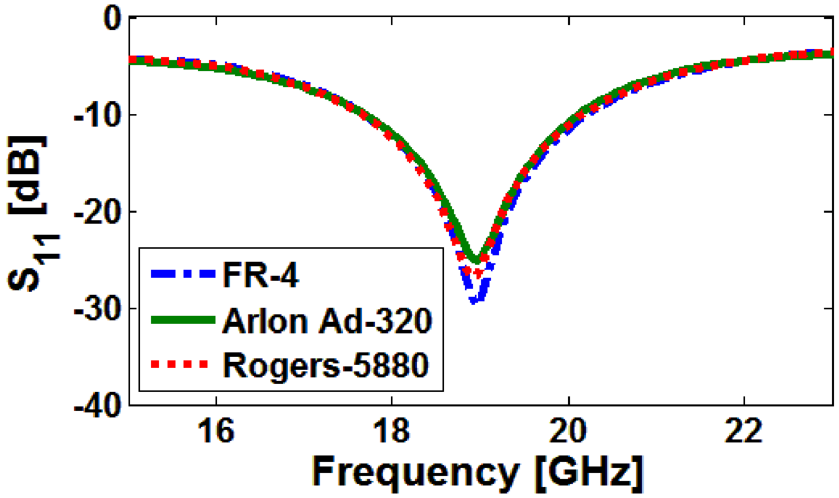


Fig. 5. The coefficient reflection (S_{11}) for various substrate-types.

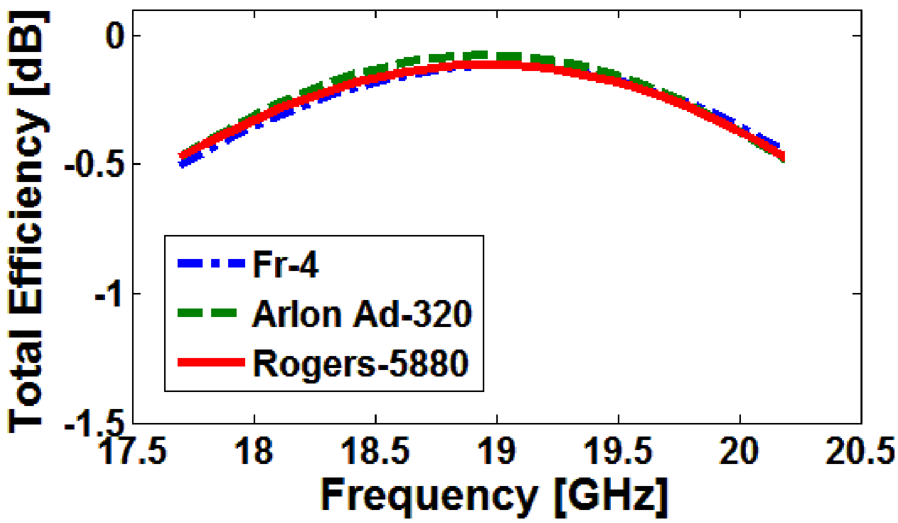


Fig. 6. The total efficiencies for various substrate-types.

The efficiencies for various substrate-types are discussed in Fig. 6. It should be noted the studied substrates have different δ (loss tangent) values which could affect the efficiency of an antenna [31-34]. However, as seen in Fig. 6, the design exhibit similar behavior with high efficiencies for various substrate-types. Figure 7 illustrates the scattering parameters (S_{11}~S_{81}) of the phased array. As illustrated, the design exhibits quite good S_{11}~S_{81}characteristics. Moreover, low coupling (S_{mn}<-15 dB) is obsreved for the introduced array design.

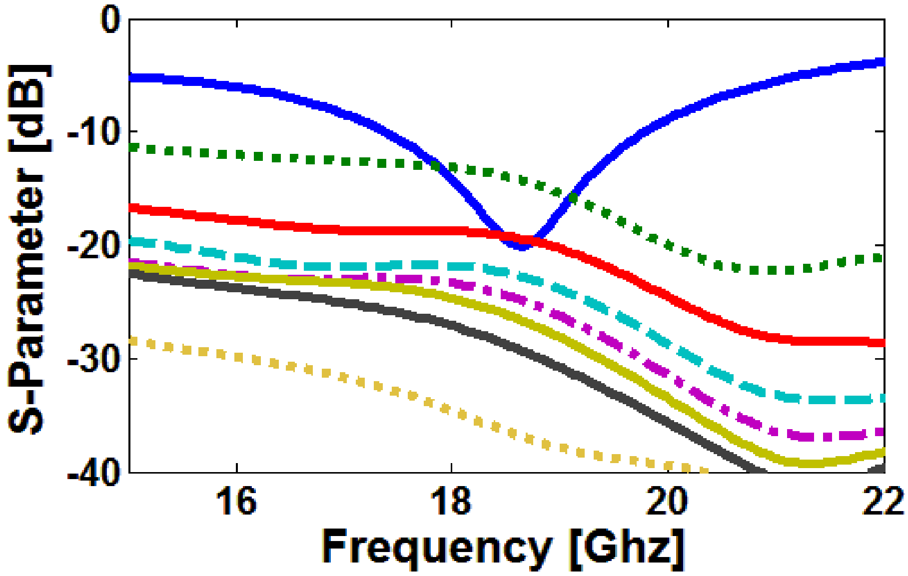


Fig. 7. S-parameters for the array.

Figure 8 illustrates the 3D beams of the designed array 5G antenna for various angles. It is seen that excellent radiation beams over of 0-70 scanning angles are provided. As shown, the design provides well-defined radiation beams at 0°,15°, 30°,45°, 60°, and 70° which could cover half-space of the radiation coverage for the smartphone mainboard [35-37]. Fundamental properties of the design including directivity and efficiencies for the steered beams of the mobile-phone array at 19 GHz design are presented in Fig. 9. Across the range of 0º to 60º, the efficiencies are greater than 90% (-0.5 dB). In addition, it provides almost constant gain levels with value around 11 dB at different scanning angles.

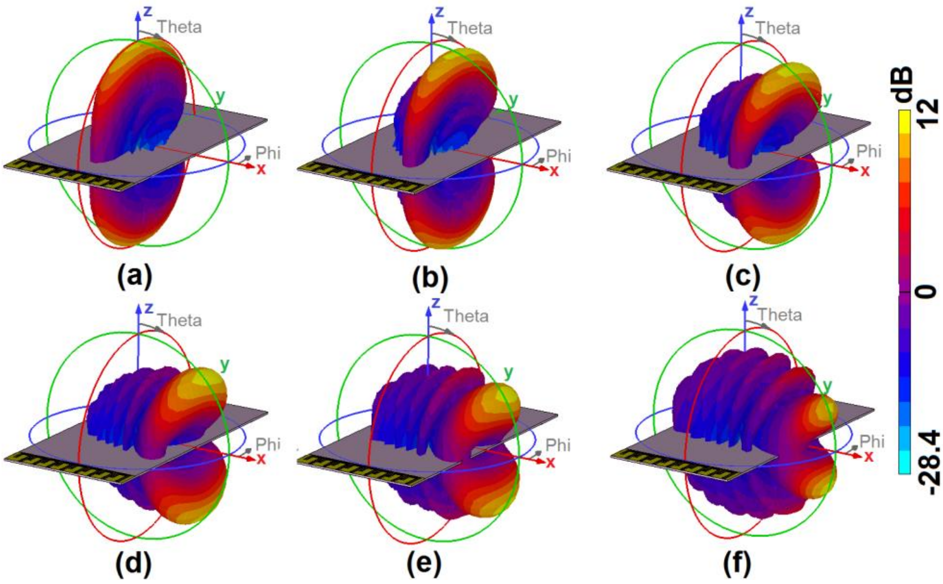


Fig. 8. 3D beams at (a) 0, (b) 15, (c) 30, (d) 45, (e) 60, and (f) 70 angles.

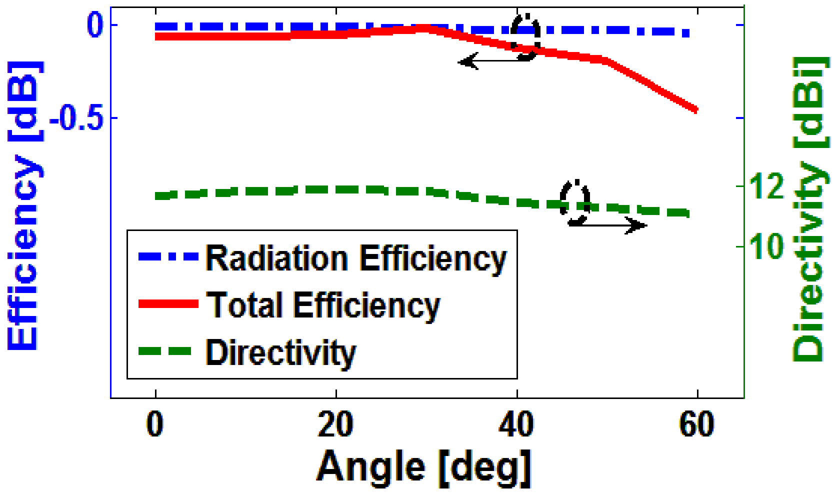


Fig. 9. Fundamental radiation characteristics at different angles (0 to 60 degrees).

The user-hand is a body-part that most frequently touch the handheld devices and usually has negative impacts on antenna performance [38-40]. Figure 10 represents the 3D beams at various angels (0°~60°). As plotted, the antenna provides well-defined radiation beams various angels at various angles. This might be due to compact sizes and insensitivity function of the employed element which are not highly affected by user-hand. As can be seen, the gain levels of the beams are reduced but not significantly.

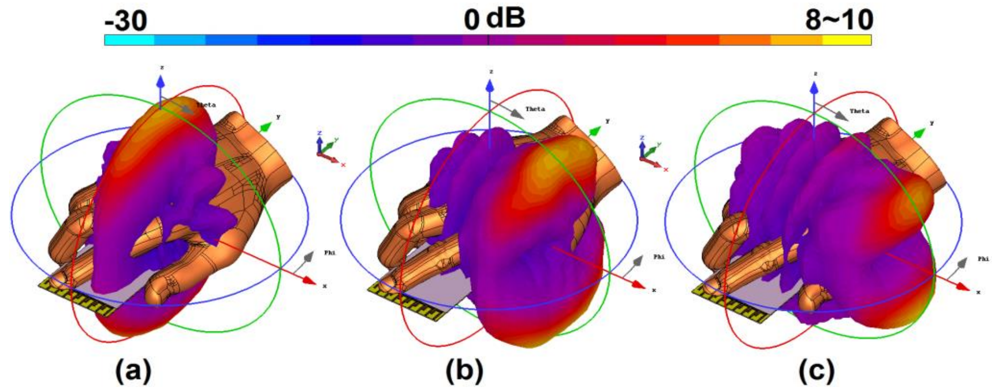


Fig. 10. 3D beams in data-mode for, (a) 0, (b) 30, and (c) 60 degrees.

Conclusion

This manuscript proposed a insensitive design of phased array for 5G mobile communications. It is designed on the FR-4 substrate and working at18 to 20 GHz. Eight elements of metal-ring elements are linearly arranged on the top f the phone PCB. Sufficient and quite good outputs have been achieved for the presented design. It also offers sufficient performance in data-mode with hand phantom.

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