Phased Array with Radiation-mode Reconfigurability for Cognitive Cellular Communications

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Abstract— A beam-steerable phased array with highly-miniaturized resonators and radiation-mode reconfigurability is studied in this paper for 28 GHz 5G cellular cognitive networks. Simple and straightforward design procedures are followed. Eight modified T-shaped slot antenna resonators with single rectangular directors have been arranged linearly across a small area at the top of the smartphone substrate, which is made of RT5880. By installing and biasing RF Diodes on the directors, the phased array can switch between end-fire and broad-side radiation modes to provide different radiation coverage. The suggested array design is exhibiting an impedance bandwidth from 27 to 29 GHz (resonating at 28 GHz). In addition, the introduced array offers several promising features such as highly miniaturized profile, well-defined radiations, wide beam steering capability, as well as sufficient efficiency and gain levels which make the suggested design suitable for cognitive communications.

1. INTRODUCTION

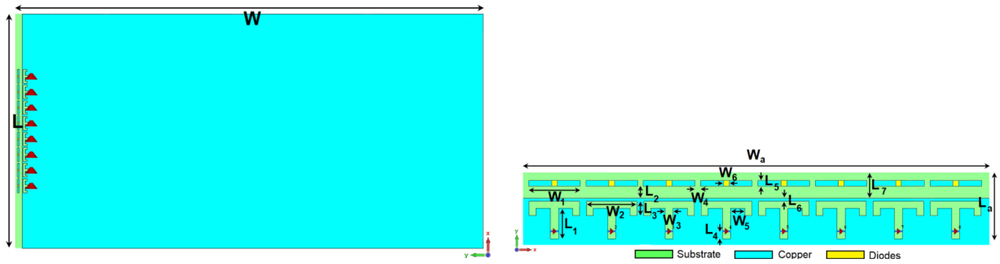
In providing broadband communication services, the mm-wave/sub-mm-wave spectrum is essential and plays an effective role in demonstrating 5G's capabilities [1, 2]. Due to its numerous benefits, it is also cost-effective and provides increased security. Therefore, this technology is a great candidate for 5G technologies because of its high resolution, data transfer speed, and availability [3, 4]. For point-to-point 5G communications, mm-Wave antenna arrays with beam-steering and an increased number of elements are required for the user equipment base stations [5, 6]. To form phased arrays, small antennas can be arranged linearly or planarly [7–10]. Smart handheld devices with beam-steerable phased array antennas are very attractive applications for 5G due to their ability to increase the capacity of coverage of the network [11–15].

In mobile and microwave communications, microstrip antennas are important, so this has led to a great deal of interest in their design. For 5G applications, different array designs have been proposed for handheld devices [16–18]. It is, however, difficult to arrange a compact phased array antenna that can resonate across multiple 5G bands. In addition, the use of reconfigurable antennas in smart systems and cognitive cellular networks has received much attention. Arrays of antennas that can switch radiation modes without affecting the operating frequency are known as radiation-mode reconfigurable arrays [19, 20]. A miniaturized multi- element beam-steerable array with reconfigurable/switchable radiation-mode is presented here, which could be incorporated into future smartphones. Its configuration includes eight modified antenna elements with T-shaped slot resonators, rectangular directors, and embedded active elements arranged in a linear phased array form at the top of the mainboard. The array is designed to resonate at 28 GHz 5G spectrum, and its radiation can be tuned from broadside to endfire supporting different sides of the mainboard. The simulation of the investigated antenna was evaluated using CST microwave studio 2020 [21].

2. SCHEMATIC AND DESIGN DETAILS

The design layout of the suggested smartphone phased array is represented in Fig. 1. As shown, it includes eight modified slot elements with low profiles and a 1×8 linear form (with $d = 5$ mm) at the mainboard's edge with an RT5880 dielectric.

The switches are represented by small yellow copper sheets. Table 1 represent the parameter values of the suggested array.



(a) (b)

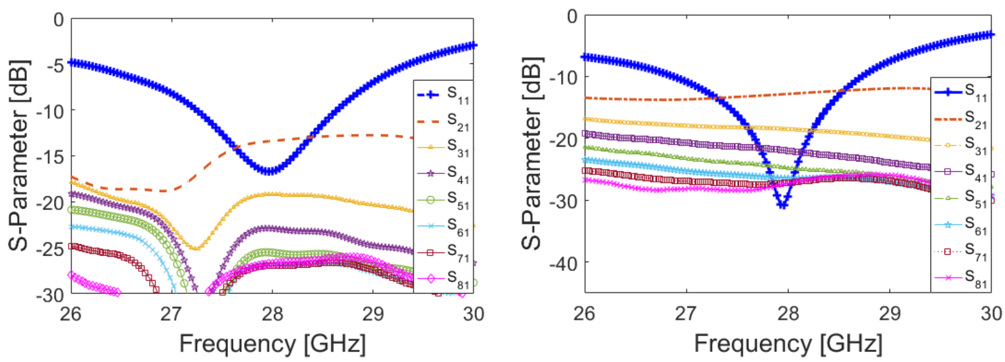
Figure 1: (a) The investigated antenna platform and (b) its linear array.

Table 1: Optimal values of the parameters.

Parameter	W	L	W_1	L_1	W_2	L_2
Value, mm	150	75	4.5	2.65	4.4	1
Parameter	W_3	L_3	W_4	L_4	L_5	W_5
Value, mm	0.7	1.25	0.5	0.65	1.25	0.5
Parameter	W_6	L_6	L_7	W_a	L_a	h
Value, mm	0.5	0.25	2.25	40	5.75	0.25

3. THE FUNDAMENTAL CHARACTERISTICS

This section discusses the fundamental characteristics of the investigated smartphone array with radiation-mode reconfigurability for cognitive networks. The array S-parameters of the array including S_{11} (antenna bandwidth) and S_{mn} (couplings) have been studied for different switching states and represented in Figs. 2(a) and (b). The results indicate that for both ON/OFF diode states, the suggested array design provides a 2 GHz bandwidth band supporting 27–29 GHz with useful couplings (better than -12 dB) over its frequency band.



(a) (b)

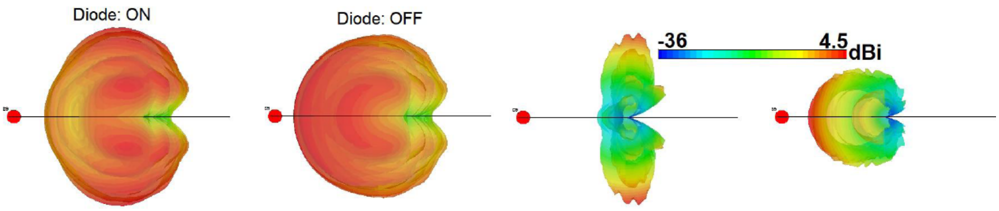
Figure 2: Simulated scattering parameters of the reconfigurable array for: (a) diodes: ON and (b) diodes: OFF.

The 3D radiations of the T-shaped antenna element are illustrated for various conditions that are associated with the employed switches have been represented in Fig. 3. It can be observed that for different diode states, the radiation mode of the modified T-shaped slot antenna element can be tuned from the broadside-mode (diode: ON) to endfire-mode (diode: OFF).

Figure 4 depicts the simulated total efficiencies of the reconfigurable elements over the operation range of the antenna system, 27–29 GHz. The results obtained are evidently satisfactory [22–25]. The presented 5G smartphone array has total efficiencies of more than 60–90% for both ON/OFF diode states, as depicted in Figs. 4(a) and (b).

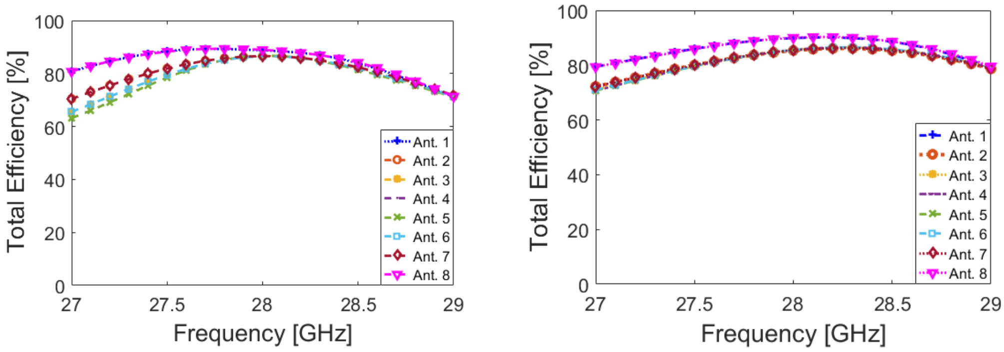
The main radiation beams (with/without linear scaling) of the suggested phased array for various conditions of the employed switches have been illustrated in Fig. 5. It can be observed that for different diode states, the radiation mode of the studied phased array can be tuned from the broadside-mode (all diodes: ON) to endfire-mode (all diodes: OFF). 3D radiation behaviour of the suggested smartphone antenna array with beam-steering and gain levels at 28 GHz for both diode-states are represented in Fig. 6. It is evident from the plot that the investigated array also provides broad scanning of 0°–60°. Meanwhile, well-defined radiations, low side/back lobes, and high gain/directivity levels were discovered at various steering angles [26, 27].

A comparison of the gain levels for the single resonator and its array for different states of the employed didoes are shown in Fig. 7. According to results from Fig. 7(a), the single modified slot resonator offers $4 \sim 6$ dBi gain in both diode states at $27 \sim 29$ GHz. On the other hand, the linear phased array exhibits high gain values (11–11.7 dBi) over its respective band. In addition, as the frequency increases, the antenna gain improves [28–30].



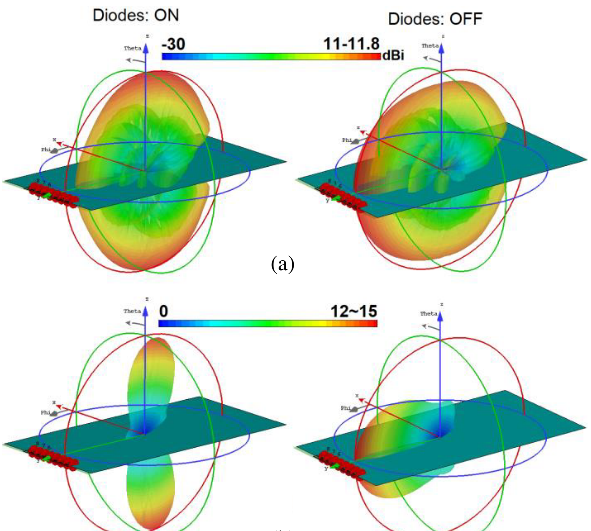
(a) (b)

Figure 3: The results of radiation reconfigurability for the single-element antenna at 28 GHz (a) without and (b) with linear-scaling for a better view.



(a) (b)

Figure 4: The results of antenna total efficiencies at 28 GHz for (a) diodes = ON and (b) diodes = OFF.



(a)

(b)

Figure 5: The results of radiation-mode reconfigurability for the smartphone array at 28 GHz (a) without and (b) with linear-scaling for a better view.

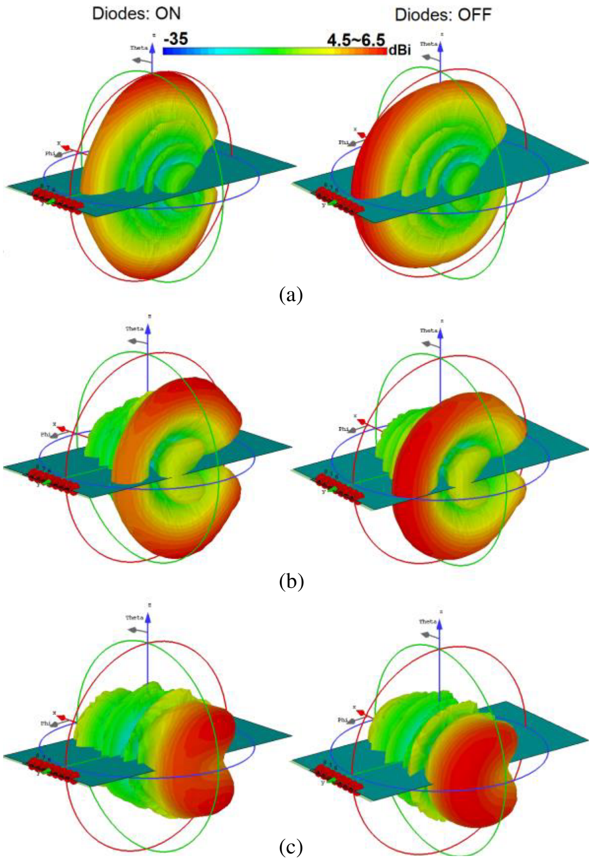


Figure 6: 3D beam-scanning at (a) 0, (b) 30, and (c) 60 degrees.

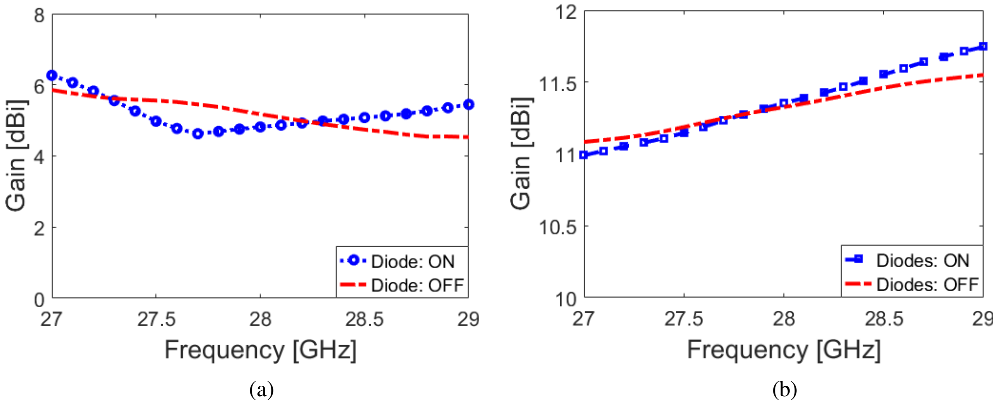


Figure 7: Maximum gain for the reconfigurable (a) single slot resonator and (b) its linear array configuration.

4. CONCLUSION

This paper described a radiation-mode reconfigurable phased array design for 5G cognitive radio cellular networks based on a simple configuration that contains modified slot resonators with embedded active elements and rectangular directors. The working principle of the single-element and the smartphone antenna array were explained in detail. There is a small clearance between the array and the ground. Several critical parameters were examined, and sufficient results were observed in terms of frequency response, beam scanning, radiation mode reconfigurability, and antenna gain/efficiency levels.

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