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Beam-Steerable Microstrip-Fed Bow-Tie Antenna Array for Fifth Generation Cellular Communications

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***Abstract*— The design and performance of mm-wave phased array antenna for 5G mobile broadband communication systems has been provided in this manuscript. The antenna is designed on a *N9000* PTFE substrate with 0.787 mm thickness and 2.2 dielectric constant and 65×130 mm^2 overall dimension. Eight elements of bow-tie antennas have been used at the top-edge region of mobile phone PCB. The antenna elements fed by microstrip lines are designed to operate at 17 GHz. The simulated results give good performances in terms of different antenna parameters. In addition, an investigation on the distance between antenna elements has been done.**

***Index Terms*— Bow-tie antenna; netx generation; mm-wave communication; mobile-phone devices.**

I. Introduction

Printed microstrip antennas are widely used in the design of phased array systems because their attractive features such as small-size, light-weight, low-cost, high-efficiency and easy methods of fabrication and integration [1]. Among the microstrip antennas are the subject of much researches, we employ the compact microstrip bow-tie antennas whose dimension allow them to be integrated into cellular devices [2].

An increasing demand for radio spectrum has resulted from the emergence of high-data-rate wireless applications such as fifth generation (5G) communications. One of the major issues in 5G cellular systems is the shift to the higher frequencies (beyond 10 GHz) due to large available bandwidth [3-4]. However, moving to the higher frequencies would bring new challenges in the designs of antennas for mobile phone devices which need careful consideration [5].

In this study, a design of microstrip-fed bow-tie antenna array with beam steering property for 5G mobile communications is proposed. The antenna element used in this design is a bow-tie with microstrip-line feed to operate at 17 GHz. Bandwidth, input impedance, gain, radiation pattern and beam steering characteristics of the proposed antenna are investigated. This paper has been structured as follows: The configuration and performance of the single element bow-tie antenna has been described in Section II. An investigation on the performance of the antenna array with different distance between radiation elements has been done in Section III. Section IV will discuss simulation results of the final design of proposed 5G mobile phone antenna. Finally, Section IV concludes the presented study.

II. Microstrip-Fed Bow-Tie Antenna

The bow-tie antenna actually is the combination of two triangular radiators which are located in the top/bottom sides of the antenna substrate. The top and bottom planes act as reflector elements for the antenna to provide end-fire radiation patterns [6]. The geometry of the single element bow-tie antenna fed by a microstrip-line is shown in Fig. 1. As the substrate is one of the most important materials in the design of microstrip antennas, its selection must be treated with care. A low-loss *N9000* PTFE substrate with thickness=0.787 mm, dielectric constant=2.2 and loss tangent=0.0009 has been used for the proposed design. The opening angle (α) of the triangular arms can be chosen in any range of 10-80 degree. It has a significant impact on the frequency response of the bow-tie antennas.

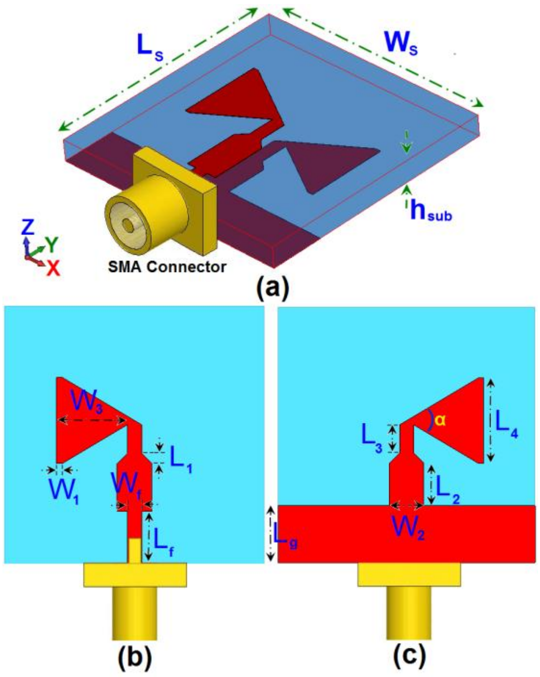

Fig. 1. Configuration of the single element bow-tie antenna, (a) 3D view, (b) front profile, and (c) back profile.

For the proposed design, α is 45°. The bow-tie antenna is designed for the operation band with central frequency of *f* = 17 GHz. The values of the antenna parameters are specified in Table I.

TABLE. I FINAL DIMESIONS OF THE 5G ANTENNA PARAMETERS

Parameter	W_{sub}	L_{sub}	h_{sub}	W_S	L_S	W_1
Value (mm)	65	130	0.787	9	9	0.2
Parameter	L_1	W_2	L_2	W_3	L_3	W_f
Value (mm)	0.35	1.2	1.5	2.45	1	0.5
Parameter	L_g	L_4	W_a	L_a	L_f	d
Value (mm)	2	3	65	9	2	8.5

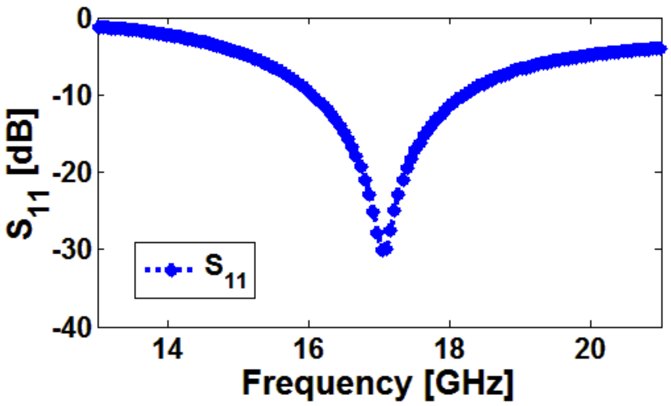

Fig. 2. Simulated frequency response of the antenna.

Figure 2 illustrates the simulated S_{11} characteristic of the antenna. As illustrated, the antenna covers the frequency bands of 16 to 18 GHz. In order to known the phenomenon behind the single-band performance, the simulated current distribution for the presented antenna at 17 GHz (resonance frequency) is presented in Fig. 3. It can be observed at the resonance frequency, the current concentrated around the antenna arms. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the bow-tie arms [6].

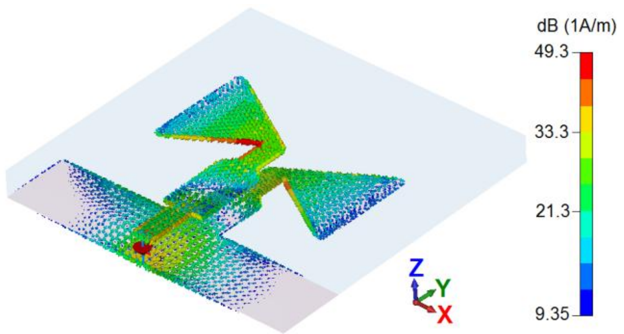

Fig. 3. Simulated current distrbution of the antenna at the center frequency of its operation band (17 GHz).

The simulated S_{11} curves with different values of W_1 is plotted in Fig. 4(a). As illustrated, when the width of the W_1 increases from 0 to 1 mm, the center of resonance decreases from 17.75 to 15.75 GHz. Another critical parameter of the proposed design is the modified trapezium shaped feed-line. Fig. 4 (b) Figure 6 illustrates the simulated S_{11} curves as a function of W_2. As the interior width of the modified feed-line increases from 1 to 1.4 mm, the resonance of the bow-tie antenna is varied from 17.8 to 16.7 GHz. As a result, we can conclude that the antenna operation band can be controlled by changing the widths of the W_1&W_2.

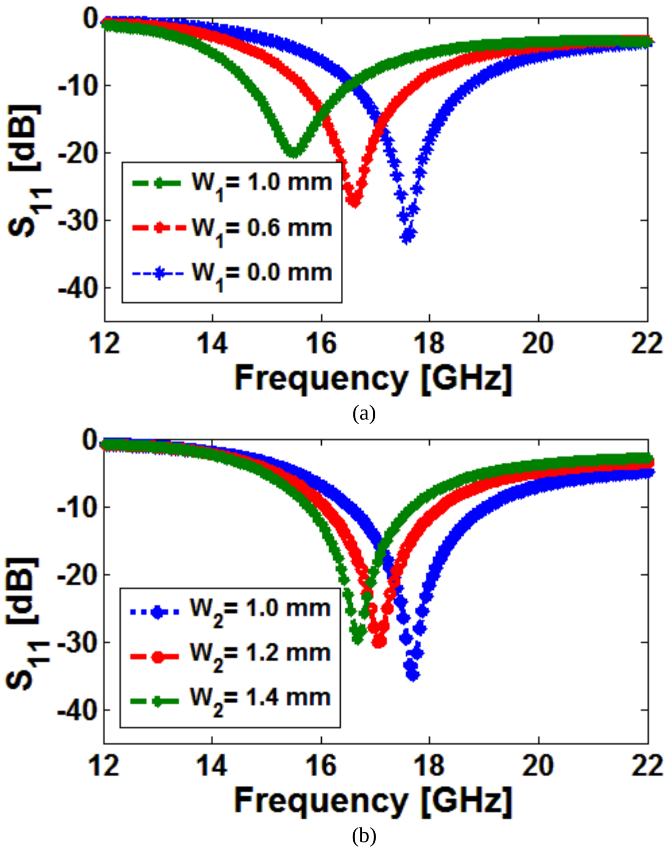

Fig. 4. Simulated S_{11} characteristics of the antenna due to different values of (a) W_1 , (b) W_2.

Simulated 3D and 2D radiation patterns of the antenna element at 17 GHz are illustrated in Fig. 5. The results show that the antenna has a good end-fire radiation behavior at the resonance frequency. In addition, the antenna has sufficient and acceptable realized gain value (4.84 dB) at 17 GHz (center frequency).

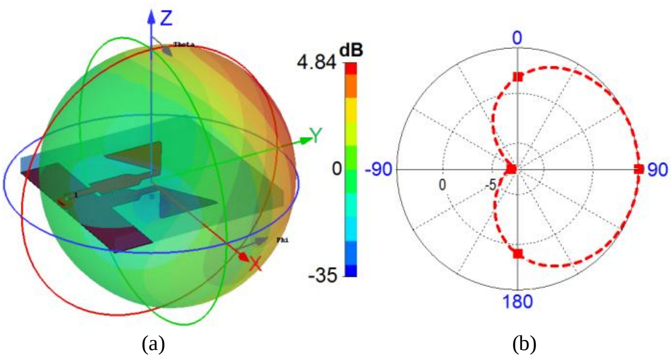

Fig. 5. (a) 3D, and (b) 2D views of the antenna radiation pattern with the realized gain value at 17 GHz.

In ordere to demonstrate that the antenna actually radiates over the operation frequency bands, its fundamental radiation properties (in terms of maximum gain, radiation efficiency and total efficiency) are illustrated in Fig. 6. As can be seen, more than -0.5 dB (90%) radiation and total efficiencies and also about 5 dBi directivity have been obtained at the frequency range of 16-18 GHz.

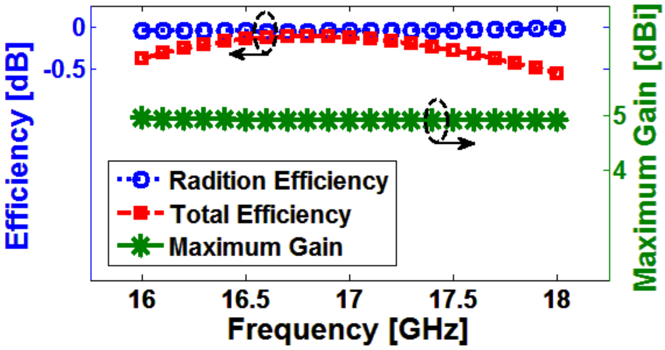

Fig. 6. Simulated fundamental radiation properties of the antenna over the operation band.

III. Investigation on the Distance Between Antenna Array Elements

Figure 7 shows the configuration of the array with eight elements of 17 GHz bow-tie antennas. The presented antenna array could be used in two sets of phased arrays in the top and bottom portion of the mobile phone PCB [7].

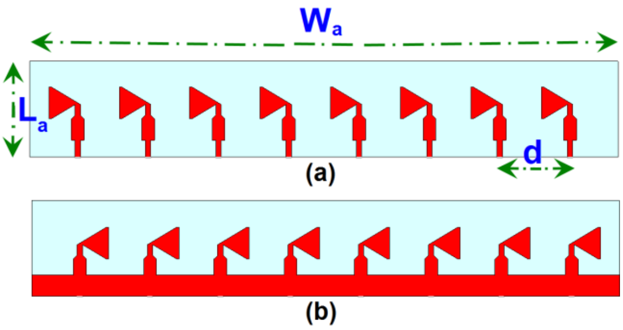

Fig. 7. Geometry of the array, (a) front view, and (b) back view.

In array designing, the adjacent element spacing must be chosen carefully due to its effect on the radiation performance of the array [8]. Figure 8 shows the configurations of the proposed array with different distance (*d*) between the elements.

Simulated S_{21} characteristics of the array for different values of *d* are illustrated in Fig. 9. As seen, in order to obtain a low mutual coupling characteristic for the antenna array, the distance between antenna elements must be near λ/2. When the distance between antenna elements increases from 0.5 λ/2 to λ/2 mm, the S_{21} characteristic of the array decreases from -6 to -16 dB. In addition, the radiation performance of the array for different values of *d* has been investigated. Figure 10 shows the main radiation beams of the array at 0º of scanning for different values of *d*. It can be seen for d=λ/2, the highest perfromace of the antenna array has been achived.

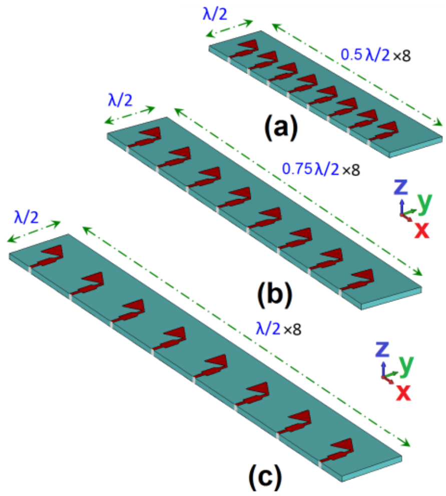

Fig. 8. Side views of the array for, (a) d=0.5×(λ/2), (b) d=0.75×(λ/2), and (c) d=λ/2.

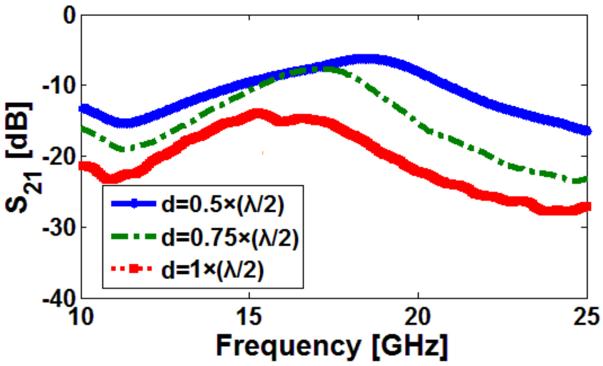

Fig. 9. Simulated S_{21} characteristics of the antenna for different values of *d*.

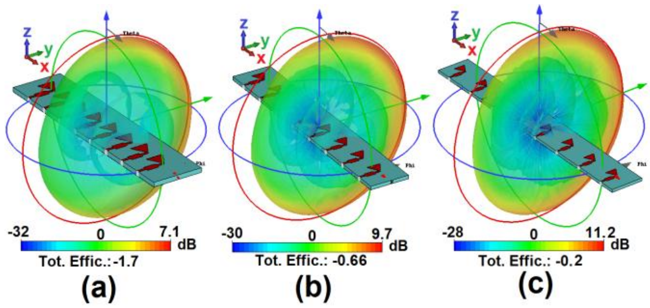

Fig. 10. 3D radiation beams (at 0°) of the array for different values of *d*, (a) d=0.5×(λ/2), (b) d=0.75×(λ/2), and (c) d=λ/2.

As illustrated, the array has 7.1, 9.7, and 11.2 dB realized gains with -1.7, -0.66, and -0.2 values of total efficiency for d=0.5×(λ/2), d=0.75×(λ/2), and d=λ/2, respectively. Based on the obtained results, in order to have high-gain, high-efficiency beams of antenna array, the distance between elements (*d*) must be calculated near λ/2 of the operation frequency.

Fig. 11 illustrate the S_{21} characteristics of the array for different values of d around λ/2. As seen, for *d*≥ 8 mm, the S_{21} characteristics of the array are less than -10 dB. In order to obtain a good beam forming issue while maintaining compact structure, the distance between elements has been calculated *d*=8.5 mm.

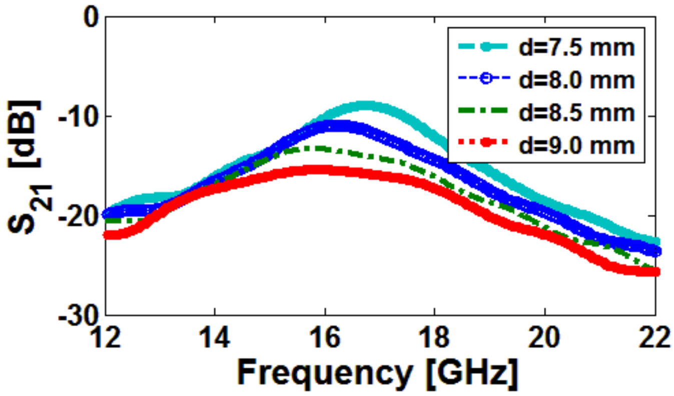

Fig. 11. Simulated S_{21} characteristics of the antenna for different values of *d*.

IV. The Proposed 5G Mobile Phone Antenna

The configuration of the presented 5G mobile-phone antenna is shown in Fig. 12 which is designed on the *N9000* PTFE substrate with thickness=0.787 mm and dielectric constant=2.2. It is comprised of eight elements of 17 GHz bow-tie antennas at the top-edge region of mobile phone PCB with overall dimension of 65×130 mm^2.

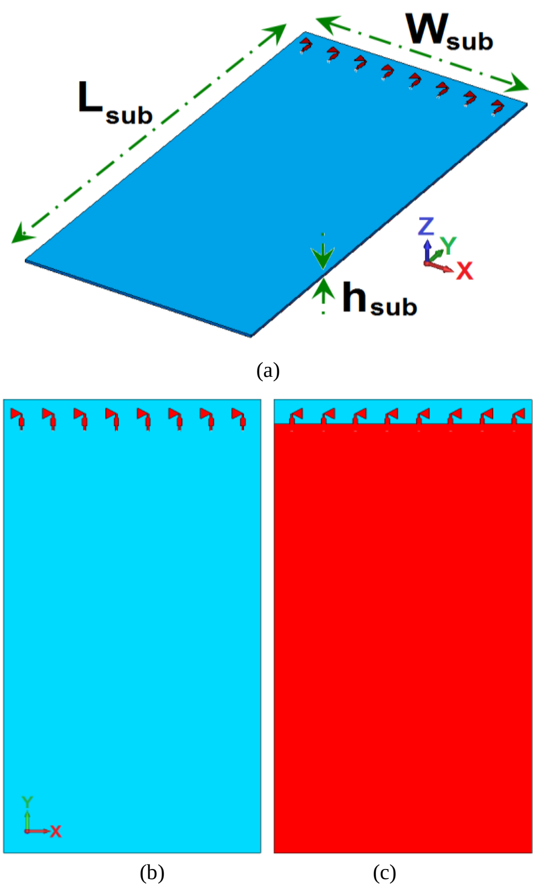

Fig. 12. Geometry of the proposed 5G mobile antenna, (a) side view, (b) front view, and (c) back view.

The simulated S-parameters of the proposed structure is illustrated in Fig. 13. As illustrated, the antenna can operate in the frequency range of 16 to 18.1 GHz (more than 2 GHz bandwidth). It should be noted to obtain the main resonance of the final design at 17 GHz, the value of W_2 must be changed from 1.2 to 1.35 mm because of the of PCB ground plane effect. It can be seen that the highest mutual-coupling characteristic between the elements are less than -12 dB which is sufficient for beam steering issue. Surface-current distributions for the proposed 5G antenna at resonance frequency (17 GHz) is shown at Fig. 14. As illustrated, the current have concentrated on the edge regions of the mobile phone PCB and most of the current flows are distributed around of the bow-tie arms.

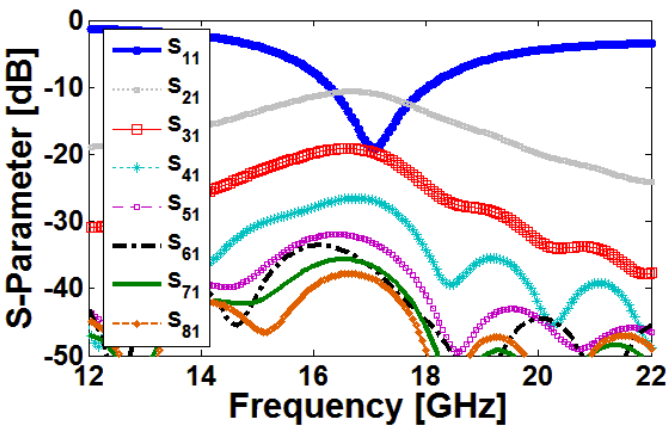

Fig. 13. Simulated S-parameters of the proposed 5G mobile-phone antenna.

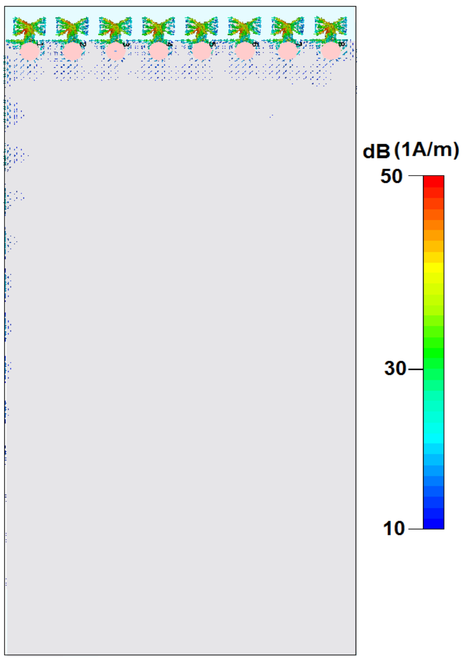

Fig. 14. Simulated current distribution at 17 GHz for the final design.

The directional radiation beams of the proposed 5G antenna for different scanning angles at 17 GHz is shown in Fig. 15. As seen, the proposed antenna has good beam steering property with end-fire mode and high directivity values which is highly effective to cover the required beam-coverage of 5G cellular handsets. The same beam-steering property could be obtained for minus (-) scanning angles.

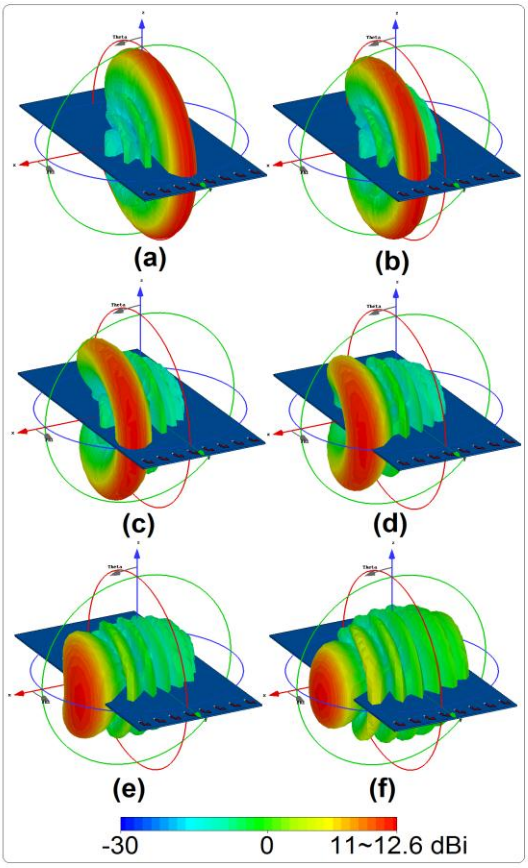

Fig. 15. 3D Radiation beams of the antenna with directivity values at, (a) 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 75°.

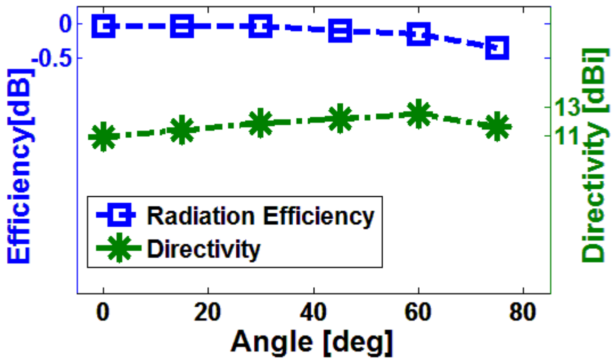

Fig. 16. Simulated directivity, radiation efficiency and total efficiency characteristics of the antenna at different scanning angles.

Simulated directivity, radiation efficiency and total efficiency characteristics of the proposed 5G antenna for the scanning range of 0 to 75 degree are shown in Fig. 16. As seen, the radiation efficiency function of the antenna is more than -0.25 dB (95%) in the scanning range of 0° to 60°. It is realized that the antenna has high efficiencies for different scanning angles. Furthermore, as can be seen, when the scanning angle of beam-steering characteristic is ≤ +75°, the proposed antenna has more than 11 dBi directivity characteristic with 1 dBi variation.

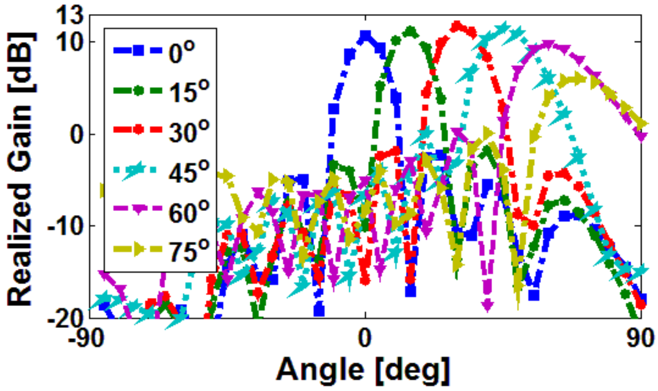

Fig. 17. Simulated realized gains of the antenna at different scanning angles.

Figure 17 illustrates the simulated realized gains (IEEE gain × mismatch losses) of the antenna in the scanning range from 0° to +75°. As illustrated, the antenna has a good beam steering characteristic with acceptable gain levels at different scanning angles. For the scanning range of 0 to 45 degree, the antenna gains are almost constant and are more than 11dB.

V. Conclusion

This study proposes a new design of microstrip-fed bow-tie array antenna with beam steering characteristic for mm-wave 5G applications. Eight elements of the 17 GHz bow-tie antennas have been employed to form a linear array with end-fire radiation beams on the top region of the cellular handset PCB. Bandwidth, gain, radiation pattern and beam steering characteristics of the proposed antenna are investigated. The investigated results show that the proposed phased array antenna provides some significant features and could be used in 5G cellular systems.

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