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UWB MM-Wave Antenna Array with Quasi Omnidirectional Beams for 5G Handheld Devices

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***Abstract*— An ultra-wideband (UWB) millimeter-wave (mm-Wave) dipole antenna array for fifth generation (5G) communications is presented in this paper. The proposed antenna is working in the frequency range of 23-33 GHz (10 GHz bandwidth with more than 35% FBW). Ten compact UWB dipole antenna elements designed on a *Rogers RT5880* substrate have been deployed along the edge region of the cell phone PCB. The feature of compact design with UWB characteristic makes them well-suited for 5G cellular devices such as laptops, tablets, mobile phones etc. Input impedance and radiation properties of the proposed antenna array have been discussed. The antenna features quasi-omnidirectional radiation beams at different scanning angles.**

I. INTRODUCTION

Compared with previous generations of mobile communication networks, 5G mobile networks will use higher frequencies to obtain broader communication bandwidth [1]. There are a number of candidate frequency bands for 5G ranging from 10 GHz to 80 GHz. Taking into account the feasibility, cost and technique readiness level, the frequency spectrum around 20 GHz to 35 GHz present as the most promising options. For example, 23 GHz, 25 GHz, 28 GHz, and 32 GHz are the frequency bands under consideration by Korea, US and Europe for 5G wireless communications [2-3]. In order to support international roaming and multiple frequency bands operation, the antenna in 5G mobile devices are preferred to have an ultra-wide bandwidth and coverage. In this paper, we represent an UWB antenna array covering 23-33 GHz for 5G mobile phone systems. The operation bandwidth of the proposed 5G antenna is wider than the antennas reported in [4-6].

The UWB technology has recently attracted considerable attention due to its potential for many applications [7]. The main contribution of this manuscript is the design of the UWB dipole antenna array with quasi-omnidirectional beam steering property operating at mm-Wave frequencies for 5G mobile phone devices. The fractional bandwidth [$(f_h-f_l)/f_C$] of the antenna is greater than 35% [8]. The center frequency of the designed dipole antenna array can be controlled by adjusting the values of the antenna parameters. The bandwidth, input impedance, antenna gain, radiation pattern and beams of the proposed UWB phased array antenna are studied. The simulations show good performance in terms of different antenna parameters.

II. SINGLE ELEMENT UWB DIPOLE ANTENNA

The configuration of the single element UWB dipole antenna is illustrated in Fig. 1. The antenna is designed on a *Rogers RT5880* substrate with dielectric constant (ε_r) and loss tangent (δ) of 2.2, and 0.0009 respectively. The dimension of the antenna and array parameters are listed in Table I.

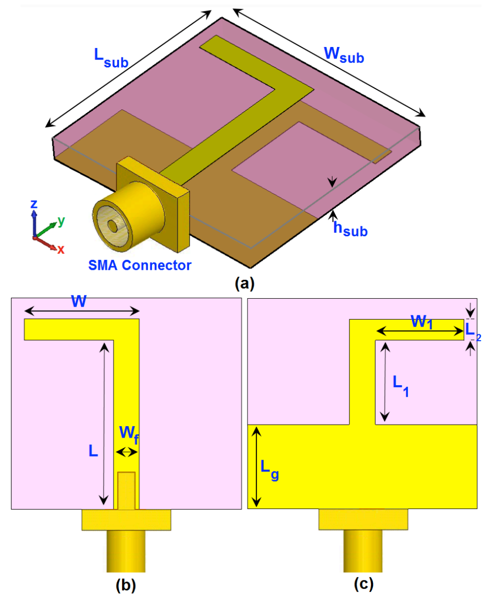

Figure 1. Configuration of the UWB dipole antenna, (a) 3D view, (b) top layer, and (c) bottom layer.

TABLE I
FINAL DIMESIONS OF THE UWB 5G ANTENNA PARAMETERS

Parameter	W_{sub}	L_{sub}	h_{sub}	W	L
Value (mm)	6	5	0.787	2.77	4.1
Parameter	W_1	L_1	L_2	W_f	L_g
Value (mm)	2.15	2.1	0.4	0.62	2
Parameter	W_S	L_S	d	d_1	d_2
Value (mm)	60	5	6	2.7	0.54

Simulated S_{11} characteristic of the designed dipole antenna is shown in Fig. 2. The result shows that the impedance bandwidth of the proposed antenna for -10 dB S_{11} is from 23 GHz to 33 GHz with more than 35% FBW.

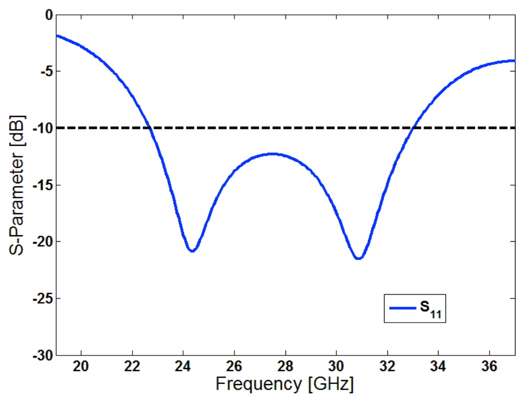

Figure 2. Simulated S_{11} of the UWB mm-Wave dipole antenna.

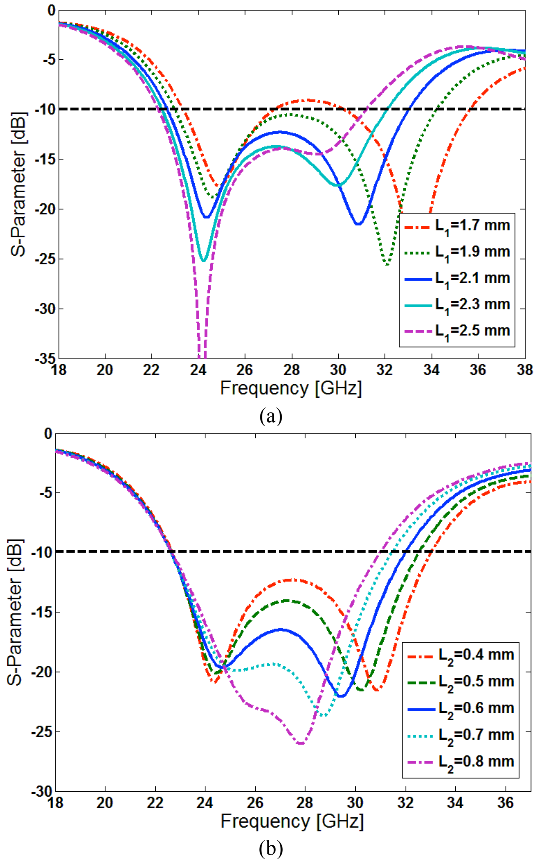

Figure 3. Simulated reflection coefficient (S_{11}) characteristics of the antenna for different values of (a) L_1 and (b) L_2.

The operation band of the designed compact UWB antenna can be controlled by adjusting the values of the antenna parameters such as widths of the antenna arms and length of the feed-line. The simulated S_{11} curves with different values of L_1&L_2 are depicted in Fig. 3. As illustrated in Fig. 3 (a), when the width of the dipole arms increases from 1.7 to 2.5 mm, the upper frequency of the antenna decreases from 35 to 31 GHz. The lengths of feed-line (L_2) is the critical parameter to control the impedance-matching characteristic of the antenna. Figure 3 (b) illustrates the simulated S_{11} characteristics with various lengths of L_2. As can bee seen, in order to have the UWB function with a good impedance matching characteristic, the lengths of L_1 and L_2 must be 2.1 and 0.4 mm, respectively. From this simulations we can conclude that the operation frequency of the antenna can be controlled by adjusting the values of the antenna parameters.

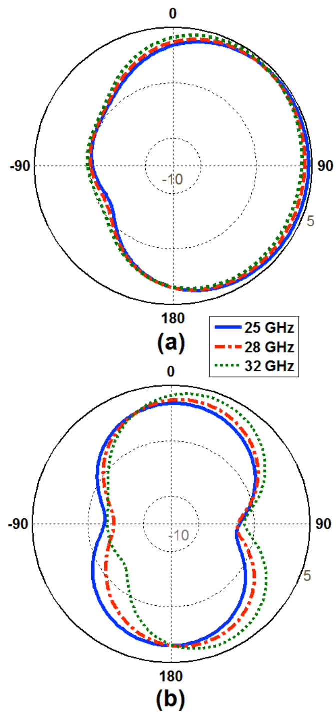

Figure 4. Simulated radiation patterns of the UWB dipole antenna, (a) E plane, and (b) H plane.

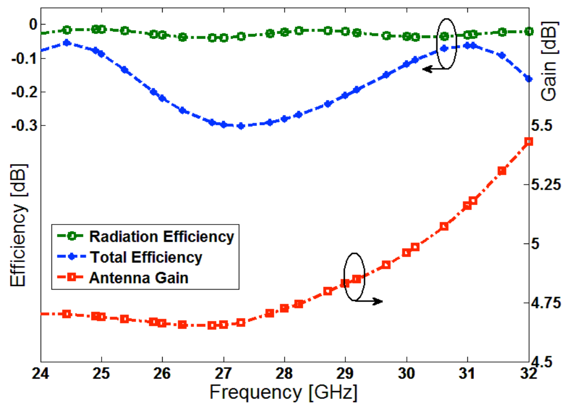

Figure 5. Simulated results for antenna gain and efficiencies.

Simulated radiation patterns of the UWB dipole antenna for E and H planes at lower, middle, and upper frequencies (25, 28, and 31 GHz) are illustrated in Fig. 4. As seen in Fig. 4 (a), the antenna has sufficient and acceptable gain levels with end-fire mode. Fundamental radiation properties (in terms of antenna gain, radiation and total efficiencies) are described in Fig. 5. As illustrated, the antenna has more than -0.05, -0.03, and 4.6 dB values for radiation efficiency, total efficiency and gain, respectively.

III. QUASI-OMINDIRECTIONAL 5G ANTENNA ARRAY

Figure 6 shows the top and bottom views of the UWB dipole antenna array employed at the edge region of mobile phone PCB for final design. In order to acquire the high gain function and also to cover wide scene of beam-steering, ten elements of UWB dipole antennas have been used in the proposed array. In this study, the gap between antenna elements (d) is calculated as about λ/2, where λ is the guided wavelength of 25 GHz [9].

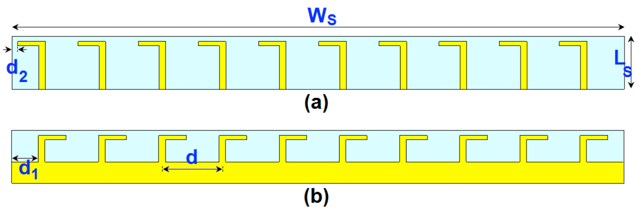

Figure 6. Configuration of the UWB dipole antenna array, (a) top layer and (b) bottom layer.

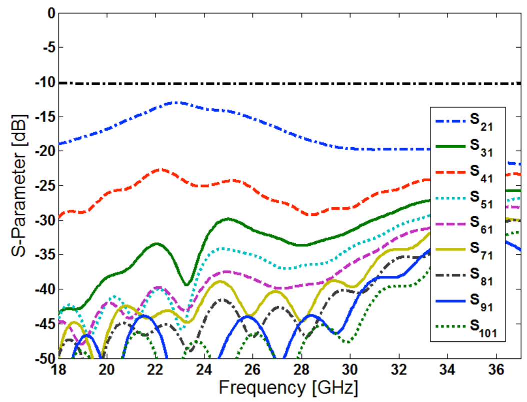

Figure 7. Simulated S_{21} to S_{101} characteristics of the antenna.

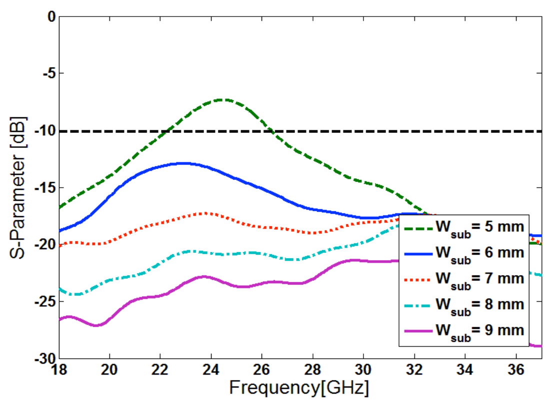

Figure 8. Simulated S_{21} characteristics of the array for different values of $W_{sub}=d$.

The simulated S-parameters (S_{21} to S_{101}) of the proposed phased array antenna are shown in Fig. 7. As illustrated, the proposed mobile-phone antenna has a good mutual coupling characteristic over its operation frequency range. Figure 8 illustrates simulated S_{21} characteristics of the antenna for different distances between antenna elements. As illustrated, in order to have a high-gain beams with good beam-steering and low mutual coupling characteristics, the distance between elements should be higher than 6 mm (λ/2 of 25 GHz).

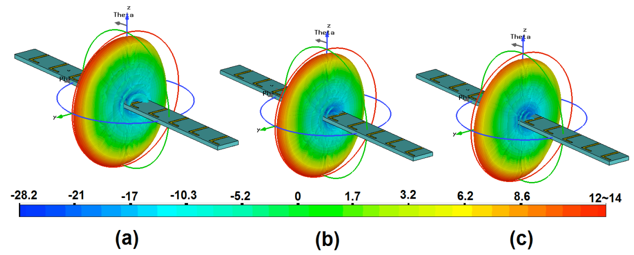

Figure 9. 3D radiation beams of the array when its beams are tilted to 0° elevation at, (a) 25 GHz, (b) 28 GHz, and (c) 32 GHz.

3D radiation beams of the compact array at 25, 28 and 32 GHz at 0° scanning angle are illustrated in Fig. 9. As seen, the dipole antenna array has quasi-omnidirectional beams with high realized-gain values in its entire operation band.

The simulated current distributions for the presented 5G antenna array at the lower/upper resonance frequencies (25 and 32 GHz) are presented in Fig. 10. As illustrated, the antenna array has been used at the edge region of the mobile phone PCB with a full ground plane and dimension of $W_{sub}\times L_{sub}=60\times 120\ mm^2$. It can be observed at the lower and upper frequencies the current concentrated on the edges of the interior and exterior of the dipole arms. In addition, the effect of full ground plane to reduce the radiation power and beam forming efficiency is insignificant.

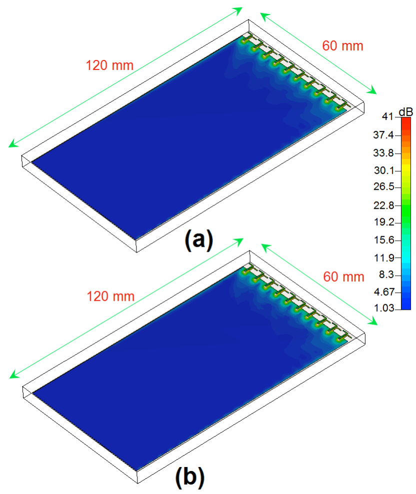

Figure 10. Simulated current distributions for the proposed antenna at, (a) 25 GHz and (b) 32 GHz.

The 3D results of the beam steering characteristic with realized gain values at 0 and 40 degrees of scanning angles are illustrated in Fig. 11. As seen, the proposed antenna has a sufficient beam-steering function with quasi-ominidirectional beams at 0° and 40°. For plus-minus (±) angles, the beam-steering property of the antenna are almost the same. As seen, the proposed antenna is highly effective in covering the required spherical beam coverage for 5G cellular handsets.

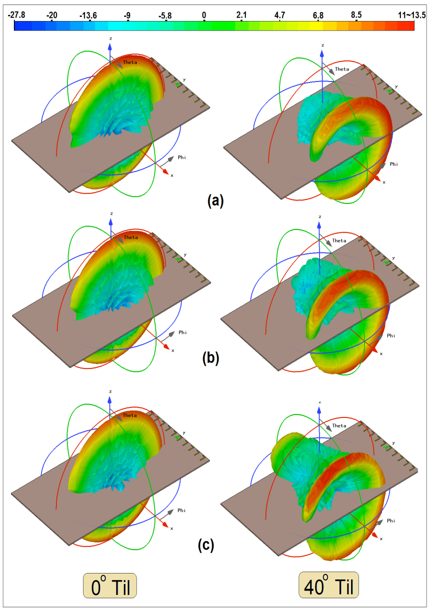

Figure 11. 3D Radiation beams of proposed mobile phone antenna at, (a) 25 GHz, (a) 28 GHz, and (c) 32 GHz.

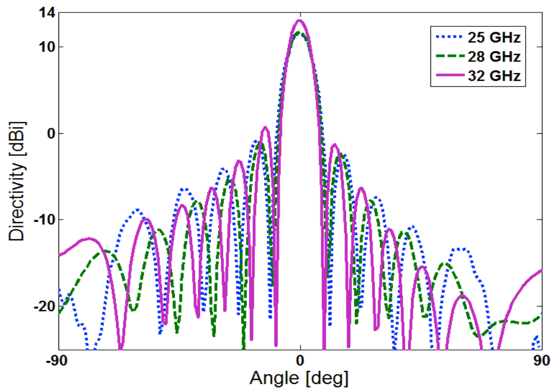

Figure 12. Simulated directivity characteristics of the antenna at main scanning angle (0°).

Figure 12 illustrates the simulated directivity characteristics of the 5G antenna when its beams are tilted to 0° (main scanning angle). As illustrated, the antenna has more than 11, 12.5, and 13.5 dBi directivity values at 25, 28, and 32 GHz, respectively. Simulated radiation and total efficiency characteristics of the proposed quasi-omnidirectional UWB antenna array are shown in Fig. 13. The results of the calculations using the CST software [10] indicates that the proposed antenna has great radiation efficiencies (-0.05 dB) with -1, -0.6, and -0.15 dB total efficiencies at 25, 28, and 32 GHz, respectively. From the results, it can be concluded that the antenna has good efficiencies in the entire operation band.

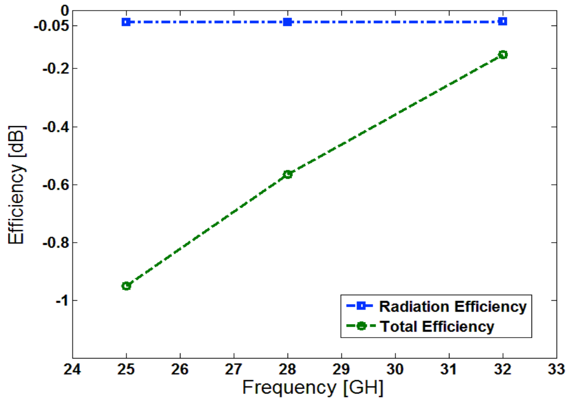

Figure 13. Simulated efficiencies of the antenna at 0° scanning angle.

IV. Conclusion

This study presents an UWB array antenna featuring quasi-omnidirectional radiation and high gain characteristics over the broad frequency band from 23 to 33 GHz. The design has been validated by full wave EM simulations and the results show good performance in terms of different antenna parameters such as S parameters, efficiency and realized gain. The design can be used to support multi frequency bands operations in 5G mobile devices.

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