Indonesian Journal of Electrical Engineering and Computer Science
Vol. 10, No. 3, June 2018, pp. 943~950
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v10.i3.pp943-950

A Wideband mm-Wave Printed Dipole Antenna for 5G Applications

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Article Info

Article history:

Received Jan 11, 2018
Revised Mar 8, 2018
Accepted Mar 23, 2018

Keywords:

5G
Antenna array
High gain antenna
Linear polarization
Wideband antenna

ABSTRACT

In this paper, a wideband millimeter-wave (mm-Wave) printed dipole antenna is proposed to be used for fifth generation (5G) communications. The single element antenna exhibits a 36 GHz bandwidth with more than 85.71% fractional bandwidth (for S_{11} <-10 dB) which covers six of the 5G candidate frequencies; 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz. The antenna also exhibits an average gain of 5.34 dB with a compact size of 7.35 x 5.85 mm^2. The antenna is further designed to be an array with eight elements and manage to increase the gain of the antenna with an average of 12.63 dB, a fractional bandwidth of 81.48% and linearly-polarized radiation pattern.

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1. INTRODUCTION

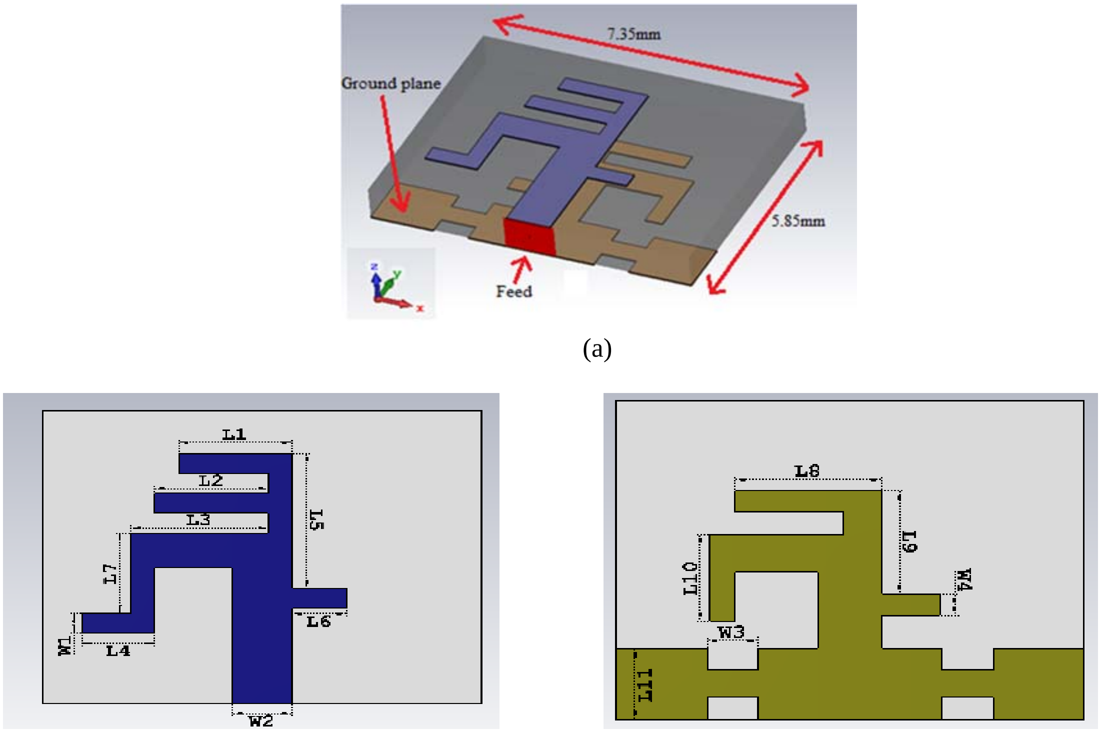
With ongoing progression of modern technology, the current fourth generation mobile communication system (4G) is now reaching its maturity. Thus, researches are now focusing on the next generation mobile communication system (5G) to meet the necessities of future traffic volume, data rates and convenience of new sorts of gadgets and services [1]. Since the frequency spectrum below 6 GHz is quite congested, there is very little scope to increase transmission rate in these bands [2]-[3]. To cater to this burgeoning demand, millimeter wave (mm-Wave) technologies are believed to play a very important role in upcoming cellular networks like 5G as it has the ability to offer wide frequency bandwidth for high data transmission [4]. Majority of the potential 5G candidate frequency bands ranging from 24 GHz to 50 GHz are contained 24.65-27 GHz, 27-29.5 GHz and 40-50 GHz [2], [5]. Korea, United States and Europe are also considering 25 GHz, 28 GHz and 32 GHz as potential 5G frequency bands [6]-[7].

Recent trends in communication requires for an antenna which display attributes of wide bandwidth, low profile, straightforward feeding structure and ease of fabrication. Printed dipole antennas have their unique advantageous features of simple structure, low manufacturing cost, ease of fabrication, high energy efficiency and omnidirectional radiation pattern which make them ideal wideband elements [8]. In order to enhance antenna gain and physical aperture, an antenna array could be employed [2].

In this paper, a wideband printed dipole antenna has been designed to be used for 5G applications at 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz. The operation bandwidth of the proposed 5G antenna is much wider than the antennas reported in [2], [4], [6], [9]-[11]. The fractional bandwidth of this antenna is greater than 85.71%. An eight elements antenna array is also designed to obtain high gain compared to previous work [2], [6]. The return loss, 2D and 3D radiation patterns, antenna gain, efficiency and 3 dB beamwidth of the proposed antenna are studied and analyzed.

2. RESEARCH METHOD

A printed dipole antenna has been designed and simulated using CST Microwave Studio (CST MWS) software for 5G applications. The antenna covers 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz of the 5G candidate frequencies. The proposed antenna is printed on a Rogers RT5880 substrate with dielectric constant (ε_r) of 2.2, loss tangent (δ) of 0.0009 and thickness of 0.8 mm. The geometry, top and bottom view for a prototype of the proposed antenna are illustrated in Figure 1. The optimized parameters are shown in Table 1. The antenna has two printed arms, one on the top and one at the bottom of the substrate. There is also a ground plane at the bottom side, which acts as a reflector to the antenna. The substrate size has a dimension of 7.35×5.85 mm^2.



(b) (c)

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

Table 1. Final dimensions of the dipole antenna parameters

Parameter	Value (mm)
L1	1.90
L2	1.90
L3	2.30
L4	1.20
L5	2.70
L6	0.90
L7	1.60
L8	2.30
L9	1.90
L10	1.60
L11	1.30
W1	0.40
W2	1.00
W3	0.80
W4	0.40

3. RESULTS AND ANALYSIS

The proposed antenna is designed in two stages; as a 1) single element dipole antenna, and 2) eight elements dipole antenna array. The simulated return loss, 2D and 3D radiation patterns, realized gain, efficiency and 3 dB beamwidth are presented and discussed.

3.1. Single Element Dipole Antenna

Simulated return loss (S_{11}) of the single element dipole antenna is shown in Figure 2. The result shows that the proposed antenna has a wide bandwidth of 36 GHz, ranging from 24 GHz to 60 GHz; i.e. S_{11} at 24 GHz = -12.623 dB, S_{11} at 25 GHz = -17.498 dB, S_{11} at 28 GHz = -14.496 dB, S_{11} at 32 GHz = -17.578 dB, S_{11} at 38 GHz = -26.738 dB, and S_{11} at 40 GHz = -16.239 dB. The antenna has a fractional bandwidth of more than 85.71% (for S_{11} <-10 dB). It can be concluded that the proposed antenna has a good potential for future 5G applications since it covers all the six 5G candidate frequencies.

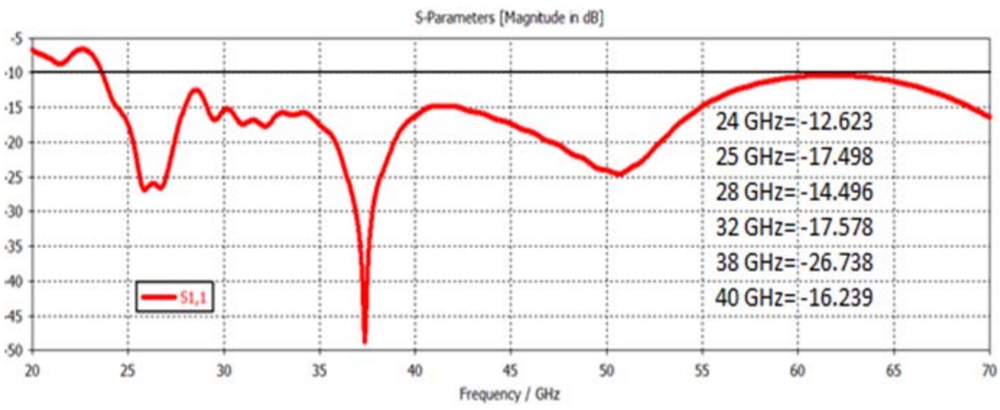
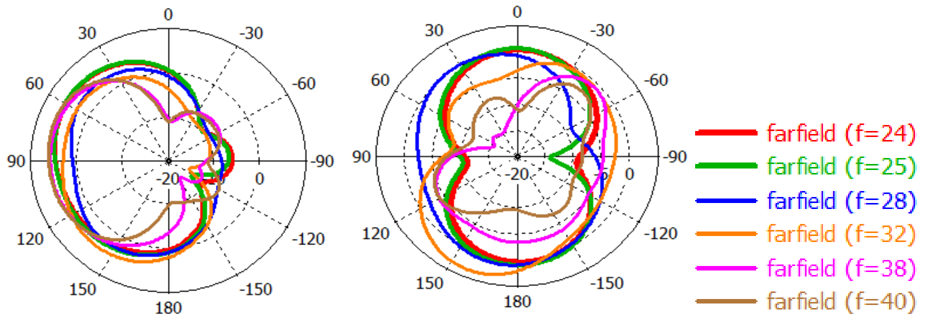


Figure 2. Simulated return loss (ideal S_{11} <-10 dB) of the wideband mm-Wave single element dipole antenna

Simulated radiation patterns of the designed antenna for E and H planes at 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz are illustrated in Figure 3. It is observed in Figure 3(a) that the antenna has acceptable and average gain levels at all the selected frequencies with end-fire mode. Figure 4 illustrates the radiation patterns of the proposed configuration in 3D.



(a) (b)

Figure 3. Simulated polar radiation patterns of the single element dipole antenna at 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz, (a) E-plane, and (b) H-plane

Table 2 summarized the performance of the printed single element dipole antenna in terms of realized gain, efficiency and 3 dB beamwidth. It demonstrates that the proposed antenna has reasonable realized gain, with an average of more than 5 dB at all the selected frequencies, except at 28 GHz with 3.353 dB gain. The antenna has approximately more than -1.4 dB and -1.56 dB of radiation efficiency and total efficiency, respectively at all the targeted frequencies which confirm the wideband feature of the proposed antenna. The designed single element antenna is also having a fairly wide beamwidth, ranging from 72.4° to 122.3°. This is due to the single element antenna architecture; as number of elements is increased, the 3 dB beamwidth narrow down further and further [12]. Hence, the single element dipole antenna design can be observed as a less directive one. In comparison, the work reported in [2] provides a bandwidth, fractional bandwidth and an average gain of 26 GHz, 70%, and 5 dB gain, respectively. The antenna design in [6] has an average gain of 4.6 dB, and a comparatively lower bandwidth (10 GHz) and fractional bandwidth (35%), respectively. It can be summarized that our proposed single element dipole antenna exhibits a wider bandwidth (36 GHz), fractional bandwidth (85.71%) and average gain (5.34 dB) compared to these reported works in [2] and [6]. Moreover, this antenna is covering six of the potential 5G frequencies whereas antenna reported in [6] covers four of the potential 5G frequency bands.

Table 2. Simulated realized gain, radiation efficiency, total efficiency and 3 dB beamwidth of the single element dipole antenna at the six 5G candidate frequencies

Frequency	Realized gain	Radiation efficiency	Total efficiency	3 dB beamwidth
24 GHz	5.787 dB	-0.445 dB	-0.687 dB	79.5°
25 GHz	5.891 dB	-0.437 dB	-0.517 dB	78.1°
28 GHz	3.353 dB	-1.395 dB	-1.557 dB	98.4°
32 GHz	5.085 dB	-0.372 dB	-0.412 dB	122.3°
38 GHz	5.622 dB	-0.804 dB	-0.864 dB	88.3°
40 GHz	6.219 dB	-1.182 dB	-1.326 dB	72.4°

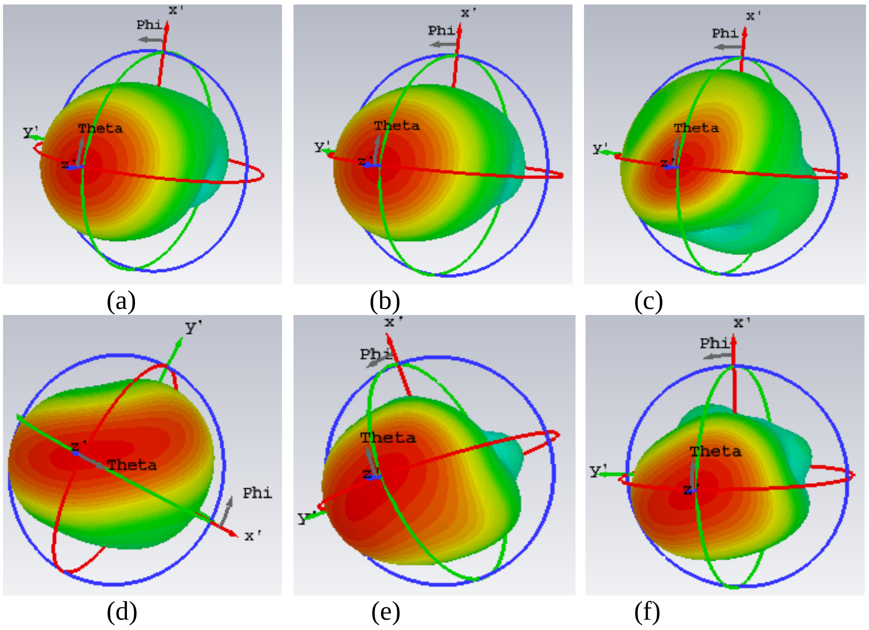
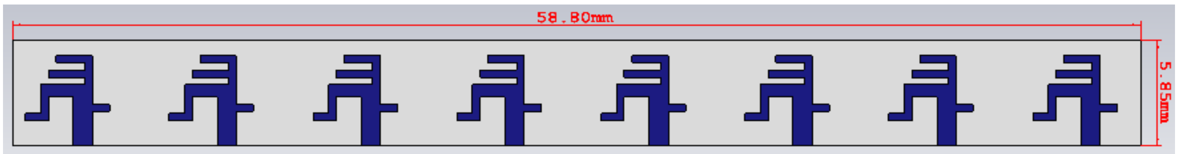


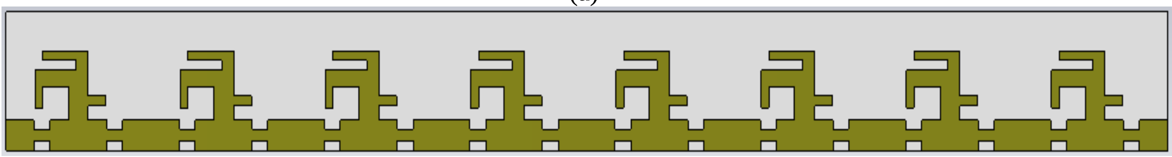
Figure 4. Simulated 3D radiation patterns of the single element dipole antenna at (a) 24 GHz, (b) 25 GHz, (c) 28 GHz, (d) 32 GHz, (e) 38 GHz, and (f) 40 GHz

3.2. Eight Elements Dipole Antenna Array

Next, in order to acquire the high gain function, eight elements of dipole antennas have been used in the proposed array. Simulation of linear N element patch antenna has shown that, as the number of elements in linear array antenna increases, it produces more side lobes and decreases the minimum return loss for each port [12]. Therefore to minimize the number of side lobes and achieve acceptable gain values for 5G applications, eight elements of linear array has been chosen. The structure of the wideband dipole antenna array is depicted in Figure 5. In this manuscript, the gap between antenna elements (d) is calculated as about $\lambda/2$**,** where λ is the guided wavelength of 30 GHz. The array configuration has a dimension of 58.8 x 5.85 mm^2.



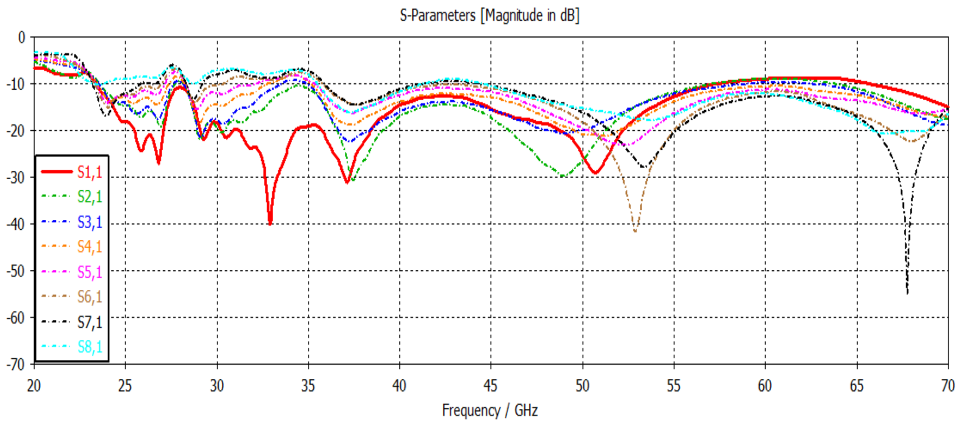
(a)



(b)

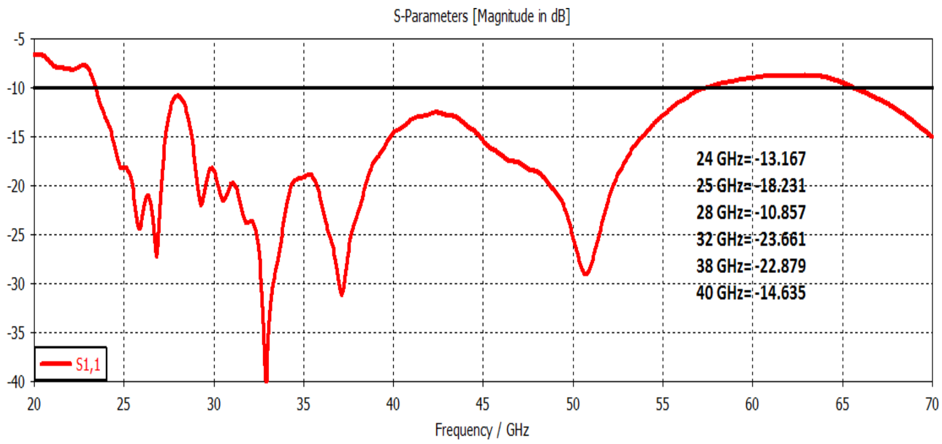
Figure 5. Configuration of the eight elements dipole antenna array, (a) top layer, and (b) bottom layer.

The simulated S-parameters of the designed antenna array are shown in Figure 6. It indicates that the operation bandwidth of the antenna array is 33 GHz, covering from 24 GHz to 57 GHz with more than 81.48% fractional bandwidth. As illustrated, the bandwidth of the antenna array configuration is slightly decreased from the single element design due to mutual-coupling effects [2].



(a)

Figure 6(a). Simulated return loss (ideal S_{11} <-10 dB) of the wideband mm-Wave eight elements dipole antenna, S_{11} to S_{81}



(b)

Figure 6(b). Simulated return loss (ideal S_{11} <-10 dB) of the wideband mm-Wave eight elements dipole antenna, S_{11}

The simulated 3D radiation patterns of the designed antenna array at 0° scanning angle are shown in Figure 7. It is observed that, as the number of array elements is increased, the gain is increased, while the beamwidth has decreased in the azimuth direction [12].

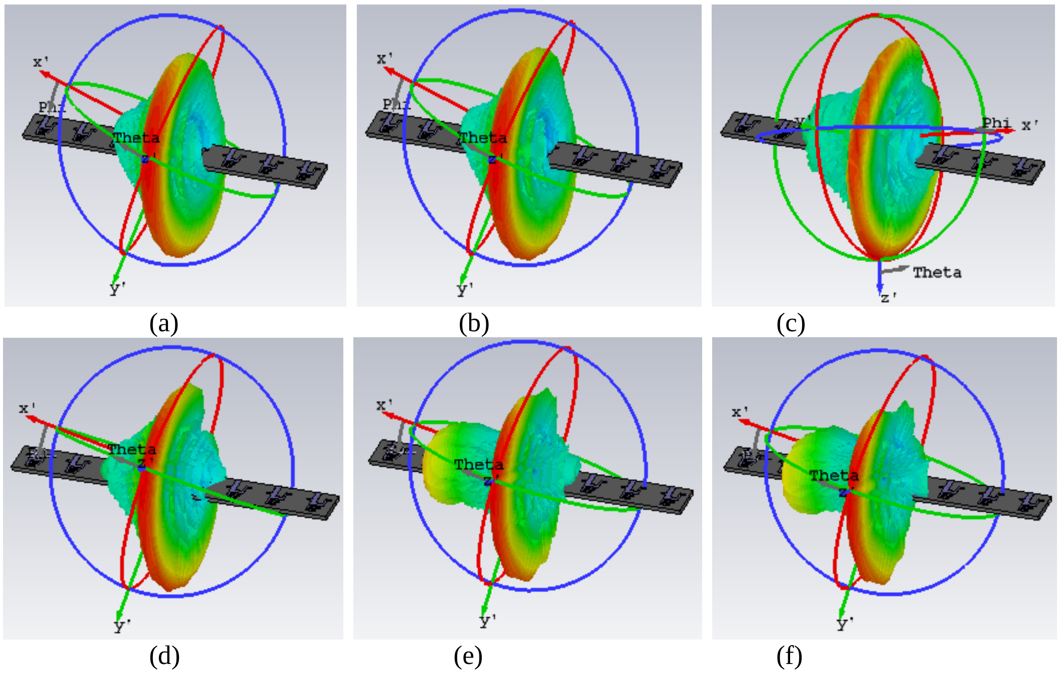


Figure 7. Simulated 3D radiation patterns of the eight elements dipole antenna array when its beams are tilted to 0° elevation at (a) 24 GHz, (b) 25 GHz, (c) 28 GHz, (d) 32 GHz, (e) 38 GHz, and (f) 40 GHz

The simulated realized gain, efficiency and 3 dB beamwidth of the antenna array are summarized in Table 3. The calculations using the CST software indicates that the proposed antenna is linearly-polarized, has narrower 3 dB beamwidth (ranging from 6.6° to 11.2°) and higher realized gain (ranging from 9.47 dB to 14.57 dB) compared to the single element structure. This eight element array is demonstrating a narrower 3 dB beamwidth as the number of elements is increased from single element to eight elements. Hence, the array structure becomes more directive with higher gain. The antenna efficiencies are moderate at the targeted frequencies which confirm the wideband feature. In comparison, the array structure reported in [2] has a bandwidth of 22 GHz with a fractional bandwidth of 60%, while the array design reported in [6] has a bandwidth of 4 GHz with a fractional bandwidth of about 16.66%. Regarding antenna gain, it is fluctuating between 12 dB to 14 dB at different frequencies (i.e. work in [2] exhibited gain of 14 dB (28 GHz) and 13 dB (45 GHz), while work in [6] exhibited a gain of 13 dB (32 GHz) and 12 dB (28 GHz and 25 GHz). It can be summarized that our proposed 8 elements array structure has a relatively high bandwidth (33 GHz), fractional bandwidth (81.48%) and average gain (12.63 dB) at six different frequencies.

Table 3. Simulated realized gain, radiation efficiency, total efficiency and 3 dB beamwidth of the eight elements dipole antenna array at the six 5G candidate frequencies

Frequency	Realized gain	Radiation efficiency	Total efficiency	3 dB beamwidth
24 GHz	12.30 dB	-0.90 dB	-1.12 dB	11.2°
25 GHz	12.21 dB	-0.98 dB	-1.22 dB	10.7°
28 GHz	9.47 dB	-2.30 dB	-2.95 dB	9.3°
32 GHz	12.96 dB	-0.81 dB	-1.17 dB	7.9°
38 GHz	14.28 dB	-1.08 dB	-1.17 dB	7°
40 GHz	14.57 dB	-1.39 dB	-1.60 dB	6.6°

4. CONCLUSION

This study presents a wideband linearly-polarized printed dipole antenna for the use of 5G applications. The antenna covers six of the potential 5G candidate frequency bands which are 24 GHz, 25 GHz, 28 GHz, 32 GHz, 38 GHz and 40 GHz. The design has been validated by full wave EM simulations. This antenna provides a wide impedance bandwidth of 85.71% in the single element, and a usable bandwidth of 81.48% in the phased array application. The eight elements array implementation enhances both antenna aperture and antenna gain (i.e. realized gain increase from an average of 5.34 dB in the single element, to an average of 12.63 dB in the phased array application). The proposed dipole antenna shows good performance in terms of bandwidth, radiation pattern and gain, which make it a good candidate for future 5G applications.

ACKNOWLEDGEMENTS

This research was supported by International Islamic University Malaysia (IIUM) through IIUM Research Initiative Grant (RIGS15-134-0134).

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