Design of Dipole Beam-steering Antenna Array for 5G Handset Applications

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Abstract—In this manuscript, a novel design of millimeter-wave (mm-Wave) dipole phased array antenna for the fifth generation (5G) handset applications is proposed. The proposed antenna is designed to cover some of the candidate bands for 5G communications from 24 to 50 GHz, and has dimension of $8 \times 5.5 \text{ mm}^2$. The antenna exhibits small and wide bandwidth. The beam steering characteristics in the operation band are presented for a linear array of this antenna.

1. INTRODUCTION
As the communication systems evolved rapidly, the higher data rates is required to meet the future huge data flow applications (such as HD video broadcast, big volume file transmission and high quality video chat). Due to heavily utilized of frequency spectrum below 6 GHz, there is little space to further increase the transmission rate in these frequency bands [1]. Consequently, 5G cellular systems move to mm-Wave bands, which have wider bandwidths to achieve high-speed rates and increase in capacity. Some of the potential 5G candidate frequency in the range of 24–50 GHz are contained 24.65–27 GHz, 27–29.5 GHz and 40–50 GHz [2]. Communication systems that operate in multiband are usually using separate antennas to cover each band. Since the trend of systems integration, it is desirable to design a single wideband antenna which can operate in more required bands.

From the Friis transmission equation, we know that the path loss from transmitter to receiver is proportional to the antenna operation frequency [3]. In order to overcome the attenuation influences, employing an antenna array could be a solution to enhance antenna gain as well as the physical aperture. The good beam steering characteristics of the phased array increase both the received signal strength and provide large spatial coverage.

The proposed design is based on the wideband printed dipole antenna [4, 5] and modified to be suited for mm-Wave band applications. A phased array that consists of eight antenna elements is also be designed to obtain high gain. It is able to cover most mm-Wave wireless communication bands. The simulation results show that dipole antenna array has acceptable performance and good beam steering function.

2. SINGLE ELEMENT DIOPLE ANTENNA
The proposed antenna is printed on a Rogers RT/Duroid 5880 substrate of a dielectric constant of 2.2, a conductor loss ($\tan \delta$) of 0.001 and thickness of 0.8 mm. The geometry, top and bottom view for a prototype of the proposed antenna are illustrated in Fig. 1. The optimized parameters are shown in Table 1. The antenna consists of two printed arms, one on the top and one on the bottom of the substrate respectively. Both the two arms are connected to the microstrip feedline and the bottom side consists of a ground plane. The substrate size is $8 \times 5.5 \text{ mm}^2$. The presented design has many advantages used in phased array such as wide bandwidth, small size, stable radiation patterns, high gain and wide 3 dB beam width in the operating band.

Compared to the conventional dipole antenna, this antenna has a much wider bandwidth, which may result from two properties of this design. First, the lengths of the long and short modified dipoles generate the lower and upper resonate mode, respectively. Second, each feeding line has an open stub that good impedance matching can easily be obtained by tuning its size and position. Fig. 2 shows the simulated return loss for the proposed dipole antenna. An impedance bandwidth of 70% ($S_{11} < -10 \text{ dB}$), corresponding to the frequency range 24–50 GHz, was obtained. The dimensions of this antenna where selected so that the lengths of the long and short dipoles are half wavelength at 25 and 45 GHz. The ground plane acts as a reflector to the radiation patterns.
Table 1: Dimensions of the proposed antenna.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mm)</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>$W_f$</td>
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<tr>
<td>$W_3$</td>
<td>0.4</td>
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</tbody>
</table>

![Geometry of microstrip dipole feed antenna.](image)

Figure 1: Geometry of microstrip dipole feed antenna. (a) 3-D view, (b) top view.

![Simulated return loss of the proposed antenna.](image)

Figure 2: Simulated return loss of the proposed antenna.

The normalized far-field radiation patterns are computed at selective frequencies and shown in Fig. 3 in the $E$ and $H$ planes, respectively, at 26, 28 and 45 GHz. The wide main beam suggesting that a large phased array scan angle is obtained. The antenna gain has an average value of 5 dB for the whole operating bands. According to these results, the operating bandwidth of the antenna can be roughly estimated from 24 to 50 for phased array applications.

### 3. PROPOSED LINEAR PHASED ARRAY

The schematic of the linear array with eight elements of the dipole antennas for handset applications is shown in Fig. 4. The antenna element spacing is design $0.5\lambda_0$ at 30 GHz and the simulated $S$-parameters of the proposed structure is illustrated in Fig. 5. It can be seen that bandwidth is decrease due to the mutual-coupling effects. The isolation between each feeding point is more than 15 dB.

The phased array antenna can adaptively change beamforming angle by tuning phases among antenna elements. The beam steering performance is demonstrated in Fig. 6 at $0^\circ$, $30^\circ$ and $60^\circ$. 

Figure 3: Computed radiation patterns at different frequency. (a) $E$-plane ($xy$-cut), (b) $H$-plane ($yz$-cut).

Figure 4: Proposed antenna array geometry.

Figure 5: Simulated $S$-parameters of the antenna array.

Figure 6: Beam forming radiation pattern in 3-D of the array at 28 GHz.

As seen, the main array beam can be steered up to 60°. For the scanning range of 0 to 60 degree, the antenna has more than 10 dB realized gain are shown in Fig. 7 at 28 and 45 GHz. It can be seen that the array has sufficient gain at different scanning angle. The computed antenna radiation efficiencies are more than 90% at the operation frequency range.
Figure 7: Simulated realized gains of the array for different scanning angles. (a) Frequency at 28 GHz. (b) Frequency at 45 GHz.

4. CONCLUSIONS

In this paper, we introduced a novel dipole antenna as single element radiators and for wideband wireless communications. The proposed dipole antenna provides a wide impedance bandwidth of 70%, and a usable bandwidth of 60% in phased array application. The simulation results show the antenna array has good performance at S-parameter, gain, efficiency and the beam steering function.

REFERENCES