Abstract—This manuscript proposes a new design of phased array antenna for future fifth generation (5G) cellular communications. The proposed phased array antenna is designed on a low-cost N9000 PTFE substrate with overall size of 60×120×0.8 mm$^3$. It consists of eight 28-GHz Vivaldi antenna elements used to form a linear phased array in the edge region (top-side) on a mobile phone PCB. The simulated results show that the antenna has the reflection coefficient (S11) less than -10 dB in the frequency range of 27.4 to 28.6 GHz. The proposed phased array antenna has good gain, efficiency, and 3D beam steering characteristics in the entire operation band, which makes it suitable for millimeter-wave 5G communications. In addition, the performance of the antenna in the vicinity of user’s hand has been investigated in this study.

Keywords—5G, antipodal Vivaldi antenna, end-fire antenna, mm-wave communication.

I. INTRODUCTION

Due to the increasing need for future applications requiring even higher data rates (such as wireless broadband connections, massive machine type communications and highly reliable networks), the new research and technological expansion of fifth-generation (5G) mobile communication systems have started. The standardization activity of this technology and commercial availability of its equipment may be done in 2016 and the early of 2020s, respectively [1-2].

Compared with previous generations, 5G mobile communication networks will use broader mm-Wave frequency bandwidths. The frequency spectrum around 22, 28, and 38 GHz are some of the promising frequency bands under consideration for 5G wireless communications [3-4].

This paper proposes a new design of phased array Vivaldi antenna for mm-Wave 5G mobile applications. The proposed design consists of eight antipodal Vivaldi antenna elements which are used along the upper edge of the mobile PCB. An antipodal Vivaldi antenna is a “surface-type” traveling-wave antenna. The electromagnetic (EM) waves travel down the curved path of the flare along the Vivaldi antenna. In the region with small separation between the two conductors, the EM waves are tightly bound [5]. The proposed antenna is designed to operate at 28 GHz. The simulated results of the antenna are obtained by using CST Microwave Studio software [6]. The simulations show this antipodal Vivaldi antenna satisfies general requirements for 5G cellular applications.

II. CONFIGURATION OF THE PROPOSED 5G ANTENNA

The presented antenna shown in Fig. 1 is designed using the N9000 PTFE substrate with 0.787 mm thickness, dielectric constant of 2.2, and dimension of 60×120 mm$^2$ ($W_{sub}$×$L_{sub}$).

Fig. 1. Proposed phased array 5G antenna configuration, (a) side view, (b) top layer, and (c) bottom layer (GND).

III. SINGLE ELEMENT VIVALDI ANTENNA

Figure 2 illustrates the configuration of the single-element antipodal Vivaldi antenna. The antenna is physically compact with an exponentially tapered opening slot used to achieve directivity in one direction. The configuration of the proposed Vivaldi antenna comprises two tapered arms which lie on the opposite sides of the substrate. The tapered-arm used on the top layer of the N9000 PTFE substrate is fed by a 50 Ohm microstrip-line. The arm on the bottom layer is connected with an exponentially tapered ground plane feed [7]. The values of the proposed antenna parameters are listed in Table 1.

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Fig. 2. Configuration of the 28 GHz Vivaldi antenna, (a) side view, (b) top layer, and (c) bottom layer.

Table 1: Final Dimensions of the Antenna Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>W_{sub}</th>
<th>L_{sub}</th>
<th>h_{sub}</th>
<th>L</th>
<th>W</th>
<th>L_{a}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value (mm)</td>
<td>60</td>
<td>130</td>
<td>0.8</td>
<td>17.25</td>
<td>5</td>
<td>17.25</td>
</tr>
<tr>
<td>Parameter</td>
<td>L_{g}</td>
<td>L_{1}</td>
<td>r</td>
<td>W_{f}</td>
<td>W_{a}</td>
<td>d</td>
</tr>
<tr>
<td>Value (mm)</td>
<td>5.15</td>
<td>6.3</td>
<td>2.3</td>
<td>0.4</td>
<td>37.5</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 3 illustrates the simulated $S_{11}$ characteristic of the antenna. As illustrated, the antenna operates at the frequency range from 27.4 to 28.6 GHz (more than 1 GHz Bandwidth).

Figure 4(a) shows the simulated current distributions for the Vivaldi antenna at 28 GHz. As illustrated, most of the currents flow around the antenna tapered arms. It can be seen, a discrete-port feeding technique has been used to feed the antenna in the simulations. In addition, the simulated 3D radiation pattern of the single element Vivaldi antenna is illustrated in Fig. 4(b). As seen that the antenna has an end-fire radiation pattern with 5.39 dB realized gain at 28 GHz.

Simulated maximum gain, radiation efficiency and total efficiency characteristics of the single element Vivaldi antenna over the operation frequency range are illustrated in Fig. 5. At the frequency range from 27.4 to 28.6 GHz, the antenna radiation and total efficiencies are more than -0.5 dB (90%). Furthermore, the antenna has a maximum gain of 6 dBi at resonance frequency (28 GHz).

IV. THE PROPOSED BEAM-STEERABLE ANTENNA ARRAY

Figure 6 shows the configuration of a linear array with eight elements of Vivaldi antennas which is used on the mobile phone PCB. One of the important parameters of array design is the distance between the antenna elements of an array. For beam forming array, the distance between elements (d) is calculated near $\lambda/2$ of the resonance frequency (28 GHz) [8-9].

The simulated S-parameters ($S_{11}$ to $S_{81}$) of the proposed 5G antenna (final design) are shown in Fig. 7. The antenna operates at the central frequency of 28 GHz (more than 1 GHz bandwidth). It can be seen that the highest mutual-coupling characteristic between the elements is less than -16 dB.

Figure 6 shows the geometry of the linear array, (a) top layer, and (b) bottom layer.
Surface-current distribution for the proposed 5G antenna at 28 GHz is shown in Fig. 8. As illustrated, the current has concentrated on the edge regions of the mobile phone PCB and most of the current flows are distributed around the tapered arms of the Vivaldi antennas. In addition, the effect of the full ground plane on the radiation beams is insignificant.

The beam steering characteristic of the antenna beams at different scanning angles (0° to 70°) are shown in Fig. 9. As seen, the proposed antenna has a sufficient beam-steering function in the scanning range of 0 to 70 degree for plus-minus (±) scanning angles, the beam-steering characteristic of the antenna are almost the same.

Figure 10 describes the fundamental properties of the proposed antenna beams for the scanning range of 0 to 70. As seen, the antenna has the radiation and total efficiencies more than -0.25 dB and -0.75 dB, respectively. It is noted that the antenna has high efficiencies for different scanning angles. Furthermore, when the scanning angle of the radiation beam is ≤70°, the proposed antenna has more than 12 dBi directivity.

Figure 11 illustrates the simulated realized gains of the proposed 5G mobile-phone antenna. From the beam steering characteristics shown in Fig. 12 it can be seen that the antenna has sufficient gains at different scanning angles. For the scanning range of 0 to 40 degree the antenna gains are almost constant and more than 12 dB.

V. THE ANTENNA PERFORMANCE WITH USER’S HAND

The handsets for mobile communication systems are practically operated in the vicinity of a human body. Especially, the user’s hand is one of the parts that touch the mobile handsets most frequently. [10].

In general, the user’s hand has a negative impact on the antenna performance in terms of efficiency, gain, impedance-matching and etc. Changing its position can increase/decrease the amount of the losses. The impact of user-hand on the
performance of the proposed phased array Vivaldi antenna has been studied in this section.

![Antenna in Vicinity of User's Hand](image1)

**Fig. 12.** Different placement of the antenna in the vicinity of user’s hand, (a) bottom position, (b) top position.

The total losses of antenna parameters in terms of realized gain, radiation efficiency, and total efficiency are about 25%, 20%, and 3 dB, respectively.

<table>
<thead>
<tr>
<th>Antenna Parameters</th>
<th>Position (a)</th>
<th>Position (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Efficiency</td>
<td>10–20%</td>
<td>15–20%</td>
</tr>
<tr>
<td>Radiation Efficiency</td>
<td>15–30%</td>
<td>20–30%</td>
</tr>
<tr>
<td>Realized Gain</td>
<td>1–2.5 dB</td>
<td>2.5–4 dB</td>
</tr>
</tbody>
</table>

### VI. CONCLUSION

In this paper, a new phased array antipodal Vivaldi antenna for 5G mobile communications is presented. The antenna is designed using the N9000 PTFE substrate to operate at 28 GHz. End-fire radiation beams with high-gain and high-efficiency characteristics have been achieved by employing eight elements of antipodal Vivaldi antennas as a linear phased array antenna on the top region of the cellular handset PCB. Simulations have been conducted to validate the design. The results show that the proposed design has good performance in terms of S-parameters, antenna gain, efficiency, and beam steering, which is fitting the need of 5G communications.

### REFERENCES