High Gain, Wideband Grid Array Antenna for 28 GHz 5G Base Station

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Abstract—This paper proposes a high gain grid array antenna (GAA) with enhanced bandwidth for 5G base station applications. The wideband GAA characteristics are achieved by loading the rhombus patch on the short radiating sides of the conventional GAA. By loading the rhombus on the short radiating sides of the conventional GAA, the additional capacitive reactance is introduced to cancel out the inductive reactance which leads to the enhancement on the bandwidth performance. The amplitude tapering is applied to reduce the side-lobes levels of the grid array antenna. From the simulated results, it can be observed that the proposed GAA manages to support a −10 dB impedance bandwidth of 16.07% which is ranging from 27.5 GHz to 32 GHz with maximum achieved gain of 14.8 dBi. The overall dimension of the proposed wideband GAA is $25 \times 25 \times 0.787$ mm$^3$.

Index Terms—Grid Array Antenna, millimeter wave, 5G, high gain, amplitude tapering.

I. INTRODUCTION

The proliferation of new wireless applications such as the Internet of things (IoTs), machine-to-machine (M2M) communication, E-health, E-business and E-learning result in increase demands for much higher data rate communication services [1]. In order to ensure the next generation wireless communication networks are capable to support this huge demand, the millimetre wave (mmWave) band has been identified to accommodate the new systems [2]–[4].

The mmWave band has been chosen to deliver high speed services in 5G wireless networks. However, as compared to the lower frequency band employed in the earlier generation telecommunication systems, the propagation pathloss in mmWave is more significant [2]. To compensate for it, advanced multiple antenna techniques have been proposed for 5G such as massive multiple-input multiple-output (MIMO) and beamforming techniques [3], [5]. These techniques can improve the gain of the antenna as well as provide a better interference suppression capabilities. Given the huge number of antenna elements that are needed, it is crucial to develop a mmWave array antennas at a low cost, low complexity, wideband performance, good integration capability and low profile.

In order to achieve high gain performance at mmWave, array antennas integrated with substrate integrated waveguide (SIW) [6] and using multi-layer stacking technologies [7] have been proposed. However, these techniques result in high volume profile which result in the increase of fabrication costs. In [8], frequency selective surface (FSS) design is proposed to improve the antenna gain. However, when the FSS is cascaded, the antenna bandwidth is dropped. Recently, a grid array antenna has been proposed to realize a wideband, high gain antenna for mmWave applications using multilayer low temperature cold fire ceramic (LTCC) substrate [9], [10]. Although the LTCC technology manages to provide a good performance, the fabrication process is complicated and incurs in high fabrication costs. Therefore, the proposed solutions become less practical for 5G base stations since a huge number of base stations are expected to be built and a large number of antennas will be employed. However, a practical solution offering low profile features can be designed using the conventional printed circuit board (PCB) technology [11].

Antennas of small-size, low-cost, high gain and wide frequency band are desired for 5G base stations. This paper presents a new broadband microstrip grid array antenna, which is designed to be directly fed from a 50Ω coaxial line without an impedance transformer. The wideband GAA is realized by loading the rhombus into the short radiating sides of the GAA. The broadband mmWave grid array antenna (GAA) with low complexity and compact size is proposed for 5G communication system without the need of using multiwaya stacking or complicated LTCC technology.

II. WIDEBAND GRID ARRAY ANTENNA DESIGN

The conventional GAA is composed of rectangular loops of conductors above a ground plane with a single or multiple feed point [12], [13]. The conventional GAA is designed to have a long sides grid length of $\lambda_g$ and short sides grid length of $\lambda_f$, where $\lambda_g$ is the guided wavelength [9], [12], [14]. Hence, the long sides of the grid having an out-of-phase instantaneous current distribution and short sides of the grid having in-phase instantaneous current distribution. Although the conventional GAA has been proven to have a good radiation performance, the impedance bandwidth performance is still insufficient to cover the entire proposed 5G frequency band that recommended by Federal Communications Commission (FCC) as the microstrip straight line radiating elements having a narrow bandwidth in nature [15].

The proposed GAA is designed on the 0.787-mm-thick Rogers RT 5880 substrate with dielectric constant of 2.2 and loss tangent 0.0009. For bandwidth enhancement purpose, a
rhombus is added on the short sides of the grid as illustrated in Fig. 1. By loading the rhombus on the short sides, the capacitive reactance and the current path of the radiating elements are increased. Hence resulting in the enhancement of the GAA impedance bandwidth. To obtain the broadside radiation pattern, the proposed GAA is fed with the 50 Ω coaxial probe, located typically at the joint of the long and short sides center elements of the antenna. The optimized dimensions of the proposed wideband GAA are as tabulated in Table I.

### III. AMPLITUDE-TAPERED WIDEBAND GAA WITH VARIABLE-SIZED RADIATING ELEMENTS

The amplitude-tapering (AT) technique is implemented on the proposed wideband GAA for side-lobes level (SLL) reduction. The AT is performed in the manner where the highest excitation is located at the centre area of the GAA. The amplitude is reduced toward the radiating elements at the edges of the GAA. Since the dimension of the short radiating elements is controlling the impedance of the radiating elements, where the smaller the size of the radiating elements, the highest the impedance of the radiator and vice versa. By implementing the AT in an aforementioned manner, the radiating elements located at the centre row of the GAA are carrying the maximum currents and vice versa. The proposed AT wideband GAA is as illustrated in Fig. 2 and the optimized dimension are tabulated in Table II. To provide a better understanding of the amplitude-tapering wideband GAA, the corresponding current distribution of the proposed wideband GAA before and after amplitude tapering is illustrated in Fig 3. As it can be observed, when the AT is applied, the current flowing on the sides radiating elements is decreased which leads to the side lobes level reduction.
Fig. 5: Comparison of the simulated gain and VSWR performance of the proposed wideband GAA with and without AT

IV. RESULTS AND DISCUSSION

The proposed wideband GAA is modelled using the Computer Simulation Technology (CST) software. Fig 4 shows the comparison of the obtained $S_{11}$ for the considered GAAs with and without AT. It can be observed that the proposed wideband GAA provides a $-10$ dB impedance bandwidth of around 16.07% which is ranging from 27.5 to 32 GHz. The proposed GAA covers the entire 28 GHz frequency band for 5G recommended by the Federal Communications Commission (FCC) [16]. The simulated gain and VSWR performance for the proposed wideband GAA with and without AT is shown in Fig 5. The simulated GAAs show broadband impedance matching with VSWR < 2 over the entire operational bandwidth for GAA without AT and with AT, respectively. As can be seen from Fig 5, the maximum achieved gain are approximately 14.3 dBi and 14.8 dBi without and with AT, respectively. Hence, the impact of the AT on the bandwidth and gain performance of the GAA is negligible.

Fig. 6 shows the simulated radiation pattern of the proposed antenna at 27.5 GHz on the E- and H-planes in subplots (a) and (b), respectively. Results are compared for designs with and without the implementation of AT. Similar results are shown in Figs. 7 and 8 for the 29 GHz and 32 GHz frequencies, respectively. As can be observed from Fig. 6(a), the SLL of the wideband GAA for the E-plane co-polar pattern is around $-4$ dBi at 27.5 GHz and enhanced to $-11$ dBi with AT applied. As for 29 GHz, the maximum achieved gain are approximately 14.3 dBi and 14.8 dBi without and with AT, respectively. Hence, the impact of the AT on the bandwidth and gain performance of the GAA is negligible.

Fig. 6: Comparison of the simulated co-polar radiation pattern at 27.5 GHz with and without AT for (a) E-plane and (b) H-plane

However, it is worthwhile to note that AT did not imply a significant enhancement of the SLL for the H-plane co-polar radiation pattern at 27.5 GHz. This can be mainly attributed to the improper control over the current phase alignment over the GAA radiating elements. As it can be observed from Fig. 6(b), the H-plane radiation pattern of the original rhombus loaded wideband GAA at 27.5 GHz, the main beam direction is slightly tilted and with presence of grading lobes. As a result, the implementation of the AT is ineffective on the H-plane co-polar radiation performance at 27.5 GHz. A similar trend is observed for the AT on the H-plane co-polar radiation pattern for 29GHz and 32GHz, where the AT does not give significant enhancement on the grading lobes reduction. Besides that, the insignificant effect of the AT can also be attributed to the arrangement of the grid and the AT method implementation illustrated in Fig. 2.

Table III shows a comparison of the performance of recent developed planar mmWave array antennas. In [9], it has been proposed to use the LTCC technology to enhance the band-
TABLE III: Performance comparison among the existing High Gain antenna for mmWave application where $f_c$ is the center frequency and $\lambda_o$ is the wavelength of the center frequency

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Antenna’s Types</th>
<th>$f_c$ (GHz)</th>
<th>Dimension</th>
<th>Bandwidth (%)</th>
<th>Peak Gain (dBi)</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>[9]</td>
<td>GAA</td>
<td>60</td>
<td>$3\lambda_o \times 3\lambda_o \times 0.12\lambda_o$</td>
<td>15.6</td>
<td>17.7</td>
<td>LTCC</td>
</tr>
<tr>
<td>[8]</td>
<td>Dielectric Patch</td>
<td>28</td>
<td>$3\lambda_o \times 3\lambda_o \times 0.7\lambda_o$</td>
<td>15.54</td>
<td>17.78</td>
<td>Cascade FSS</td>
</tr>
<tr>
<td>[7]</td>
<td>Linear Array</td>
<td>28</td>
<td>$6.96\lambda_o \times 8.37\lambda_o \times 0.1\lambda_o$</td>
<td>6.3</td>
<td>21.4</td>
<td>Multilayer stacking</td>
</tr>
<tr>
<td>[6]</td>
<td>Phased Array</td>
<td>28</td>
<td>$6.54\lambda_o \times 5.95\lambda_o \times 0.21\lambda_o$</td>
<td>8.21</td>
<td>13.97</td>
<td>Multilayer substrate and using SIW Feeding</td>
</tr>
<tr>
<td>[14]</td>
<td>GAA</td>
<td>28</td>
<td>$0.84\lambda_o \times 1.17\lambda_o \times 0.14\lambda_o$</td>
<td>13</td>
<td>7.3</td>
<td>PCB Substrate</td>
</tr>
<tr>
<td>This Work</td>
<td>GAA</td>
<td>28</td>
<td>$2.35\lambda_o \times 2.35\lambda_o \times 0.074\lambda_o$</td>
<td>16.07</td>
<td>14.8</td>
<td>PCB Substrate</td>
</tr>
</tbody>
</table>

width performance of the conventional GAA with achievable bandwidth of around 15.6%, while in [14] a thicker substrate is proposed to get wider bandwidth of around 13% for the conventional miniaturized GAA. In our paper, we manage to achieve a wider bandwidth of 16.07% while keeping a low volume profile. In addition, comparing to other high gain antenna solutions which proposed FSS [8], multilayer stacking [7] and SIW feeding [6], it is clear that the GAA manage to provide a good gain performance at low profile. This make GAAs a potential candidate for the 5G massive MIMO antenna systems.

Fig. 7: Comparison of the simulated co-polar radiation pattern at 29 GHz with and without AT for (a) E-plane and (b) H-plane

Fig. 8: Comparison of the simulated co-polar radiation pattern at 32 GHz with and without AT for (a) E-plane and (b) H-plane

V. CONCLUSION

The bandwidth performance of the grid array antenna is enhanced by loading the rhombus on the short radiating sides of the conventional GAA. The amplitude tapering technique has been applied to reduce the side-lobe levels of the proposed wideband GAA. The dimensions of the proposed antenna are $25 \times 25 \times 0.787$ mm$^3$. The simulation results show that the proposed wideband GAA having an impedance bandwidth of 16.07% with a maximum gain of 14.8 dBi. Comparing the proposed design with other recently works using PCB technology, the GAA has a high potential to be utilized as the
antenna element for 5G massive MIMO base station. It manages to provide wideband and high gain performance while keeping low-profile using the conventional PCB technology. This work has opened up several questions that requires further investigation. First, it is crucial to figure out a solution for further SLL reduction for both E-plane and H-plane to get the optimum radiation pattern. It is also important to eliminating the grating lobes of the wideband GAA by properly control over current phase synchronization of the GAA elements. We will also develop a dual polarized wideband GAA for the Massive MIMO base station.

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