Design of a phased-array antenna for 5G base station applications in the 3.4-3.8 GHz band

Citation for published version (APA):

DOI:
10.1049/cp.2018.1102

Document status and date:
Published: 09/04/2018

Document Version:
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.

Download date: 08. Jun. 2022
Design of a Phased-Array Antenna for 5G Base Station Applications in the 3.4-3.8 GHz Band

R. Schulpens\textsuperscript{1}, U. Johannsen\textsuperscript{1}, S.C. Pires\textsuperscript{2}, A.B. Smolders\textsuperscript{1}
\textsuperscript{1}Dept. of Electrical Engineering, Eindhoven University of Technology, Eindhoven, the Netherlands, r.schulpen@tue.nl
\textsuperscript{2}Ampleon Netherlands B.V., Nijmegen, the Netherlands

Abstract—A phased-array antenna design for 5G base station applications in the 3.4-3.8 GHz band is presented. End-fire bow-tie antenna elements are used to maximize the available space for electronics that can be placed closely to the antenna elements in the array. Infinite array simulations of a phased-array bow-tie antenna show that a -10 dB reflection coefficient can be achieved in the whole 3.4-3.8 GHz band for elevation scan angles up to 45° and all azimuth scan angles. Simulation and measurement results of a 4x4 bow-tie phased-array demonstrator antenna show good performance in the 3.4-3.8 GHz band for most elevation scan angles up to 45°.

Index Terms—5G, Phased-Array Antenna, Bow-Tie Antenna, Impedance Bandwidth, Active Reflection Coefficient.

I. INTRODUCTION

Mobile data usage has grown exponentially in recent years and is expected to increase even further [1], [2]. Three ways to meet this increase in demand are increasing spectral efficiency, shrinking cell sizes and using more spectrum [3]. Since the options to increase the spectral efficiency further are limited, and capacity scales only linearly with the number of cells, acquiring more spectrum for mobile broadband is required to increase the capacity of next generation (5G) mobile communication [4]. Moreover, phased-array antennas can be used to further increase capacity and reduce co-channel interference [5]. The RSPG (Radio Spectrum Policy Group) has identified the 3.4-3.8 GHz band as primary band for the introduction of 5G-based services [6]. Therefore, it is interesting to explore the possibility of using a phased array antenna for base station applications in the 3.4-3.8 GHz band.

In this paper, the design of a phased-array antenna for 5G base station applications in the 3.4-3.8 GHz band is discussed. The phased-array antenna must be able to electronically steer its beam in two dimensions with elevation scan angles up to 45° and it should cover the whole 3.4-3.8 GHz band. The antenna elements of the array should have a half free-space wavelength spacing at the center frequency to ensure compactness of the array and to eliminate the possibility of grating lobes in the required scan range. The antenna elements are linearly polarized, but the design should be adaptable to dual linear polarization.

This paper is organized as follows: Section II discusses possible antenna element types. An infinite bow-tie phased-array design is discussed in Section III. In Section IV, simulation results of a demonstrator design are compared with measurement results. Finally, conclusions are drawn in Section V followed by acknowledgments in Section VI.

II. ANTENNA ELEMENT TYPE

Multiple printed or microstrip antennas can be used as element in the phased-array antenna. These antennas can be divided into two groups: broadside and end-fire radiators. The radiation of broadside antennas is in the perpendicular direction to the antenna plane, while the radiation of end-fire radiators is parallel to the antenna plane. Examples of broadside radiators are the patch and slot antenna, and examples of end-fire radiators are the dipole, bow-tie and Vivaldi antenna. Reflectors are needed at the back of the end-fire radiators to minimize back radiation.

An advantage of end-fire radiators when used in a phased-array antenna is that there is a (theoretically) semi-infinite space for feed lines and electronics on the substrate behind the reflector. This makes it possible to place the electronics closely to the elements without the need for complex and costly multilayer stacks. Moreover, the above mentioned end-fire radiators are more wideband than the broadside radiators and can easily achieve the 400 MHz impedance bandwidth requirement. In particular, the printed bow-tie antenna is chosen as antenna element in the phased-array antenna presented here, because it is more wideband than the dipole antenna and it has a larger angular width in the plane parallel to the substrate than the Vivaldi antenna, which improves scan performance in this plane. A similar printed bow-tie antenna array with much larger spacing between the elements than a half free-space wavelength is discussed in [7]. The smaller spacing between the elements that is required here increases mutual coupling, which is taken into account in the remaining of this paper.

III. INFINITE ARRAY SIMULATION OF BOW-TIE ANTENNA DESIGN

The infinite array simulation is a good approximation of large finite arrays, because edge effects have a small influence on the performance of these arrays. Also, the infinite array simulation has a much smaller computational load than simulations of large finite arrays. The infinite array simulation results of a bow-tie antenna element will be presented here. The simulations are performed with CST Microwave Studio 2016. The infinite phased-array antenna is designed to have a reflection coefficient of -10 dB in the whole 3.4-3.8 GHz band for elevation scan angles $|\theta_0| \leq 45^\circ$ and all azimuth scan angles $\phi_0$. The spacing between the elements is $\lambda_0/2$, where $\lambda_0$ is the free-space wavelength at 3.6 GHz. The design and...
its parameters are given in Fig. 1, where $\epsilon_r$ is the relative permittivity of the substrate.

Fig. 2 shows the active reflection coefficient, $\Gamma_{\text{act}}$, of the optimized bow-tie element as function of scan angle at 3.4, 3.6 and 3.8 GHz. The active reflection coefficient includes mutual coupling effects. The reference impedance is 200 $\Omega$. The infinite array is symmetric in both the x- and y-axis, except for the substrate in the x-axis. However, simulation results show that this substrate does not affect the symmetry of the results. Therefore, the plots in Fig. 2 can be mirrored in the $u_0$ and $v_0$ axes to obtain the reflection coefficients for scan angles $(\theta_0, \phi_0)$ with $0^\circ \leq \phi_0 \leq 360^\circ$ and $-45^\circ \leq \theta_0 \leq 45^\circ$.

It can be concluded from Fig. 2 that the active reflection coefficient of the infinite bow-tie phased-array is below -10 dB in the 3.4-3.8 GHz range for all above mentioned scan angles.

IV. BOW-TIE PHASED-ARRAY ANTENNA DEMONSTRATOR

A demonstrator phased-array antenna is designed to demonstrate the performance of a finite phased-array antenna. Fig. 4 depicts the designed array. It is a $4 \times 4$ active array with terminated elements at its sides to reduce edge effects. The array is re-optimized to improve scan performance, because edge effects have a large influence on the active input impedance of the border elements, which form the majority of the elements
in this small array. Therefore, the array is not optimized for the center elements, but for the overall performance of all elements.

The layout of the array elements is depicted in Fig. 5. A similar Marchand balun as described in [8] is used to match the bow-tie element to a 50 Ω microstrip line. The elements at the sides do not have a balun and are terminated in 150 Ω at the end of the co-planar strip (CPS) lines.

Simulation and measurement results of the demonstrator array are compared. The simulation includes a solid reflector inside the substrate, while the manufactured array uses a via fence with a via radius of 0.25 mm and a via separation of 1 mm as reflector inside the substrate. Moreover, the mechanical support structure is not taken into account in the simulation. Also, the thickness of the manufactured array is 1.84 mm instead of the designed 1.7 mm and aluminum reflectors are used in the manufactured array instead of the simulated copper reflectors in order to reduce weight. Small scale simulations of these differences show that they have negligible effects on the results.

The S-parameter measurement setup is depicted in Fig. 6. S-parameter measurements are performed with a Keysight N9914A FieldFox RF Analyzer and two Suhner Sucoflex 104PA SMA cables. The VNA, including the cables, is calibrated using the Maury Microwave 8050B 3.5 mm calibration kit.

Fig. 7 depicts the numbering of the array. Fig. 8 shows simulation and measurement results of the main S-parameters of center element 6. The main variation between the simulation and measurement results is in the $S_{66}$ parameter. The measured coupling coefficient match the corresponding simulated coupling coefficients well. Mutual coupling in the horizontal plane is larger than mutual coupling in the vertical plane in the 3.4-3.8 GHz band, which is caused by surface waves.

The active reflection coefficient of center element 6 is
depicted in Fig. 9 for multiple scan angles and as function of the frequency $f$. Both the simulation and measurement results are constructed from all 16 S-parameters using superposition. The variation between simulation and measurement results is largest at low reflection levels and frequencies at which the variation in the $S_{66}$-parameter is largest. For the center element, the impedance bandwidth requirement is not met for all scan angles up to $\theta_0 = 45^\circ$ in the 3.4-3.8 GHz band. Fig. 10 shows that the impedance bandwidth requirement is met for edge element 4 for all these scan angles. The edge element has better active reflection coefficients, because the array is optimized for best overall performance. The degraded performance of the center elements at some scan angles is mitigated by the good performance of the edge elements. Thus, the simulation and measurement results show that the overall performance in the 3.4-3.8 GHz band is good for most elevation scan angles up to 45°. For large arrays, it is better to optimize the center elements of the array and use amplitude tapering to reduce edge effects.

Fig. 6: Measurement setup for S-parameter measurements of the demonstrator array.

<table>
<thead>
<tr>
<th>-</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>-</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>-</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

Fig. 7: Backside view of antenna element numbering of the demonstrator array.

Fig. 8: Simulation and measurement results of the main S-parameters of center element 6.

Fig. 9: Active reflection coefficient of center element 6 for scan angles $(\theta_0, \phi_0)$.

Fig. 10 shows the impedance bandwidth requirement is met for edge element 4 for all these scan angles. The edge element has better active reflection coefficients, because the array is optimized for best overall performance. The degraded performance of the center elements at some scan angles is mitigated by the good performance of the edge elements. Thus, the simulation and measurement results show that the overall performance in the 3.4-3.8 GHz band is good for most elevation scan angles up to 45°. For large arrays, it is better to optimize the center elements of the array and use amplitude tapering to reduce edge effects.

Fig. 11 depicts the normalized radiation pattern cuts for multiple scan angles $(\theta_0, \phi_0)$ at 3.6 GHz. Fig. 12 depicts the array in the anechoic chamber of the Eindhoven University of Technology where the measurement were performed. The measurement results match the simulation results for small
V. CONCLUSIONS

The design of a phased-array antenna for base station application in the 3.4-3.8 GHz band is discussed. The bow-tie antenna is chosen as element in the array, because it has a large impedance bandwidth and the bow-tie array has a semi-infinite space for feed lines and electronics behind the antenna. An infinite bow-tie phased-array design is presented that has a reflection coefficient below -10 dB in the whole 3.4-3.8 GHz band for elevation scan angles up to ±45° and all azimuth scan angles. Finally, a 4 × 4 demonstrator phased-array antenna is presented. The obtained active reflection coefficients show good performance for the edge elements, and slightly degraded performance for center elements at some large elevation scan angles. However, the overall performance is good for most elevation scan angles up to 45°. From these results, it can be concluded that this bow-tie phased-array antenna is a viable solution for the application in base stations.

VI. ACKNOWLEDGMENTS

The authors would like to thank Ampleon Netherlands B.V. for their collaboration in this project.

REFERENCES


