Beam-Steering Array for Handheld Devices Targeting 5G

Alexandru Tatomirescu, Adriana Oprian, Stanislav Zhekov and Gert Frølund Pedersen

***Abstract*—In this paper, we present an array design for an implementation of a mobile terminal targeted for the fifth generation mobile communication network (5G).**

The design has a compact low loss array element printed on a low loss dielectric. To obtain a back lobe radiation, the ground plane is etched under the array elements and a parasitic scatterer is used to manipulate the gain pattern of the dipole in order to improve the peak gain. The array is placed on the top edge of the PCB in an 8 element array configuration.

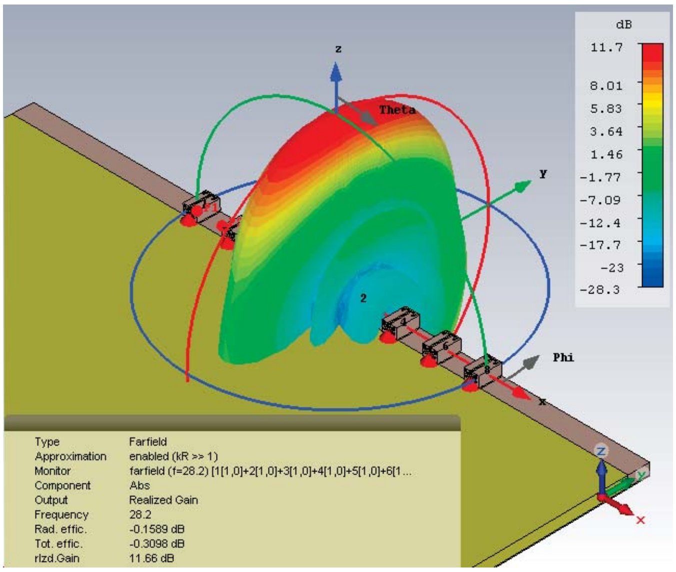
The design is evaluated using simulations and the simulated realized gain is 11.6 dBi at boresight, the array has a bandwidth of 1 GHz around 28 GHz with a good beam steering characteristics. About 80% of all the achievable angles for the incoming power distribution are covered with a gain better than 5 dB. Noteworthy is that a fine resolution of 15 degrees steps have been chosen for the phase shifters in the beamforming network.

***Index Terms*—5G, Antenna Array, Handset, Beamforming, Smart Phones.**

I. INTRODUCTION

THE mobile communications have undergone a significant development over the past decade. The driving force behind this progress is the demand for better quality of service, as the main attention is focused on the desire for continuously increasing the data rate. It has been projected that, with the extensive adoption of modern wireless mobile devices (e.g. smartphones, tablets and etc.), in the next decade, a mobile traffic increase on the order of 1,000 times is expected compared to what we experience today [1], [2].

The satisfaction of this traffic is impossible due to the strongly limited currently used spectrum. Almost all cellular mobile communication systems today use radio spectrum in the range of 300MHz - 3GHz also known as an Ultra High Frequency (UHF) band [3]. This part of the spectrum has started to become crowded, due to the constantly increasing number of users, amount of data and almost nothing can be done to achieve future significant improvements [4]. The way to meet the aforementioned problems is to use the underutilized or unexploited new parts of the microwave spectrum. The next generation cellular communication system 5G is expected to support very high data rate by exploiting parts of the underutilized spectrum 3-300GHz, as the main attention is on the frequency band 30 - 300 GHz [5]. An advantage of the smaller wavelengths of high frequency signals is that they allow miniaturization and deployment of large number antennas in a small physical area. This is very suitable for handheld terminals in contrast to the low frequencies case, where the electrical size is serious constraint. Nevertheless, mobile phone applications are extremely susceptible to variations in cost thus, a simple manufacturing technique is needed which will not add too much complexity to the existing processes. By using such antenna arrays with an appropriate beamforming technique, a high gain can be obtained and thus reducing the higher signal attenuation at high frequencies. The realization of a high gain requires adaptive beamforming to cope with the dynamic properties of the channel. For a better radio link is necessary that the beams follow the multipath propagation thus a steerable antenna is a design requirement [2].



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Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=28.2) [1[1,0]+2[1,0]+3[1,0]+4[1,0]+5[1,0]+6[1...
Component      Abs
Output         Realized Gain
Frequency      28.2
Rad. effic.    -0.1589 dB
Tot. effic.    -0.3098 dB
rlzd.Gain      11.66 dB
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Fig. 1. Illustration of the boresight realized gain of the proposed 8 element linear array placed at one edge of the PCB .

To address this challenge, the authors in [6] have presented two phased antenna arrays each with 16 elements placed in the top and bottom of the cellar phone PCB. The center frequency of these arrays is at 28 GHz and bandwidth is 1 GHz with a return loss below -10 dB. By using a beamforming technique, the obtained scanning angle of each array is (plus minus) 70 (degree) as well as high peak gain. A single array consisting of 4 patch antennas has been presented in [7]. The obtained bandwidth is 5 GHz from 27 to 32 GHz with return loss below -10 dB and realized gain approximately 16 dBi, still a fixed beam solution is not suited for mobile applications. Another antenna array for 28 GHz band has been presented in [8]. The proposed of the authors mesh-grid patch antenna array consist of 16 elements and the covered bandwidth is more than 3 GHz

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with 10.9 dBi maximum gain at boresight while having a 3 dB beamwidth equal to 12 degree. In addition, the main beam can be steered up to (plus minus) 75 (degree) in the azimuth plane.

Recent studies have shown that the band around 28 GHz is suitable for 5G [1]–[3]. This paper proposes a highly efficient 5G antenna array working at 28GHz which can be implemented in a mobile handset with good beam+steering capabilities. To address this application, the design emphasis has been on the beam+steering ability and ease of manufacturing. Each array element can be treated independently, as if was a pick and place component. Therefore, the array can be implemented using as many elements as necessary. The following sections will elaborate on the design.

II. ARRAY ELEMENTS DESIGN

The design of the antenna is mainly constrained by the overall design of the cellular handset. A reasonable assumption is that the legacy technologies (2G,3G and 4G) will still be present in future mobile terminals thus, the next generation mobile handsets will have similar constraints as the currently available ones, the antenna will need to cope with the already overpopulated volume. Since compactness is a major driving factor, an array element that can be designed as a pick and place component will provide a great deal of design freedom, especially in the latter stages of the development.

Since the antenna efficiency translates directly into complexity in the front-end, doubling the antenna losses would mean a doubling in the number of elements for the same gain. Thus, one of the design goals was to keep the antenna away from the lossy FR4. The solution for the proposed element is simple, as shown in Figure 2. It consists of a dipole placed on dielectric brick and a scatterer placed on the opposite side of the Arlon Cu 217 Lx brick with $\epsilon = 2.2$ and $\tan\delta = 0.0009$. The ground plane is removed in all layers under the antenna with a cut back of 2 mm. This enables a low Q near-field area leading to a simulated radiation efficiency of only 0.2 dB.

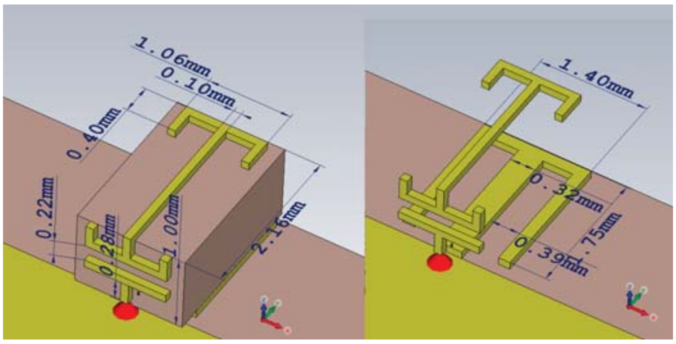

Fig. 2. Numerical model of the array element. The left side illustrates the complete element whereas in the right side, the substrate is made invisible and the shorted scattering element is visible.

The main challenge for the RF front end of the 5^{th} generation devices is beam steering. Since the orientation of the mobile device is arbitrary, a wide beam scanning space is needed to provide a quality of service. A close to isotropic element radiation pattern would provide a excellent beam steering space however, peak gain will suffer.

An electromagnetically fed dipole was chosen in an attempt to preserve omnidirectionality in the plane perpendicular to the phone. A direct feeding solution would have confined the radiation to on side of the PCB, as in the case of a Patch antenna or a Planar Inverted F antenna. In addition, the scatterer under the dipole provides a tradeoff between beam steering flexibility and peak gain. A dipole was preferred to a slot due to the dipole's better miniaturization characteristics and better coverage of the blind angles at broadside. Simulations carried out with a commercial full wave simulator software [9] confirm that the element does not have deep nulls and it has a relatively small peak gain of only 4 dBi, as illustrated in Figure 3. This makes it a suitable candidate for a beam steered antenna array.

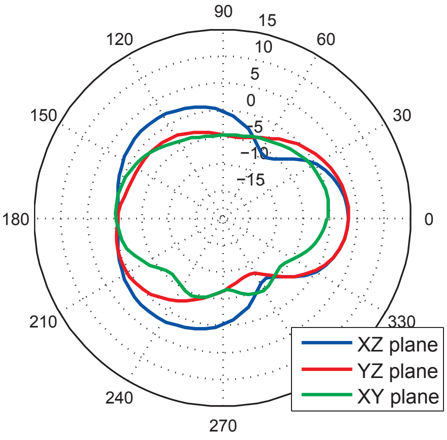

Fig. 3. Simulated principal cuts of the realized gain pattern for a single array element.

III. ARRAY CONFIGURATION AND SIMULATION RESULTS

The chosen configuration for the application is an 8 element line array with identical elements which can beam steer in the XZ theta cut. The array is chosen to be placed at the upper edge of the handset since this is a likely area with less interference from the user.

The elements have 2.5 mm spacing between them which provides a tradeoff between mutual coupling, grating lobes and array size with a total array length of only 28 mm. The mutual coupling is better than -15 dB and the edge elements suffer only a marginal de-tuning, as shown in Figures 4 and 5.

The beam forming network design is neglected for this work and it is simulated as an ideal discrete phase shifting network with 15 degrees steps. The peak gain and example of possible beams with these constraints, are illustrated in Figure 6. Noteworthy, that the array covers both sides of the board with one excitation vector due to the omnidirectional element pattern. In addition the radiation efficiency is affected when the beam-steering angle approaches broadside radiation going down for 0.2 dB to 1.3 dB which is visible trough the low realized gain around theta 90 degrees.

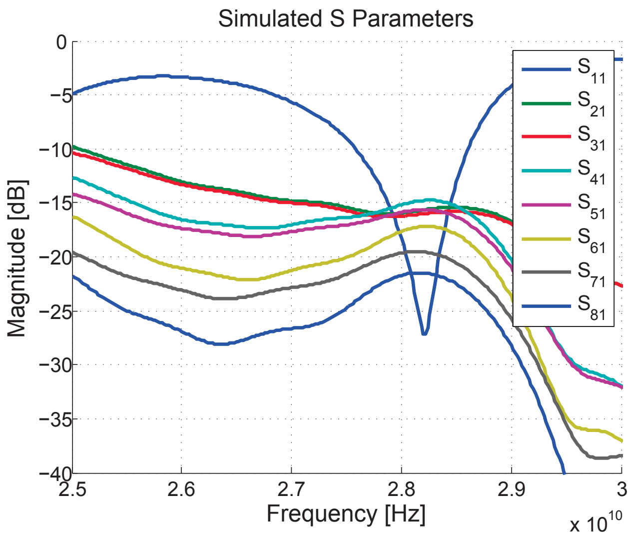

Fig. 4. Simulated S parameters of the array illustrated in Figure 1.

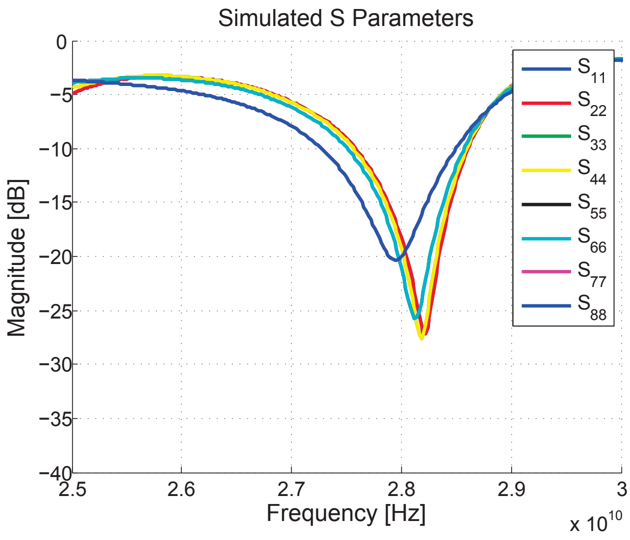

Fig. 5. Simulated input reflection coefficient. Only the edge elements 7 and 8 are affect by the lack of loading ($S_{77} = S_{88}$ due to symmetry).

By using such antenna arrays and appropriate beam-forming technique can be obtained high gain and thus reducing the higher signal attenuation at high frequencies, as illustrated by the maximum obtainable gain for all beams plotted in Figure 7. The low gain element design enables a good coverage of the beam space, only 20% of the angle space is covered with less 5 DBi, as shown in Figure 8.

IV. CONCLUSIONS

One of the biggest engineering challenges faced by antenna designs for the fifth generation networks is the the successful implementation of the steerable beam antenna. As any antenna design problem, the best solution is a complex tradeoff between size, complexity and flexibility.

The design of the array element sets the standard for the overall performance of the array. In this work we have reduced the number of elements by increasing the directivity of the single array element using scatterers. Furthermore, the efficiency of each element is increased by placing the antennas on a low loss antenna carrier.

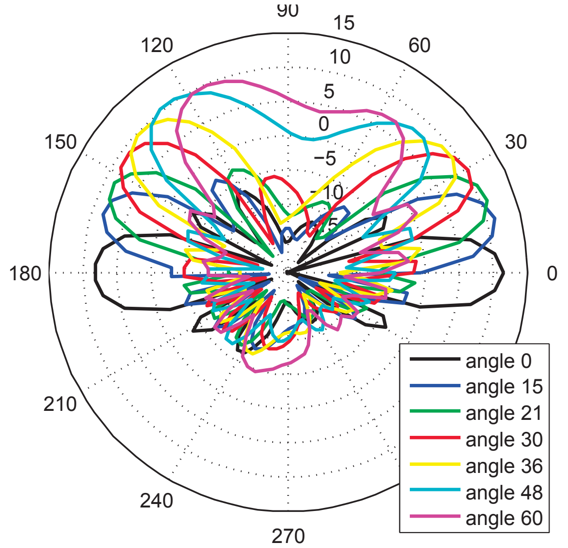

Fig. 6. Simulated radiation patterns assuming ideal beam-forming network with 15 degrees phase shifting steps.

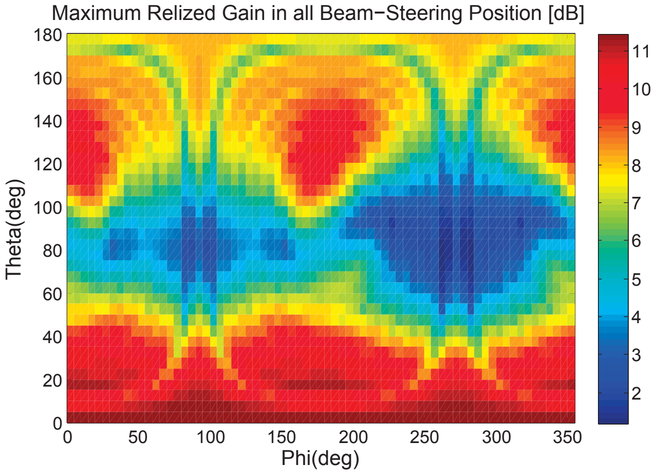

Fig. 7. Superposition of all the possible beam combinations showing the full 3D coverage level.

The omnidirectional nature of the electromagnetically fed dipole enables a good coverage of the tunable beam space even with a course phase shifting at the feed. To reduce the requirements of the phase shifters, arrays with a broader beam can be used in combination with bigger steps but the peak gain will suffer.

V. FUTURE WORK

The beam-forming network is a key element in the successful implementation of the millimeter wave for 5G. Until now, the dynamics of the wireless channel characteristics at the mm-Wave have been neglected in the design of the antenna array however, continuing this trend can prove to be costly in the

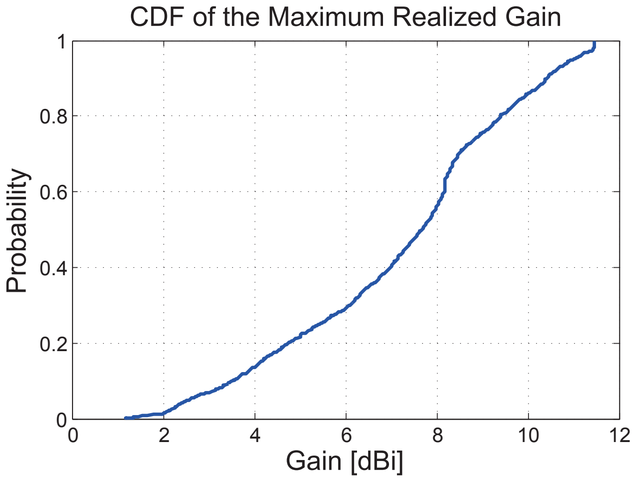

Fig. 8. Empirical cumulative distribution function of the maximum gain possible for all beam steering combinations.

long run since a global solution for all propagation scenarios is sub-optimal. Thus it will be investigated in further work.

REFERENCES

[1] M. Akdeniz, Y. Liu, M. Samimi, S. Sun, S. Rangan, T. Rappaport, and E. Erkip, “Millimeter wave channel modeling and cellular capacity evaluation,” *Selected Areas in Communications, IEEE Journal on*, vol. 32, no. 6, pp. 1164–1179, June 2014.

[2] S. Rangan, T. Rappaport, and E. Erkip, “Millimeter-wave cellular wireless networks: Potentials and challenges,” *Proceedings of the IEEE*, vol. 102, no. 3, pp. 366–385, March 2014.

[3] T. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. Wong, J. Schulz, M. Samimi, and F. Gutierrez, “Millimeter wave mobile communications for 5g cellular: It will work!” *Access, IEEE*, vol. 1, pp. 335–349, 2013.

[4] J. Andrews, S. Buzzi, W. Choi, S. Hanly, A. Lozano, A. Soong, and J. Zhang, “What will 5g be?” *Selected Areas in Communications, IEEE Journal on*, vol. 32, no. 6, pp. 1065–1082, June 2014.

[5] Z. Pi and F. Khan, “An introduction to millimeter-wave mobile broadband systems,” *Communications Magazine, IEEE*, vol. 49, no. 6, pp. 101–107, June 2011.

[6] W. Hong, K.-H. Baek, Y. Lee, Y. Kim, and S.-T. Ko, “Study and prototyping of practically large-scale mmwave antenna systems for 5g cellular devices,” *Communications Magazine, IEEE*, vol. 52, no. 9, pp. 63–69, September 2014.

[7] O. Haraz, A. Elboushi, S. Alshebeili, and A.-R. Sebak, “Dense dielectric patch array antenna with improved radiation characteristics using ebg ground structure and dielectric superstrate for future 5g cellular networks,” *Access, IEEE*, vol. 2, pp. 909–913, 2014.

[8] W. Hong, K. Baek, Y. Lee, and Y. G. Kim, “Design and analysis of a low-profile 28 ghz beam steering antenna solution for future 5g cellular applications,” in *Microwave Symposium (IMS), 2014 IEEE MTT-S International*, June 2014, pp. 1–4.

[9] CST Computer Simulation Technology AG. (2002) CST STUDIO SUITE. [Online]. Available: https://www.cst.com/