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Published in:
2019 13th European Conference on Antennas and Propagation (EuCAP)

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Printed Vertically-Polarized Quasi-Endfire Beam Steering Array with Full Ground Plane for 5G Mobile Applications

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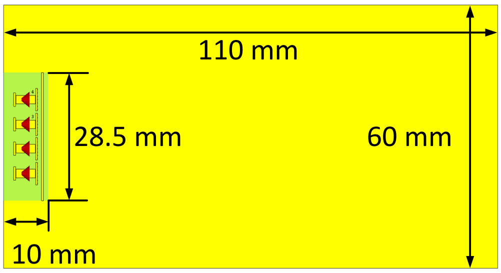
***Abstract*—This paper proposes a quasi-endfire vertical polarized antenna array at 28.8 GHz for 5G mobile applications. The array element is composed of a dipole antenna with its two ends shorted by metallic via walls. The via walls have the same omni-directional radiation and 180° phase shift which generates a bi-directional radiation pattern. By adding another metallic via wall behind the array elements, it can act as a reflector, with the array radiating in only one direction. The antenna and array's performance are verified in the simulations. The structure presents good impedance matching and vertically-polarized quasi-endfire radiation patterns. Moreover, the array has low profile and needs no clearance on the ground plane.**

***Index Terms*—endfire array, vertical polarization, 5G mobile.**

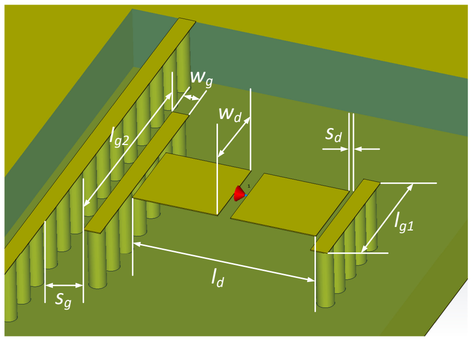
I. Introduction

Phased arrays are selected as candidates for the mobile phone antennas in the upcoming 5th generation of mobile communications because of their high gain and spacial coverage[1], [2]. Since the screen and components in the mobile phone are acting as conductors to the antennas, a clean area must be left to guarantee the proper operation of the antennas. On the other hand, this clearance is expected to be reduced because of the increasing demand of screen size. This requirement presents a big challenge for the endfire antenna design for mobile phones. For endfire antennas, a clearance on the ground plane is always needed. There are some solutions for the zero clearance endfire antenna design. For instance, in [3], the cavity-backed slot antennas are integrated with the mobile phone's metal case. This array requires the edge to be 4 mm high and considering the thickness of screen and the PCB of the other circuits, the total thickness of the mobile phone will be higher. On the other hand, vertically-polarized arrays are preferred because they are influenced less by the low frequency antennas which are horizontal-oriented surrounding the phone. In literature, vertically-polarized endfire arrays always have high profile [4], [5]. In this paper, the proposed array is printed on one layer of PCB which keeps both low profile and zero clearance. The array elements are vertically-polarized and operate at 28.8 GHz. The design concept is verified by the simulation results.

This paper is organized as follows: section II introduces the array and array element configuration; section III explains the working principle; section IV gives the array's performance; and the paper is concluded in section V.



(a) Array configuration



(b) Array element configuration

Fig. 1: The 4-element array and the array element configurations.

II. Array Configuration

The array configuration is shown in Fig.1a. It includes 4 array elements and occupies an area of $10\ mm \times 28.5\ mm \times 1.5\ mm$. The array is mounted on a big ground plane of $60\ mm \times 110\ mm$. The material in the array area is Taconic TLP-5 with $\epsilon_r = 2.2$ and $tan\delta = 0.001$. The array element configuration is shown in Fig.1b. The detailed dimensions are listed in Table.I. The array element is made by a dipole with balanced feeding in the middle. The length and width of the dipole are l_d and w_d, respectively. The two ends of the dipole are shorted by two via walls. Two narrow slots s_d are etched between the dipole and the via walls, which can be considered as two series capacitances. The height of the via walls is the same as the thickness of the material (1.5 mm) which is approximately equivalent to $\lambda_g/4$ at 28 GHz. The array element has a bi-directional radiation pattern so another via wall is utilized to add a reflection and make it radiate to only one direction. The two via walls have different length l_{g1} and l_{g2} for improving the endfire gain.

l_d	w_d	s_d	s_g
4.3	1.9	0.1	0.9
l_{g1}	l_{g2}	w_g	
3	5	0.4	

TABLE I: The dimensions of the array element. (unit: mm)

III. Working Principle

Fig.2 shows the surface current distribution at 28.8 GHz. The maximum appears at the feeding point and the two grounding points of the via walls. The nulls appear at the top of the via walls. Therefore, the analysis of the two via walls can be separated from the whole structure. Regardless of the dipole in the middle, the two via walls can be seen as two $\lambda/4$ monoples with one end grounded. They resonate with the same magnitude but out of phase. As a result, they are acting as a sub-array with the separation of the length of the dipole, which is exactly $\lambda/2$. The same as the monopole, each of the via wall has a vertically-polarized and omni-directional radiation pattern. Since they also have $180°$ phase shift, the radiation of the two via walls will cancel each other in the y direction and add in phase in the x direction, which is expressed as a bi-directional radiation pattern. By introducing another via wall behind the array element, its radiation pattern is reflected to only -x direction. Also because of influence of the ground plane, the radiation pattern will be tilted to the +z direction.

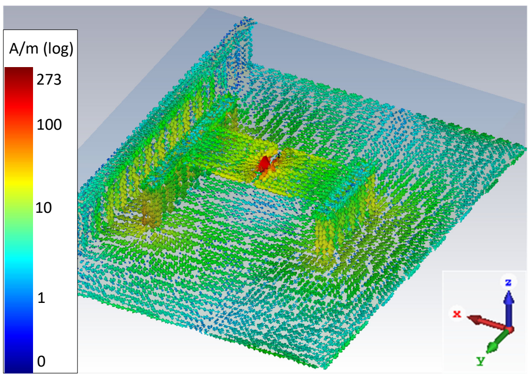


Fig. 2: The current distribution at 28.8 GHz on the array element.

The different length of the two via walls can help improving the antenna gain. Fig.3 compares the radiation patterns when l_{g1} is constant and l_{g2} changes from 3.5 mm to 6.5 mm. When l_{g2} increases from 3.5 mm to 6.5 mm, the main beam direction remains the same around $30°$, while the gain increases from 5.2 dB to 6.04 dB and 6.58 dB. The longer via wall is, the higher the gain, but the increment of gain is not linear. When l_{g2} increases from 3.5 mm to 5 mm, the increment of gain is 0.8 dB but when l_{g2} increases from 5 mm to 6.5 mm, the increment is only 0.5 dB. It can be speculated that when the length increases after 6.5 mm, the improvement on gain is not obvious. On the other hand, the longer via wall means

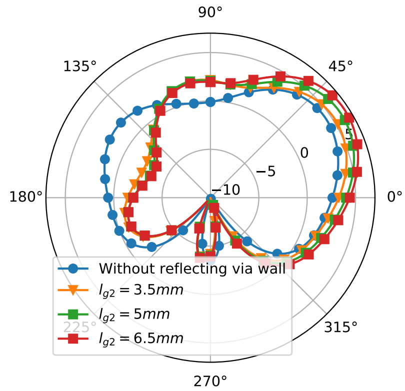


Fig. 3: The radiation patterns with different length of l_{g2}.

larger array element distance and smaller the scanning angle, which are unexpected of the mobile antennas. In our design, the element distance is chosen as 5.5 mm, according to the half wavelength at working frequency, and l_{g2} is chosen as 5 mm. The radiation pattern without the reflecting via wall is also shown in Fig.3. In this case, l_{g1} and l_{g2} are 3 mm and 5 mm, respectively. As we can see, the gain at $30°$ and $140°$ becomes similar. If l_{g1} and l_{g2} have the same length, the radiation pattern will be symmetric. In Fig.3, the radiation on the broadside direction ($90°$) can be also observed and barely varies with the modification of via walls because some energy is radiated from the dipole. However, it is a good feature for the mobile antennas, since the spacial coverage is increased.

IV. The 4-Element Array

The S-parameters of the proposed array are shown in Fig.4. The impedance matching bandwidth is from 27 GHz to 40 GHz but the endfire radiation pattern only exists in narrow

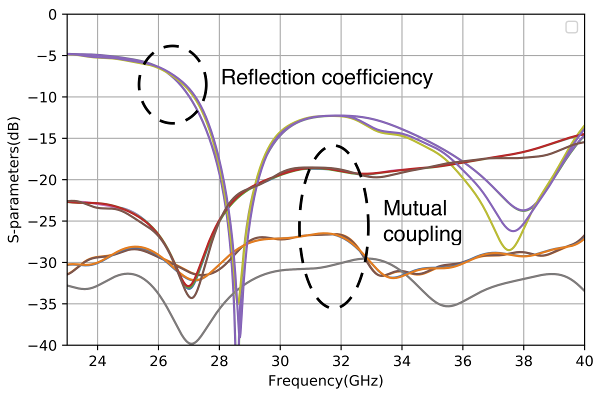


Fig. 4: The S-parameters of the 4-element array.

band, which is from 28 GHz to 29 GHz. Even though, it is still enough to cover one channel for 5G communication. The mutual coupling between the array elements is lower than -20 dB in the working band. The beam scanning pattern at 28.8 GHz on the azimuth plane (XY) is shown in Fig.5. The scanning range is from 30° to 150°. The array main beam direction for every scanning angles in the elevation plane is ranging from 23° to 33°, which also matches with the element radiation pattern in Fig.3. The array gain is varies from 8.35 dB to 10.94 dB. Because of the tilted radiation pattern, the gain in the azimuth plane is lower, which is from 4.07 dB to 8.9 dB. In Fig.5, the cross-polarization level increases as the scanning angle increasing. This is also because the main beam direction is not on the azimuth plane. When the scanning angle increases, the cross-polarization increases fast in this direction. Fig.6 shows the 3D radiation pattern of the scanning angle 150°. The horizontal pattern, which represents the cross-polarization, has a null on -y direction and also not so high gain on the main beam direction of the co-polarization pattern. Considering the vertical polarization, gain drops on the azimuth plane while the cross-polarization grows, and becomes similar in Fig.5.

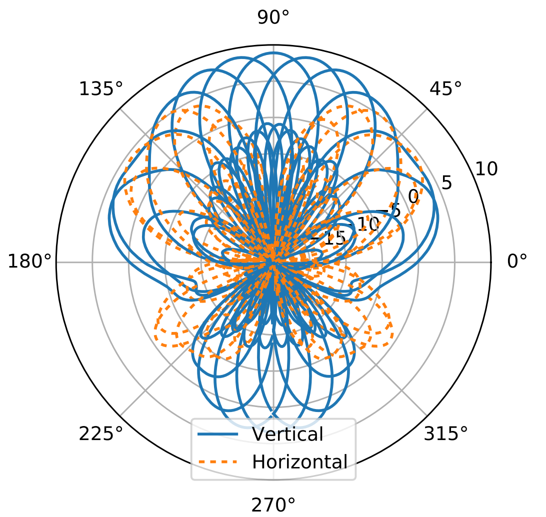


Fig. 5: The scanning pattern on the azimuth plane (XY).

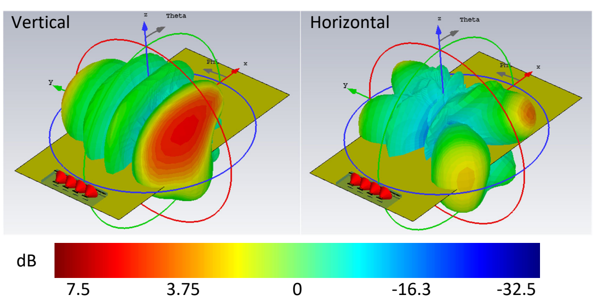


Fig. 6: The 3D radiation pattern at scanning angle 150°.

V. Conclusion

This paper provided a vertically-polarized quasi-endfire array for 5G mobile applications. The array has low profile and requires zero clearance on the ground plane which makes it compatible with big screen and the other components in the mobile phone. The simulation results show good performance of the proposed array.

Acknowledgment

This work is supported by the AAU Young Talent Program and in part by the Innovations Fonden Project of RANGE.

References

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

[2] W. Feng, Y. Li, D. Jin, L. Su, and S. Chen, "Millimetre-wave backhaul for 5G networks: Challenges and solutions," *Sensors*, vol. 16, no. 6, 2016. [Online]. Available: http://www.mdpi.com/1424-8220/16/6/892

[3] B. Yu, K. Yang, C. Sim, and G. Yang, "A novel 28 GHz beam steering array for 5G mobile device with metallic casing application," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 1, pp. 462–466, Jan 2018.

[4] W. Hong, K. Baek, and S. Ko, "Millimeter-wave 5G antennas for smartphones: Overview and experimental demonstration," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 12, pp. 6250–6261, Dec 2017.

[5] W. El-Halwagy, R. Mirzavand, J. Melzer, M. Hossain, and P. Mousavi, "Investigation of wideband substrate-integrated vertically-polarized electric dipole antenna and arrays for mm-wave 5G mobile devices," *IEEE Access*, vol. 6, pp. 2145–2157, 2018.