Frequency Reconfigurable Endfire Vertical Polarized Array for 5G Handset Applications

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Frequency Reconfigurable Endfire Vertical Polarized Array for 5G Handset Applications

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***Abstract*—This paper proposes a frequency reconfigurable phased array with endfire vertical polarized radiation pattern for 5G handset applications. The array element consists of a magnetic dipole and two reconfigurable strips, which are controlled independently by two PIN diodes. By combining the two PIN diodes, three resonanting frequencies are achieved from 24 GHz to 27 GHz. An eight-element array is then constructed based on the proposed antenna. The scanning angle is from 130^o to 220^o with realized gain ranging from 7 dBi to 9 dBi. Moreover, the array has low profile of 0.508 mm and small clearance of 3.35 mm. The performances of the proposed antenna and array are verified by simulations.**

***Index Terms*—frequency reconfigurable antenna, endfire, vertical polarization, 5G handset.**

I. Introduction

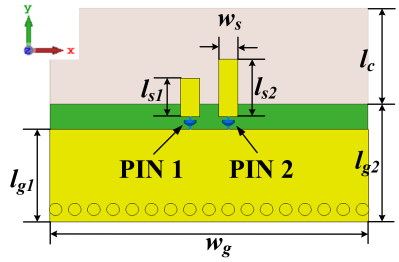
Wideband is one of the most important features for 5G communication system [1]. Phased array with endfire radiation patterns are preferred due to the wide spatial coverage. However, it has been challenging to integrate endfire arrays into mobile devices. First of all, the 5G array has to be compact with the low frequency antennas, which have been integrated on the bezel. The bezel shows a significant blockage and reflection to the endfire beams of millimeter-wave (mm-wave) array, if the array has horizontal polarization [2]. In [3], two layers of tilted strips are added in order to lead the beam to the endfire direction, although this design requires a minimum 7 mm clearance on the ground plane which is too big for 5G handsets. Vertical polarized arrays are much less influenced by the horizontal oriented metal bezel (see for e.g. [2], [4]), but their bandwidth is unavoidably highly related to the thickness of the substrate. For instance, in [4], five layers of substrates are applied in order to form a vertically oriented dipole antenna. The work in [5] provides a dual-polarized endfire array. The vertical mode has a much smaller bandwidth than the horizontal mode due to the limited height of the Substrate Integrated Waveguide (SIW). Therefore, a frequency reconfigurable array may be a solution, which would satisfy the requirements of thickness, polarization, and band coverage. The use of PIN diodes at mm-wave band reconfigurable array for 5G handsets is presented in [6], where the control is simple, the cost is low, and the total efficiency is high. The PIN diodes are hence chosen as the switching method also in this work.

In the paper, a endfire vertically polarized array is proposed with small clearance and low profile. The frequency reconfigurable feature allows it to cover a wide band from 24 GHz to 27 GHz. This paper is organized as follows: section II introduces the configuration of reconfigurable array element; section III provides the array performances; finally in Section IV the conclusions are drawn. CST STUDIO SUITE 2018 is used for all the simulations in this paper.

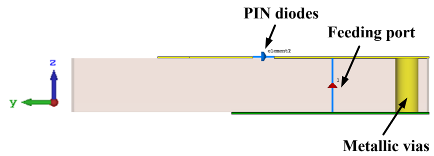
TABLE I: Dimensions (mm)

w_g	l_{g1}	l_{g2}	l_c
5	1.45	1.85	1.5
w_s	l_{s1}	l_{s2}	
0.3	0.6	0.9	

II. Configuration of Reconfigurable Array Element



(a)



(b)

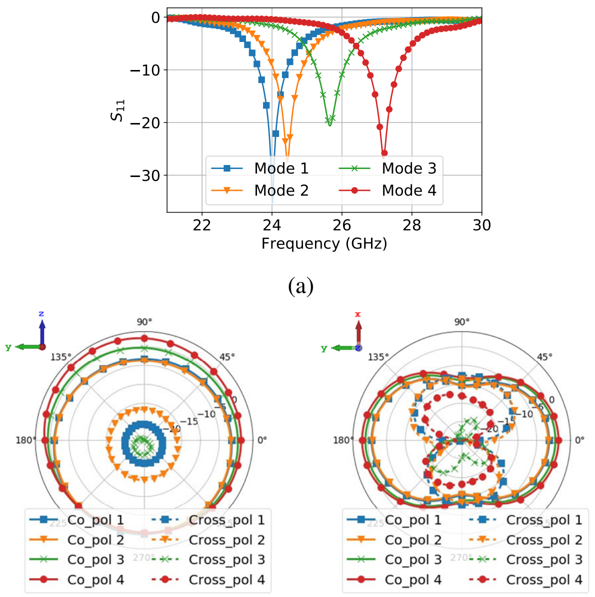
Fig. 1: Antenna configuration. (a) Top view. (b) Side view.

Fig.1 shows the configuration of the proposed frequency reconfigurable antenna. The thickness of the substrate is 0.508 mm. The dielectric constant is 3.66 and tanδ is 0.002. The dimensions are shown in Table I. The one-end-grounded patch operates as a magnetic dipole, which is fed by a lumped port between the patch and the ground plane. The magnetic dipole is placed at the edge of the ground plane, so to provide an endfire radiation pattern. Two strips are connected with the patch by two PIN diodes, which are controlled independently. Each PIN diode has an "on" state and an "off" state. Therefore, the combination of the two PIN diodes provides four different resonances, corresponding to four different operating frequencies. Fig.2(a) shows the reflection coefficients. The four modes and the corresponding operating frequencies and PIN diodes states are listed in Table II. The radiation patterns of each modes are shown in Fig.2(b) and Fig.2(c). The realized gain is ranging from 0.12 dBi to 0.17 dBi. The front-to-back ratio

TABLE II: Working modes

	Mode 1	Mode 2	Mode 3	Mode 4
PIN 1	on	off	on	off
PIN 2	on	on	off	off
Frequency	24 GHz	24.5 GHz	25.5 GHz	27 GHz

and the gain can both be improved by increasing the ground plane size.



(a)

(b) (c)

Fig. 2: Reflection coefficients and radiation patterns. (a) Reflection coefficients. (b) E-plane radiation patterns. (c) H-plane radiation patterns.

The highest frequency is achieved when both PIN diodes are off, which means that both the strips are detached from the patch. When one of the strips is attached to the patch, the resonance drops between the highest and the lowest frequencies. The lowest frequency is achieved when both PIN diodes are on and both strips are connected to the patch. In this case, the resonant frequency is decided only by the length of the patch. However, the length of the patch does not only decide the higher bound of the frequency tuning, it also influences the frequency ratio of the higher and lower bound. Fig.3 shows the highest and lowest resonant frequencies with different l_{g1}. When the patch is shorter, the frequency ratio is higher and vice versa.

The PIN diode is built as a resistor ($R_s = 4.2\ \Omega$) for the "on" mode and a capacitor ($C_t = 0.02$ pF) for the "off" mode. In practice, the package of the PIN diodes will also introduce a small inductance. It may lower the operating frequencies but can be easily compensated by adjusting the antenna parameters. The capacitance influence is shown in Fig.4(a), when both PIN diodes are off. As the capacitance increasing, more current will flow through the PIN diodes and the impact of the strips becomes stronger. As shown in Fig.4(a), the resonant frequency shifts lower as the capacitance increases. The resistance influence is shown in Fig.4(b), when both the PIN diodes are on. As the resistance increases, the resonant frequency does not change but the total efficiency decreases. The total efficiency is still

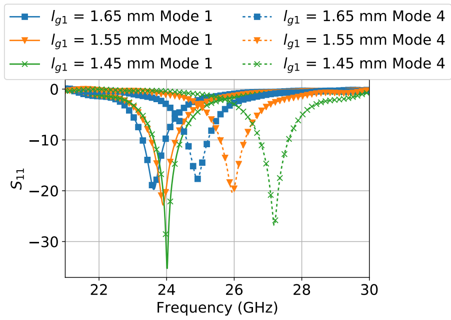
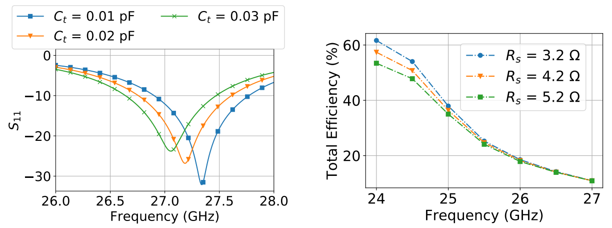


Fig. 3: Operating frequencies of Mode 1 and Mode 4 with different l_{g1}.

at an acceptable level between 50% to 60% even when R_s reaches 5.2 Ω, which is much higher than the one supported by the current PIN diodes.



(a) (b)

Fig. 4: PIN diodes parasitics influences (a) Reflection coefficients of Mode 4 with different C_t. (b) Total efficiency of Mode 1 with different R_s.

III. Array Performances

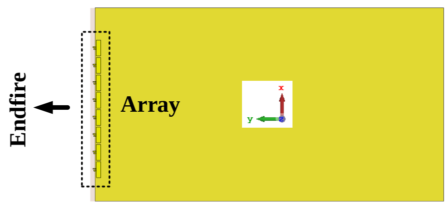


Fig. 5: Array configuration on a big ground plane.

An 8-element array is proposed as shown in Fig.5. The array is mounted on a big ground plane with size 61.25 mm × 111.5 mm, which is close to the size of a mobile phone. The element separation is 5.5 mm, which is half wavelength of 27 GHz in the free space. The array elements are always operating at the same frequency mode. Due to the interference between the array elements, the feeding position needs to be adjusted in order to reach a good impedance matching over the whole operating band. Fig.6 shows the reflection coefficients of array element 1, 2, 3, and 4. Array elements 5 to 8 operate the same due to the symmetric structure. The overlapped -10-dB impedance matching band covers from 24 GHz to 28 GHz. The mutual coupling is below -12 dB over the whole operating band. Fig.7 shows the beam scanning patterns of all operating modes. The scanning range is from 130^o to 220^o. The realized gain is ranging from 7 dBi to 9 dBi. The cross-polarization level is below -12 dB.

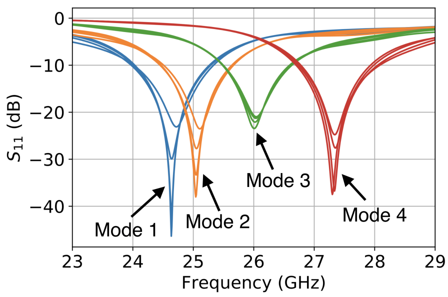


Fig. 6: Reflection coefficients of array element 1 to 4.

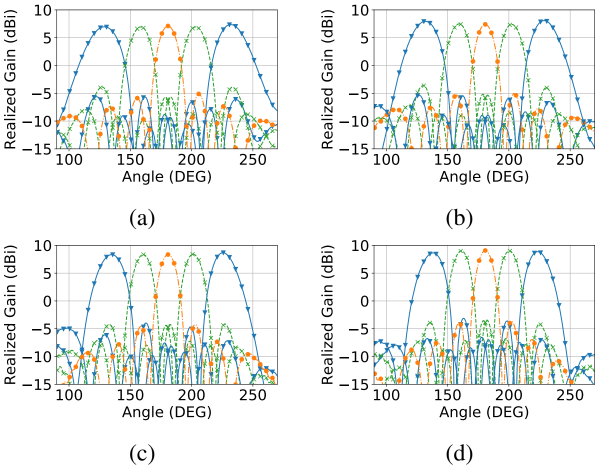


Fig. 7: Array scanning patterns. (a) 24 GHz. (b) 25 GHz. (c) 26 GHz. (d) 27 GHz.

IV. Conclusion

This paper shows a frequency reconfigurable phased array with endfire radiation patterns and vertical polarization for 5G handset applications. Four operating frequencies are achieved by using two independent PIN diodes. The frequency scanning range covers from 24 GHz to 28 GHz. The array has a good impedance matching and shows low cross-polarization over the beam scanning range.

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