A High-Gain Beam-Steering Quasi-Yagi Antenna

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1. Introduction

Recently, beam-steering reconfigurable antennas have gained considerable attention due to their capability of enhancing the performance of wireless communication systems [1]-[5]. By changing the main beam direction, they have the potential to avoid noise sources, to mitigate the multipath fading, to provide larger coverage, and to save energy. Unfortunately, most of the currently reported beam steering antennas suffer from either the low realized gain or the very small overlapped impedance bandwidth. In [1] and [2], rectangular single-arm spiral antennas are employed to realize beam scanning. The gains of the antennas in [1] and [2] are between 3-6 dBi and 4 dBi, respectively, and the bandwidths of the two antennas are about 6% (axial ratio bandwidth) and about 1.4% (50MHz at 3.7 GHz), respectively. In addition, a four-element L-shaped antenna array is proposed that can switch the main beam to 8 directions [3]. The gain of this design is around -0.5-2.1 dBi and the impedance bandwidth is 4% (2.42-2.54 GHz). In [4], a reconfigurable patch-slot-ring antenna is designed with both elevation and azimuth beam switching. The 6-dB impedance bandwidth for all modes is 2.6% centred at 2.05 GHz, and the measured peak gains are 6.1–6.7 dBi. Furthermore, a beam-tilting pattern reconfigurable microstrip parasitic dipole array is shown in [5] with an impedance bandwidth of 5%. The gain of this antenna is not reported. There is no doubt that the small impedance bandwidth or the low gain of the above antennas can significantly limit their applications.

In this paper, a beam-steering quasi-Yagi planar dipole antenna is proposed with improved bandwidth and much higher realized gain for WLAN applications. The antenna is capable of changing its E-plane maximum beam direction towards 20^0, 0^0, and -20^0 with respect to the end-fire direction. It can achieve a realized gain of 10.7 dBi and a 11.5% overlapped impedance bandwidth centred at 5.3 GHz. The beam scanning of the proposed antenna is realized by changing the length of the microstrip-to-coplanar-strip (CPS) balun. Specifically, the length of the balun affects the phase difference of the currents on the two arms of the dipole. Different phase differences of the currents will lead to different E-plane main beam directions.

2. Beam Steering Mechanism

A very thin (ideally zero diameter) half-wavelength dipole oriented along the x-axis is shown in Fig. 1. When $I_{right} = \vec{x} I_0 coskz, 0 \le x \le l$, and $I_{left} = \vec{x} I_0 coskz, -l \le x \le 0$ where $I_0 = constant$ and k is the propagation constant, the maximum beam of the antenna is towards φ=90°. In this case, the normalized far-field electric field pattern can be written as [6]

$$F(\varphi) = \frac{\cos\left(\frac{\pi}{2}\cos(\varphi)\right)}{\sin(\varphi)} \quad (1)$$

If there is a phase difference between the currents on the two arms, which is given below:

$$I_{right} = I_{left} \cdot e^{j\alpha}, -180^0 \le \alpha \le 180^0 \quad (2)$$

where α is the phase difference between the currents on the right and left arms of the dipole. In this case, the normalized far-field electric field pattern can be calculated, which is given by

$$F(\varphi,\alpha)=\frac{\cos\left(\frac{\pi}{2}\cos(\varphi)\right)\left(1+e^{j\alpha}\right)+j\left[\cos(\varphi)-\sin\left(\frac{\pi}{2}\cos(\varphi)\right)\right]\left(1-e^{j\alpha}\right)}{2\sin(\varphi)} \quad (3)$$

When $\alpha = 0$, equation (3) is identical to equation (1). Using equation (3), for each α, the value of φ corresponding to the maximum value of $F(\varphi,\alpha)$ can be calculated, which is plotted in Fig. 2. From Fig. 2, it is seen that the maximum beam direction is a function of the phase difference α. When $\alpha = 0$, the maximum beam direction is at 90°. When α is equal to 118° and -118°, the maximum beam direction is at 110° and 70°, respectively. Therefore, if the phase of the currents on the dipole can be manipulated, the main beam of the antenna will be steered.

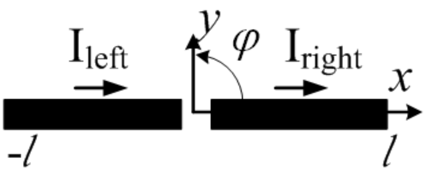


Fig. 1 Currents on a half-wavelength dipole.

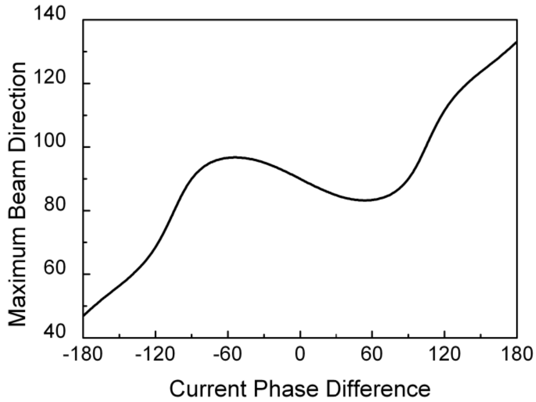


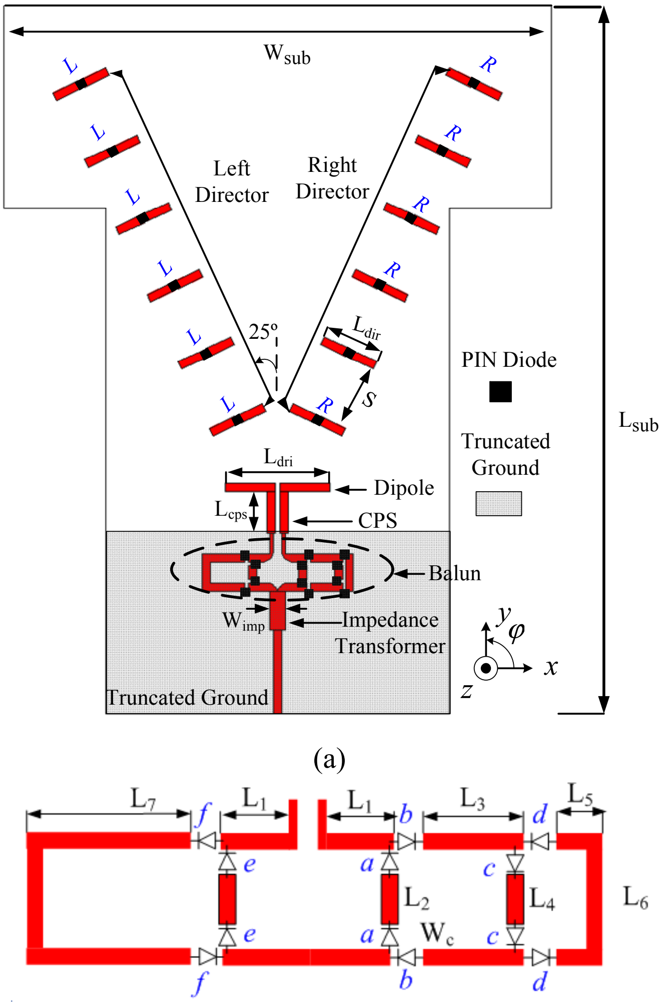
Fig. 2 E-plane maximum beam direction as a function of the phase difference of the currents on the two arms of the dipole.

3. Pattern Reconfigurable Antenna Design

The basic structure of the pattern reconfigurable antenna is designed on the base of a planar quasi-Yagi dipole antenna with fixed beam [7]. The layout of the antenna is shown in Fig. 3. A 1.27-mm-thick Rogers 6010 substrate (dielectric constant 10.2) is used. The top side of the substrate consists of a microstrip feed, a broad-band microstrip-to-CPS balun, a dipole driver fed by the CPS, and two tilted rows of directors. The bottom side is a truncated ground, serving as the reflector. The combination of the directors and reflector directs the radiation of the antenna towards the end-fire direction. The dimensions of the antenna are given in Table I.

The microstrip-to-CPS balun is used to introduce a phase difference for the currents on the two arms of the dipole. Details of the balun are shown in Fig. 3 (b). It can be seen that the right-hand part of the balun is split into three parts with length of L_1, L_3, L_5 connected by PIN diodes, and the left-hand part is split into two parts with length of L_1, L_7. The width of the gap between different parts of the balun is W_c. By controlling the PIN diodes on the balun, the phase difference of the currents on the dipole arms can be changed, thereby making the antenna radiate towards different directions. The PIN diodes on the directors are used to choose the proper directors for a certain main beam direction in order to enlarge the beam tilting angle.

The antenna can operate in three states. For State 1, diodes *e*, *b*, *c* and the diodes on the two rows of directors (diodes *L* and *R*) are switched on, and all the others are switched off. The phase difference of the currents on the left-hand and right-hand arms of the CPS is $\beta\times2(L_3+W_c)$, where β is the propagation constant in the substrate and L_3+W_c is designed to be $\lambda_g/4$ (λ_g is the guided wavelength). In this case, the currents on the two arms of the dipole are of the same phase. Therefore, the maximum beam directs at φ=90° (end-fire direction). For State 2, diodes *e*, *b*, *d* and the diode group *L* are on and all the others are off. In this case, the phase difference of the currents on the CPS is $\beta\times2(L_3+L_5+2W_c)$, which can make the maximum beam in E plane (*x-y* plane) radiate towards φ=110° direction. For State 3, diodes *f*, *a*, and diode group *R* are on, and all the others are off. The phase difference of the currents on the CPS is $-\beta\times2(L_7+W_c)$. In this case, the maximum beam direction is at φ=70° direction.



(b)

Fig. 3 (a) Schematics of the pattern reconfigurable antenna;(b) Balun of the antenna

Table I Dimensions of the pattern reconfigurable antenna

Parameter	L_1	L_2	L_3	L_4	L_5	L_6	L_7	W_c
Value (mm)	3.8	2.3	4.1	2.3	1.1	5.5	5.6	0.4
Parameter	L_{dir}	L_{dri}	L_{cps}	L_{imp}	W_{imp}	S	L_{sub}	W_{sub}
Value (mm)	8.6	14.8	6.2	5.8	2.5	9.8	105	85

4. Simulated Results

The antenna was simulated using CST Microwave Studio. According to the PIN diode datasheet [8], the diode was modelled as a resistor of 3Ω for the ON state and a parallel circuit consisting of a 10KΩ resistor and a 0.03 pF capacitor for the OFF state. In this way, the losses of PIN diodes are taken into account for the reflection coefficient and realized gain calculation. Fig. 4 shows the reflection coefficient versus frequency for the three states of the antenna. It can be noted that the overlapped impedance bandwidth ($|S_{11}|\leq$-10 dB) is 11.5% with a centre frequency of 5.3GHz. The E-plane far-field radiation patterns of the realized gain for the three states of the antenna are displayed in Fig. 5. It is shown that the maximum beam direction in E-plane can be changed towards 70^0, 90^0, and 110^0. The gains of State 1, State 2, and State 3 are 10.7 dBi, 10.6 dBi, and 10.7 dBi, respectively. The H-plan radiation patterns maintain almost the same for the three states. Due to the limited space, they are not presented in this paper.

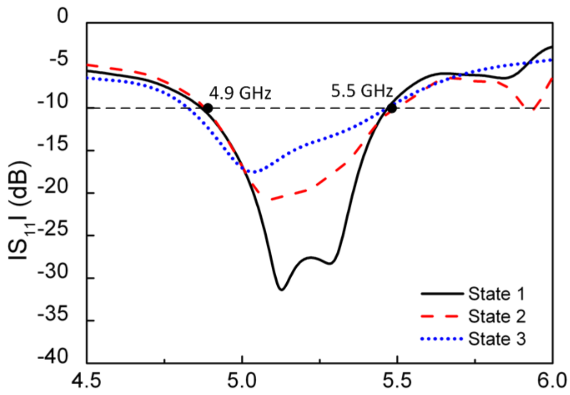


Fig. 4 Simulated input reflection coefficient for the different states of the antenna.

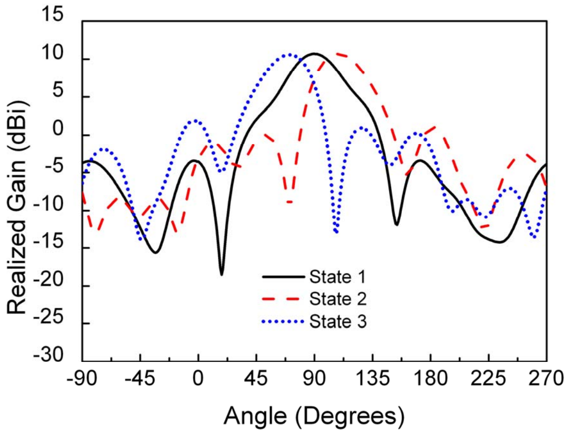


Fig. 5 Simulated E-plane (x-y plane) radiation patterns of the realized gain at 5.2 GHz.

5. Conclusion

A printed pattern reconfigurable quasi-Yagi dipole antenna is proposed. The maximum beam of the antenna can be switched towards 20°, 0°, -20° with respect to the end-fire direction in E plane by changing the length of the microstrip-to-CPS balun. For the three radiation states, the simulated overlapped impedance bandwidth is 11.5% with a centre frequency of 5.3 GHz and the simulated gain is 10.7 dBi. Compared to most of the reported beam-steering antennas, the proposed design has a much larger impedance bandwidth and a much higher gain. Future work on the antenna includes building a prototype with biasing network and conducting measurement of the antenna performance.

References

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