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A NOVEL PATTERN AND FREQUENCY RECONFIGURABLE MICROSTRIP PARASITIC ARRAY

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Abstract—In this paper, a novel pattern reconfigurable microstrip parasitic array is proposed, which is similar to the microstrip Yagi antenna. The antenna is printed on a dielectric substrate and has a probe feeding center strip with two parasitic strips on both sides of a higher plane. The driven patch is equipped with four RF PIN diodes by which we can change the antenna's state and vary its frequency at 2.1 GHz, 2.4 GHz and 2.6 GHz, respectively. Each of the parasitic patches is equipped with six switched connections symmetrically which is utilized as a director or a reflector for pattern reconfiguration. Compared with conventional antenna, the proposed antenna combines both radiation pattern reconfiguration and frequency reconfiguration together, and by raising the plane of the dielectric substrate of the parasitic patch, the tilt angel of this antenna's maximum radiation direction is lager and the gain is higher.

1. INTRODUCTION

The recent wireless communication systems tend to be high-capacious, multifunctional and cover more frequency bands. Therefore, the quantity of the antenna is becoming larger and larger. This will lead to large communication system equipment, increased costs, and electromagnetic compatibility problems. Reconfigurable antennas, which offer diverse functions in radiation pattern, frequency, or polarization, can realize the function of the multiple antennas since it can dynamically adapt its behavior to different measurements situations and operational contexts. Therefore, it effectively reduces the adverse effects on the wireless communication system brought by the antenna number.

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Nowadays seen from most studies of the reconfigurable antenna by numerous institutions, reconfigurable antenna according to its function is divided into frequency reconfigurable antenna [1], polarization reconfigurable antenna [2], pattern reconfigurable antenna [3] and hybrid reconfigurable antenna [4]. The implementation methods contain using switches [5], changing material electromagnetic properties, loading variable reactance, using mechanical methods, using the parasitic units [6], using switchable feeding networks to improve their performances [7, 8] and so on. However, the above-mentioned antennas have several shortcomings. Classically, the pattern reconfiguration feature is attained with phased antenna arrays, which may be too large and complex to satisfy the requirements of many applications [9, 10]. The back-to-front radiation ratios of several antennas are much worse than 10 dB [11, 12]. What's more, function of only one part's reconfigurability is limited [13]. As more compact and lighter devices are necessary in recent wireless communication systems, hybrid reconfigurable antenna which contains pattern reconfigurability should be taken into consideration.

This communication presents a novel pattern and frequency reconfigurable microstrip parasitic array. Four switches (RF PIN diodes) are used to change the microstrip's electric length so as to reconfigure three different frequencies at 2.1 GHz, 2.4 GHz and 2.6 GHz, respectively. Another twelve switches are used to reconfigure the radiation pattern into three variations. The measured results and the simulated ones are presented and compared. The experimental results show that the proposed antenna can clearly offer nine different modes altogether. Compared with the traditional antenna, the function of frequency reconfigurable is added. What's more, through changing the design of the antenna, the gain and tilt angle of the radiation pattern are increased obviously.

2. PHYSICAL STRUCTURE AND RADIATION MECHANISM

The reconfigurable antenna proposed here is similar to microstrip Yagi antenna. As is shown in Fig. 1, the physical parameters for this antenna are: $H = 14\,\text{mm}$, $W_m = 5.4\,\text{mm}$, $L_m = 52.2\,\text{mm}$, $S = 37.8\,\text{mm}$, $W = 11\,\text{mm}$, $L_d = 41.4\,\text{mm}$, delta $= 7.6\,\text{mm}$, $g = 17\,\text{mm}$, $L_z = 12\,\text{mm}$. A1 to A6, B1 to B6 and C1 to C4 are all switches. It is constituted by an inspired patch and two parasitic patches. Its effective length is available through controlling PIN diodes on it. Thus, the center frequency of the antenna and the maximum radiation direction can be changed respectively. The dielectric substrates which the parasitic

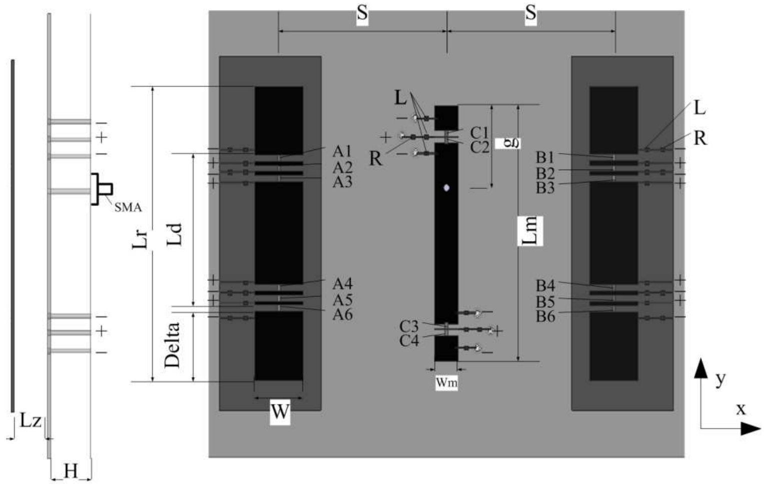

Figure 1. Physical structure and parameters of the reconfigurable microstrip parasitic array.

strips are printed on are higher than that of the incentive strip. The vertical distance of the two dielectric substrates is L_z and the spacing between strips is S. The strips are etched on a FR4 substrate of 1-mm thickness with a relative permittivity of 4.4. The center strip is approximately one-half of a guided wavelength at the resonant frequency, and is fed with an SMA probe of radius 0.65 mm. To achieve the desired input impedance, this probe can be moved along the y axis of the center strip. The parasitic strips on either side of this center driven element can be lengthened or shortened by the PIN diodes on it with respect to the center strip. Due to the geometry of the antenna, which is similar to a printed dipole, it is linearly polarized and exhibits low cross polarization. By changing the length of the two parasitic units, antenna can work in one of three modes which all share a common impedance bandwidth: RD, DD and DR-modes, where R and D stand for "reflector" and "director", respectively.

The operation of the antenna is as follows. When all of the four switches on the center strip are closed, the center resonant frequency of the antenna is 2.1 GHz. Meanwhile, for the parasitic patches, with B1, B6 on the right side open and others closed, the antenna works in the RD-mode at the frequency of 2.1 GHz. In this mode, the left element is longer than the required resonant length. Conversely, the right element is shorter than it. So the left patch is equivalent to a reflector (R), and the right one is equal to a director (D). Since the presence of a finite ground plane directs the radiation of the element into the upper half space, inhibits the downward radiation, the H-plane radiation pattern tilts toward the positive x axis. The DR-mode is symmetric to the RD-mode when A1, A6 open and others closed, in which mode, the H-plane radiation pattern tilts toward the negative x axis. When A1, A6, B1 and B6 are all open, both of the parasitic elements work as directors (D) which are symmetric with respect to the center element and the antenna is in the DD-mode. The induced currents on the parasitic elements are much weaker than the driven currents on the center element, therefor they have little effect on the radiation pattern. As a result, there is a broadside radiation pattern in the DD-mode. When the switches on both of the parasitic strips are closed, the two patches are equal to two reflectors. It is called RR-mode, which is similar to the DD-mode in the radiation results. In addition, by changing the states of the switches on center strip, such as C1, C2, C3 and C4, the center frequency of the antenna can be altered for its effective electrical length varies. According to proportion, changing switches on the left and right parasitic patches correspondingly to realize the turning of the radiation direction at 2.4 GHz and 2.6 GHz. The photo of the antenna is shown in Fig. 2.

In order to accurately predict the reconfigurability of the proposed antenna, it is necessary to extract the diode's characteristics. The detailed diagram of bias circuit of PIN diode is displayed in Fig. 3. The selected PIN diode is Infineon BAR63-02L. When the PIN diode is forward-biased, it works as a resistance of 1 Ω. When the PIN diode is reverse-biased, it is equivalent to a series capacitance of 0.3 pF and a resistance of 5 kΩ. In the bias circuit, an inductance L is used for AC blocking which is added to the antenna, and a resistor R is used to control the bias current.

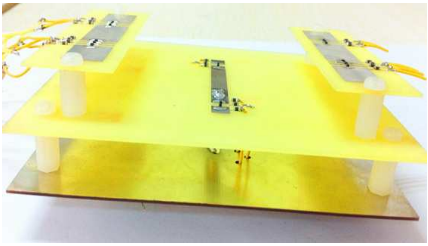

Figure 2. Photo of the antenna.

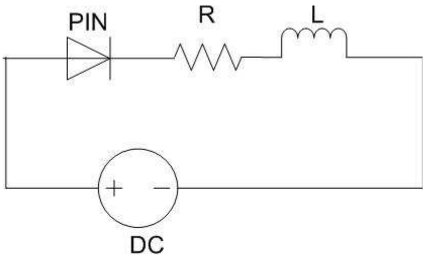

Figure 3. Diagram of bias circuit of PIN diode.

3. ANALYSIS AND RESULTS

In the RD mode, a reference microstrip Yagi antenna [13] is displayed here, whose center strip and parasitic strips are on the same floor, that is $L_z = 0\,\text{mm}$. When the frequency is 2.1 GHz, from the simulated results, the tilt angle of the xoz-plane is $+20^\circ$ and the gain is 4.25 dB for the reference antenna. For the proposed antenna, the maximum radiation direction of the xoz-plane is $+37^\circ$ and the gain is 4.68 dB. It is obvious that the maximum radiation direction of the xoz-plane increases greatly and the gain of the antenna improves a bit. Here the parameter L_z is studied and its effect is presented in Fig. 4. It can be seen that to some extend, the tilt angel of this antenna's maximum radiation direction becomes larger as the vertical distance is higher. When the $L_z = 2\,\text{mm}$, 6 mm, 10 mm, the tilt angle is 27°, 33°, 36°. Firstly, it is because different distances have different influences to the driven antenna. Secondly, different distances also result in angle differences between the center strip and the direction strip. This is the result of the two reasons. Therefore, it is effective to increase the maximum radiation direction and the gain of the antenna when we raise the plane of the parasitic strips. What's more, seen from the simulation results, both the distance between the patches S and the width of the parasitic patch W will affect the radiation pattern of the xoz-plane. Within a certain range of W, the wider the W is, the larger the tilt angle will be, while the shared impedance bandwidth of the three configuration decreases at the same time. The spacing S influences the radiation direction a bit.

When C1, C2, C3 and C4 are all closed, the center frequency is

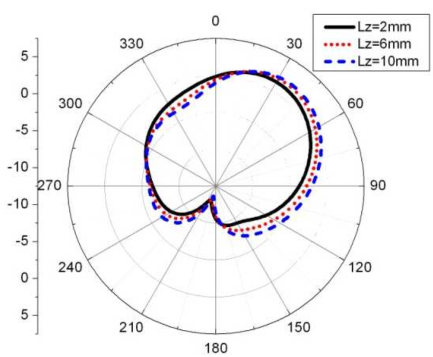

Figure 4. The simulated radiation pattern of xoz-plane at $F = 2.1\,\text{GHz}$ for different values of L_z.

2.1 GHz. The return losses of the three states DR, DD, RD are shown in Fig. 5, and the simulated and measured radiation patterns of *xoz*-plane and *yoz*-plane are displayed in Fig. 6. It can be seen that the return losses of the three different modes are almost the same and the impedance bandwidth is from 2.32 to 2.48 GHz for a return loss greater than 10 dB. In the *xoz*-plane, the DR mode has beam maximum at $-37°$ ("$-$" indicates that the pattern tilts toward the negative x axis), and the gain is 5.01 dB. The DD mode has beam maximum at 0° and the gain is 2.55 dB. The RD mode has beam maximum at $+37°$ ("$+$" indicates that the radiation pattern tilts toward the positive x axis) and the gain is 4.68 dB. In the *yoz*-plane the maximum radiation is always directed toward 0°.

When C1, C4 are open and C2, C3 closed, the center frequency

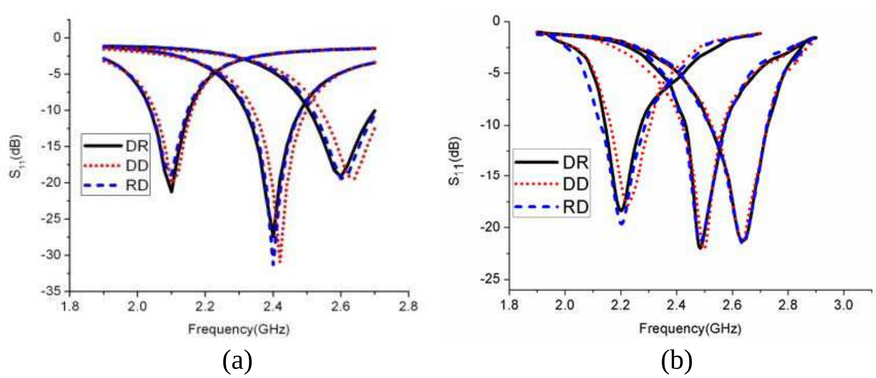

Figure 5. (a) The simulated return losses of the three states DR, DD, RD. (b) The measured return losses of the three states DR, DD, RD.

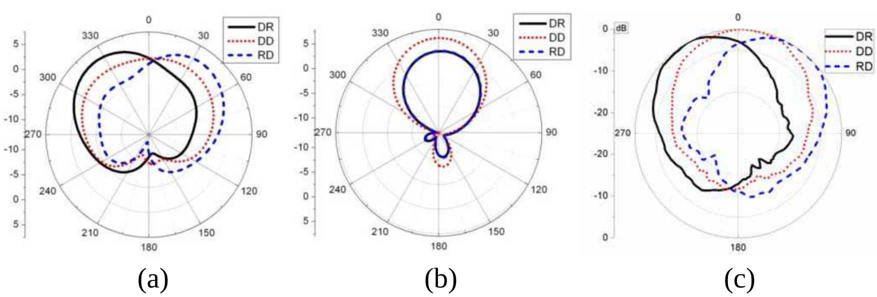

Figure 6. (a) Simulated radiation pattern of *xoz*-plane at $F = 2.1$ GHz. (b) Radiation pattern of *yoz*-plane at $F = 2.1$ GHz. (c) Measured radiation pattern of *xoz*-plane at $F = 2.1$ GHz.

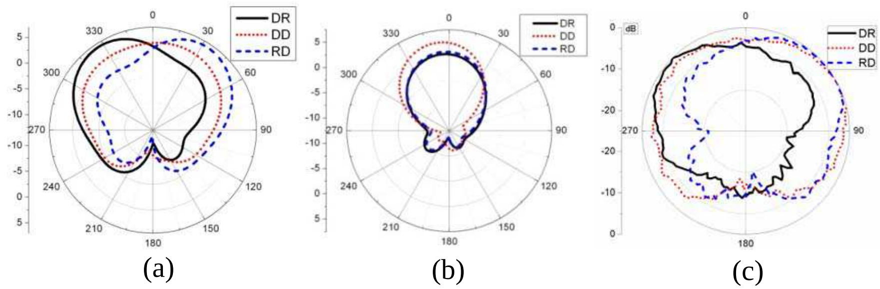

Figure 7. (a) Simulated radiation pattern of xoz-plane at $F = 2.4\,\text{GHz}$. (b) Radiation pattern of yoz-plane at $F = 2.4\,\text{GHz}$. (c) Measured radiation pattern of xoz-plane at $F = 2.4\,\text{GHz}$.

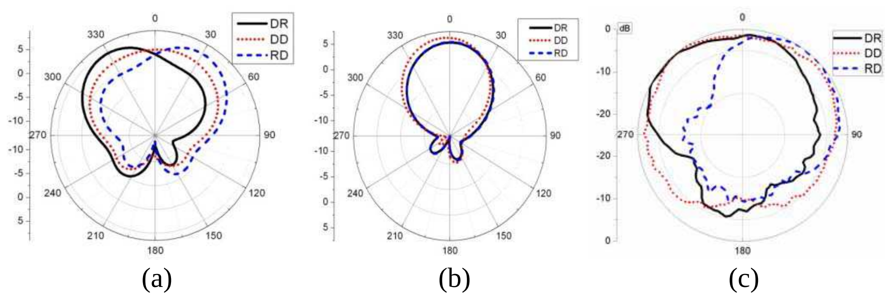

Figure 8. (a) Simulated radiation pattern of xoz-plane at $F = 2.6\,\text{GHz}$. (b) Radiation pattern of yoz-plane at $F = 2.6\,\text{GHz}$. (c) Measured radiation pattern of xoz-plane at $F = 2.6\,\text{GHz}$.

is 2.4 GHz. The return losses of the three states DR, DD, RD are shown in Fig. 5, and the simulated and measured radiation patterns of xoz-plane and yoz-plane are displayed in Fig. 7. It can be seen that the return losses of the three different modes are almost the same and the impedance bandwidth is from 2.05 to 2.16 GHz for a return loss greater than 10 dB. In the xoz-plane, the DR mode has beam maximum at -33° and the gain is 6.28 dB. The DD mode has beam maximum at 0° and the gain is 3.82 dB. The RD mode has beam maximum at $+33^\circ$ and the gain is 6.32 dB. In the yoz-plane the maximum radiation is always directed toward 0°.

When C1, C2, C3 and C4 are all open, the center frequency is 2.6 GHz. The return losses of the three states DR, DD, RD are shown in Fig. 5 and the simulated and measured radiation pattern of xoz-plane and yoz-plane is displayed in Fig. 8. It can be seen that the impedance bandwidth is from 2.55 to 2.68 GHz for a return loss greater than 10 dB. In the xoz-plane, the DR mode has beam maximum at $-24°$ and the gain is 7.39 dB. The DD mode has beam maximum at 0° and the gain is 7.11 dB. The RD mode has beam maximum at $+23°$ and the gain is 7.31 dB. In the E-plane the maximum radiation is always directed toward 0°.

Above all, the experiment results of the tilt angel and the gains of the antenna's maximum radiation direction are displayed in Table 1 as follow.

Table 1. The tilt angel and the gain of the proposed antenna's maximum radiation direction.

	DR	DD	RD
Reference 2.1 GHz	−18°/4.52 dB	0°/3.79 dB	+20°/4.25 dB
2.1 GHz	−37°/5.01 dB	0°/2.55 dB	+37°/4.68 dB
2.4 GHz	−33°/6.28 dB	0°/3.82 dB	+33°/6.32 dB
2.6 GHz	−24°/7.39 dB	0°/7.11 dB	−23°/7.31 dB

4. CONCLUSIONS

A novel pattern reconfigurable microstrip parasitic array has been presented. Compared with the traditional antenna, the function of frequency reconfigurable is added. Moreover, through changing the design of the antenna, the gain and tilt angle of the radiation pattern are increased obviously. The combination of 16 switches makes it possible for the antenna to have three different directions in radiation pattern and three different frequencies at 2.1 GHz, 2.4 GHz and 2.6 GHz. Since the reconfigurable antenna is economic and practical, and can reduce the number and the volume of antennas in equipment, it has broad application prospect in wireless communication field. We can group this antenna unit to design an antenna array which will have different pattern directions in different planes.

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REFERENCES

1. Abutarboush, H. F., R. Nilavalan, S. W. Cheung, K. M. Nasr, T. Peter, D. Budimir, and H. Al-Raweshidy, "A reconfigurable wideband and multiband antenna using dual-patch elements for compact wireless devices," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 1, 36–43, 2012.
2. Cao, W., B. Zhang, A. Liu, T. Yu, D. Guo, and K. Pan, "A reconfigurable microstrip antenna with radiation pattern selectivity and polarization diversity," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 453–456, 2012.
3. Huff, G. H. and J. T. Bernhard, "Integration of packaged RF MEMS switches with radiation pattern reconfigurable square spiral microstrip antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 2, 464–469, 2006.
4. Nikolaou, S., R. Bairavasubramanian, C. Lugo, Jr., I. Carrasquillo, D. C. Thompson, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, "Pattern and frequency reconfigurable annular slot antenna using PIN diode," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 2, 439–448, 2006.
5. Wu, W., B. Z. Wang, X. Yang, and Y. Zhang, "Pattern reconfigurable planar fractal antenna and its characteristic mode analysis," *IEEE Antennas Propag. Mag.*, Vol. 49, No. 3, 68–75, 2007.
6. Kawakami, H. and T. Ohira, "Electrically steerable passive array radiator (ESPAR) antennas," *IEEE Antennas Propag. Mag.*, Vol. 47, No. 2, 43–50, Apr. 2005.
7. Poussot, B., J. M. Laheurte, L. Cirio, O. Picon, D. Delcroix, and L. Dussopt, "Diversity measurements of a reconfigurable antenna with switched polarizations and patterns," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 1, 31–38, 2008.
8. Yang, S.-L. S. and K.-M. Luk, "Design of a wide-band L-probe patch antenna for pattern reconfiguration or diversity applications," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 2, 433–438, 2006.
9. Li, R. L., V. F. Fusco, and R. Cahill, "Pattern shaping using a reactively loaded wire loop antenna," *Proc. Inst. Elect. Eng. Microw. Antennas Propagat.*, Vol. 148, 203–208. Jun. 2001.
10. Ramadan, A., K. Y. Kabalan, A. El-Hajj, S. Khoury, and M. Al-Husseini, "A reconfigurable U-Koch microstrip antenna for wireless applications," *Progress In Electromagnetic Research*, Vol. 93, 355–367, 2009.

11. Lim, S. and H. Ling, "Design of electrically small, pattern reconfigurable Yagi antenna," *Electron. Lett.*, Vol. 43, No. 24, 1326–1327, 2010.
12. Kang, W., S. Lee, and K. Kim, "Design of symmetric beam pattern reconfigurable antenna," *Electron. Lett.*, Vol. 46, No. 23, 1536–1537, 2010.
13. Zhang, S., G. H. Huff, J. Feng, and J. T. Bernhard, "A pattern reconfigurable microstrip parasitic array," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 10, 2773–2776, 2004.