A Reconfigurable Patch Antenna Using Switchable Slots for Circular Polarization Diversity

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***Abstract*—A novel design of a microstrip patch antenna with switchable slots (PASS) is proposed to achieve circular polarization diversity. Two orthogonal slots are incorporated into the patch and two pin diodes are utilized to switch the slots on and off. By turning the diodes on or off, this antenna can radiate with either right hand circular polarization (RHCP) or left hand circular polarization (LHCP) using the same feeding probe. Experimental results validate this concept. This design demonstrates useful features for wireless communication applications and future planetary missions.**

***Index Terms*—Diversity method, microstrip antennas, polarization.**

I. Introduction

ANTENNA systems that utilize polarization diversity are gaining popularity due to the development of wireless communication in recent years. In broadband wireless communication systems, such as wireless local area networks (WLAN) [1], [2], they are used to mitigate the detrimental fading caused by multipath effects. In active read/write microwave tagging systems, polarization diversity antennas provide a powerful modulation scheme [3]. They are also utilized to realize frequency reuse for doubling the system capability in satellite communication systems [4]. In a recent project to build a Mars rover, a patch antenna with dual-frequency and dual-polarization capabilities is required [5]. In light of these applications, we present a novel antenna for polarization diversity: a patch antenna with switchable slots (PASS) that can achieve right hand circular polarization (RHCP) and left hand circular polarization (LHCP) with a single feeding port. The patch antenna is selected due to the desirable features it possesses such as low profile, light weight, and conformability with RF circuitry. Two orthogonal slots are incorporated into the square patch and two pin diodes are positioned in the center of the slots to control their status. By turning the diodes on or off, either RHCP or LHCP can be obtained with the same feeding probe which is located on the diagonal line of the patch. Compared to previous designs, this antenna is simple and attractive in that it involves only one patch and a single feed. It is also worthwhile to point out that the RHCP and LHCP are time separated (depending on the switch time of the diodes) so that there is no coupling between these two polarizations. The validity of this concept is demonstrated by experimental results with good axial ratios achieved in both RHCP and LHCP operations.

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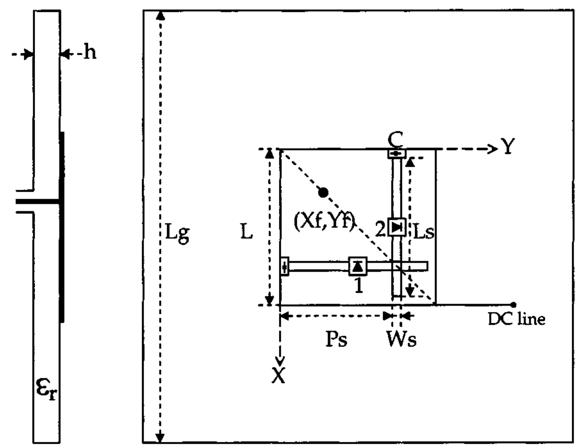
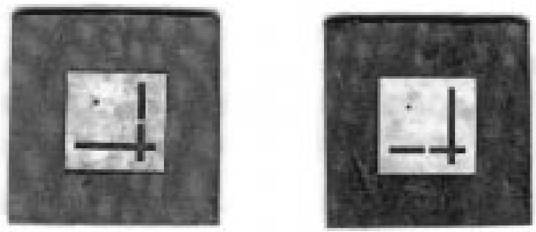


Fig. 1. Geometry of a patch antenna with switchable slots (PASS) for RHCP/LHCP diversity. A bias circuit is also designed using dc blocking capacitors (C) and a quarter-wavelength grounded dc line.

II. Antenna Structure and Its Operational Mechanism

Fig. 1 shows the schematic of the proposed antenna. A square patch with length L is mounted on a sqaure substrate with thickness h, permittivity ε_r, and length L_g. A feeding probe is located on the diagonal line of the patch at (X_f, Y_f). Two orthogonal and identical slots are incorporated into the patch with parameters L_s, W_s, and P_s. Two pin diodes are inserted into the center of the slots with diode number 1 oriented toward the feeding point and diode number 2 oriented away from the feeding point.

The radiation of the antenna can be described using the cavity model. For a normal square patch antenna, when the feeding point is located on its diagonal line, both the TM_{10} and TM_{01} modes are excited at the same frequency. After adding the slots, the resonant frequencies of both modes change [6]. Using the geometry in Fig. 1, when the horizontal slot is cut into the patch, it only affects the TM_{10} mode and does not affect the TM_{01} mode. If diode 1 is on, the horizontal slot is split into two short slots and the electric current of the TM_{10} mode can flow through diode 1. Therefore, the effect of the horizontal slot on the TM_{10} mode is trivial and the resonant frequency of the TM_{10} mode changes slightly. When the vertical slot is cut into the patch, only the TM_{01} mode is affected. If diode 2 is off, the electric current of the TM_{01} mode cannot flow through diode 2 thus forcing the current to travel around the slot. Therefore, the effect



(a) (b)

Fig. 2. Photos of (a) LHCP and (b) RHCP patch antennas. Diodes that are on in Fig. 1 are represented by conductive metal tabs in the center of the slots while those that are off are represented by leaving the slots unchanged. [7] has shown that these simplified implementations of switches provide acceptable representations for the actual switches. The patch size is 18×18 mm for operation at 4.64 GHz and the ground plane size is 40×40 mm.

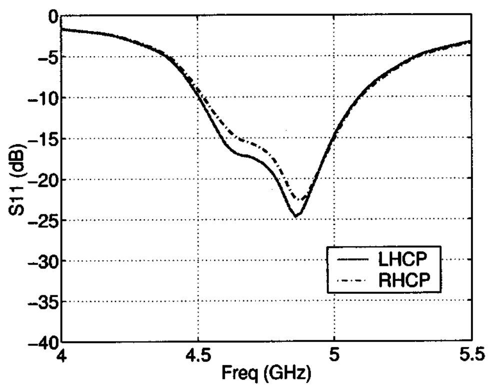


Fig. 3. Measured return loss of the PASS.

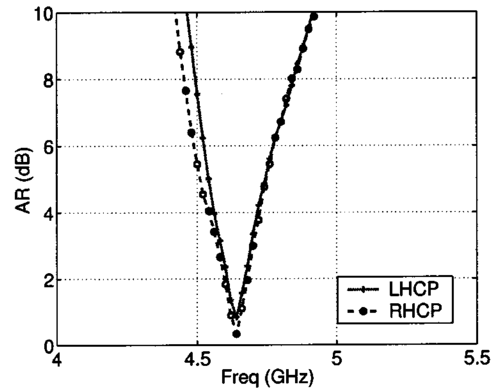


Fig. 4. Measured axial ratio versus frequency at boresight of the PASS.

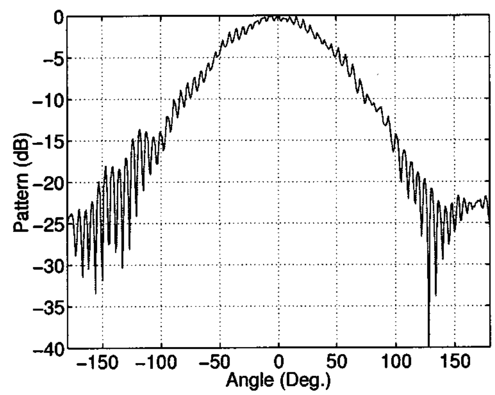


Fig. 5. Measured spinning linear pattern of the PASS in the xz plane with LHCP polarization, $\text{freq.} = 4.64$ GHz.

of the vertical slot on the TM_{01} mode is significant and the resonant frequency of the TM_{01} greatly decreases. Thus, when both slots are incorporated into the patch with diode 1 on and diode 2 off, the resonant frequencies of the TM_{10} and TM_{01} modes are different. The frequency difference is controlled by the slots' length and position. If the frequency difference is properly designed, the radiation fields of the TM_{10} mode and the TM_{01} mode have the same magnitude and are 90 degrees out of phase at a midpoint frequency. As a result, a RHCP pattern can be obtained. On the other hand, if the two slots are incorporated with diode 1 off and diode 2 on, the roles of the modes are reversed and a LHCP pattern can be obtained.

To control the status of the diodes, a bias circuit is required. To isolate the dc while maintaining continuity for the RF, two capacitors are soldered onto the edges of the slots, as shown in Fig. 1. A shorted quarter wavelength strip is connected to the right-bottom corner of the patch as a ground at dc but does not affect the behavior of the RF. The control voltage is supplied from the coax probe. Therefore, the diodes have different dc voltages on their two sides. If a positive voltage (such as $+2$ V for a HPND 4005 pin diode) is supplied, diode 1 is turned off and diode 2 is turned on. Otherwise, if a negative voltage is supplied, diode 1 is turned on and diode 2 is turned off. A similar biasing structure has been successfully applied in [7], [8] for dual frequency operations instead of polarization diversity. It's also worthwhile to point out that MEMS switches can be utilized here for the same functionality with a lower insertion loss.

III. Experimental Results

Several experiments have been carried out to demonstrate the functionality of this polarization diversity antenna. Two square patch antennas are fabricated for 4.64 GHz operation with the following parameters:

$$\begin{aligned} L =& 18 \text{ mm}, \quad h = 3.18 \text{ mm}, \\ \varepsilon_r =& 2.20, \quad L_g = 40 \text{ mm}, \\ (X_f, Y_f) =& (5,5) \text{ mm}, \quad L_s = 12 \text{ mm}, \\ W_s =& 1 \text{ mm}, \quad P_s = 13 \text{ mm}. \end{aligned}$$

Fig. 2 shows the photos of these two antennas: Fig. 2(a) has a metal tab in the center of the vertical slot and Fig. 2(b) has a metal tab in the horizontal slot. The metal tab is used to represent a diode that is on and several experiments by the authors in [7] using beam lead pin diodes, such as a HPND-4005, have demonstrated the validity of this simplification. Fig. 2(a) represents the situation when diode 1 is off and diode 2 is on, this results in a LHCP pattern. In contrast, Fig. 2(b) represents a RHCP antenna. Due to the symmetry, the LHCP and RHCP antenna have very similar input matches, better than -10 dB from 4.5 GHz to 5.1 GHz, as shown in Fig. 3. This frequency range was chosen for the ease of the measurement setup at the UCLA antenna lab and it has been scaled to other frequencies. As revealed in Fig. 4, the best axial ratio at boresight is achieved at 4.64 GHz with 3% CP bandwidth (according to an axial ratio criteria of 3 dB).

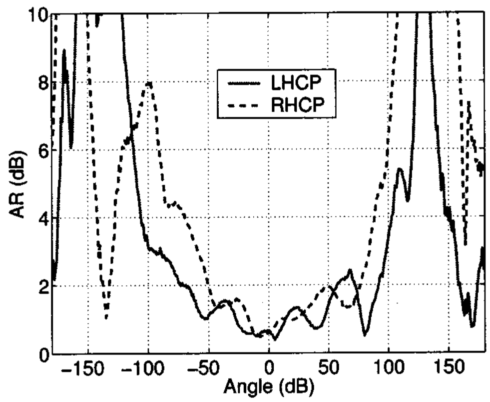


Fig. 6. Measured axial ratio of the PASS in the xz plane, $\mathrm{freq.} = 4.64$ GHz.

Fig. 5 shows the measured spinning linear patterns of the LHCP antenna in the xz plane. Similar radiation patterns have been observed in the yz plane and also for the RHCP antenna. Fig. 6 depicts the axial ratios (AR) of both antennas in the xz plane. An acceptable axial ratio $(AR < 3 \text{ dB})$ is obtained in a broad angular range from −70 to 70 degrees from boresight.

IV. Conclusion

A novel patch antenna with switchable slots (PASS) is presented in this paper that can be used in applications requiring polarization diversity. By controlling the bias voltage, the antenna can switch between radiating a RHCP and LHCP pattern with the same feeding port. This antenna design demonstrates desirable features for wireless communication applications such as wireless local area networks (WLAN), satellite links, and space robots.

References

[1] S.-T. Fang, "A novel polarization diversity antenna for WLAN applications," in *2000 IEEE AP-S Dig.*, July 2000, pp. 282–285.

[2] K. Hettak, G. Y. Delisle, and M. G. Stubbs, "A novel variant of dual polarized CPW fed patch antenna for broadband wireless communications," in *2000 IEEE AP-S Dig.*, July 2000, pp. 286–289.

[3] M. Boti, L. Dussopt, and J.-M. Laheurte, "Circularly polarized antenna with switchable polarization sense," *Electron. Lett.*, vol. 36, no. 18, pp. 1518–1519, Aug. 2000.

[4] X.-X. Yang and S.-S. Zhong, "Analysis of two dual-polarization square-patch antennas," *Microwave Opt. Technol. Lett.*, vol. 26, no. 3, pp. 153–156, Aug. 2000.

[5] J. Huang, "Miniaturized UHF microstrip antenna for a Mars mission," in *2001 IEEE AP-S Dig.*, vol. 4, July 2001, pp. 486–489.

[6] X.-X. Zhang and F. Yang, "The study of slit cut on the microstrip antenna and its applications," *Microwave Opt. Technol. Lett.*, vol. 18, no. 4, pp. 297–300, July 1998.

[7] F. Yang and Y. Rahmat-Samii, "Patch antenna with switchable slot (PASS): Dual frequency operation," *Microwave Opt. Technol. Lett.*, vol. 31, no. 3, pp. 165–168, Nov. 2001.

[8] ——, "Switchable dual-band circularly polarized patch antenna with single feed," *Electron. Lett.*, vol. 37, no. 16, pp. 1002–1003, Aug. 2001.