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A Novel Patch Antenna With Switchable Slot (PASS): Dual-Frequency Operation With Reversed Circular Polarizations

Nanbo Jin, Fan Yang, and Yahya Rahmat-Samii

***Abstract*—In this paper, the recently proposed patch antenna with switchable slot (PASS) concept is implemented to design a novel reconfigurable antenna with both frequency and polarization diversities. Using only one switch and a single patch, the antenna operates at 4.20 GHz with right-handed circular polarization and at 4.55 GHz with left-handed circular polarization. The fabricated antenna has both an acceptable return loss and a broadside axial ratio (AR) lower than 2 dB at each operation frequency. The frequency and polarization diversities of this design could potentially improve the reliability of wireless communication systems.**

***Index Terms*—Circular polarization, dual-frequency, patch antenna, reconfigurable antenna, switchable slot.**

I. INTRODUCTION

The development of reconfigurable antennas has received much attention in recent years. Functional diversities are integrated in small antennas to accommodate the ever demanding requirements of modern wireless communication systems [1], [2]. Recently, the concept of patch antenna with switchable slot (PASS) [3] has been proposed to achieve the antenna reconfigurability. By mounting a switching diode at the center of a slot cut on a patch antenna, one may control the antenna operation status using dc bias. This concept has shown its simplicity and effectiveness in obtaining either frequency [3] or polarization [4] diversity. Similar designs are presented in [5] with the capability of switching linear polarization (LP)/left-handed circular polarization (LHCP) or LHCP/right-handed circular polarization (RHCP).

This paper presents a novel reconfigurable antenna that applies the PASS concept. Using only one switching diode in a single patch, the antenna is capable to operate at two distinct frequencies with reversed circular polarizations. An antenna prototype with a Schottky diode and a biasing circuit is designed, fabricated and measured to demonstrate the radiation performance. In addition, a practical design that has switchable RHCP/LHCP at each operation frequency is suggested based on the intrinsic symmetry of the antenna configuration.

II. ANTENNA CONFIGURATION AND ITS OPERATION MECHANISM

The antenna configuration is shown in Fig. 1. A rectangular patch is used and a coaxial feed is located on the diagonal line to excite two orthogonal modes (TM_{01}^{z} and TM_{10}^{z}). An x-oriented slot is incorporated into the patch with a switching diode mounted at the center to control the slot configuration. The antenna parameters are also labeled in Fig. 1.

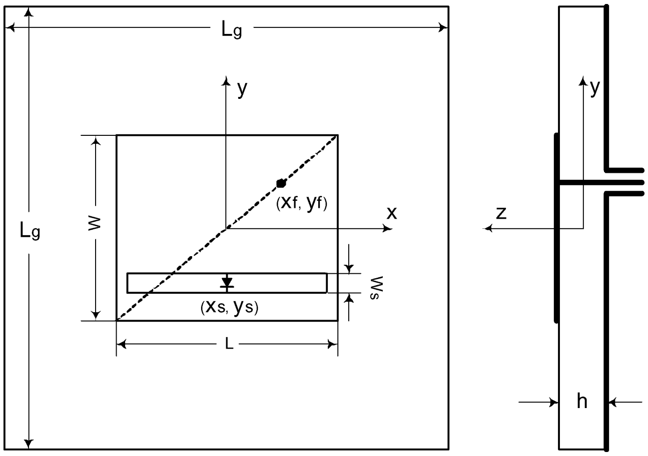

Fig. 1. Configuration of the proposed patch antenna with a switchable slot. A switching diode is mounted at (x_s, y_s) to control the slot configuration. A diagonal coaxial feed located at (x_f, y_f) excites circular polarizations.

The reconfigurable slot has different effects on TM_{01}^{z} and TM_{10}^{z} modes. For the TM_{01}^{z} mode, the electric current flows along y direction. When the switch is ON, the electric current flows through the switch without being significantly disturbed by the slot. Hence, with the switch ON, the TM_{01}^{z} mode resonates at approximately the same frequency as the patch without a slot. On the other hand, when the switch is OFF, the current has to flow around the edge of the slot, resulting in a longer resonant length. Hence, with the switch OFF, the TM_{01}^{z} mode resonates at a lower frequency than the "switch-on" status [6]. For the TM_{10}^{z} mode, the electric current flows along x direction. Since the slot is parallel to the electric current, it has little effect on the TM_{10}^{z} mode. The frequency of the TM_{10}^{z} mode remains unchanged regardless of the ON/OFF status of the switch.

To determine the frequency and polarization sense of each operation status, the amplitude and phase relationships between TM_{01}^{z} and TM_{10}^{z} modes [7] at each operation status are conceptually sketched in Fig. 2. The notations L_y and L_x are used to represent the resonant lengths of the TM_{01}^{z} mode and the TM_{10}^{z} mode, respectively. At the "switch-on" status, the resonant lengths are approximately determined by

$$L_x \approx L; \quad L_y \approx W. \tag{1}$$

Let us consider the case of $L > W$. By adjusting L and W, it is always possible to obtain quadrature phase relationship between TM_{01}^{z} and TM_{10}^{z} modes at a certain frequency (this frequency is denoted as f_h in Fig. 2) so that

$$\phi_{01} - \phi_{10} = 90^\circ. \tag{2}$$

This indicates that the y-polarized field leads the x-polarized field by 90°. When the antenna topology is properly designed so that the two

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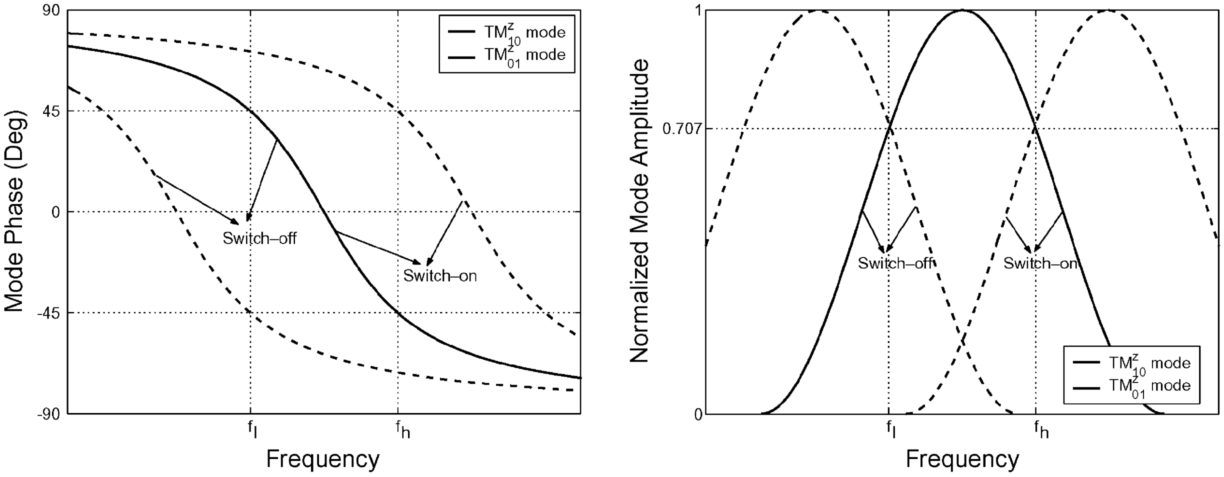


(a) (b)

Fig. 2. Conceptual sketches of (a) the phase and (b) the amplitude of TM^z_{01} and TM^z_{10} modes that determine the frequency and the polarization sense at each operation status. Note that TM^z_{10} mode remains the same while TM^z_{01} mode changes with the ON/OFF status of the switch.

orthogonal modes have the same amplitude at this frequency, a perfect LHCP will be generated.

In contrast, at the "switch-off" status, L_y is disturbed by the open slot and the resonant lengths are approximately determined by

$$L_x \approx L; \quad L_y \approx W + \Delta L_s \tag{3}$$

where ΔL_s represents the slot effect in the resonant length. Provided $W < L < W + \Delta L_s$ is satisfied, a reversed phase quadrature can be achieved by selecting a proper slot length and position so that

$$\phi_{10} - \phi_{01} = 90^\circ. \tag{4}$$

The polarization sense is also reversed because the x-polarized field exhibits a 90° phase lead in this case. The frequency where the RHCP is observed is denoted as f_l. It will be shown in the next section that the frequency separation between two operation status, $f_h - f_l$, is much greater than the coherent bandwidth in most indoor communication environments [8] if the antenna is designed to operate in C-band. Therefore, it provides two diversity branches: one may transmit the same information through two independent channels of f_l/RHCP and f_h/LHCP for more reliable communications [9].

An improved design that combines frequency and polarization diversities can be developed from the antenna discussed above. The symmetry in the antenna topology shown in Fig. 3 allows one to use a second diagonal feed located at $(-x_f, y_f)$ to achieve LHCP at f_l (switch-off) and RHCP at f_h (switch-on), respectively. With another switch between the two diagonal feeds, this antenna has switchable LHCP/RHCP at each operation frequency. Different switch combinations and their associated operation status are summarized in Table I. Four possible diversity branches are achieved by this improved design.

In summary, the proposed antenna utilizes a switchable slot to change the resonant features of TM^z_{01} and TM^z_{10} modes at its multiple operation status. The unique combination of reconfigurable components and diagonal feeds enables either reversed or switchable circular polarizations at different operation frequencies of the antenna.

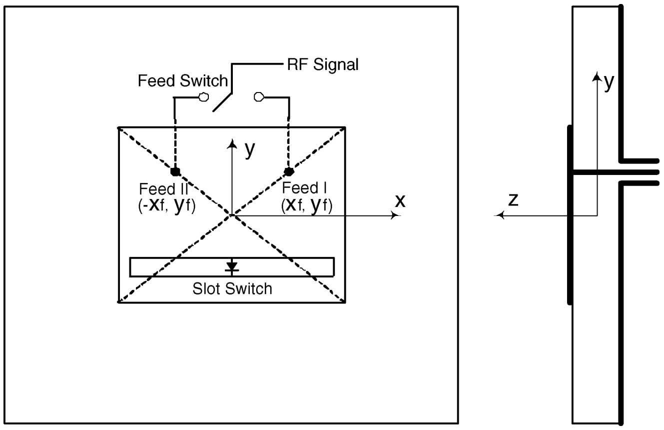


Fig. 3. An improved design is suggested to combine frequency and polarization diversities using another coaxial feed located at $(-x_f, y_f)$ and an RF switch between the two feeds. This antenna has switchable RHCP/LHCP at each operation frequency.

TABLE I
DIFFERENT SWITCH COMBINATIONS OF THE IMPROVED DESIGN SHOWN IN FIG. 3 AND THE ASSOCIATED OPERATION STATUS

Feed Switch	Slot Switch	Frequency	Polarization
I	OFF	f_l	RHCP
I	ON	f_h	LHCP
II	OFF	f_l	LHCP
II	ON	f_h	RHCP

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

To validate the antenna's operation mechanism discussed in the previous section, an antenna prototype is designed and fabricated to operate at 4.55 GHz with LHCP and 4.20 GHz with RHCP, respectively. Fig. 4 shows the photograph of the fabricated antenna prototype. The patch is etched on a RT/Duroid 5880 $(\epsilon_r = 2.2)$ substrate. It has been

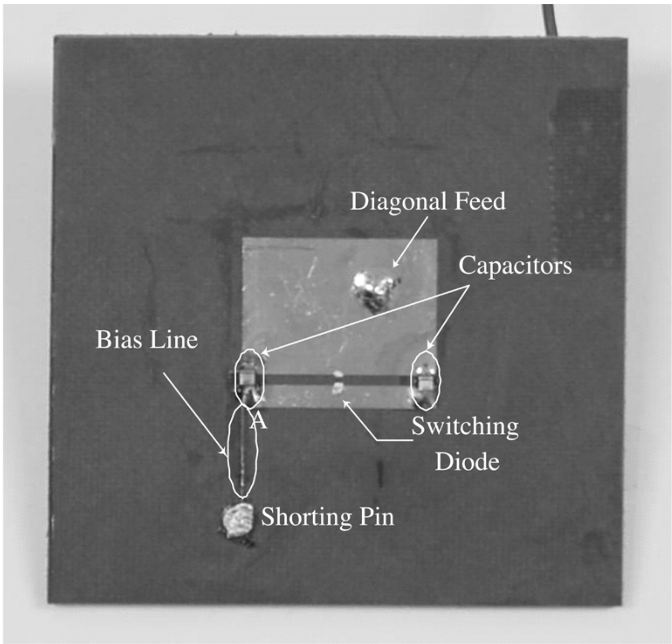


Fig. 4. Photograph of a fabricated antenna prototype in Fig. 1. A Schottky diode is utilized to implement the switch. The slot is cut across the patch, with two 47 pF capacitors soldered at the ends to isolate DC bias while keeping the RF connection. The length of the bias line is $\lambda/4$ so that the antenna return loss will not be appreciably affected.

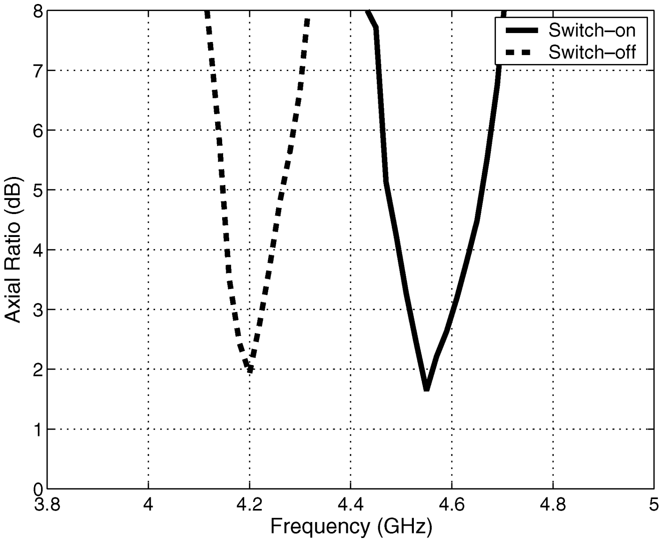


Fig. 5. Measured results of broadside axial ratio versus frequency. The best broadside axial ratios are observed at 4.55 GHz (LHCP) and 4.20 GHz (RHCP). The associated $AR < 3\ \mathrm{dB}$ bandwidths are 80 MHz and 60 MHz, respectively.

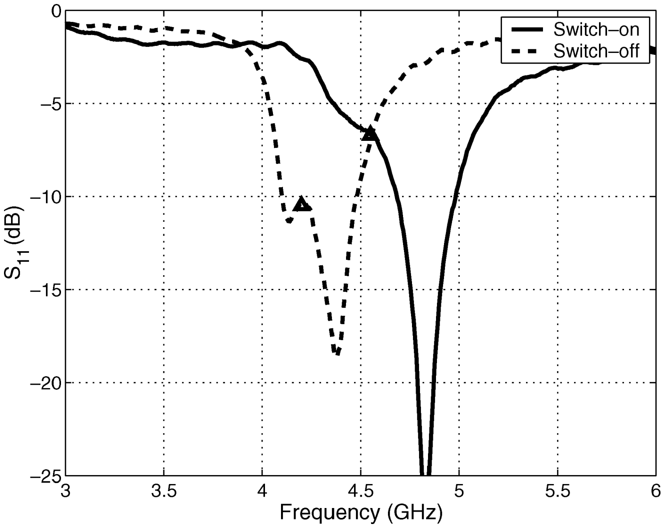


Fig. 6. Measured antenna return loss at each operation status. The black triplets show the frequencies where the best broadside axial ratios are observed.

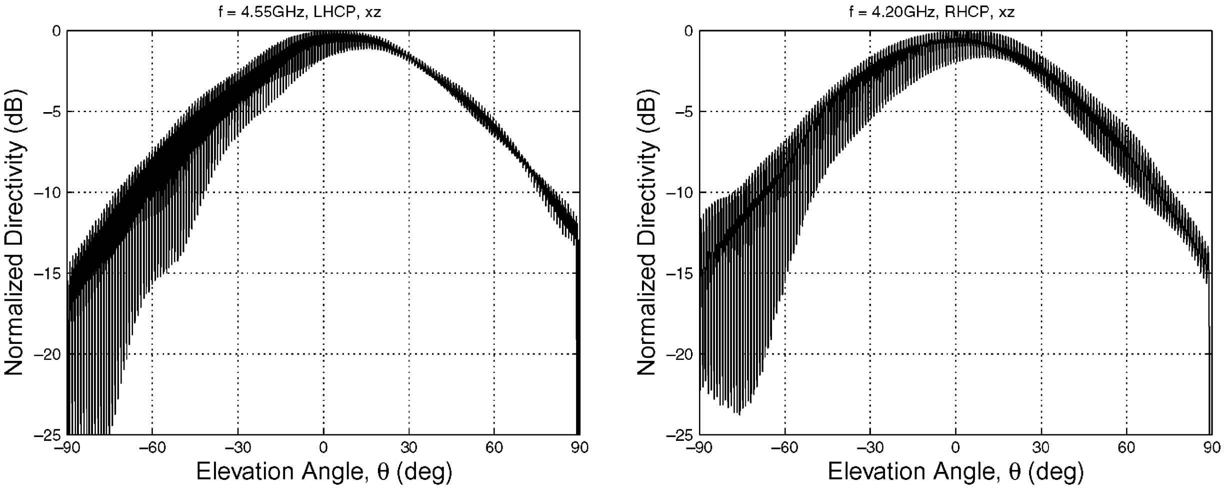
shown in [3] that the PASS structure has the flexibility in implementing different types of switches. In this paper, a Schottky diode (MSS40155) is utilized to obtain a high switching speed with an estimated insertion loss of 2 dB. One can also use a *p-i-n* diode to trade off between the switching speed and the insertion loss (typically 1 dB). Ultimately, the microelectromechanical systems (MEMS) switches can be applied to further reduce the insertion loss. A 1.5 V/0 V dc bias of the diode is combined with RF signal using a bias network. It should be noted that in the antenna prototype, the slot is cut across the patch to isolate the dc bias. Two 47 pF capacitors are soldered at the ends of the slot to maintain the RF connection. The lower part of the patch is dc grounded by a shorting pin using a $\lambda/4$ bias line. Since the transmission line is an RF open-circuit at point A, the antenna return loss is not appreciably affected by the biasing circuit.

The geometrical parameters of the fabricated antenna are (unit: mm)

$$L_g = 60;\ L = 20.5;\ W = 18;\ W_s = 1;\ h = 3.18;$$
$$(x_f, y_f) = (3.7, 3.1);\ (x_s, y_s) = (0, -6). \tag{5}$$

These parameters are selected via trial-and-error. The most critical parameter is the ratio between patch length L and patch width W. It is observed that for a fixed L, both f_l and f_h shift down by increasing W, and the axial ratio of RHCP is considerably affected. In contrast, both f_l and f_h shift up when W is reduced, and the axial ratio of LHCP is deteriorated. In other words, once L is fixed, there is only one optimal value of W to achieve the best axial ratios at both operation status. The operation frequencies, f_l and f_h, are inherently determined by the selection of L and W. The frequency ratio f_h/f_l can be adjusted by changing the Q-factor of the patch, i.e., using substrates with different permittivities or thicknesses. In addition, the antenna dimension can be scaled to accommodate applications at other frequency ranges while maintaining the frequency ratio.

Fig. 5 shows the measured axial ratio versus frequency at each operation status. The best broadside axial ratios are observed at 4.55 GHz (1.65 dB, switch-on, LHCP) and 4.20 GHz (1.95 dB, switch-off, RHCP). The frequency ratio between different operation status is $4.55/4.20 = 1.08$ and the frequency separation is 350 MHz. The associated AR $<$ 3 dB bandwidths are 80 MHz and 60 MHz, respectively. Fig. 6 shows the measured S_{11} results. The antenna has acceptable S_{11} of -6.8 dB at 4.55 GHz and -10.5 dB at 4.20 GHz. The measured linear spinning patterns in xz-plane are shown in Fig. 7. Similar radiation patterns are observed in yz-plane. AR $<$ 3 dB is achieved within a 40° beamwidth. The asymmetries in the radiation patterns are attributed to the biasing circuit. This is demonstrated in



(a) (b)

Fig. 7. Measured linear spinning patterns in xz-plane. (a) Switch-on, 4.55 GHz, LHCP; (b) switch-off, 4.20 GHz, RHCP. Acceptable AR less than 3 dB is achieved within a 40° beamwidth. The asymmetries in the patterns are attributed to the biasing circuit.

[10], where equivalent antenna prototypes without basing circuit and diode switches are fabricated and measured, and the radiation patterns are observed to be almost symmetric.

IV. CONCLUSION

This paper proposes the possibility of combining frequency and polarization diversities using a novel reconfigurable antenna. Applying the PASS structure and a diagonal feed, a candidate design is built and measured to operate at 4.20 GHz with RHCP and at 4.55 GHz with LHCP, respectively. The antenna operation status are simply controlled using a 1.5 V/0 V dc bias. A dual-frequency antenna with switchable LHCP/RHCP at each frequency is also suggested for practical antenna diversity applications.

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Wide-Band Dual Sleeve Antenna

K. George Thomas, N. Lenin, and M. Sreenivasan

***Abstract*—This correspondence presents a top loaded dual sleeve antenna with a substantially small ground plane for broad band applications. The impedance and radiation properties of the monopole were investigated numerically and experimentally. The antenna features excellent radiation characteristics within a broad impedance bandwidth of 4.2:1, covering 0.5–2.1 GHz.**

***Index Terms*—Dual sleeve, impedance bandwidth, monopole antenna, planar element, toploaded antenna, wideband.**

I. INTRODUCTION

Monopole is one of the most widely used antennas throughout the RF spectrum, ranging from VHF to UHF. New communication technologies, especially spread spectrum, frequency hopping and frequency-agile systems demand the widest possible antenna bandwidth. Although these systems are currently used primarily for military communications, commercial applications are generating more pressure for wider bandwidth.

The simple structure of monopole coupled with performance properties such as pure vertical polarization and horizontal omni directional coverage, makes its extensive use possible in a variety of

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