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A Reconfigurable Patch Antenna with Controllable Polarization Sense and Beam Direction

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1. Introduction

It is well known that directional antennas and circular polarization (CP) antennas are effective in reducing degradations of receiving power caused by multipath propagation effects [1]. Therefore, simultaneous controlling these two features—directivity and polarization—is expected to considerably reduce such adverse effects.

Some papers have reported CP antennas with beam steering means [2], [3]. In those antennas, their main beams are tilted from their bore sight and Axial Ratios (AR) of their main beam directions are less than 3 dB. However, their polarizations were still fixed.

In contrast, choosing their polarizations so as to avoid the detrimental fading loss caused by multipath propagation has been also reported in [4] and [5]. In those antennas, right-hand CP (RHCP) and left-hand CP (LHCP) can be switched with respect to phasing conditions. Although, their main beam directions were fixed.

This paper presents a novel reconfigurable antenna, which is able to control both polarization sense and main beam direction. Four slots are introduced in the ground plane of a conventional patch antenna to excite the CP mode and tilt the main beam direction of the antenna. And we demonstrate that polarization sense and main beam direction of the antenna are controlled by switching PIN diodes mounted across the slot.

2. Antenna Design

Figure 1 shows the schematic of the proposed antenna. The dashed lines in Figure 1 (a) and (b) show the formation of the ground plane. The square radiation patch is printed on the upper side of the substrate and the ground plane is on the bottom side. Four identical slots with a loop shape are formed in the ground plane of the antenna. The centers of the four slots are located at ϕ=45°, 135°, 225°, and 315° with respect to the feed point. The perimeters of each slot are designed as one effective wavelength. The four slots overlap with the patch and are formed symmetrically to the x-axis and y-axis.

Three switches are mounted across the each slot. One switch, which is denoted as switch A, is mounted in overlapped region, and the others, which are denoted as switch B, are mounted out of the overlapped region. CP sense and main beam direction of the antenna can be controlled by using those switches independently.

CP sense of the antenna can be controlled by using the four switches A. CP is generally obtained by geometrical perturbations on a printed element such as truncating corners of a single-feed symmetrical patch [6]. In this study, we form the slots in the ground plane just below the corners of square patch. The current path on the ground plane is transformed by forming the slots. When one of the four switches A is turned on, CP is obtained because the current path on the ground plane becomes asymmetric. Moreover, CP sense can be determined as either RHCP or LHCP by the position of the chosen PIN diodes with respect to the feed point. The amount of perturbation, which means the areas of above mentioned overlapped region, is determined by the unloaded Q_0 of the patch antenna as in conventional single-feed patch antenna.

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The other switches B is employed to control the main beam direction of the antenna in addition to the function of switches A. When three switches (switch A and Bs) mounted in one slot are turned off at the same instant, the slot operates as a parasitic element to tilt main beam direction of a driven element. When CP mode is excited in a driven element, CP mode with the same sense is excited in the parasitic element, too. By bringing above mentioned two effects for the slot with loop shape, main beam of the antenna can be tilted to the direction of the slot without deteriorating the axial ratio (AR) of the CP.

The antenna is built on a 3.2 mm thick dielectric (ε_r=2.08, tanδ=0.00085). The square patch is designed to resonate at a frequency of 2.38 GHz, and the slot is designed to resonate at a frequency of 2.50 GHz, respectively.

PIN diodes (Avago Technology, HSMP-389Y) are used for the switching requiring 3 mA of bias current. For the RF-signal the diode represents an ohmic resistance of 2.5 Ω in the forward biased state and a capacitance of 0.15 pF in the reverse biased voltage.

DC bias voltage for the switching PIN diode is supplied to eight bias lines connected with the inner metal plate of the slot. The inner metal plate of the slot is separated into two parts to switch the PIN diodes A and B independently. On the other hand, RF-signal is shorted by capacitors (2pF) between two separated metal plates.

3. Measurement Results and Discussion

Figure 2 shows examples of the PIN diode on/off state to control the main beam direction and CP sense of the antenna along the ϕ = 45 degree plane. In Figure 2, the black switch is turned on and the white switch is turned off. Figure 3 (a), (b), and (c) shows the measured results of the radiation pattern and AR of the fabricated antenna when the PIN diodes are controlled as in Figure 2 (a), (b), and (c), respectively. The radiation pattern and AR were measured in the ϕ=45 degree plane at 2.44 GHz.

Comparing Figure. 3 (a) and (b), main beam direction of the antenna was tilteded from about θ = - 30 to + 30 (degree) with same CP sense. ARs in main beam direction are less than 3 dB. And comparing Figure 3 (a) and (c), CP sense of the antenna was switched between LHCP and RHCP, keeping the main beam direction tilted.

All results of polarization sense and main beam direction of the antenna controlled by DC bias voltage are shown in Table 1. In Table 1, main beam direction of the antenna can be controlled among five directions in both CP senses. It is confirmed that our proposed antenna shows high reconfigurability for controlling CP sense and main beam direction. In addition, linear polarization was obtained when the four switches A were simultaneously turned off.

Compared with Figure 3 (a), a gain of main beam direction (θ = + 30 degree) has decreased and a gain of opposite direction (θ = - 30 degree) has increased in Figure 3 (b). This difference of radiation pattern is due to coupling of radiation fields with the DC-line and RF-feed cable.

4. Conclusion

A novel reconfigurable antenna, which is able to control both polarization sense and main beam direction, is presented. Four identical slots with a loop shape are formed in the ground plane of the patch antenna to obtain CP and tilt main beam direction of the antenna. CP sense and main beam direction of the antenna can be controlled by using the switches A and Bs independently.

We demonstrate that CP sense of the antenna is controlled between LHCP and RHCP, and main beam direction of the antenna is electrically controlled in five directions. It is confirmed that our proposed antenna shows high reconfigurability for controlling CP sense and main beam direction.

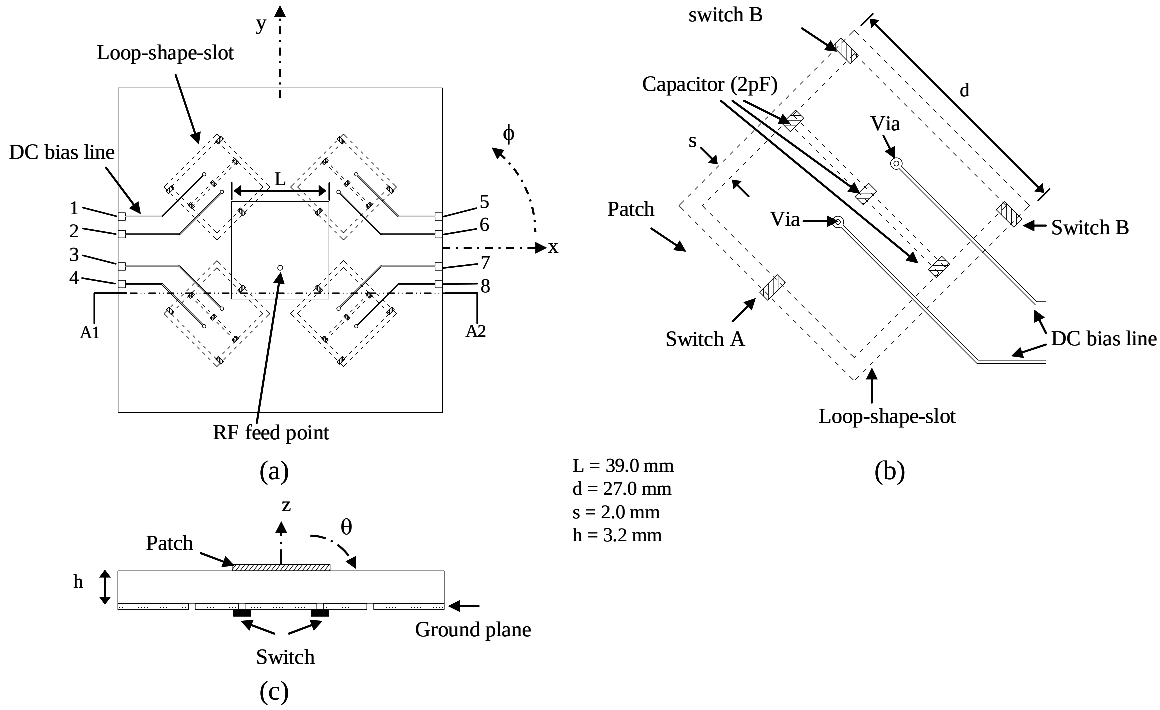

Figure 1: Schematic view of a fabricated antenna: (a) top view; (b) enlarged view of slot; (c) cross-section view along the line A1-A2.

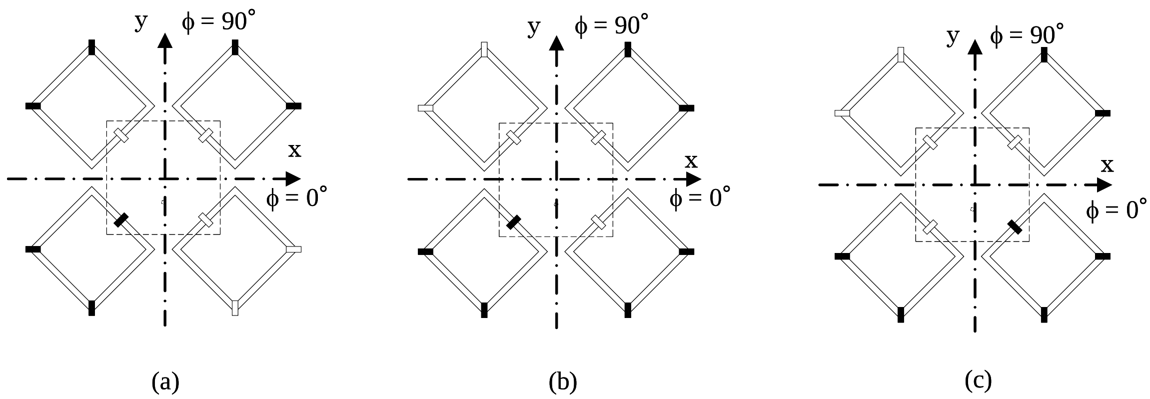

Figure 2: Example of PIN diode switch state, black switch is turned ON and white switch is turned OFF.

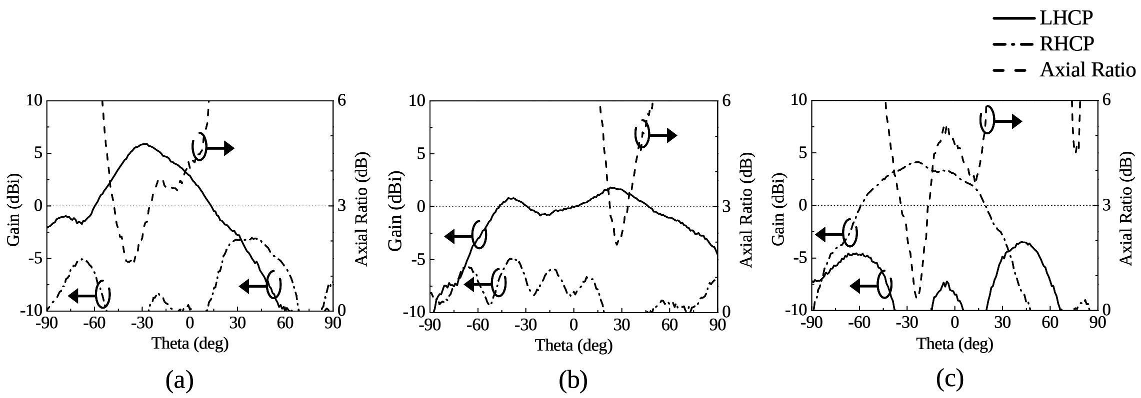

Figure 3: Measured radiation gain and AR correspond to Fig. 2.

Table 1: CP sense and main beam direction controlled by DC bias voltage

DC Bias								CP sense	Main beam direction	
1	2	3	4	5	6	7	8		ϕ [deg]	θ [deg]
−	−	−	+	+	+	−	+	LHCP	135	25
+	−	−	+	+	+	−	−	LHCP	-135	27
+	−	−	−	+	+	−	+	LHCP	-45	27
+	−	+	+	−	−	−	+	LHCP	45	24
+	−	−	+	+	+	−	+	LHCP	0	0
−	−	−	+	+	−	+	+	RHCP	135	27
+	+	−	+	+	−	−	−	RHCP	-135	25
+	+	−	−	+	−	−	+	RHCP	-45	24
+	+	−	+	−	−	−	+	RHCP	45	27
+	+	−	+	+	−	−	+	RHCP	0	0

+ : 3.0 mA, - : -3.0 V

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