A Modified U-Slot Patch Antenna with Full Polarization Agility

Yang Lu and Shih-Yuan Chen
Department of Electrical Engineering and Graduate Institute of Communication Engineering
National Taiwan University, Taipei 10617, Taiwan
E-mail: shihyuan@ntu.edu.tw

***Abstract*—A modified U-slot patch antenna that is capable of switching among linear, right-handed circular, and left-handed circular polarization is proposed. The main contribution of this work is the proposal of a simple integrated dc bias circuit for U-slot patch to enable independent control of the two pin diodes. Meanwhile, the resonant current distributions with and without the bias circuit remain nearly the same for all polarization states. To verify the feasibility of our proposed design, a 2.4-GHz prototype antenna is designed, fabricated, and tested. The measured results agree excellently with those simulated.**

***Keywords*—dc bias circuits, polarization-reconfigurable antennas, U-slot patch antennas.**

I. Introduction

The U-slot patch antenna was first proposed in 1995 by Huynh and Lee [1]. It is a variant of microstrip patch antenna and well-known for its wider bandwidth [2]-[4]. It can also be designed for circular polarization (CP). In [5], the CP U-slot patch antenna radiates left-handed circularly polarized (LHCP) waves when the left vertical arm of the U-shaped slot is properly longer than the right arm and radiates right-handed circularly polarized (RHCP) waves if the right arm is longer. Based on the operational principles of the linearly (LP) and circularly polarized U-slot patches detailed in [1] and [5], a polarization-agile U-slot patch antenna loaded with two pin diodes was proposed in [6]. The pin diodes enable the change of the lengths of the U-slot arms. The U-slot arm can be made longer by turning off the associated pin diode, while it becomes shorter when the pin diode is turned on. However, due to the limitation of the dc bias circuit used in [6], the pin diodes cannot be controlled independently. As a result, the polarization-agile design proposed in [6] can only switch between LP and one sense of CP or between LHCP and RHCP. In this work, we proposed a simple dc bias circuit that facilitates independent control of the two pin diodes without degrading the antenna performance and integrated it into the U-slot patch antenna. Our proposed design can thus switch among RHCP, LHCP, and LP.

II. Antenna Structure and Design

The geometry of the proposed polarization-agile probe-fed U-slot square patch antenna is shown in Fig. 1. To provide mechanical support, the U-slot patch symmetrically loaded with a pair of pin diodes, four RF choke inductors, and four dc block capacitors is printed on the top face of a FR4 substrate placed at the top, and a large copper sheet acting as the ground

TABLE I. Biasing States of Pin Diodes Versus Polarization States.

		Right pin diode	
		On	Off
Left pin diode	On	LP	RHCP
	Off	LHCP	LP (lower frequency)

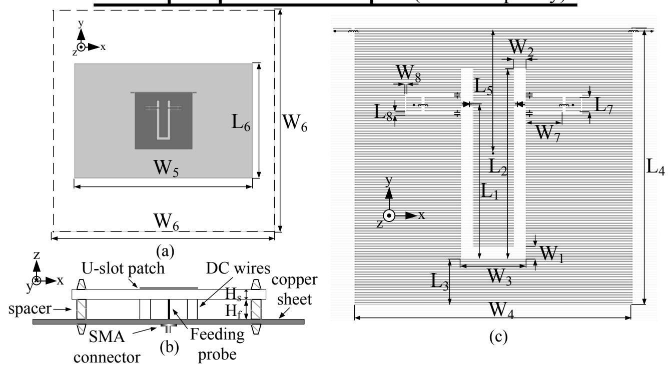

Fig. 1. Geometry of the proposed polarization-reconfigurable U-slot patch antenna. (a) Top view, (b) side view, and (c) enlarged view of U-slot patch.

plane for both radiator and bias circuit is placed at the bottom of the antenna structure. In between them is an air layer of thickness H_f supported by four dielectric spacers at the corners. The pin diodes are symmetrically placed at the two vertical arms of the U-shaped slot, and their positions (L_1) are chosen so that the antenna could radiate CP wave when one of the pin diodes is turned on while the other is off. The sense of handedness is determined in the same way as described in [6].

The dc bias circuit is formed by a pair of symmetric bilateral slit structures as shown in Fig. 1(c). The purpose of the two small square dc pads enclosed by the slit structure pair is to provide independent dc bias voltages for the pin diodes, whereas the two thin strips symmetrically protruding from the upper left and right corners of the patch are connected to the bottom ground plane. An RF choke inductor is added between each thin strip and the nearby patch corner to ensure good RF isolation and dc connection. Note that in our proposed design, the structural symmetry is maintained in both radiator and dc bias circuit to circumvent degradation of radiation performance. The symmetric slit structures cut on both sides of the U-shaped slot not only provide dc isolation for the two small dc pads but also form two biasing strips for the pin diodes as the dc pads are purposely placed in the middle between the edge of the vertical arm of the U-shaped slot and the patch edge. In between each dc pad and adjacent biasing strip is an RF choke inductor to ensure RF isolation and dc connection. In this way, the two pin diodes can be controlled independently.

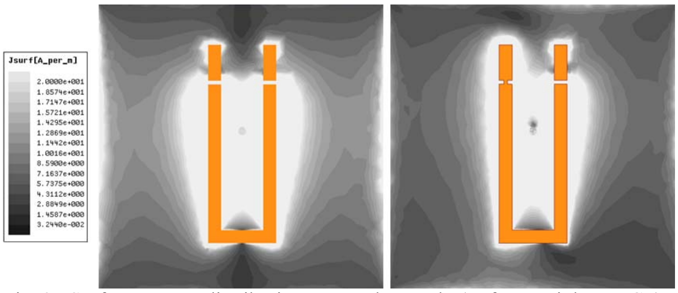

Fig. 2. Surface current distributions on U-slot patch. (Left: LP; right: LHCP)

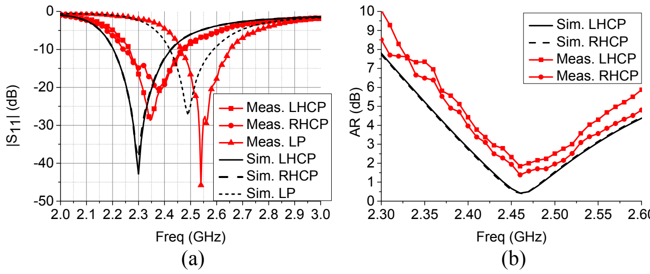

Fig. 3. (a) $|S_{11}|$ and (b) AR responses of 2.4-GHz prototype antenna operating at different polarization states.

Fig. 2 shows the resonant current distributions on the U-slot patch without dc bias circuit. Regardless of polarization states, the current density is stronger near the edges of the U-shaped slot and far weaker in the middle between the edges of the vertical arms of the U-shaped slot and resonating edges of the patch. To circumvent the adverse effect of bias circuit on the current distributions, the bilateral slit structures are designed so that the two small dc pads are placed at the locations where the current density is minimal. Further, four dc blocks capacitors are added at four junctions of the U-shaped slot and slit structures to ensure unperturbed resonant current distributions on the patch, eliminating any adverse influence on radiation performance. With the aid of our proposed bias circuit, the polarization state of the U-slot patch antenna can switch among LP, LHCP, and RHCP. Table I tabulates the combinations of biasing states of the pin diodes for different polarization states.

III. Simulated and Measured Results

A 2.4-GHz prototype antenna was designed and fabricated. All geometric parameters are listed in Table II. All simulations were carried out using Ansys HFSS v.15. The simulated and measured $|S_{11}|$ and axial-ratio (AR) responses of the prototype antenna for LP, LHCP, and RHCP operation are plotted in Fig. 3, and the corresponding impedance bandwidths are listed in Table III. Clearly, the LP mode operates at a frequency slightly higher than CP modes. The simulated and measured radiation patterns for the three polarization states are shown in Fig. 4, and they agree very well. Note that the main beams of the y-z plane patterns for all polarization states tilt slightly owing to the structural asymmetry with respect to x-z plane. As for x-z plane patterns, the LP mode exhibits a symmetric pattern because of identical biasing states of the pin diodes while the main beams of the two CP modes tilt slightly toward opposite directions from broadside. Nonetheless, their patterns still remain well shaped. The measured gains for LP and CP operation are 6 dBi and 6.1 dBic, respectively.

TABLE II. Geometric Parameters of 2.4-GHz Prototype Antenna.

L_1	21.5	L_6	77.5	W_1	1.7	W_6	150
L_2	26.5	L_7	2	W_2	1.7	W_7	5
L_3	6.3	L_8	0.5	W_3	9.1	W_8	0.3
L_4	38.5	H_s	1	W_4	38.5	Unit: mm	
L_5	17.1	H_f	10	W_5	120		

TABLE III. Bandwidths and Center Frequencies of Prototype.

	Measurement			Simulation		
	LHCP	RHCP	LP	LHCP	RHCP	LP
−10 dB BW	8.51%	9.66%	7.42%	9.56%	9.56%	6.42%
f_0 (GHz)	2.35	2.38	2.56	2.30	2.30	2.49
3-dB AR BW	4.47%	4.47%		6.5%	6.5%	

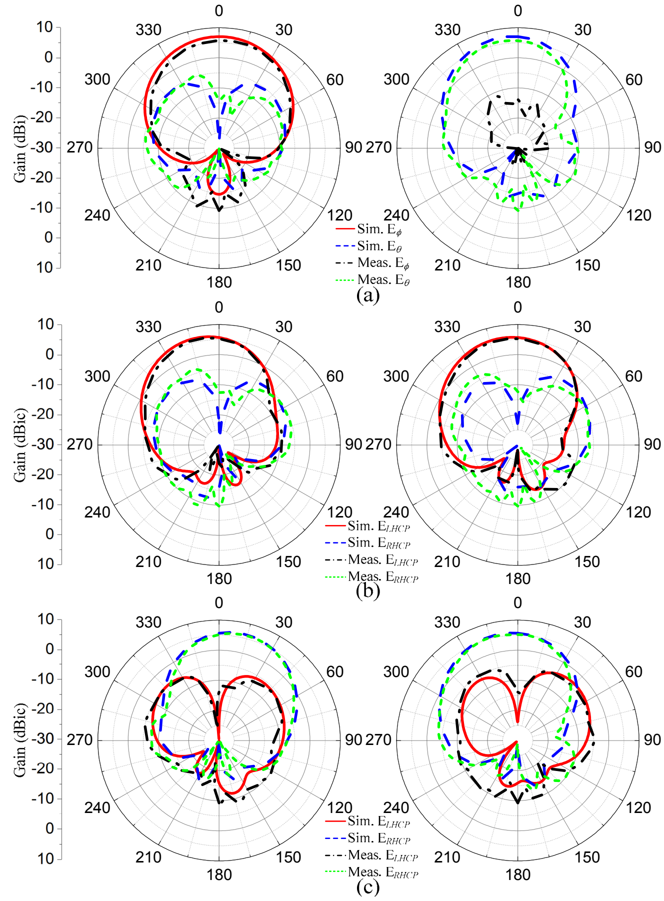

Fig. 4. Radiation patterns of 2.4-GHz prototype antenna for (a) LP, (b) LHCP, and (c) RHCP operation. (Left: x-z plane, right: y-z plane)

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