A Corner-Fed Microstrip Circular Antenna with Switchable Polarization

Youngje Sung

In this paper, a design for a novel microstrip antenna with circular polarization diversity is proposed and experimentally investigated. This antenna is excited by a microstrip line, which is located at the corner of a circular patch. The polarization state can be switched electrically by setting a diode to on or off. The novel structure we describe here enables the optimization of the input match for both polarizations. From the measured result, good axial ratios are observed at the operating frequencies.

Keywords: Polarization diversity, circular polarization, microstrip antenna.

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I. Introduction

An important development in satellite and wireless mobile communication systems is the integration of several applications into a single and compact system [1]. Since each application operates in a different frequency band with different types of polarization and radiation characteristics, these complex systems require different antenna designs. Due to the limitations on the physical size of these systems, it is not practical to construct separate antennas for each application. Recently, the design of multi-function antennas which could incorporate different radiation characteristics in a single antenna element, has become an important research area for antenna engineers [2]. A polarization diversity antenna, which is an example of a multi-function antenna, allows the user to roam any existing network and use only a single handset to access a great number of services. Therefore, these antennas can be utilized to realize frequency reuse [3]. Additionally, polarization diversity of reception is important to counter the effects of fading in communication, especially in mobile communication [4].

Microstrip antennas are usually designed for a single-mode operation that radiates linear polarization (LP). However, in some applications, such as satellite communications, a circular polarization (CP) system is more suitable than an LP system because of its insensitivity to transmitter and receiver orientations [5].

Thus, circular polarized operation and polarization diversity are becoming major design considerations for practical applications of microstrip antennas. In a recent project to build a Mars rover, a microstrip antenna with dual-polarization capabilities was required [6]. Practical applications of this technique were described in [3], [4], [7]. Based on a similar

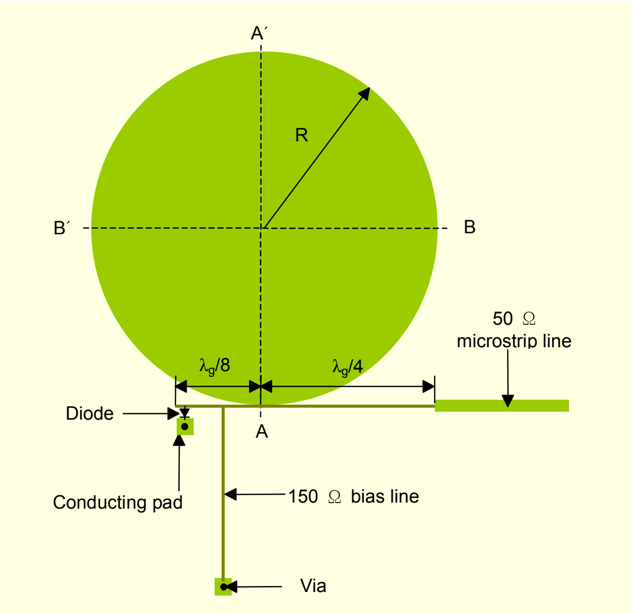

Fig. 1. Configuration of the corner-fed microstrip antenna with switchable polarization.

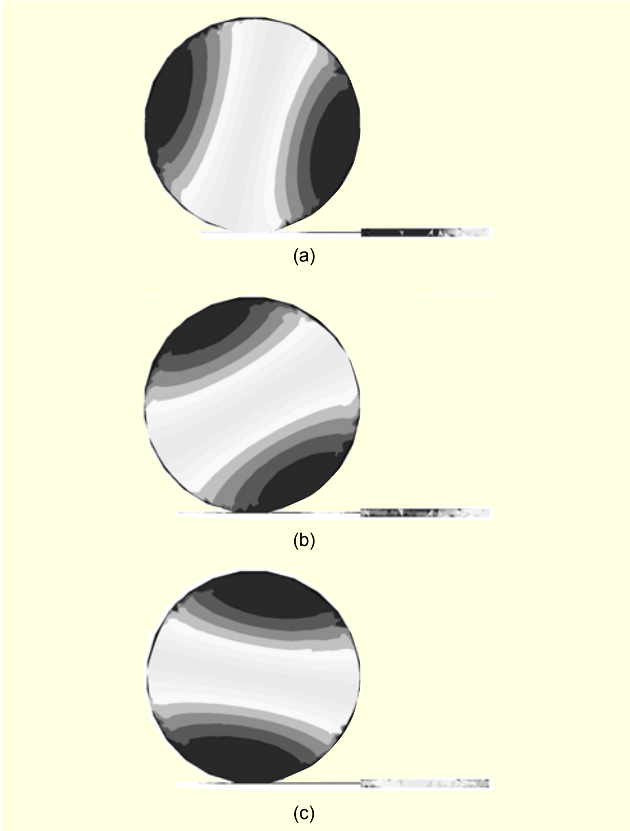

Fig. 2. Simulated E-field distribution at f = 2.04 GHz: (a) phase = 0°, (b) phase = 45°, and (c) phase = 90°.

concept, a novel microstrip antenna allowing polarization switching is proposed and carefully examined in this study.

Two or four diodes were used to achieve microstrip antennas with CP diversity in other works [3], [4], [7]. Therefore, a DC bias circuit is complicated and the size of a microstrip antenna increases as the number of PIN diodes increases. Little information on a polarization diversity antenna with a single PIN diode is currently available in the literature. In our work, one PIN diode is inserted into the gap between the end of the tuning stub and the conducting pad. Because the antenna structure is simple and compact, this antenna can be easily constructed. In addition, to isolate the DC bias circuit from the RF signal, capacitors or the etching of thin slits on the ground plane has been required in previous microstrip antenna designs [3], [4]. However, there is no need to use a capacitor or thin slits in the structure proposed here.

II. Operating Principle

A quasi-square patch fed at one corner was used as an element of CP [8], [9], which excited two orthogonally polarized modes with equal amplitude and 90° phase shift. In this paper, a circular patch fed at the corner point on a thin single-layer substrate is used as an antenna element for CP operation. Figure 1 shows the proposed circular patch antenna with switchable polarization. Introducing a proper asymmetry in the feed structure can remove degeneracy by having one mode increase with the frequency while the orthogonal mode decreases with the frequency by the same amount. Since the two modes will have slightly different frequencies, the field of one mode can lead by 45° while that of the other can lag by 45° resulting in a 90° phase difference necessary for CP. The degenerate modes consist of TM_{10} mode, which is related to the vertical axis AA´, and TM_{01} mode, which is related to the horizontal axis BB´.

The case of the proposed antenna with the diode off is first considered. It is referred to as antenna 1 in this study. The PIN diode represents a capacitance of 0.35 pF in the reverse biased state and behaves almost as open impedance. Figure 2 shows the E-field distribution for the left-hand circular polarization (LHCP) antenna on the patch surface. The simulated frequency was 2.04 GHz, which is defined as the frequency with the minimum axial ratio in the operating bandwidth. The dark region represents the peak E-field, while the white area has almost no E-field. Both plots were normalized at the same minimum and maximum values. The simulation results show that the current rotates clockwise over the whole conductor surface of the patch resonator (see Fig. 2). The rotation direction (RHCP or LHCP) of a circularly polarized wave is determined by the rotation direction of the current on the circular patch. A right-hand circular polarization (RHCP) signal is generated when the rotation direction is counterclockwise,

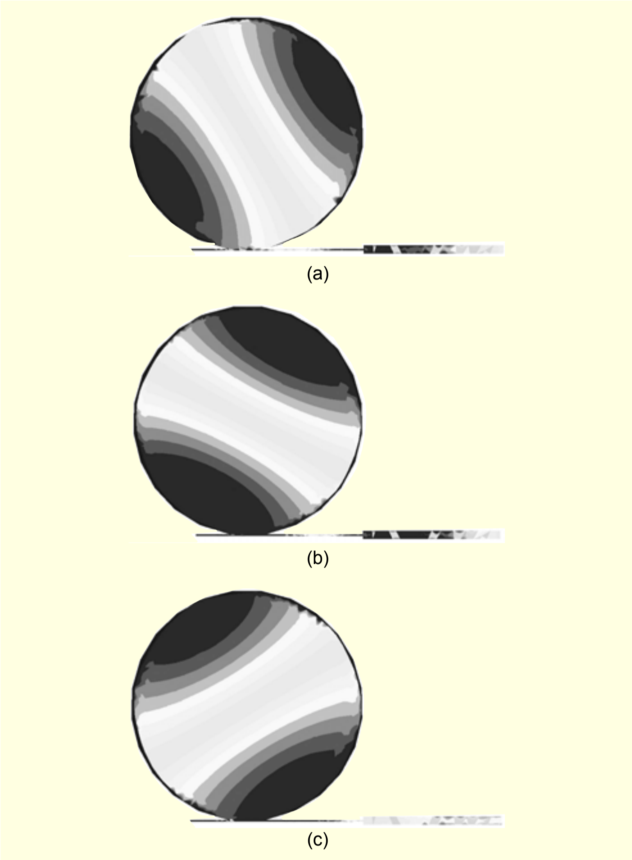

Fig. 3. Simulated E-field distribution at f=2.05 GHz: (a) phase = 0°, (b) phase = 45°, and (c) phase = 90°.

and for a LHCP wave, the vector rotates clockwise [10]. Because the phase of the vertical axis is 90° faster than the phase of the horizontal axis, an LHCP pattern can be obtained. It should be noted that the rotation is viewed from the rear of the wave in the direction of propagation. In our study, the wave was traveling from the page into the observation point. Therefore, the rotation was examined from the page looking into an observation point and perpendicular to it [11].

Next we consider the diode in the on position, which will be referred to as antenna 2. Figure 3 shows the E-field distribution for the RHCP antenna on the patch surface. The simulated frequency was 2.05 GHz, which is also defined as the frequency with the minimum axial ratio in the operating bandwidth. With applied forward bias, the PIN diode exhibited an ohmic resistance of 1.5 Ω; therefore, there is a connection between the tuning stub and the conducting pad. As a result, the open-circuited stub with the length of $\lambda_g/8$ was changed into a short-circuited stub.

This means that the phase changed by 180° at the feed structure with the $\lambda_g/8$ matching stub. Accordingly, the phase of the vertical axis AA′ changed by 180°, whereas the phase of the horizontal axis BB′ remained unchanged. Therefore, the

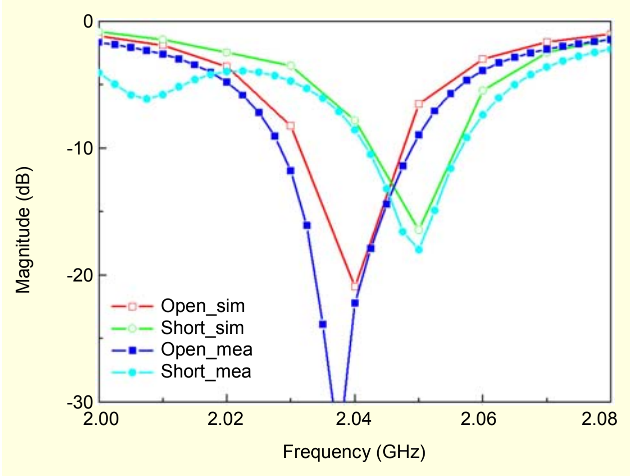

Fig. 4. Return loss for various diode states.

proposed antenna produced an RHCP (see Fig. 3).

III. Reconfigurable Antenna with Polarization Diversity

The microstrip antenna was formed on a substrate with a dielectric constant ε_r of 2.5 and a thickness h of 25 mil. The radius R of the circular patch is 27.4 mm, and its resonant frequency is 2 GHz. The matching circuit consists of a quarter-wave transformer and a tuning stub. The width of the quarter-wave transformer line is 0.4 mm, which corresponds to 110 Ω, and its length is 27.2 mm. The width and length of the tuning stub were adjusted to obtain a good axial ratio [9]. For simple analysis, the width of the tuning stub was chosen to be 0.4 mm, which is same as that of the quarter-wave transformer. The simulated results demonstrate that the axial ratio of the proposed antenna is sensitive to variation in the tuning stub. In this study, the length of the designed open stub was chosen to be 13.6 mm, which corresponds to $\lambda_g/8$. Simulation was carried out using IE3D, a commercial electromagnetic simulator based on an integral equation method and the method of moment. To control the termination of the feedline, a PIN diode was inserted between the end of the stub, and a 150 Ω microstrip line with a one-quarter wavelength was connected to the ground plane in the patch.

Figure 4 shows the return loss of the microstrip antenna for each state of the diode. In this study, two different sets were considered. A DC bias circuit was practically considered in the simulation. The measured results indicate that the best match of antenna 1 is obtained at 2.037 GHz while the resonant frequency of antenna 2 is 2.051 GHz. The shift in frequency between the simulation and the measurement is less than 10 MHz (less than 0.5 % with respect to the resonant frequency). The diffracted fields at the edge of the substrate, which were not considered in the simulation, contribute to the

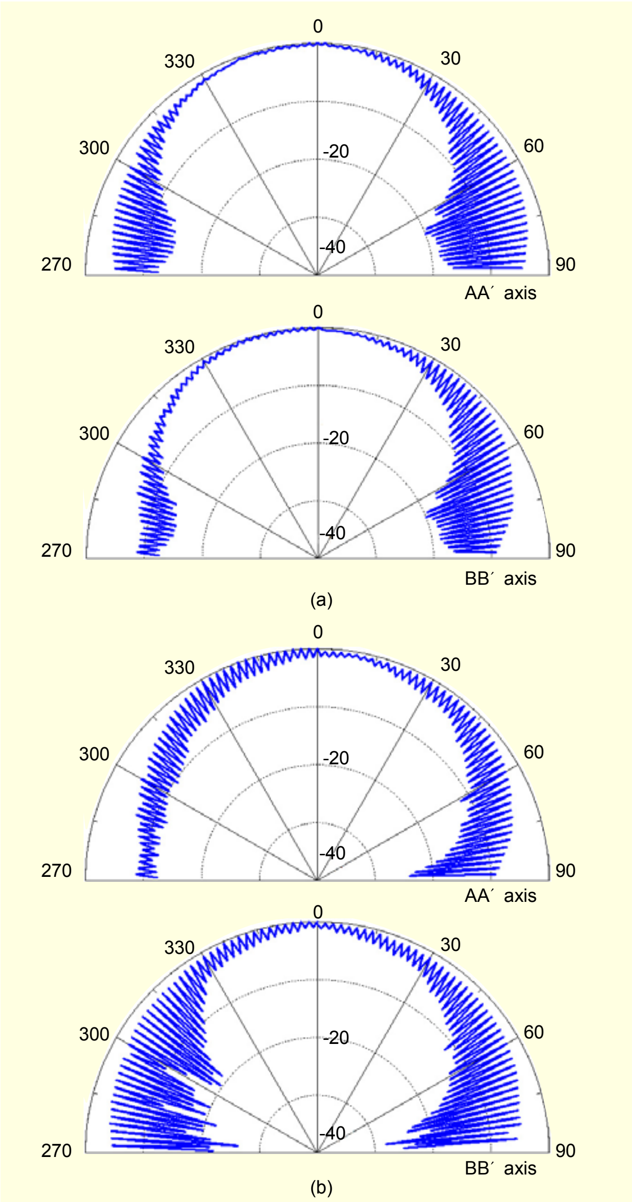

Fig. 5. Measured radiation pattern for (a) antenna 1 and (b) antenna 2.

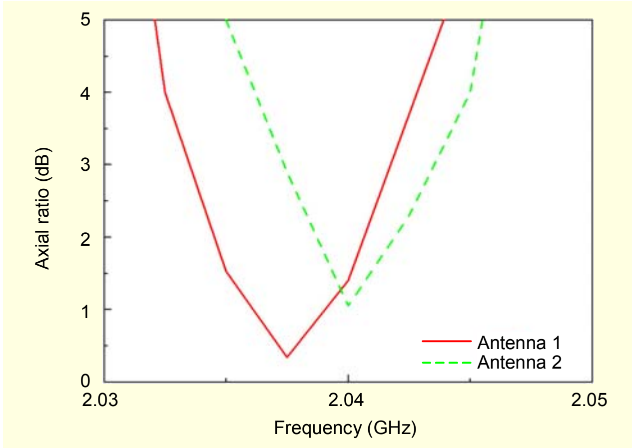

Fig. 6. Measured axial ratio for antennas 1 and 2.

small deviation between simulation and measurements. A PIN diode (HSMP-3894) was used for the switching, requiring a bias current of 15 mA and a bias voltage of 0.74 V.

Radiation patterns were measured at the resonant frequency, where the parameters of the proposed antennas are the same as those given in Fig. 1. The electrical size of the ground plane is approximately $1.2\lambda_0 \times 1.2\lambda_0$. A linearly polarized spinning source antenna was used in the experimental setup. Figure 5 plots the measured radiation patterns of antennas 1 and 2 at 2.03 GHz and 2.04 GHz, respectively, which are the frequencies with the minimum axial ratio in the operating bandwidth. The measured gains of antennas 1 and 2 are 5.2 dBi and 4.9 dBi, respectively. The measured results show that broadside radiation patterns with good CP characteristics are obtained at the resonant frequencies. The measured axial ratios for antennas 1 and 2 are shown in Fig. 6. The measured results demonstrate that CP diversity operation can be achieved by turning the diode on or off. Although the resonant frequencies with the minimum axial ratio are different, the 3-dB axial ratio bandwidth overlaps around 2.04 GHz. Also, an asymmetry in the radiation patterns is observed, which is probably due to the introduced asymmetry in the proposed antenna.

IV. Conclusion

A switchable microstrip antenna has been proposed which has high potential for multi-operation applications. The proposed antenna can produce LHCP or RHCP in relation to bias voltages. The technique has been successfully applied to microstrip antennas with switchable polarization, and it offers a solution to the problem of the change in impedance when switching between polarizations. The proposed antenna is suitable for applications in wireless communications and mobile satellite communications.

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