# Circularly Polarized Square Ring Slot Antenna with Arrow-Shaped Structure

Youngje Sung

**A novel design of a compact square-ring slot microstrip antenna for achieving circular polarization (CP) operation is proposed and experimentally studied. By using an arrow-shaped slot structure as a radiating element, the resonant frequency of the proposed antenna is significantly lowered, which can lead to a large size reduction for fixed frequency operation. The CP radiation characteristics are achieved by loading with proper asymmetry, which can be placed diagonally. A prototype of the proposed design is implemented and its performance is measured. Measured results show that radiation patterns with good CP characteristics are obtained at the resonant frequency.**

**Keywords: Circular polarization, microstrip antenna.**

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## I. Introduction

Microstrip antennas have several advantages over conventional antennas, namely, small size, light weight, and low cost [1]. Because of lengthening of the excited current path, a ring microstrip antenna is smaller than a microstrip patch antenna for a given frequency [2]. Therefore, the ring microstrip antenna is very attractive because wireless communication systems usually require smaller devices to meet circuit miniaturization and cost reduction requirements.

The radiation characteristics of a ring slot microstrip antenna are complementary to those of a ring microstrip antenna with electric and magnetic fields interchanged using Babinet's principle. Ring slot microstrip antennas are usually designed for linear polarization. However, circularly polarized antennas have been attracting much attention in recent years. In some applications such as satellite communication systems, a circular polarization (CP) antenna is more suitable because of its insensitivity to transmitter and receiver orientations. They are also used in radar to reduce the clutter from spherically symmetric objects like raindrops, hail, and so on [3]. For the design of the single-feed ring slot microstrip antenna with CP operation, the two required orthogonal modes with equal amplitude and 90° phase difference can generally be excited by dual feeding [4], protruding a tuning stub [5], or a pair of perturbations located at one of the diagonals [6]. In [7], CP radiation of the proposed design is achieved by introducing proper asymmetry in the ring slot structure and feeding the ring slot using a microstrip line at 45° from the introduced asymmetry.

In this paper, we demonstrate that a novel arrow-shaped ring slot antenna can be applied in compact CP operation. Due to the arrow-shaped structure, the route of the magnetic current

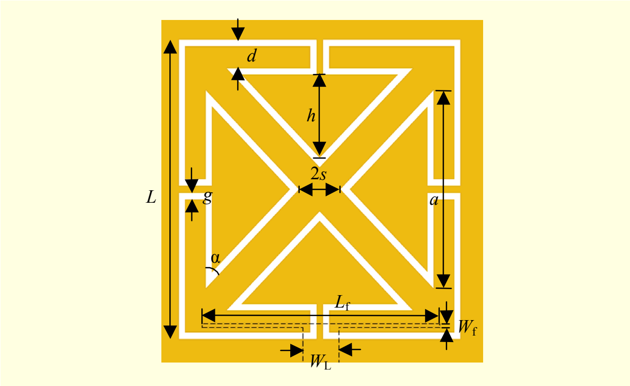


Fig. 1. Compact microstrip arrow-shaped ring slot antenna.

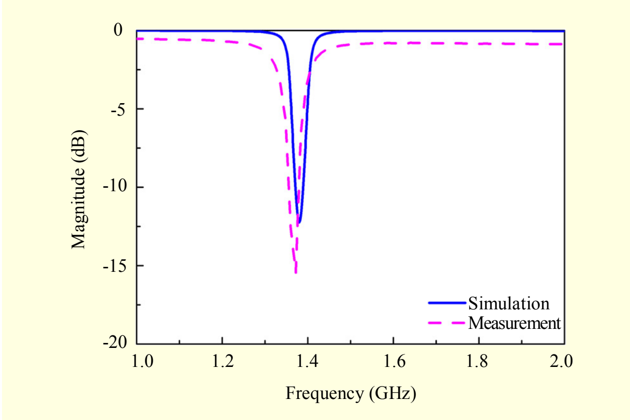


Fig. 2. Simulated and measured return loss for the arrow-shaped ring slot antenna.

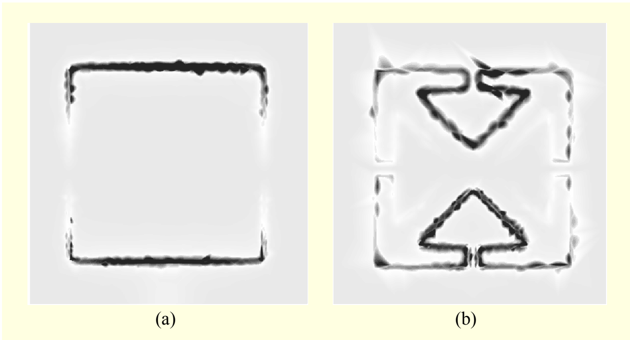


Fig. 3. Simulated E-field distribution: (a) conventional antenna and (b) proposed antenna.

distribution in the slot lengthens, which results in lowering of the resonant frequency. Compared with a conventional ring slot microstrip antenna, about 50% size reduction is achieved.

Also, by introducing proper asymmetry to the proposed ring slot antenna, the symmetry of the structure can be perturbed, which makes it possible for excitation of two near-degenerate orthogonal modes for CP operation. The proper asymmetry is a difference in slot widths, which can be placed diagonally.

## II. Linear Polarized Antenna

The basic configuration investigated in this paper is shown in Fig. 1. White regions represent the slots etched on the ground plane. The dotted line represents the 50 Ω microstrip line on the opposite side. To maintain the structural symmetry of the antenna, the four arrows on the top, bottom, left, and right are designed with the same shape. The angle $\alpha$ at the ends of the two sides formed by the slots is kept at 45° so that the sides of nearby slots are aligned. The antenna proposed here is fabricated on commercially available FR4 substrate with $h = 1.6$ mm, $\varepsilon_r = 4.4$, and $\tan\delta = 0.01$. To simplify the design and discussion, the width $W_L$ of the feed line is chosen to be 3 mm, which corresponds to the characteristic impedance of 50 Ω. The antenna is fed by a microstrip line through proximity (electromagnetic) coupling. The simulated results demonstrate that the dimensions ($L_f$ and $W_f$) and position of the T-shaped feed structure can be adjusted for good impedance matching. Simulation is carried out using IE3D, a commercial electromagnetic simulator based on an integral equation method and the method of moment.

Figure 2 shows the simulated and measured return loss for the proposed antenna. The side length of the slot is selected to be 20 mm. The other parameter values used are the following: $a = 13.2$ mm, $g = 0.4$ mm, and $s = 2$ mm. The impedance matching condition can be optimized when $L_f = 18$ mm and $W_f = 0.2$ mm. For the proposed antenna, the impedance bandwidth, which is determined from the 10 dB return loss, is about 1.2%. The proposed antenna has a gain of 1.74 dBi at the frequency of 1.36 GHz. The radiation efficiency is 51.2%. For a simple square-ring slot antenna with $L = 20$ mm and $g = 0.4$ mm, the 10 dB impedance bandwidth is 6.1%. A conventional simple ring slot antenna has a gain of 4.32 dBi, and the radiation efficiency is 92.2%. Figure 3 shows the simulated E-field distributions for a simple structure and the proposed structure. The dark region represents the peak E-field, while the white area has almost no E-field. Both plots have been normalized at the minimum and maximum values. In a conventional ring slot microstrip antenna, the total length of the ring slot should be around one effective wavelength at the resonant frequency. The resonant frequency in the proposed antenna is significantly lowered by the arrow-shaped structure, which introduces longer current paths along its contours. This effect results in a much more compact antenna than its conventional counterpart.

## III. Compact Ring Slot Antenna for Circular Polarization

Figure 4 shows the structure of the proposed circularly

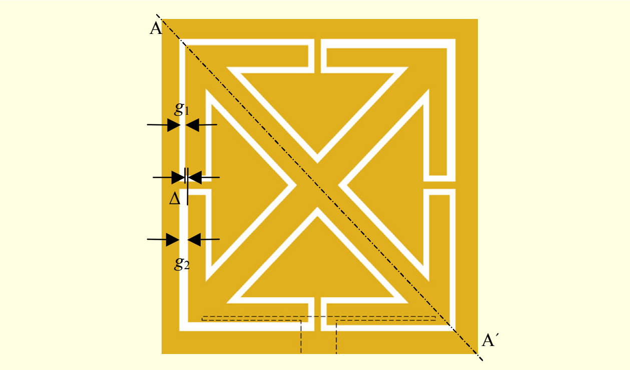


Fig. 4. Compact microstrip slot antenna for CP operation.

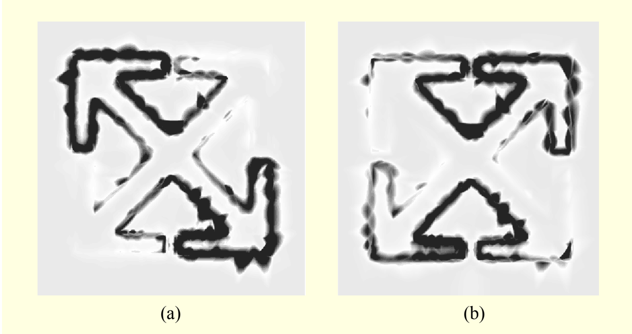


Fig. 6. Simulated E-field distribution of the circularly polarized antenna: (a) phase = 0° and (b) phase = 90°.

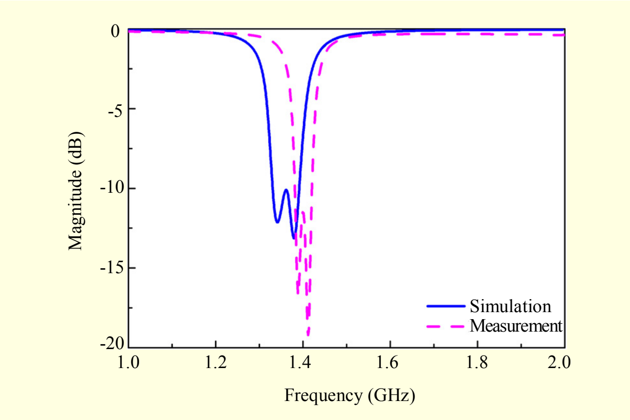


Fig. 5. Simulated and measured return loss for the CP microstrip antenna.

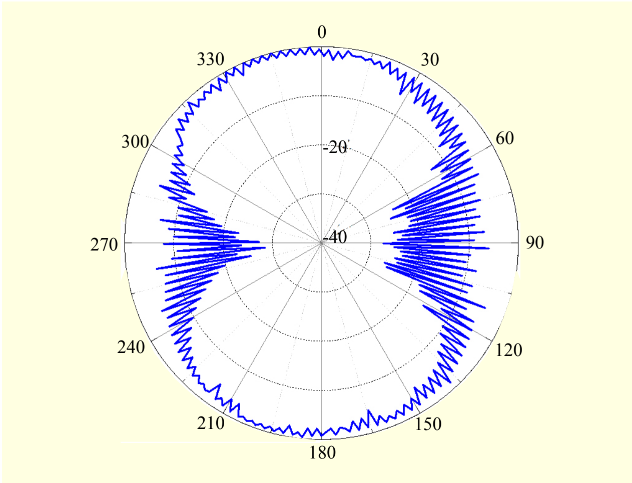


Fig. 7. Measured radiation pattern for CP operation at the frequency of 1.38 GHz.

polarized ring slot microstrip antenna, which is based on the structure shown in Fig. 1. The width of the opposite slot on the section marked as diagonal line AA′ is denoted by $g_1$, and the width of the slot on the opposite diagonal line is denoted by $g_2$. The difference between slot widths on different diagonal lines is represented by $\Delta$. In the proposed antenna design, its structural asymmetry is implemented through the difference in slot widths.

Figure 5 shows the simulated and measured return loss for the circularly polarized ring slot antenna. Design parameter $\Delta$ for proper asymmetry is chosen to be 0.1 mm (here, $g_1 = 0.4$ mm and $g_2 = 0.5$ mm). In this case, the side length of the slot is selected to be 20 mm. Length $a$ is fixed to be 13.2 mm. The gap $g$ is fixed to be 0.4 mm. The impedance matching condition for CP radiation can be optimized when $L_f = 17$ mm and $W_f = 0.2$ mm. The 10 dB impedance bandwidth is found to be about 2.04% for the operating band centered at 1.38 GHz. The center frequency is defined here as the frequency with the minimum axial ratio (AR) in the operating bandwidth. The measured results show that the proposed antenna has a minimum AR of 1.66 dB at 1.38 GHz, and the 3 dB AR CP bandwidth obtained for the left-hand circularly polarized (LHCP) mode is about 0.94%. If the resolution for $\Delta$ was higher, the proposed antenna could have a lower minimum AR. From the simulated result, the proposed antenna with $\Delta = 0.13$ mm has a minimum AR of 0.83 dB. The conductor and dielectric losses, which are not considered in the simulation, contribute to the slight deviation between the simulated and measured results. Figure 6 shows the simulated E-field distribution on the surface for the proposed circularly polarized antenna at the resonant frequency of 1.38 GHz.

Figure 7 shows a typical far-field radiation pattern measured for the proposed antenna, where excellent CP operation can be obtained in the broadside directions. The far-field patterns of the proposed antenna are measured by using the SATIMO SG64 antenna measurement system. In the region within ± 45° from the broadside directions, the ARs are all smaller than 3 dB. The measured gain is 1.6 dBi. The design arrangements shown in Fig. 4 radiate LHCP wave in the upper half and right-hand circularly polarized (RHCP) wave in the lower half. When $g_1$ is greater than $g_2$, opposite CP radiation can be achieved. The overall size of the ground plane is 80 mm × 80 mm. Figure 8 shows the measured axial ratio of a constructed prototype. The

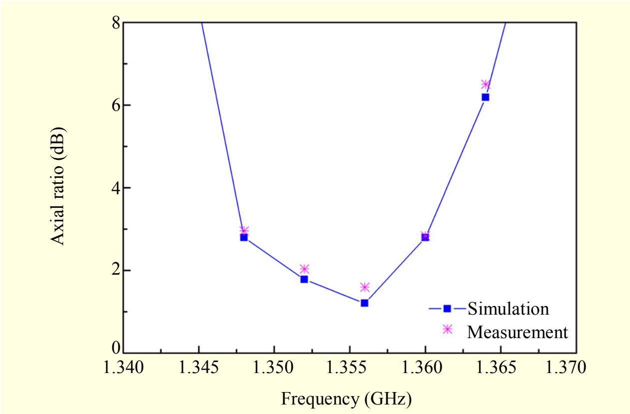


Fig. 8. Simulated and measured axial ratio.

minimum AR decreases as the ground plane size increases. The simulated results show that the minimum AR increases from 0.83 to 2.18 as the ground plane size decreases from 80 mm to 40 mm.

## IV. Conclusion

A compact circularly polarized ring slot microstrip antenna with an arrow-shaped structure has been proposed and experimentally studied. The measured results demonstrate that this design can reduce the circuit size by 48%. Also, the proposed antenna exhibits CP operation because the difference in slot widths, which can be place diagonally, is used as a perturbation. Due to its compactness and circular polarization, the proposed antenna represents an interesting alternative for mobile communication systems.

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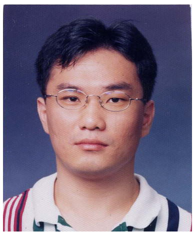

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