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DESIGN OF CPW-FED CIRCULARLY POLARIZED ANTENNA WITH TWO ORTHOGONAL SLOTS

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Abstract—A design of coplanar waveguide (CPW)-fed circularly polarized slot antenna is presented. The proposed antenna consists of two orthogonal slots. By making use of the symmetric current and electric-field distributions of the two gaps of CPW-fed, a simple power divider is easily achieved. By adjusting the length of the two orthogonal slots and CPW-fed bent slot, a circularly polarized wave of two orthogonal modes with equal amplitude and phase difference of 90 degree is excited. The numerical results show that the 10 dB return loss bandwidth and 3 dB axial ratio (AR) bandwidth are 50.8% and 11.2% respectively. A prototype antenna is fabricated and measured, the measured results show that the proposed antenna achieves a good performance of circularly polarization.

1. INTRODUCTION

The circularly polarized (CP) antenna can receive the incident waves of any polarization and its radiating circularly polarized wave can be easily received by antenna of any polarization except for its orthogonal polarization wave [1]. Therefore, circularly polarized antenna is widely used in current wireless communication systems, such as radar and satellite systems. A circularly polarized wave can be radiated by exciting two orthogonally linearly polarized modes with equal amplitude and 90 degree phase difference. The feeding structure of circularly polarized antenna can be classified into two types: single feed type and dual- or multi-feed type. A multi-feed circularly polarized antenna has complicated feeding structure and is difficult to design. A single feed type is inclined to be adopted because of its simplicity. A corners-truncated antenna and a square antenna with a diagonal slot

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are analysed [2], which have the experimental values of bandwidths (for axial ratio to be less than 6 dB) of 0.9% and 1.2%, respectively. An extra metal part is added at one of the peripheries of the annular ring antenna [3], two orthogonal degenerate modes are separated to obtain circularly polarized radiation and a wider axial ratio bandwidth (less than 6 dB) of 6% is achieved. A microstrip antenna embedding a cross slot on the radiating patch is proposed [4], a proximity coupled feed method is used and the axial ratio bandwidth (less than 2 dB) of 0.65% is obtained. The perturbation technology used above can be realized to generate CP radiation. However, the bandwidth of axial ratio is limited and the dimensions of the perturbation segments are very sensitivity to the CP axial ratio, resulting in strict manufacturing tolerances. Because coplanar waveguide (CPW) fed printed slot antennas have lots of attractive features such as wide impedance, single metallic layer and easy integration with active devices, they have been increasingly used in design of circularly polarized antennas [5–8].

In this article, a simple design of CPW-fed circularly polarized antenna with two orthogonal slots is proposed. Two orthogonal slots are etched in the ground. By making use of the symmetric current and electric-field distributions of the two gaps of CPW-fed, a simple power divider is designed. By introducing a CPW-fed bent slot on one side of CPW-feeding lines, 90 degree phase difference is obtained. Then two orthogonal electric field vectors with equal amplitude can be excited by connecting the two orthogonal slots to the gaps of CPW-feeding lines. The parameters of the antenna are properly tuned and the optimized results can be easily achieved. This design has relaxed manufacturing tolerances because of its simplicity of the structure and its insensitivity to axial ratio. Besides, the designed CP antenna can cover the GPS and INMARSAT frequency bands [9]. More details of the antenna design are discussed below, and simulated and measured results are given to demonstrate the performance of the proposed antenna.

2. ANTENNA DESIGN

The proposed CPW-fed circularly polarized slot antenna is depicted in Figure 1. The ground plane has the dimensions of $L \times W$ and is printed on a substrate of thickness $h = 1.5$ mm and relative permittivity $\varepsilon_r = 2.55$. The antenna is fed by a $50\,\Omega$ CPW where the signal strip and two identical gaps have width of W_f and g, respectively. A vertical slot with a length L_2 and width W_2 is located at the end of CPW and directly connected to the left gap of CPW-feeding line, and then a bent slot connects a horizontal slot with a length L_1 and width W_1 to the other side gap of CPW-feeding line. The bent slot length with the same

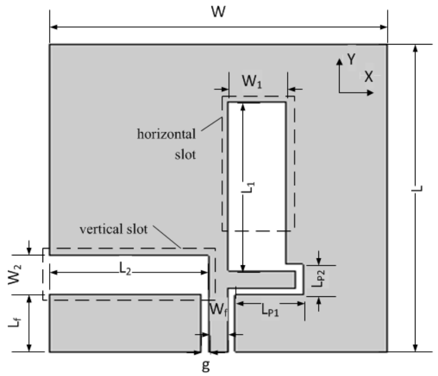

Figure 1. Configuration of the proposed CP antenna.

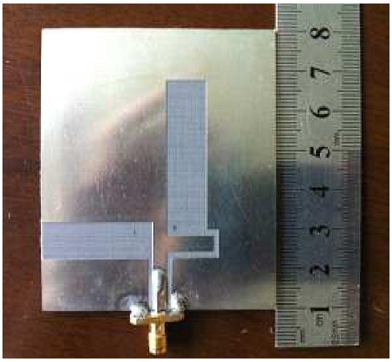

Figure 2. Photograph of the antenna.

width as the gaps of CPW introduces a 90 degree phase difference. The bent slot length is approximately determined by

$$L_{P1} + L_{P2} \approx \lambda/4$$

where

$$\begin{aligned} \lambda &= \frac{c}{f\sqrt{\varepsilon_{eff}}} = \text{wavelength;} \\ f &= \text{resonant frequency;} \\ \varepsilon_{eff} &= \text{effective relative permittivity.} \end{aligned}$$

The bent slot length is usually less than $\lambda/4$, because a part of the horizontal slot serves as a phase shifter. The vertical slot is open while the horizontal slot is short due to the fact that a bent slot is introduced, which ensures the balanced current distributions of the two gaps of the CPW-feeding lines and improves the performance of axial ratio.

To investigate the electrical characteristics and the manufacturing tolerances of the proposed antenna, simulator Ansoft HFSS is used in this study to perform the design and optimization process, which is based on finite element method (FEM). It was experimentally found that the impedance matching and AR bandwidth are primarily dependent on the two orthogonal slots. Moreover, operating frequency of the antenna can be adjusted by the length L_f of signal strip of the CPW. As shown in Figure 3, VSWR and AR as a function of frequency were simulated for different lengths of L_f ($L_f = 5\,\text{mm}$, $10\,\text{mm}$, $15\,\text{mm}$, $20\,\text{mm}$). When increasing L_f, the lower resonance moves down slowly and the upper resonance shifts down quickly, the center frequency of axial ratio shifts down. So L_f can be fine tuned to achieve the required

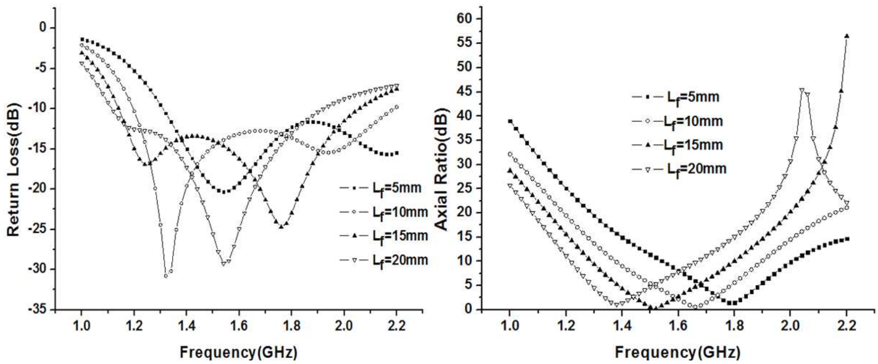

Figure 3. Return loss and axial ratios of proposed antenna during the various frequencies for different signal strip lengths of 5, 10, 15 and 20 mm.

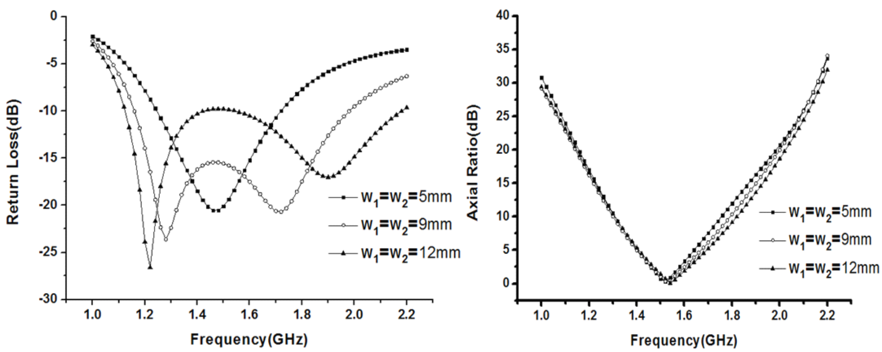

Figure 4. Return loss and axial ratios of proposed antenna during the various frequencies for different slot widths of 5, 9 and 12 mm.

frequency bands. Figure 4 presents simulated VSWR and AR curves for different values of the width $W_1 = W_2$ ($W_1 = W_2 = 5$, 9, 12 mm), it can be seen from the figure that this parameter has a great effect on enhancement of the impedance bandwidth and it is insensitive to axial ratio. The length of the bent slot has been tuned to achieve the 90 degree phase difference. From the tuning process of the antenna, the parameters of the antenna are not highly sensitive to produce good CP performance, resulting in relaxed manufacturing tolerances. Finally, the optimized dimensions of the proposed antenna listed in Table 1 are selected to show the circularly polarized radiation of the slot antenna.

To perceive why the CP can be generated by the designed antenna,

Table 1. The optimized dimensions of the proposed antenna (mm).

L	W	W_f	g	L_f	L_1	W_1	L_2	W_2	L_{P1}	L_{P2}
70	70	4	1.5	13	38.5	12	33	9	14	7

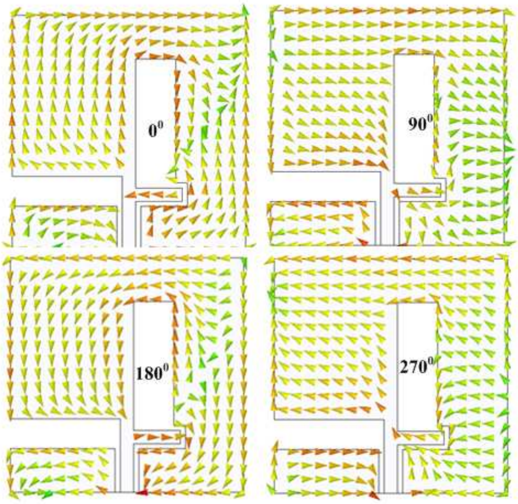

Figure 5. Surface current distributions on the ground plane for four different phases.

the current distribution of the ground varying with time is examined. Figure 5 shows the simulated surface current distribution of the proposed antenna at 1.58 GHz. It can be seen that the surface current distribution in 180° and 270° are equal in magnitude and opposite in phase of 0° and 90°. Because the two slots of CPW-fed line holds the same symmetric current and electric-field distributions, if the vertical and horizontal slot was directly connected to and excited by the CPW-fed slots without the bent slot, the vertical and horizontal slot would have the same current and electric-field distributions with their directions orthogonal. As is seen from the current distribution, the direction of the current around the vertical slot is orthogonal to that around the horizontal slot. To achieve 90 degree phase difference between the vertical and horizontal slot, a bent slot that connects the horizontal slot to one of the CPW-fed slots is used. As is seen from the current distribution of 0° and 90°, the current distribution of 0° around the short side of the horizontal slot is maximum while that around the vertical slot is minimum. However, the maximum and minimum current distribution of 90° is in the opposite way, as is the fact that the current distribution of 90° around the short side of the horizontal slot is minimum while that around the vertical slot is maximum. Besides, the two slots are excited in the way described above, and so the current on the other region of the patch rotates in a clock-wise direction, then a circularly polarized antenna is achieved. By observing the dynamic distribution of the simulated surface current, the circular polarization of the proposed antenna is left-hand (LH) in the $+Z$ direction.

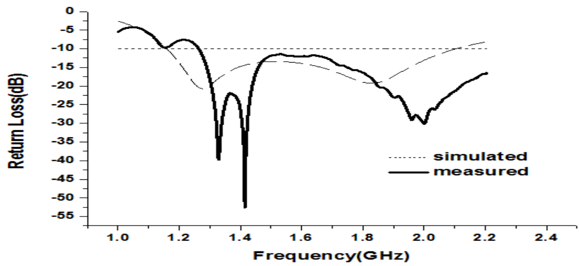

Figure 6. Simulated and measured return loss of presented antenna.

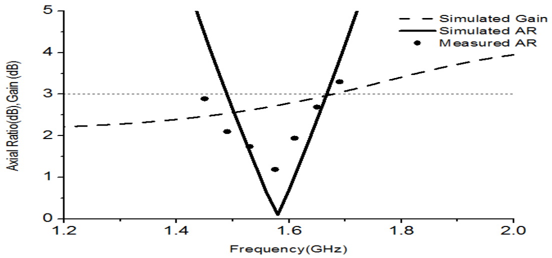

Figure 7. Axial ratio and gain versus frequency of the proposed antenna.

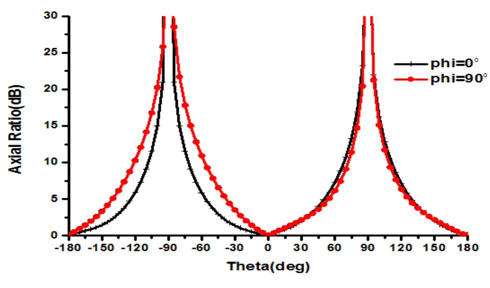

Figure 8. Simulated AR against elevation angle (θ) at the frequency of 1.58 GHz with different azimuthal angles of $\varphi = 0°$ and $90°$.

3. RESULTS AND ANALYSES

The CPW-fed circularly polarized slot antenna with above dimensions was fabricated and measured. A constructed prototype of the proposed antenna shown in Figure 2 is measured in a Wiltron 37269A vector network analyzer. A 50 Ω-SMA is used to feed the antenna. The simulated and measured return loss versus frequency curves are shown in Figure 6, axial ratio and gain versus frequency is shown in Figure 7.

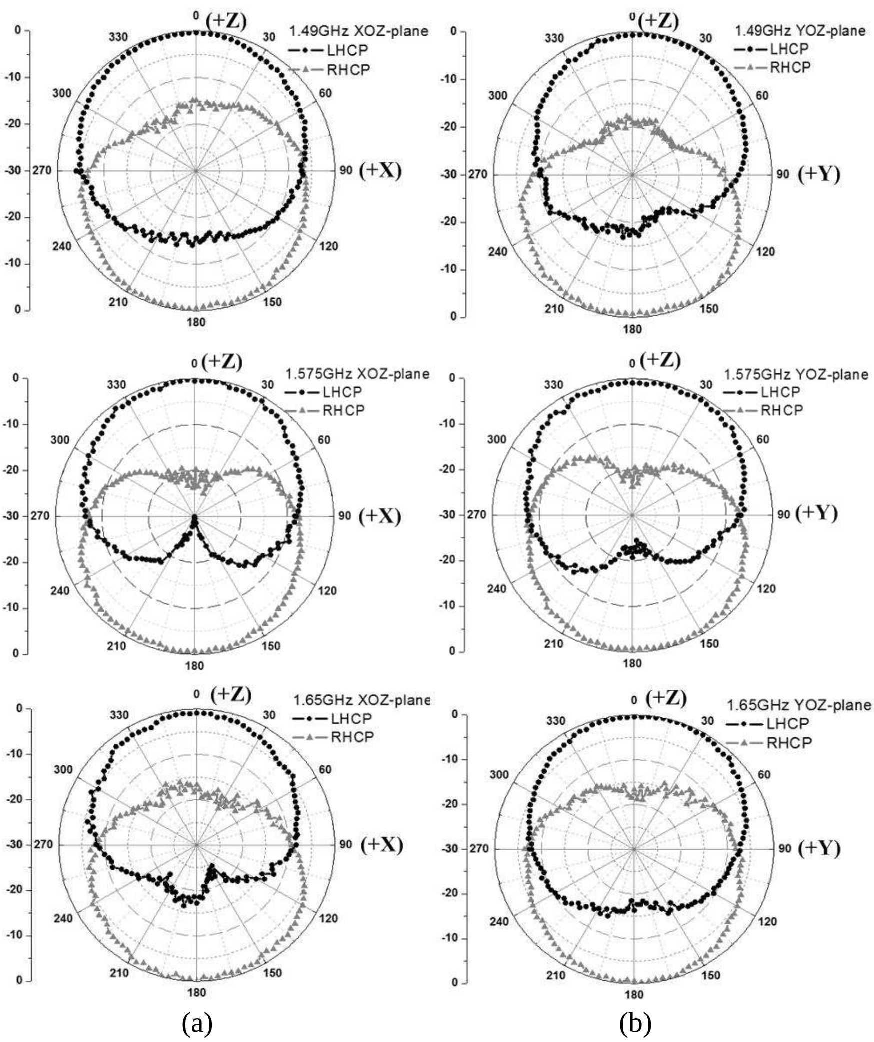

Figure 9. Measured CP radiation patterns of proposed antenna at 1.49 GHz, 1.575 GHz and 1.65 GHz, (a) XOZ-plane, (b) YOZ-plane.

From the measured results we can observe that the impedance bandwidth ($|S_{11}| \leq -10\,\mathrm{dB}$) is 50.8% (1260 MHz to 2120 MHz), and the 3-dB AR bandwidth is 11.2% (1489 MHz to 1667 MHz). The gain reaches to 2.1 dB with variation less than 2 dB in the direction of boresight.

Figure 8 compares the simulated AR values of the proposed antenna against the elevation angle (θ) with different azimuthal angles for $\varphi = 0^\circ$ and 90° at the resonant frequency of 1.58 GHz. When the elevation angles range from -45° to 40° at $\varphi = 0^\circ$, the AR value is lower than 3 dB. Correspondingly, as φ is at 90° and θ range from -30° to 40°, we found that the AR is less than 3 dB.

The radiation patterns of the proposed antenna centered at 1.49 GHz, 1.575 GHz and 1.65 GHz in two orthogonal planes are presented in Figure 9. Note that the CPW-fed slot antenna is a bidirectional radiator and the radiation patterns in both sides are almost the same. The CP of the antenna at $+Z$ and $-Z$ direction is the opposite polarization. The radiation pattern is left hand circular polarization (LHCP) for $Z > 0$ region and right hand circular polarization (RHCP) for $Z < 0$ region. The reason is that the vertical component of the electric field on the top and bottom surface of the substrate remains the same phase; however, the horizontal component of the electric field on the top and bottom surface of the substrate is 180° out of phase. The measured 3-dB AR beam widths are about 105 degree for RHCP radiation and LHCP radiation. Therefore, we conclude that the proposed antenna demonstrates a good CP characteristic in space distribution.

4. CONCLUSION

A simple design of coplanar waveguide (CPW)-fed circularly polarized antenna with two orthogonal slots has been investigated and successfully implemented. By making use of the symmetric current and electric-field distributions of the two gaps of CPW-fed, a simple power divider can be easily achieved. By introducing two orthogonal slots in the ground, two orthogonal resonant modes for CP radiation are excited. An antenna was fabricated based on simulations and optimizations. The obtained results show that the impedance bandwidth ($|S_{11}| \leq -10\,\mathrm{dB}$) and the 3 dB AR bandwidth can reach as large as around 50.8% (1260 MHz to 2120 MHz) and 11.2% (1489 MHz to 1667 MHz), respectively. The antenna has relaxed manufacturing tolerances due to the simplicity of the structure and its insensitivity to axial ratio. Moreover, the CP antenna can cover the GPS and INMARSAT frequency bands.

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